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# Effects of Clearcutting on Rain-on-Snow Runoff in Western Oregon: A New Look at Old Studies

R. Dennis Harr

*U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station*
*Forestry Sciences Laboratory, Corvallis, Oregon*

Results of updating and reanalyzing streamflow data from studies in two experimental watersheds in western Oregon suggest that clearcut logging has altered snow accumulation and melt enough to have increased the size of peak flows caused by snowmelt during rainfall. In a 96-ha clearcut watershed in the transient snow zone, peak flows with return periods of roughly 3–8 years were higher than predicted by prelogging data. In a similarly clearcut 10-ha watershed, sizes of peak flows caused by melting of relatively deep snowpacks during rainfall were also higher after logging. Higher peak flows indicate a higher rate of water delivery to soils, which, in turn, suggests increased potential for both hillslope and channel erosion.

## Introduction

Although the vast majority of precipitation in the mountains of western Oregon falls as rain, most of the critical hydrologic events from an erosion standpoint are dominated by snow. Rapid melting of relatively shallow snowpacks during rainfall can result in higher rates of water input to soil than would commonly result from rainfall alone [*Harr*, 1981]. This can lead to higher pore water pressures in soils on unstable slopes and higher peak streamflows than would occur from rain alone. Most landslides and channel erosion occur during high flows that result from rapid melting of snow during rainfall. In most rain-on-snow events, rain commonly accounts for 70–90% of total water input, but under some weather conditions snowmelt can contribute over a third of total water input.

Roughly half the commercial forest land in western Oregon is located in the transient snow zone, the range of elevations (about 350–1100 m) where snowpacks accumulate and melt several times each winter. Here, logging is proceeding at a relatively rapid rate. The effect of timber removal on snow accumulation and on subsequent melt during cloudy, rainy periods is controversial from western British Columbia to northwestern California. There is concern that logging, by altering snow accumulation and subsequent melt during rainfall, can increase hillslope and channel erosion by altering the rate of water input to soils and by increasing the size of peak streamflows [*Christner and Harr*, 1982].

The processes involved in snowmelt during rainfall have been described by the *U.S. Army Corps of Engineers* [1956]. Although the components of the general snowmelt equation are the same everywhere, their relative importance varies from place to place. In western Oregon snowpacks in the transient snow zone typically remain at or near 0°C. Net shortwave radiation, the major source of energy for melt in most of the United States, is relatively unimportant during predominantly cloudy winter weather in western Oregon. The major source of energy for melt during rainfall is the convective transfer of sensible and latent heats from the atmosphere to the snow [*U.S. Army Corps of Engineers*, 1956]. Because the convective transfer of energy for melt depends on windspeed and turbulence, *Harr* [1981] hypothesized greater rates of melt and water input to slopes after clearcut logging. Net longwave radiation flux and the heat contained in warm rain are also important sources of energy during rain-on-snow conditions but are of less concern because they can be altered less by clearcut logging.

Despite a fairly strong physical basis, the hypothesis seems to be contradicted by published results of two case studies conducted in the western Cascade Range in Oregon. In one study, *Rothacher* [1973] reported that sizes of major peak flows were mainly unchanged during 5 years after clearcut logging, and in the other, *Harr and McCorison* [1979] described lower, delayed peak flows in a small watershed the first year after clearcut logging. Both papers are being cited by authors dealing with effects of logging on streamflow and hillslope and channel erosion processes. *Lyons and Beschta* [1983], for example, list change in snowmelt during rainfall as a possible cause for increases in size of peak flows they observed in the Middle Fork of the Willamette River in Oregon. They then discount it, citing *Rothacher*'s [1973] summary of changes in size of peak flows after timber harvest along with the *Harr and McCorison* [1979] paper. Both papers have also been used to downplay potential effects of clearcut logging on peak streamflows in coastal British Columbia (R. P. Willington and A. N. Chatterton, unpublished manuscript, 1983). And Rothacher's paper was used to help support the contention that the presence or absence of forest vegetation has no bearing on major rain-on-snow runoff in the Cascade Range in Washington [*Hess*, 1984].

