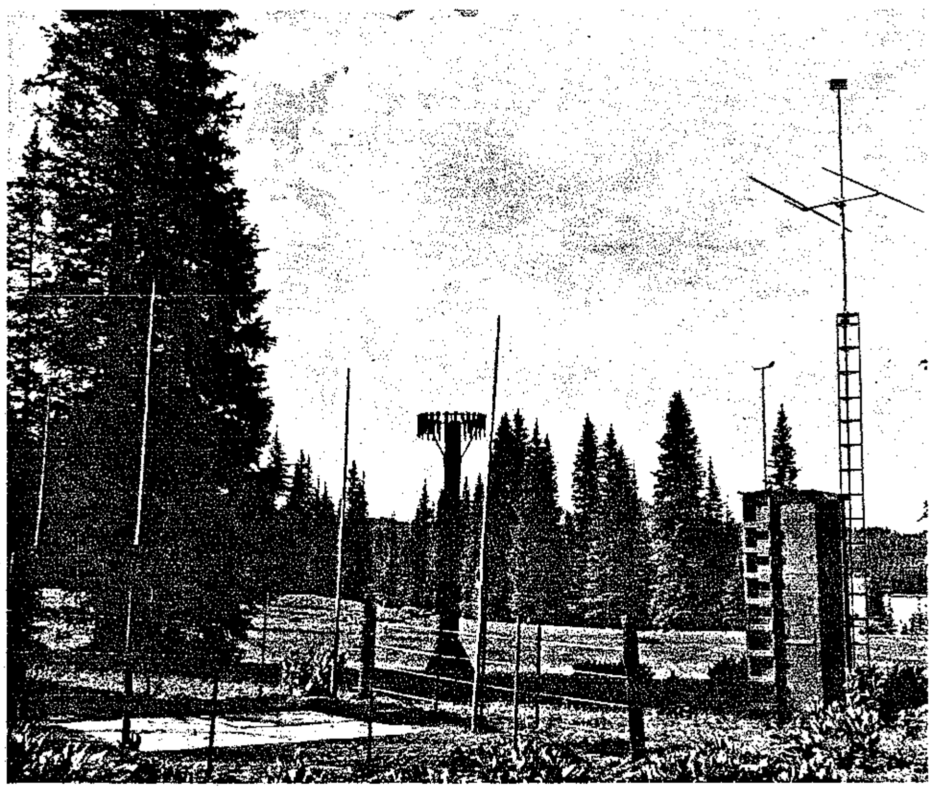
50th ANNUAL MEETING WESTERN SNOW CONFERENCE

April 19-23, 1982

Reno, Nevada



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WESTERN SNOW CONFERENCE

Reno, Nevada

April 19-23, 1982

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PEAK STREAMFLOWS FROM THE TRANSIENT SNOW ZONE, WESTERN CASCADES, OREGON

By

J. Christner[1] and R. D. Harr[2]

INTRODUCTION

Rapid melting of shallow snowpacks during rainfall in the western Cascades of Oregon has contributed to landslides in upland areas, damaging high flows in mountain streams, and downstream flooding. Frequent flooding of cities and farmland led to the the construction of 10 major flood control dams in the middle and upper Willamette River watershed. Bank-full flows in headwater areas are the major mechanisms that form channels, and steep stream channels are eroded and aquatic habitats damaged during high flows. Decisions related to management of National Forest lands must consider the hydrologic function of watersheds and the possible influence of management activities on peak flows, aquatic habitat, and water quality. The National Forest Management Act of 1976 specifically calls for the USDA Forest Service in its planning to consider long-term trends and cumulative effects of management activities on soil and water resources.

In this paper we discuss peak streamflows from watersheds in the Willamette National Forest and some snowmelt factors that may affect the size of these flows. The Willamette National Forest produces nearly 10 percent of the nation's softwood timber for lumber and other wood products. In general, the Forest's land has moderately high productivity, and a sizeable investment has been made in roads, bridges, and forest management activities.

As a starting point we define some terms used throughout this paper:

(1) Peak flow: Maximum instantaneous rate of streamflow.

