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Initial Effects of Clearcut Logging on Size and Timing of Peak Flows in a Small Watershed in Western Oregon

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Size of annual peak flow in a small watershed in western Oregon was reduced 32%, and average delay of all peak flows was nearly 9 hours following clearcut logging. Size of annual peak flows caused by rain with snowmelt was reduced 36%, and peak flows resulting from rain with snowmelt were delayed an average of nearly 12 hours following logging. Changes are attributed mainly to differences in short-term accumulation and melting of snow. No significant changes were detected in size or timing of peak flows that resulted from rainfall alone.

INTRODUCTION

The effect of timber harvest activities on storm runoff in the Pacific Northwest remains a controversial subject. Although *Anderson and Hobba* [1959] concluded that logging had increased the size of peak streamflow in numerous large watersheds in western Oregon, most subsequent studies have not detected statistically significant increases in size of peak flows after clearcut logging without soil disturbance [*Rothacher,* 1973; *Harris,* 1973, 1977; *Harr et al.*, 1975]. Substantial increases in magnitude of peak flow have been observed, however, where severe soil disturbance by road building, tractor skidding of logs, or slash burning has occupied at least 12% of total area within small experimental headwater basins [*Harr et al.*, 1975; *Harr,* 1976]. On the other hand, in a recent study in southwestern British Columbia, size of peak flows was significantly reduced after clearcut logging [*Cheng et al.*, 1975]. The reduction was attributed to the disruption of subsurface channel networks by logging activities. These authors concluded that sealing the channel networks, which had previously transmitted water rapidly during storms, forced water to follow slower routes through the soil matrix after logging.

STUDY

During the U.S. International Biological Program's analysis of ecosystems an intensive study site within the Coniferous Forest Biome was established in watershed 10 (HJA-10), a 10.2-ha headwater basin in the H. J. Andrews Experimental Forest 72 km east of Eugene, Oregon. When this watershed was logged in order to provide a basis for evaluating the predictive capability of various simulation models of ecosystem processes, an opportunity was presented to see if clearcut logging had affected storm runoff in this watershed as it had elsewhere in western Oregon. Specifically, the objective of this study was to determine the effect of clearcut logging on the size and timing of instantaneous peak flows in HJA-10.

In addition to HJA-10, HJA-9, an 8.5-ha control watershed, was used in this study. Located about 1.7 km apart between 425 and 700 m in elevation, the watersheds are steep with slopes ranging from 60% to over 100% and contain residual and colluvial clay loam soils derived from pyroclastic rocks. Soils in HJA-10 are approximately 130 cm deep and are underlain by highly weathered volcanic tuffs and breccias. This parent material is commonly weathered to a depth of 3.7 m over much of the watershed. In HJA-9 the soil mantle is thinner, and rock outcrops are more numerous. Soils on both watersheds have extremely high conductivities and can transmit subsurface water rapidly to stream channels without the occurrence of overland flow [*Harr,* 1977]. Prior to logging, vegetation on both watersheds consisted primarily of 450-year-old Douglas fir mixed with western hemlock and younger Douglas fir.

The climate of the study area is typical of much of the mountainous area of western Oregon. Annual precipitation at a climatic station about 1.5 km from each watershed averages 230 cm, 80% of which occurs between October and April during long-duration, low-intensity frontal storms. At the 425- to 700-m elevation range of the watersheds, snow is common, rarely persists longer than 1–2 weeks, and generally melts within 1–2 days.

During the spring and summer of 1975, timber in HJA-10 was clearcut, and a running skyline system yarded all logs and unmerchantable material >20 cm in diameter or >2.4 m in length uphill to a single landing. HJA-9 remained undisturbed.