Updating and reexamining the *Rothacher* [1973] and *Harr and McCorison* [1979] studies should be helpful, specifically as they relate to the hypothesis of greater snowmelt and water input to soil after logging. Pertinent questions include (1) do results of updating and reanalysis suggest different conclusions than those reached by Rothacher and by Harr and McCorison? and (2) do the updated and reanalyzed data support the contention that the presence or absence of forest vegetation has no effect on rain-on-snow runoff as *Hess* [1984] concluded? The purpose of the updatings and reanalyses is not to discredit either case study but rather to answer these two questions.

Both studies were conducted in the H. J. Andrews Experimental Forest 72 km east of Eugene, Oregon. All experimental

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TABLE 1. Summary of Watershed Characteristics and Harvesting Activities

| | HJA-1 | HJA-2 | HJA-9 | HJA-10 |
|---|---|---|---|---|
| Area, ha | 96.0 | 60.3 | 8.5 | 10.2 |
| Elevation range, m | 441–1013 | 526–1067 | 436–719 | 433–664 |
| Aspect | west/northwest | northwest | west/southwest | west/southwest |
| Type of cut* | clearcut | uncut | uncut | clearcut |
| Percent cut | 100 | 0 | 0 | 100 |
| Residue disposal | broadcast burned† | none | none | piled and burned‡ |

*HJA-1 was logged between 1962 and 1965. HJA-10 was logged in 1975.

†Logging residue was burned in 1967.

‡Unmerchantable logging residue was yarded to a landing at the top of the watershed where it was burned in the spring of 1976.

watersheds (Table 1) in the studies are within the transient snow zone. Annual precipitation at the elevation of the stream gages averages 2340 mm, of which usually less than 5% falls as snow. Differences in snow accumulation between logged and unlogged areas have varied with air temperature. Greatest differences have occurred after a series of snowfalls at or followed by air temperatures above freezing when melt rate of intercepted snow has exceeded that of the snowpack in clearcut areas [*Berris*, 1984]. Snow redistribution by wind is minimal in most winters. In some years, snow accumulates to depths of 150–250 mm 6–10 times per year at elevations above 825 m.

Slopes are steep, and all watersheds originally supported old growth Douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco) and western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) forests. Streamflow measurement was begun in watersheds HJA-1 and HJA-2 in 1952 and in HJA-9 and HJA-10 in 1967. HJA-1 was clearcut between 1962 and 1966, logging residue was broadcast burned in 1967, and the watershed currently supports Douglas fir 10–15 yr old and various shrubby species. HJA-10 was clearcut in 1975 and currently supports brush and 10-yr-old Douglas-fir. HJA-2 and HJA-9 have remained unlogged. Neither study had any provisions for detecting changes in snow accumulation or subsequent melt during rainfall because, at the time the studies were initiated, snow was thought to be important only in extreme cases [*Rothacher et al.*, 1967]. Differences in snow accumulation and melt between logged and unlogged watersheds have been deduced from measurements [*Berris*, 1984] and observations made during similar conditions elsewhere in the experimental forest.

## THE HJA-1 AND HJA-2 CASE STUDY

### *Review*

*Rothacher* [1973] tabulated all peak flows exceeding 1.1 L $s^{-1}$ $ha^{-1}$ (10 $ft^3$ $s^{-1}$ $mi^{-2}$) at unlogged watershed HJA-2 during the prelogging period and corresponding flows at HJA-1, the watershed to be clearcut. A linear regression was developed for the prelogging period to serve as a basis for evaluating change in size of postlogging peak flows in logged watershed HJA-1. A second regression was developed for flows of the same size during the 1965–1969 postlogging period. (Because logging was 70% complete in 1965, this year has been considered a postlogging year.) Analysis of covariance showed that the slopes of the two regressions were significantly different at the 0.05 level of probability; i.e., logging had changed peak streamflow. Most of this general increase appeared to have resulted from drastic increases in size of fall peak flows in logged HJA-1. Wetter soils at the end of the growing season enabled HJA-1 to respond more efficiently to initial fall storms. Because the positions of the upper parts of the two regressions were similar, Rothacher concluded that extremely high peak flows may be no greater after logging than would have been expected before logging. His conclusion, however, does not consider changes in size of moderate-sized peak flows that, because of logging, may have been greater after clearcut logging.