(2) Rain-on-snow: A general term for conditions when snowmelt occurs during rainfall. Rain heat does melt some snow; but during most conditions, the convective transfer of sensible heat and latent heat from warm air to the snow is the greatest source of energy for melt.

(3) Transient snow zone: Land in a range of elevations over which the snow level fluctuates throughout the winter as warm and cold fronts alternately transit the area. In this zone shallow snowpacks can accumulate and then melt quickly during prolonged rainfall. In western Oregon the transient snow zone is located between about 450- and about 1 200-m elevation.

(4) Warm snowpack: A snowpack whose internal temperature remains at or near freezing throughout its existence. Cold snowpacks occur in areas having a continental climate; warm snowpacks generally occur in the coast ranges of western North America where the winter climate is moderated by the Pacific Ocean.

PAST SNOW HYDROLOGY RESEARCH

The major portion of snow hydrology research in the West has been conducted in the Sierra Nevada of California and in the Rocky Mountains. The central Rocky Mountains are characterized by winter precipitation as snow; and cold snowpacks persist until spring when sufficient energy has been transferred to the snowpack from soil, air, and short- and longwave radiation to initiate melt (Troendle, 1979).

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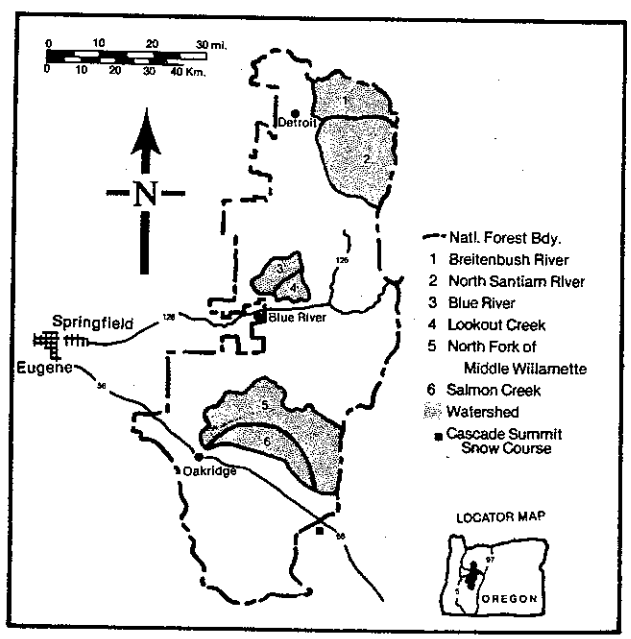
Because considerable energy is required to raise the snowpack's temperature to the melting point, appreciable amounts of meltwater generally are not released until spring. In the northern Rocky Mountains of Idaho and western Montana, winter precipitation may occur as either rain or snow. Melt can occur throughout the winter, but generally a snowpack persists into the spring (Haupt, 1972: 1979). The central Sierra Nevada has a warm snowpack, and occasionally there are warm, rainy periods in winter during which snowmelt occurs, but most melt occurs during clear, sunny weather (United States Army Corps of Engineers, 1956).

Although the sources of energy for snowmelt are the same everywhere, differences in relative importance of these sources exist between the transient snowpack zone of western Oregon and the permanent snow zones of the Rocky Mountains or the Sierra Nevada where the bulk of snow research has been done. In our opinion these differences are hindering our understanding of the so-called rain-on-snow phenomenon and how it might be affected by timber harvest. For example, published accounts of research at the Central Sierra Snow Laboratory have dealt almost exclusively with the processes involved in the accumulation of deep snowpacks, how the pack changes internally, and how vegetation and its removal by logging influences these processes (Anderson et al., 1958; Anderson, 1960; Smith and Halvorsen, 1969; Smith, 1974: 1975). In the transient snowpack zone of western Oregon, many of the short-term accumulation processes are identical to those in the Sierra Nevada but pack development may be substantially different because of its short life. Also, like melt in the Rocky Mountain area, melt in the Sierra Nevada depends to a large extent on shortwave radiation. In contrast, melt of concern in western Oregon generally occurs when there is cloud cover and significant rainfall.