Peak flows greater than 2.2 l/s/ha at HJA-9 and corresponding peak flows at HJA-10 were tabulated. There were 90 such events in the 1967–1975 prelogging period and 13 in the 1976 postlogging period. We used linear regression to obtain prelogging and postlogging prediction equations for estimating peak flow at HJA-10 from peak flow at HJA-9. A difference between prelogging and postlogging data was hypothesized and tested by the principle of 'extra sum of squares' [*Draper and Smith,* 1966, pp. 67–69]. The actual hypothesis was that there was no difference between the two regressions, i.e., $\alpha_1 = \alpha_2$ and $\beta_1 = \beta_2$, where α is the intercept of the regression line, β is the slope, and subscripts 1 and 2 denote prelogging and postlogging, respectively. First, the residual sum of squares of the prelogging and postlogging regressions are summed to give a sum of squares ($SS\Omega$) with $(n_1 + n_2 - 4)$ degrees of freedom. Next, a residual sum of squares ($SS\omega$) is determined by regression analysis of pooled prelogging and postlogging data. This sum of squares has $(n_1 + n_2 - 2)$ degrees of freedom. The difference between these sums of squares is the sum of squares due to the hypothesis and has $[(n_1$

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TABLE 1. Effects of Clearcut Logging on Size of Peak Flow at HJA-10

Type of Peak Flow	No. of Peaks	Predicted HJA-10 Peak Flow at HJA-9 Annual Peak Flow,* l/s/ha	Change in Size, %
	All Peaks	*of >2.2 l/s/ha*	
Prelogging	90	12.09	−32†
Postlogging	13	8.27	
	Snow Peaks	*of >2.2 l/s/ha*	
Prelogging	45	12.40	−36†
Postlogging	9	7.95	
	Rain Peaks	*of >1.6 l/s/ha*	
Prelogging	49	6.95	+1
Postlogging	7	7.05	

*There is a 50% probability that annual peak flow will be equaled or exceeded in any one year. An annual 'rain' peak flow at HJA-9 is estimated at 6.3 l/s/ha, considerably less than the annual 'snow' peak flow of 10.0 l/s/ha.

†Change in size is significant at the 0.01 level of probability.

$+ n_2 - 2) - (n_1 + n_2 - 4)]$ degrees of freedom. Respective mean squares are compared with the F test:

$$F = \frac{(SS\omega - SS\Omega)/(n_1 + n_2 - 2) - (n_1 + n_2 - 4)}{SS\Omega/(n_1 + n_2 - 4)}$$

$$= \frac{(SS\omega - SS\Omega)/2}{SS\Omega/(n_1 + n_2 - 4)}$$

If the computed F value is greater than the tabulated value, the hypothesis is rejected in favor of the alternate hypothesis that prelogging and postlogging regressions are different.

In addition to size of peak flow the difference between times of occurrence of peak flow at each watershed was determined for each storm runoff event. The time of peak flow at HJA-9 was subtracted from the time of peak flow at HJA-10; the time difference between watersheds was positive if HJA-9 peaked first and negative if HJA-10 peaked first. Next, we determined mean time difference between watersheds for prelogging and postlogging periods. The hypothesis that there is no difference between prelogging and postlogging means was tested by an unpaired t test using a pooled mean-square estimate of variance [*Dixon and Massey*, 1957, p. 121].

All hypotheses were tested at the 0.01 level of probability.

RESULTS AND DISCUSSION

Both magnitude and timing of peak flow in HJA-10 were changed after clearcutting. The hypothesis that there is no difference between prelogging and postlogging regressions was rejected; i.e., the regressions are significantly different. The size of a peak flow at HJA-10 corresponding to the HJA-9 annual peak flow, a peak flow with a 50% chance of being equaled or exceeded in any one year, was reduced 32% after logging (Table 1).

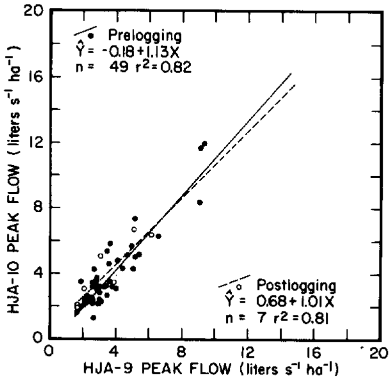

Fig. 1. Peak flow relationships between watersheds for rain events of >1.6 l/s/ha.

The hypothesis that there is no difference between prelogging and postlogging mean differences in peak flow timing was also rejected; i.e., the means are significantly different (Table 2). Before clearcutting, HJA-10 streamflow peaked an average of 1 hour later than HJA-9 streamflow but more than 9 hours later than HJA-9 streamflow after clearcutting.