*Rothacher* [1973] also discounted the fact that several of his postlogging peaks, two of which resulted from snowmelt during rainfall, were much larger than predicted because "none of those that were larger than predicted have exceeded previous high stream flow peaks." This argument is irrelevant. If the stream draining a logged watershed is able to dislodge and move substantial amounts of channel material during storm runoff when flows are above a threshold level, whether or not the size of postlogging peak flows were increased to levels higher than the highest prelogging flows is not the important issue. What is important is whether flows that could not have moved sediment or bedload before logging could do so after logging because of higher flows caused by logging-induced changes in snow accumulation and subsequent melt during rainfall [*Berris*, 1984]. In other words, after removal of forest cover, runoff events that transport sediment and bedload may become more common, and those that would have occurred before removal of forest cover may be greater and of longer duration as a result of the removal.

A major problem with *Rothacher*'s [1973] analysis is that all peak flows, large and small, rain-caused and snowmelt-related, were lumped together in accordance with the objectives of his study. The position of the lower end of both prelogging and postlogging regression lines is greatly influenced by the more frequent smaller peak flows, nearly all of which resulted from rainfall alone, primarily in the fall. On the other hand, the position of the upper end of the prelogging curve is controlled mainly by the extremely high peak flow of December 22, 1964, a flow with a return period of roughly 100 yr which resulted in regional flooding. Thus any changes in moderate-size winter peak flows associated with changes in snow accumulation or melt rate may not have been discernible because of masking by the largely unchanged response of HJA-1 to rainfall alone. Also, because *Rothacher*'s [1973] analysis included data from only 5 postlogging years, few postlogging peak flows associated with snowmelt during rainfall were available for inclusion in the analysis, thus limiting the strength of conclusions drawn from this study.

### *Update and Reanalysis*

In updating the *Rothacher* [1973] study, I separated peak flows by size and by type for the 1952–1964 calibration period and the 1965–1982 postlogging period. All peak flows greater than the arbitrary level of 9.8 L $s^{-1}$ $ha^{-1}$ (90 $ft^3$ $s^{-1}$ $mi^{-2}$) at HJA-1 and corresponding flows at HJA-2 were tabulated for both periods. Under unlogged conditions, such flows would have had a return period of roughly 2–3 years. Only flows that resulted from snowmelt during rainfall were included in the analysis; there were 8 such flows in the prelogging period and 18 in the postlogging period.

In most cases, periods of snow accumulation could be identified fairly reliably from air temperature and precipitation records and from streamflow responses relative to rate of precipitation. In other cases, it is likely that snow accumulated at upper elevations of the watersheds but not 500 m lower at the weather station located 50 m below the elevation of the HJA-2 stream gage. Amounts of snow accumulation and water equivalents are unknown because the study was not designed to assess changes in either snow accumulation or melt after logging. Consequently, there is considerable variation in snowpack conditions associated with the rain-on-snow peak flows, and there is no information with which to reduce this variation.

Prelogging and postlogging peak flows and regressions are plotted in Figure 1. The regressions fit the data reasonably well, accounting for 77% of total variance ($r^2 = 0.77$) before logging and 71% ($r^2 = 0.71$) after logging. Of the 18 postlogging peak flows, 13 are located above the regression line that describes the prelogging relationship between watersheds. According to a statistical comparison of slopes and intercepts of the two regression lines [*Neter and Wasserman*, 1974, pp. 160–167], the regressions are significantly different at the 0.10 level of probability. On the average, peak flows associated with snowmelt were higher after clearcut logging in HJA-1. Moderate-size peak flows (roughly 5–9 L $s^{-1}$ $ha^{-1}$ at unlogged watershed HJA-2) appear to have been changed most. Little can be said about the largest flows because there are too few such flows available for analysis.

Because the event of November 22, 1964 (plotted at the extreme left of Figure 1), was the first of the 1965 water year, its position relative to the prelogging regression line is at least partially due to differences in soil water contents between the logged and unlogged watersheds. When this event was omitted from the data analysis, however, results were unchanged; the prelogging and postlogging regressions were still significantly different at the 0.10 level of probability.