Despite a report by Anderson and Hobba (1959) that argued that the size of rain, rain-on-snow, and snowmelt peak flows of several large streams in western Oregon had been increased by logging, snow hydrology in this region has received little attention. With the exception of a snow accumulation-melt study by Rothacher (1965) in strip cuttings in the permanent snowpack zone in the Oregon Cascades and a recent comparative evaluation of peak flows caused by rain and rain-on-snow (Harr and McCorison, 1979), no snow hydrology research has been carried out in western Oregon since the early 1950's. None of the early work examined effects of timber harvest on rate of snowmelt during rainfall.

THE STUDY AREA

Six watersheds ranging in size from 62 to 637 km^2 were selected for study (Figure 1). Where logging has not been done, slopes are covered with forests of old-growth Douglas-fir and western hemlock or younger post-wildfire stands generally less than 100 yr old. Annual precipitation varies from about 115 cm at lower elevations of the watersheds to over 250 cm at higher elevations. Slope gradients of 80-100 percent are common, soils are highly permeable, and stream drainage densities are high (Table 1). Streams in all watersheds have been gaged by the U. S. Geological Survey for at least 15 yr, and larger streams have over 50 yr of flow records. Management history is available for National Forest lands and was estimated for private inholdings from maps and aerial photographs (Table 2).



Map of the study area

Figure 1

Table 1

Physical characteristics of study watersheds

Stream	Area	Mean elevation	Drainage density	Flow record
	km ^{2}	m	km/km ^{2}	yr
Salmon Creek	303	1 262	1.80	54
N. Fk. Middle Fk. Willamette River	637	1 146	1.86	51
Blue River	119	914	3.17	15
Lookout Creek	62	972	2.61	25
Breitenbush River	275	1 134	2.11	47
N. Santiam River	559	1 134	1.62	54

Table 2

Cumulative area logged as a percentage of total watershed area below 1 200 m elevation

Year	Salmon Creek	North Fork Willamette R.	Blue River	Lookout Creek	Breitenbush River	N. Santiam River
1925	--	2.9	0.3	—	4.0	1.1
1935	1.2	9.9	0.5	—	4.3	3.0
1945	4.1	17.5	0.8	—	4.3	14.4
1950	4.7[1/]	18.1[1/]	1.1[1/]	0.6	5.3[1/]	16.4
1955	5.3	18.7	1.4[1/]	6.9	6.3	18.3
1960	6.2	20.3	2.5	11.4	8.1	20.0
1965	13.0	22.9	5.0	16.1	13.0	23.6
1970	19.2	25.7	5.3	19.4	15.8	25.8
1975	25.3	30.0	11.3	19.9[1/]	17.9	28.9
1977	27.5	30.8	12.7	19.9[1/]	18.8	30.4
1978	27.8	31.0	13.3	20.0[1/]	19.3	31.0
1979	27.8+[3/]	31.3	13.6	20.0[2/]	19.3+[3/]	31.0+[3/]

[1/] Estimated value for interval.

[2/] Timber in small areas was salvaged during 1974-1979 period.

[3/] Exact percentages were unavailable at the time this paper was prepared.

Some weather information is available, but the utility of these records is limited for this analysis. Major problems with the weather data are:

(1) Most weather stations are located in valleys or at low elevations in the mountains and provide little information about weather conditions in headwater areas.

(2) Records are frequently broken, particularly during weekends when observations may not be made. As a result, amounts of daily precipitation on weekends may be combined.

(3) In general, long-term snow course data provide only periodic cumulative amounts of snow and water equivalent rather than daily snow accumulation and melt information.

(4) Antecedent snow conditions for winter rain storms are not well defined.

(5) Location of some weather stations has changed, influencing the utility of records in any analysis.

Although the lack of weather information at higher elevations limits our knowledge of both the form of precipitation and antecedent snow conditions, the network of stream gages operated by the U. S. Geological Survey allows definition of the transient snow zone. Figure 2 shows the relationship between mean basin elevation and magnitude of a peak flow with a recurrence interval of 10 yr. Because watersheds with mean elevations between 450 and 1 200 m receive both rain and snow during winter, snowmelt during rainfall has resulted in higher flows in these watersheds than in watersheds in either of the other two elevation zones. Watersheds with mean elevations below about 450 m do not receive snow frequently enough to have appreciable rain-on-snow runoff, and watersheds with mean elevations above about 1 200 m do not receive rainfall frequently enough while snowpacks exist. Similar plots of peak flows of other recurrence intervals also show that the most active hydrologic zone is between 450 and 1200 m.