Of the various components of the hydrologic system which could have been altered by clearcutting, the two most likely to have caused the reduction in size of and the delay of postlogging peak flows are soil water movement and snow accumulation and melt. Although surface soil is generally disturbed on only a small portion of a watershed during tree falling and cable yarding [*Dyrness*, 1967], disturbance on critical runoff-producing areas could change unsaturated conductivity of soil by altering pore size distribution. This would slow down water movement through the soils. Because the hydrologic response of small watersheds in western Oregon to rainfall and snowmelt is rapid [*Harr*, 1976], increasing snow accumulation and delaying melt on a cutover watershed also could cause delayed, smaller peak flows.

To evaluate the relative importance of soil disturbance and snow accumulation and melt in effecting changes in storm runoff, we separated runoff events into 'rain' events and 'snow' events (Figures 1 and 2). A rain event results from rainfall alone, while a snow event could result either from rain with melt of snow on the ground prior to rainfall or from a substantial part of storm precipitation occurring as snow. In the prelogging period, there were 45 rain events and 45 snow events of >2.2 l/s/ha; and in the postlogging period, there were 9 snow events and only 4 rain events.

TABLE 2. Change in Timing of Peak Flows After Logging in Watershed 10

	Prelogging		Postlogging		
Type of Peak Flow	No. of Peaks	Time Difference,* hr	No. of Peaks	Time Difference,* hr	t
All peaks of >2.2 l/s/ha	90	1.1	13	9.7	7.34†
Rain of >1.6 l/s/ha	49	0.7	7	1.3	0.97
Snow of >2.2 l/s/ha	45	1.3	9	12.8	7.25†

*Watershed 10 peaked later than watershed 9.

†The change is significant at the 0.01 level of probability.

TABLE 3. Percent Surface Soil Condition After Clearcut Logging in Watershed 10

Compaction Class*	Disturbance Class†		
	1	2	3
1	48.8	11.8	9.4
2	1.0	3.4	5.8
3		0.6	19.2

*Compaction class 1, no evidence of compaction; class 2, evidence of 1–2 passes of equipment or logs; and class 3, evidence of >2 passes of equipment or logs.

† Disturbance class 1, litter still in place; class 2, litter and soil mixed to a depth of 5 cm; and class 3, subsoil exposed or litter and soil mixed to a depth of >5 cm.

As before, regression analysis and unpaired *t* tests were used to detect changes in size and timing of rain and snow peak flows. Hypotheses teseted include (1) there is no difference between prelogging and postlogging regressions for rain events, (2) there is no difference between prelogging and postlogging regressions for snow events, (3) there is no difference between prelogging and postlogging mean differences in peak flow timing for rain events, and (4) there is no difference between prelogging and postlogging mean differences in peak flow timing for snow events. Again, all hypotheses were tested at the 0.01 level of probability.

Partly because of the small number of postlogging rain events we failed to reject the hypothesis that there is no difference betweeen prelogging and postlogging regressions for rain events alone. Although we increased sample size by adding 8 rain peak flows of 1.6–2.2 l/s/ha in size to the prelogging data and 5 to the postlogging set (Figure 1) and retested the hypothesis at the 0.05 level of probability, we still failed to reject the hypothesis that prelogging and postlogging regressions are not different. We also failed to reject the hypothesis that there was no difference between prelogging and postlogging mean differences in timing of rain peak flows.

On the other hand, we did reject the hypothesis that there is no difference between prelogging and postlogging size of snow peak flows. After logging, annual snow peak flows were 36% smaller. (An annual peak flow has a return period of about 2 yr, or a 50% probability of being equaled or exceeded in any one year.) We also rejected the hypothesis that there is no difference between mean differences in peak flow timing for snow peak flows. Before logging, snow peak flows in HJA-10 occurred an average of 1.3 hours later than HJA-9 peak flows, but after logging they occurred 12.8 hours later than HJA-9 peak flows—an average delay of over 11 hours (Table 2).