## THE HJA-9 AND HJA-10 CASE STUDY

### *Review*

*Harr and McCorison* [1979] reported first-year results of a study to point out the importance of snowmelt during rainfall and the wide range of runoff conditions that can result from logging in the transient snow zone. Their original analysis included all snow-related peak flows greater than 2.2 L $s^{-1}$ $ha^{-1}$ at unlogged watershed HJA-9 and corresponding flows at logged watershed HJA-10 for the 1967–1975 prelogging period. Similar-size flows from the first postlogging year (1976) were also included. According to a test of both slopes and intercepts, regressions computed for each period were significantly different at the 0.01 level of probability.

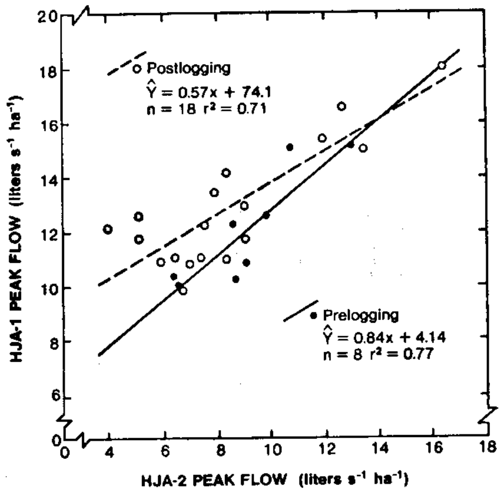

Fig. 1. Prelogging and postlogging peak flows that resulted from snowmelt during rainfall at logged watershed HJA-1 and unlogged watershed HJA-2, H. J. Andrews Experimental Forest, Oregon, 1952–1982.

Many of the postlogging runoff events reported by *Harr and McCorison* [1979] resulted from rain and snow in storms when surface air temperatures were near 0°C. In some instances, when initial storm precipitation was in the form of rain, storm runoff in both logged and unlogged watersheds began simultaneously and proceeded at nearly the same rate. As precipitation changed to snow, interception of snow and its subsequent rapid melt and drip from the canopy allowed forested HJA-9 to continue a "rain response" as indicated by a continued steep rising limb of the storm hydrograph. But logged HJA-10, apparently because its snow had less surface area exposed to melt-causing sources of heat, began accumulating snow that was less susceptible to sensible and latent heat transfer from air. Consequently, melt rate was lower, and the steepness of the rising limb of the HJA-10 hydrograph decreased when rain changed to snow as indicated by air temperature data from a weather station nearby. The shallow snowpack in logged HJA-10 did not melt for several hours, so the hydrograph was delayed and lower.

In other instances, storm precipitation began as snow, and forested HJA-9 again intercepted most snow in tree canopies where it quickly melted. As in the case above, this enabled HJA-9 to show a rain response. The response of logged HJA-10 was delayed in this situation, too, as rainfall was temporarily stored by the snow. As a result, peak flow was lower and delayed several hours in HJA-10.

These precipitation sequences, however, are only two of a number of scenarios involving snow and rain that could lead to different runoff responses between logged and unlogged watersheds. Moreover, it seems unlikely that either would be of any consequence in terms of erosion processes because the amounts of snow involved probably are small if interception and canopy melt could cause major differences in storm runoff between logged and unlogged watersheds. *Harr and McCorison* [1979] had reported these first-year data simply to illustrate unexpected watershed responses to clearcut logging and to illustrate the role of rain-on-snow in these responses.

Of far greater importance are situations in which (1) prolonged rain falls on two snowpacks of dissimilar depths and water equivalents or (2) similar snowpacks exhibit differential melt rates. In the first case, differences in snow accumulation between logged and unlogged areas would result from eliminating canopy interception and melt. Consequently, the clear-

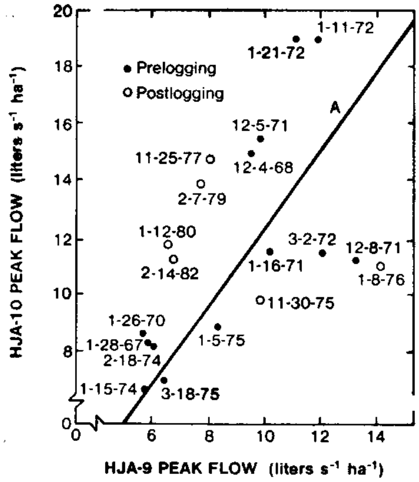

Fig. 2. Prelogging and postlogging peak flows that resulted from snowmelt during rainfall at unlogged watershed HJA-9 and logged watershed HJA-10, H. J. Andrews Experimental Forest, Oregon, 1967–1982. Line A is *Harr and McCorison*'s [1979] prelogging regression.