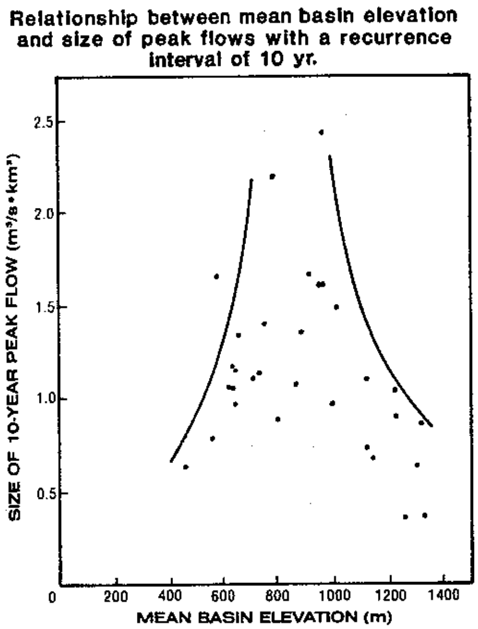


Figure 2

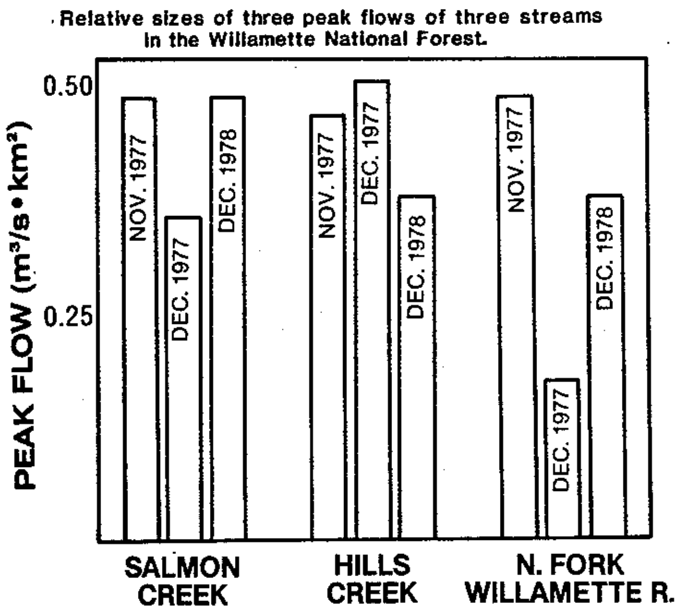


Figure 3

CHANGES IN RUNOFF

In a comparison of peak flows from three rain-on-snow events from 1977 and 1978, three nearby drainage basins appeared to behave differently (Figure 3). Of the three peak flows, the one of November 1977 was the highest for the North Fork of the Middle Fork of the Willamette River (hereinafter, the North Fork), the event of December 1977 was the highest for Hills Creek, and the flow of December 1978 was the highest for Salmon Creek (Christner, 1981). Differences in land use among basins had not changed substantially during the year, nor was there any indication that amounts of precipitation had varied sufficiently among basins to have accounted for the differences in peak flows. One reason for the difference in ranking of these three peak flows among watersheds may be contrasts in snow accumulation and subsequent melting among the three watersheds.

The most widely used method of determining changes in streamflow between two watersheds is the paired watershed technique used in watershed management research. Flow relationships between two watersheds are evaluated before and after one of the watersheds is altered by timber harvest or road construction, and changes in flow are attributed to the alteration. This technique could not be used in this study because timber harvest has been carried out to varying degrees and over an extended period of time in all six watersheds. Thus, there are no true pre- and post-logging periods. For this reason, several other types of analyses were used to detect and evaluate flow changes in the watersheds.