Although most of the change in size and timing of peak flows detected in the original analyses of pooled rain and snow peak flow data appeared to be the result of changes in runoff during snow runoff events, we looked further at soil disturbance and snow hydrology to strengthen our conclusions. We used the line intercept method of assessing soil conditions along four transects in HJA-10. Three disturbance classes and three compaction classes were used to express surface soil condition (Table 3). According to this system, 49% of the watershed fell into the undisturbed-uncompacted category. The remaining 51% of HJA-10 was disturbed to some degree; i.e., soil was exposed or compacted. About 19% of the watershed fell into the heavy disturbance-heavy compaction category, which probably has the greatest potential for altering storm runoff. These percentages, however, are only qualitative, as we did not examine changes in soil hydrologic properties associated with each combination of disturbance and compaction classes. Although it seems improbable that soil disturbance was sufficient to alter movement of subsurface water appreciably, we feel results of our attempts to relate changes in storm runoff to soil disturbance are inconclusive.

The effects of logging on short-term snow accumulation and melt appear to be more readily discernible. For example, Figure 3 shows two pairs of hydrographs for HJA-9 and HJA-10 typical of the prelogging period. The first pair resulted from rainfall alone, and the second pair resulted from rain with snowmelt. Both pairs exhibit sharp rising and falling limbs, and peak flows in both cases occur within 1–2 hours of one another.

In contrast, Figure 4 shows two pairs of hydrographs typical of the postlogging period. During the first half of the storm on December 3–4, precipitation fell as rain, and again both watersheds responded quickly with steep, rising limbs. About halfway through the storm, rain changed to snow, and almost immediately, the rate of hydrograph rise at HJA-10 decreased. Eventually, streamflow at HJA-10 peaked about 11 hours after HJA-9 streamflow. In the second case, precipitation during the first half of the storm on December 5 fell as snow, and HJA-9 streamflow increased, while that in HJA-10 continued to decrease. Then shortly before noon on December 6, rain began to fall, and HJA-10 streamflow began to increase at the same time that HJA-9 streamflow began to increase more rapidly. Here again, HJA-10 peaked about 10 hours later than HJA-9.

To determine the reasons for the variation of snow peak flows around the prelogging regression line (Figure 2), we examined the snow accumulation–snowmelt conditions of the nine largest prelogging snow peak flows at HJA-9. We were able to make only broad generalizations about these peak flows, however, because of inadequate information about snow conditions. On the average, only about 5.0 cm (2%) of annual precipitation occurs as snow at the elevation of these experimental watersheds; therefore detailed measurements of snowpack characteristics and of the meteorological variables that influence snowmelt have never been made. Nevertheless, based on air temperature, precipitation, and streamflow records, we can say that three of the four low outliers (located below the prelogging regression line) with flows of 7.0–13.5 l/s/ha at HJA-9 were associated with little or no antecedent snowpack and relatively heavy snowfall (about 3–4 cm of water equivalent) during the initial portion of the peak-producing storm. We can also say that four of the five high outliers with flows of 9.8–19.0 l/s/ha at HJA-10 were associ-

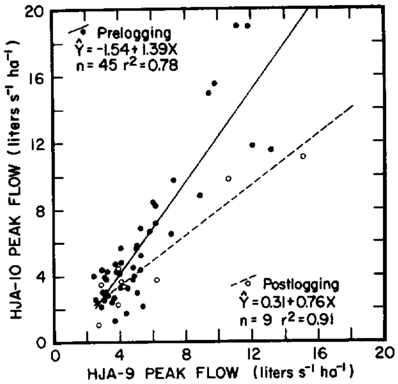

Fig. 2. Peak flow relationships between watersheds for snow events of >2.2 l/s/ha.