cut area would accumulate more snow over the course of several small snowfalls and would be able to contribute more water during a subsequent rain-on-snow event [*Harr and Berris*, 1983; *Berris*, 1984]. In the second case, greater windspeed and turbulence in a clearcut area could increase the transfer of sensible and latent heats to the snowpack and also enable a clearcut area to contribute more water during a rain-on-snow event. A combination of both situations would cause a clearcut area to accumulate more snow that would melt at a higher rate during cloudy, rainy weather. Unfortunately, the paucity of snow accumulation melt–data precludes an assessment of the relative frequencies of occurrence of the various melt scenarios at any location in the transient snow zone of western Oregon.

### *Update and Reanalysis*

I reanalyzed postlogging peak flow data after eliminating the smaller snow-related peak flows included in the original analysis. Such peak flows are unimportant in channel erosion processes or as indices of rates of water inputs critical in hillslope erosion processes discussed by *Lyons and Beschta* [1983] and *Hess* [1984]. Included in the reanalysis were only peak flows greater than 5.5 L s$^{-1}$ ha$^{-1}$ at the unlogged watershed, moderate size and larger flows that generally occur several times a year. There were 13 such flows in the prelogging period and 5 in the postlogging period (Figure 2).

As before, separation of peak flows by type of snow conditions was difficult because there is little quantified information about snow accumulation and melt. Again, the separation procedure for rain and snow events was based mainly on air temperature, precipitation, and streamflow records as well as on observations made by field personnel. Thus the procedure did not yield the type of information necessary to explain why the two watersheds have exhibited such a wide range of responses to snowmelt during rainfall in the prelogging period (Figure 3). In many cases, whether or not snow was occurring at the weather station or at the stream gages could be reliably estimated, but little could be said of snow conditions higher in the watersheds with elevations spanning 450 m. In some cases, HJA-10 apparently received more snow than did HJA-9 even though its upper slopes are slightly lower in elevation than HJA-9. Consequently, HJA-10 on occasion has produced more snowmelt water during rainfall than has HJA-9 (Figure 3).

The prelogging regression developed by *Harr and McCorison* [1979] for all 45 prelogging peak flows greater than 2.2 L s$^{-1}$ ha$^{-1}$ at the unlogged watershed does not fit the data for the larger flows very well (Figure 2). Part of the variation of prelogging data points appears to be due to differences in antecedent snowpack. Three of the four flows between 9.3 and 12 L s$^{-1}$ ha$^{-1}$ at HJA-10 (located below the plotted curve) were associated with little or no antecedent snowpack and 30-40 mm of snow water equivalent in storm precipitation. On the other hand, three of the four highest flows at HJA-10 (roughly 15–19 L s$^{-1}$ ha$^{-1}$) were associated with relatively deep snowpacks for the transient snow zone (250–500 mm of snow with about 100–200 mm of water equivalent) and little or no snowfall as storm precipitation.

Similar groupings of postlogging data are evident in Figure 2. Two postlogging peak flows are located far below the plotted regression line, as in the original analysis of first-year peak flows by *Harr and McCorison* [1979]. These two peak flows both resulted from little antecedent snowpack and some storm precipitation in the form of snow (Figure 4). According to snowmelt indices developed by the U.S. Army Corps of Engineers [*Harr*, 1981], snowmelt accounted for only about 7% of total water input during these two runoff events; air temperatures were too low to cause appreciable melt during rainfall. With temperatures only slightly above freezing, differences in wind characteristics between logged and unlogged watersheds would have been irrelevant. Vapor pressure and temperature gradients between the air and snow would have been too small to effect sizable differences in latent and sensible heat transfers, the melt components dependent on air movement.