One technique is double-mass analysis, a relatively simple way to detect a change in the hydrologic condition of a watershed (Searcy and Hardison, 1960). In this study, the double-mass analysis consists of plotting cumulative values of peak flows in one watershed over corresponding values of peak flow in another watershed. Figure 4 compares cumulative annual maximum peak flows of Salmon Creek and the North Fork. A change in slope is apparent around 1962; i.e., since 1962, peak flows at Salmon Creek on the average have been about 28 percent larger relative to flows at the North Fork than they were before 1962. The double-mass plot of peak flows of the Breitenbush and North Santiam Rivers shows two changes in slope (Figure 5). Prior to 1940, the slope of the curve is about 1.12, increases to 1.42 during the 1945-1968 period, and then decreases to 1.15, nearly the same slope as before 1940. These slope changes suggest that either peak flows of the North Santiam River during the 1945-1968 period were about 27 percent larger than before 1945, flows of the Breitenbush River decreased 21 percent during the 1945-1968 period, or a combination of both occurred. A check of U. S. Geological Survey records revealed no changes in stream gage rating curves or location of gaging stations that would account for the apparent changes in flow.

Double-mass plot of cumulative peak flows of Salmon Creek and the North Fork of the Willamette Middle Fork. Curve was fitted by eye.

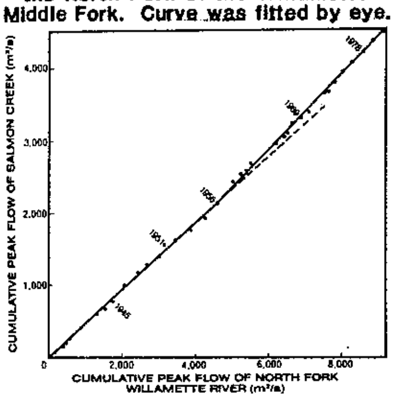


Figure 4

Double-mass plot of cumulative peak flows of the North Santiam and Breitenbush Rivers. Curve was fitted by eye.

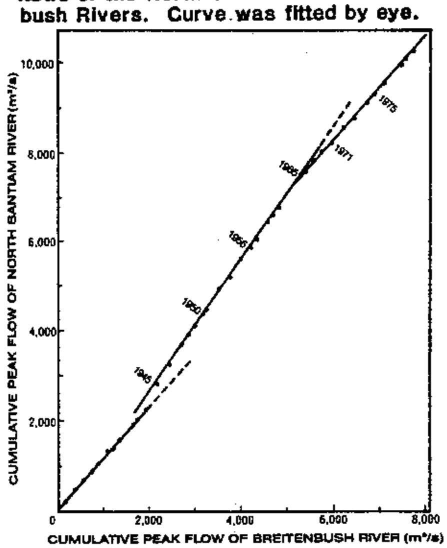


Figure 5

Double-mass plot of cumulative peak flows of Blue River and Lookout Creek. Curve was fitted by eye.

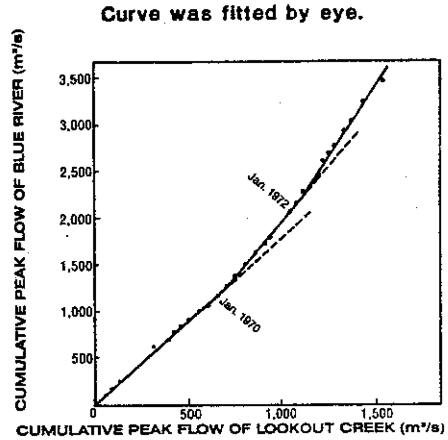
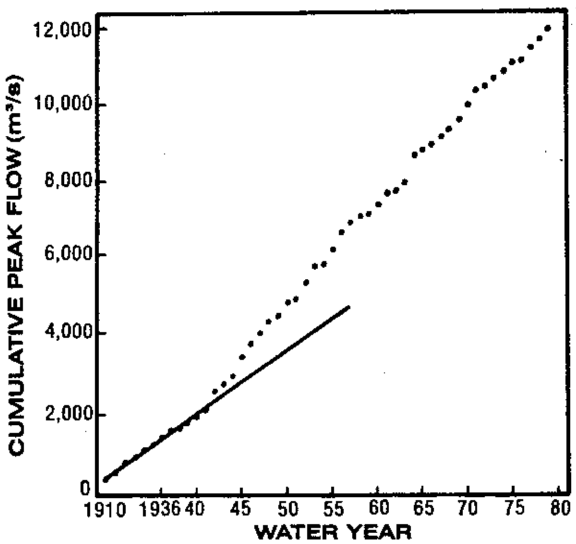