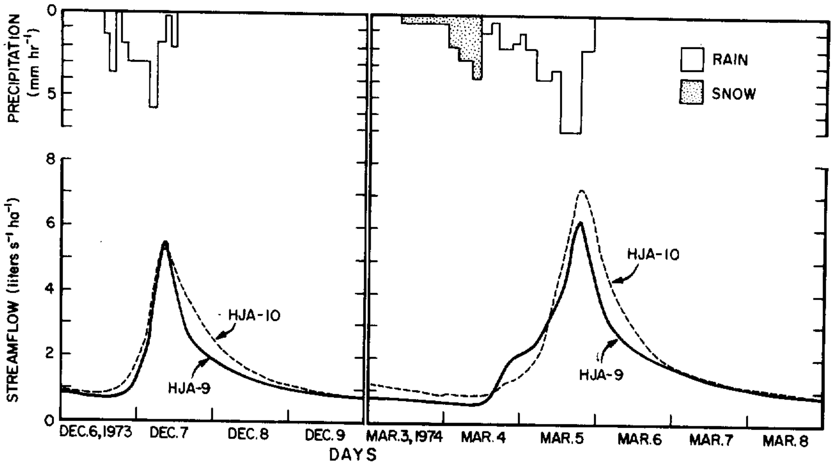

Fig. 3. Storm hydrographs for prelogging period.

ated with a relatively deep snowpack (25–50 cm of snow with about 10–20 cm of water equivalent) and little or no snowfall as storm precipitation.

There were slight differences in watershed characteristics, such as aspect, topographic shading, and forest canopy density, which logically could have accounted for differences in runoff under the two broad categories of snow conditions described above. But any discussion of cause and effect here would be highly speculative without additional information about snow conditions.

According to snowmelt indices for forested and open areas developed to forecast floods [*U.S. Army Corps of Engineers*, 1960], timber cutting could increase substantially the rate of snowmelt during rainfall. Yet, to our knowledge, there has been no research on this type of snowmelt and how it is affected by timber cutting in the Pacific Northwest. This research, which appears to be long overdue, must be designed to relate snowmelt to the meteorological variables that influence melt rather than simply try to relate melt to gross climatic measurements that are usually part of rain hydrology studies, as we have done here.

CONCLUSIONS

We conclude that removing trees most likely altered snow accumulation and melt sufficiently to affect peak flows even though postlogging snow peak flows resulted generally from only small amounts of snow, i.e., water equivalents of >2 cm.

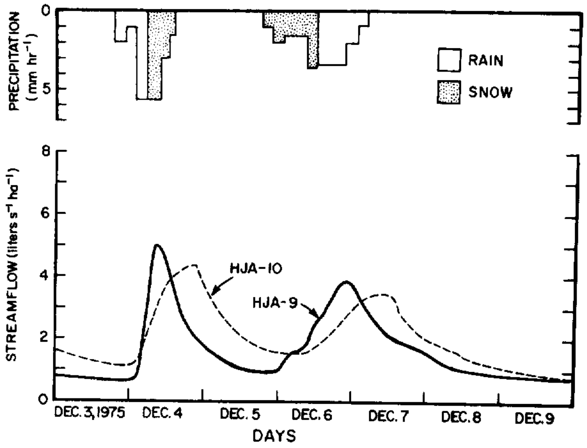

Fig. 4. Storm hydrographs for postlogging period.

A sizable amount of snow was intercepted by the forest canopy in HJA-9. Snow intercepted by tree crowns had a greater surface area exposed to moist moving air than did snow on the ground in the clearcut areas. Thus snow in tree crowns was more susceptible to condensation-convection melt, the major form of melt in this region [*U.S. Army Corps of Engineers*, 1960]. More rapid melting in tree crowns resulted in precipitation being only temporarily detained by vegetation because melt water rapidly reached the ground under forest trees mainly as drip. *Haupt* [1972] has observed similar rapid melt of snow caught by tree crowns in northern Idaho. On the other hand, precipitation falling as snow in the clearcut watershed reached the ground as snow and melted more slowly because it was less exposed to the various sources of energy for melt. Thus this snow did not affect streamflow as quickly on HJA-10, the clearcut watershed. In HJA-9, the forested watershed, snow melted quickly, and water fell to the forest floor like rain, so that HJA-9 responded hydrologically to the snow as if it were rain. If soil properties were altered by logging, the effect of this alteration was overshadowed by the changes in snow accumulation and melt.

That timber cutting can alter short-term snow accumulation and melt, which in turn can affect storm runoff, is an important consideration in the development of computer hydrology models. If a model is to accurately simulate winter storm runoff in headwater basins of the Pacific Northwest, then it must have a snow model that is based on environmental parameters which adequately describe snow accumulation and melt processes in this region.

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