The other three postlogging peak flows, which were not part of the original analysis, indicate much different relative watershed responses to snowmelt during rainfall. All of these runoff events (Figure 5) were associated with relatively deep (300–450

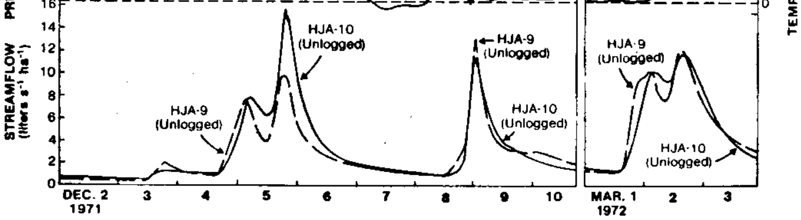

Fig. 3. Streamflow, precipitation, and air temperature associated with selected runoff events in the prelogging period at watersheds HJA-9 and HJA-10, H. J. Andrews Experimental Forest, Oregon.

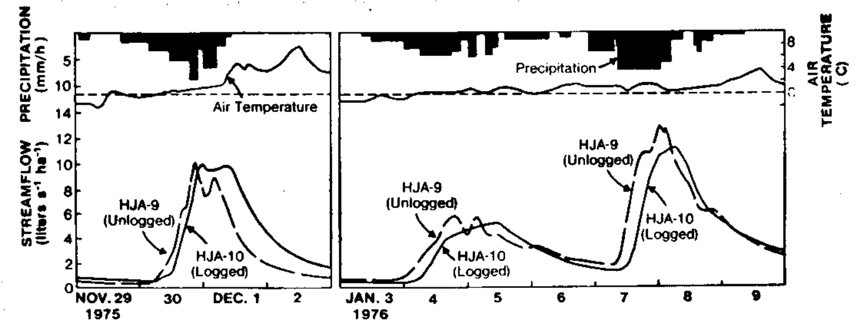

Fig. 4. Streamflow, precipitation, and air temperature associated with selected runoff events in the postlogging period at unlogged watershed HJA-9 and logged watershed HJA-10, H. J. Andrews Experimental Forest, Oregon.

mm) antecedent snowpacks with water equivalents in the range of 100–150 mm. In addition, air temperatures were higher than those preceding the peak flows of November 30, 1975, and January 8, 1976, the events in which peak flows in logged HJA-10 were the lowest relative to corresponding flows in unlogged HJA-9. This is especially true for the events of November 25, 1977, and January 12, 1980. In the 12 h preceding the January 12, 1980, peak, air temperature averaged above 8°C. In the 12 h preceding the November 25, 1977, peak air temperature remained above 6°C and climbed to 13°C at the time of the peak. If winds had accompanied the warm rain, conditions would have been extremely favorable for differences in transfer of sensible and latent heats from the atmosphere to the snow between the logged and unlogged watersheds. High winds did precede the event of January 12, 1980, as is evidenced by an entry on a field crew data sheet that describes a very warm, gusty wind at logged HJA-10. Unfortunately, there is no quantitative wind data available for any rain-on-snow event at either watershed. Weather stations throughout western Oregon, however, commonly measure windspeeds of 5-10 m/s during fall and winter rainstorms, so winds most likely preceded the November 25, 1977, and February 7, 1979, events, too.

## DISCUSSION

The type of storm runoff events included in an analysis obviously affects both the outcome of the analysis and the kind and strength of conclusions that can be drawn from it. Attempting to determine the effects of clearcut logging on snowmelt during rainfall by examining peak flows necessitates using only peak flows that result from snowmelt during rainfall. Thus *Rothacher*'s [1973] inclusion of rain-caused runoff events (in accordance with his study's objectives) seriously restricted observations about how snow accumulation and melt in the transient snow zone might be altered by clearcut logging as is reflected in higher storm flows. Consequently, his conclusions cannot be used to argue against the link between logging and rate of snowmelt during rainfall.

Including only snow-related peak flows in my reanalysis eliminated some but by no means all of the variance in size of postlogging peak flows. Considerable variance remains unaccounted for because of wide ranges of antecedent snow conditions, snow storm characteristics, and climatological variables that combined to produce a range of melt situations and a variety of runoff events. The updating and reanalysis of the *Rothacher* [1973] study did show a difference between prelogging and postlogging peak flow relationships that was statistically significant but at only the 0.10 level of probability.