Figure 6

A similar plot of peak flows of Blue River and adjacent Lookout Creek shows a similarly abrupt change in slope around 1970 (Figure 6). Because of the relatively short record of streamflow at Blue River, all peak flows greater than the U. S. Geological Survey's base level were used in order to obtain a greater number of events. Prior to 1970, the slope of the double-mass line was about 1.8. Between 1970 and 1972, slope increased to about 2.3, and then to 2.8 after 1972. These slope changes suggest peak flows at Blue River increased in size relative to those of Lookout Creek by about 27 percent between 1970 and 1972 and 56 percent after 1972. As in the two cases described above, this could be due to increasing size of peak flows of Blue River, decreasing size of peak flows of Lookout Creek, or a combination of both. Again, a check of stream gaging records and procedures revealed nothing that could account for the apparent changes in flow between watersheds.

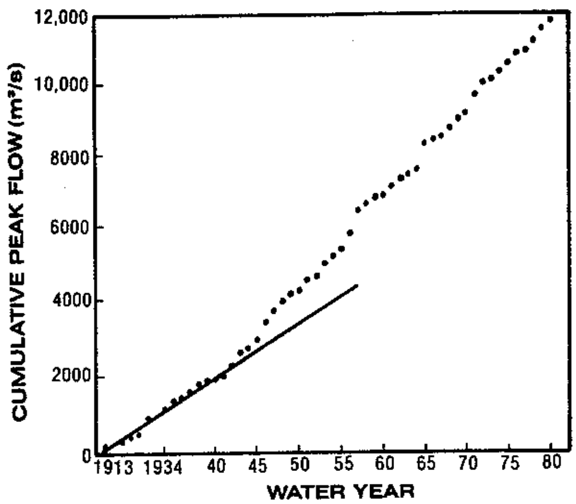
Another simple analysis supports our contention that a change in watershed condition has affected size of peak flows in watersheds of the Willamette National Forest. Plots of cumulative maximum annual peak flows over time show increasing size of flows over the last 30-40 yr for all streams with more than 40 yr of record (Figures 7 and 8). Changes in slope of the curves in Figures 7 and 8 and in similar plots for other streams begin in the early to middle 1940's.

Figure 7



Plot of cumulative peak flow of the North Fork of the Willamette Middle Fork over time. Curve was fitted by eye.

Figure 8



Plot of cumulative peak flow of Salmon Creek over time. Curve was fitted by eye.

Table 3

Coefficients and statistics for relationships between size of peak flow and 3-day antecedent precipitation and between time and deviations of predicted flows from the prediction equation

	$\hat{Y} = a + bX$ 1/					$\hat{Y} = a + bX$ 2/	
Stream	a	b	r^2	n	F	a	b
Lookout Creek	32.5	4.74	0.24	20	5.67 3/	-35.59	20.0
Blue River	112.1	8.04	0.15	10	1.37	-- 4/	-- 4/
Salmon Creek	45.8	10.5	0.47	21	17.1 3/	-1454	26.0
North Fk. Willamette R.	1325	179	0.50	21	20.0 3/	-101.8	54.0
Breitenbush River	190.2	5.22	0.18	22	4.68 3/	-108.2	58.7
N. Santiam River	110.0	14.5	0.38	21	18.8 3/	-106.2	59.5

1/ Y = Predicted peak flow (m^3/s), and X = 3-day precipitation (cm).

2/ Y = Deviation from regression (m^3/s), and X = time (yr).

3/ The equation is significant at the 0.05-level of probability.

4/ Equation for deviation of predicted peak flow from regression was not determined because the regression was not significant.