Similarly, because *Harr and McCorison*'s [1979] postlogging data did not include snow-related runoff events associated with appreciable antecedent snow, their study of the data of the first postlogging year, too, can shed little light on logging-induced differences in rate of snowmelt during rainfall between logged and unlogged watersheds. On the other hand, the updating and reanalysis of data in this study do suggest that, in some instances, snow processes influencing storm runoff have been greatly altered by clearcut logging.

Increased size of peak flows in small, experimental watersheds after clearcut logging, as is suggested by the updatings and reanalyses described here, has implications for several water-related processes both on-site (where logging occurred) and off-site (downstream). First, higher peak flows can directly affect sediment routing on-site in first and second order watersheds similar in size to the experimental watersheds where flow changes are measured. If sediment and bedload materials are available for transport, greater water velocities accompanying higher flows could move more material than would otherwise be the case. Second, higher peak flows in small,

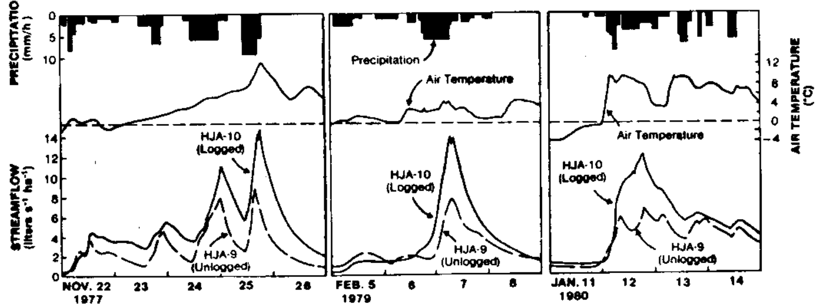

Fig. 5. Streamflow, precipitation, and air temperature associated with selected runoff events in the postlogging period at unlogged watershed HJA-9 and logged HJA-10, H. J. Andrews Experimental Forest, Oregon.

experimental watersheds can indicate increased rate of water delivery at a point downstream where increased flows from logged areas would be additive. This may be one cumulative effect of logging in western Oregon as *Christner and Harr* [1982] suggested for fourth- and fifth-order streams whose watersheds have undergone different rates of logging.

A third implication of increased size of peak streamflows in small, experimental watersheds is that rate of water input has been altered by clearcut logging. Size of peak flow is directly related to the rate of water input to the soils of a watershed preceding the peak flow [*Rothacher et al.*, 1967]. A greater rate of water delivery to the soil surface on site can lead to localized saturation of soil and increases in pore water pressures sufficient to trigger landslides that in turn could deposit debris in streams downslope. Thus on-site changes in water routing can indirectly affect sediment delivery downstream and the channel erosion that *Lyons and Beschta* [1983] associated with such sediment in higher-order streams.

Where do these updatings and reanalyses leave us in the concern about how removal of forest cover affects rate of snowmelt during rainfall? One could argue correctly that they do not show conclusively that removal of cover by clearcutting in the transient snow zone increases rate of snowmelt during rainfall sufficiently to increase peak streamflows. That was not the intent. They do suggest that rate of melt has been drastically altered in some cases, but our understanding of the rain-on-snow phenomenon and runoff production in general is inadequate to take the argument farther. Additionally, the updatings and reanalyses not only suggest conclusions different from those made by *Rothacher* [1973] and *Harr and McCorison* [1979], they also support the hypothesis of higher rates of water input to soil after clearcutting.

Perhaps equally as important as what the updatings and reanalyses do support is what arguments they do not support. In an analysis of the role of logging in channel erosion during major rain-on-snow runoff in the Washington Cascades, *Hess* [1984], citing the *Rothacher* [1973] study among others, states that wet mantle flood peaks (which include nearly all rain-on-snow runoff in the Pacific Northwest) are not affected by the presence or absence of vegetation. Neither *Rothacher*'s [1973] nor *Harr and McCorison*'s [1979] study can support this argument because neither was designed to address the effects of logging on rain-on-snow. And the updatings and reanalyses suggest that the presence or absence of vegetation may indeed be a critical variable in many situations.

Results of the reanalyses described here and other information [*Anderson and Hobba*, 1959; *Christner and Harr*, 1982; *Lyons and Beschta*, 1983; *Harr and Berris*, 1983] raise some interesting questions about the effects of logging on soil water relations and runoff during rain-on-snow conditions. How should this information be used in making forest land management decisions? If changes in water input and runoff can be suggested but not demonstrated conclusively, should prudent land stewardship call for both public and private forest land managers to incorporate such changes in their planning even though they cannot yet be shown conclusively?

A few field studies are attempting to examine the rain-on-snow phenomenon in western Oregon and elsewhere to determine how it is affected by clearcut logging. Preliminary results have been reported [*Beaudry and Golding*, 1983; *Harr an* *Berris*, 1983], but until these studies and future ones have bee completed, questions about the effect of logging on snowmel during rainfall cannot be answered conclusively.

## SUMMARY

The updating and reanalysis of *Rothacher*'s [1973] data suggest that clearcut logging has altered snow accumulation and melt sufficiently to have affected size of peak flows resulting from snowmelt during rainfall. A similar updating and reanalysis of *Harr and McCorison*'s [1979] data, although less conclusive, also indicates that snow accumulation and melt both may have been altered by clearcut logging. Care must be used in selecting published reports to support a particular position in the logging-snowmelt question.

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## REFERENCES

Anderson, H. W., and R. L. Hobba, Forests and floods in the northwestern United States, *Int. Assoc. Sci. Hydrol. Publ.*, *48*, 30–39, 1959.

Beaudry, P., and D. L. Golding, Snowmelt during rain on snow in coastal British Columbia, in *Proceedings of the 51st Western Snow Conference*, pp. 55–66, Colorado State University, Fort Collins, 1983.

Berris, S. N., Comparative snow accumulation and melt during rainfall in forest and clearcut plots in western Oregon, M.S. thesis, 152 pp., Oregon State Univ., Corvallis, December 1984.

Christner, J., and R. D. Harr, Peak streamflows from the transient snow zone, western Cascades, Oregon, in *Proceedings of the 50th Western Snow Conference*, pp. 27–38, Colorado State University, Fort Collins, 1982.

Harr, R. D., Some characteristics and consequences of snowmelt during rainfall in western Oregon, *J. Hydrol.*, *53*, 277–304, 1981.

Harr, R. D., and S. N. Berris, Snow accumulation and subsequent melt during rainfall in forested and clearcut plots in western Oregon, in *Proceedings of the 51st Western Snow Conference*, pp. 38–45, Colorado State University, Fort Collins, 1983.

Harr, R. D., and F. M. McCorison, Initial effects of clearcut logging on size and timing of peak flows in a small watershed in western Oregon, *Water Resour. Res.*, *15*(1), 90–94, 1979.

Hess, S., Timber harvesting and flooding, *J. Soil Water Conserv.*, *39*(2), 115–117, 1984.

Lyons, J. K., and R. L. Beschta, Land use, floods, and channel changes: Upper Middle Fork Willamette River, Oregon (1936–1980), *Water Resour. Res.*, *19*(2), 463–471, 1983.

Neter, J., and W. Wasserman, *Applied Linear Statistical Models*, 842 pp., Richard D. Irwin, Inc., Homewood, Illinois, 1974.

Rothacher, J., Does harvest in west slope Douglas-fir increase peak flow in small forest streams? *U.S. Dep. Agric. Forest Serv. Res. Pap. PNW-163*, 13 pp., Washington, D. C., 1973.

Rothacher, J., C. T. Dyrness, and R. L. Fredriksen, Hydrologic and related characteristics of three small watersheds in the Oregon Cascades, technical report, 54 pp., U.S. Dep. Agric. Forest. Serv., Pac. Northw. Forest and Range Exp. Stn., Portland, Oreg., 1967.

U.S. Army Corps of Engineers, Snow hydrology, technical report, 437 pp., U.S. Army Corps of Engineers, Portland, Oreg., 1956.

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R. D. Harr, U.S. Department of Agriculture, Forest Service Pacific Northwest Research Station, Forestry Sciences Laboratory, Corvallis, OR 97331.

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