A third analysis was made to detect a change in watershed condition over time. Regression analysis was used to predict size of peak flow as a function of 3-day precipitation which includes both rain and snow. For all streams, all peak flows with a recurrence interval greater than 2 yr were tabulated along with the sum of precipitation on the day of the peak flow and that of the previous two days. A regression equation was developed, and the residuals or deviations of individual data points from the regression equation were plotted over time. As shown in Table 3, there has been an increasing trend over time in all cases, i.e. the slope of the regression line for deviations of individual data points over time is positive. This suggests that prediction equations based on antecedent precipitation have been more likely to underestimate sizes of peak flows in more recent years. Flows with the greatest deviation from the prediction equations could have resulted from rain-on-snow, but available weather data did not allow us to separate runoff events according to causal mechanism.

CAUSES OF PEAK FLOW CHANGES

We admit each argument such as double-mass curves and plotting of residuals over time is not strong if it is considered alone. We feel, however, that results of all analyses, if considered collectively, do support our view that the hydrologic conditions of these six watersheds have changed. We believe these analyses have detected trends that are real and that indicate subtle, cumulative changes in the hydrologic conditions of the six watersheds. And most importantly, we believe that timber harvest activities are responsible for the changes in size of peak flows.

Timber harvest began in the 1920's in four of the watersheds, in the 1930's in one, and in the 1950's in two others. Harvest has continued in five of the six watersheds. In the remaining watershed, that of Lookout Creek, logging began in the early 1950's and continued until 1970. Since that time, only salvage logging or logging as part of research projects has been done in the Lookout Creek watershed, which is also the H. J. Andrews Experimental Forest.

There are a number of plausible explanations for these apparent changes in hydrologic condition. First, is climatic change. If rainy seasons are wetter now than they were 30-40 yr ago, the 3-day antecedent precipitation may have a greater possibility of falling on already wet soils and producing a larger peak flow. Such a change in climate would also affect the shape of plotted curves in only Figures 7 and 8 where time occupies one axis. In Figures 4, 5, and 6, climatic change would not affect the shape of the curves because streamflow, a partial product of climate, occupies both axes, and climate would have changed in the same way on two adjacent watersheds. Also, there may have been changes in the proportion of storm precipitation occurring as snow at different elevations that could magnify slight elevational differences between watersheds, there are no snow data to evaluate this possibility. Between 1945 and 1970, average annual precipitation and runoff were both above respective long-term averages. Because relationships between peak flow and annual streamflow indicate peak flows before 1945 were greater for a given value of annual streamflow than between 1945 and 1970, climatic change does not appear to have caused flow increases.

The other broad area of possible influences on watershed behavior involves the effects of logging and associated activities on snow accumulation, snow melt, and the routing of water through watersheds. Numerous studies have shown that more snow is deposited in openings than in forests (U. S. Army Corps of Engineers, 1956; Anderson et al., 1958; Rothacher, 1965). Because most snowpacks in the transient snow zone are relatively wet and cohesive, deposition or redistribution of snow by wind appears less common than in other parts of the West. During snow storms at air temperatures of 1°-2°C, wet snow caught by needles and twigs in the forest canopy has a greater surface area exposed to warm moist air, is quickly melted, and water falls to the forest floor (Harr and McCorison, 1979). Conversely, snow in openings, because it has less surface area exposed to moist, warm, moving air, tends to accumulate. The result is that more snow is deposited in clearcuts than in forests.

A second effect of timber harvest that bears on the question of change in hydrologic condition concerns the energy balance of melting, shallow snowpacks during rainfall. According to the U. S. Army Corps of Engineers (1956), the turbulent transfer of heat from warm, moist air to the snow surface is the major source of energy for melt during cloudy, rainy periods. Recently, Harr (1981) speculated that clearcutting in the transient snow zone could increase rate of snowmelt during rainfall because open areas have higher windspeed and turbulence than do forests. A frequency analysis of 24-h total water input (rain plus snowmelt water) for a site in the transient snow zone of the H. J. Andrews Experimental Forest, shows that an increase in total water input of only 10 percent could cut recurrence interval in half. In other words, after logging, the antecedent snow conditions and frontal storm activity that caused a water input event with a 5-yr recurrence interval under forested conditions could cause a larger event whose recurrence interval would have been 10 yr under forested conditions. Larger runoff events could be becoming more frequent.

Preliminary results from a study being conducted by the Pacific Northwest Forest and Range Experiment Station at various sites in the Willamette National Forest indicate the magnitude of the differences in both windspeed and turbulence between forest and adjacent clearcut areas. In that study, the turbulent exchange of sensible heat and water vapor from warm, moist air is being estimated by a method that uses both average windspeed and the variance in windspeed over short time periods to estimate relative values of K_m, the exchange coefficient for momentum transfer. K_m is then used to index both K_h, the eddy conductivity for heat, and K_v, the eddy diffusivity for water vapor. If both air temperature and humidity are identical in a forest and an adjacent clearcut area during rain-on-snow melt conditions, differences in values of K_m between the forest and the clearcut area would suggest differences in rate of transfer of both sensible and latent heat to the snowpack and in rate of snowmelt, especially during cloudy, windy, rainy periods. As shown in Table 4, differences in values of K_m do exist and appear to persist at least 17 yr. Other data indicate full recovery may require 20-25 yr. These differences, however, cannot be translated directly into similarly-sized differences in snowmelt without extensive frequency analysis of windspeeds for the duration of entire snow seasons. They are presented here simply to indicate that the physical basis for differences in energy balances of melting snowpacks during rainfall does exist between forests and clearcut areas and that recovery of clearcut area from a snowmelt point of view may take several decades.

Table 4

Mean windspeeds $\bar{u}$ and transfer coefficients of momentum K_m for paired forest-clearcut plots. Each line represents one measurement run at a particular site

Site	Age of clearcut	$\bar{u}$		K_m	
		Forest	Clearcut	Forest	Clearcut
		- - - (cm/s) - - -		- - (cm^2/s) - -	
Driptorch	1	55	227	1 092	9 524
Driptorch	1	62	188	449	3 421
Fall Creek	3	37	70	902	2 175
Fall Creek	3	33	58	802	1 148
Dogleg	3	49	171	1 500	2 852
Dogleg	3	95	335	3 093	4 910
Crale Creek	3	45	63	298	624
Crale Creek	3	53	100	1 021	1 322
Rug Mountain	10[1/]	53	99	609	3 602
Rug Mountain	10[1/]	54	115	1 093	2 307
Jasper	17[2/]	29	61	252	858
Jasper	17[2/]	24	96	635	1 716
Jasper	17[2/]	30	73	906	2 145

[1/]Trees numbered 160 per hectare and averaged 1.4 m in height.

[2/]The reforested area was precommercially thinned at about age 16. At the time wind measurements were made, trees numbered 140-165 per hectare and ranged up to 11 m in height.

Relating changes in slope of the double-mass curves in Figures 4, 5, and 6 to percentage of watersheds in forest stands 25 yr old or younger further supports our contention that cumulative harvest has been responsible for the apparent changes in size of peak flows. Figure 9 is a plot of cumulative percentage of the Salmon Creek and North Fork Willamette River basins below 1 200-m elevation that is comprised of clearcut areas 25 yr old or younger. Between 1935 and about 1958, the percentage of the North Fork basin in this category was 2-3 times greater than that of Salmon Creek. By 1960, the percentages were roughly equal, and over the next 10 years, the Salmon Creek percentage was about double that of the North Fork drainage. During this latter 10-yr period, size of peak flows of Salmon Creek increased relative to flows of the North Fork. We believe this increase was due primarily to increased rate of snowmelt during rainfall on clearcut areas, and that the increased rate of snowmelt in turn was due to increased rate of exchange of energy with the snow surface that resulted from increased wind speed and turbulence after removal of forest vegetation.

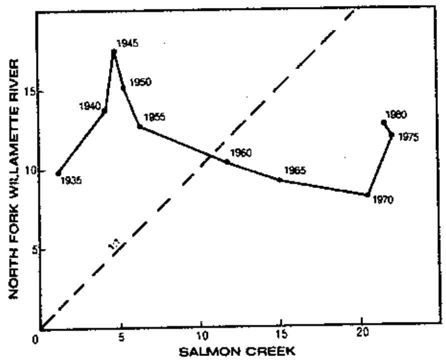
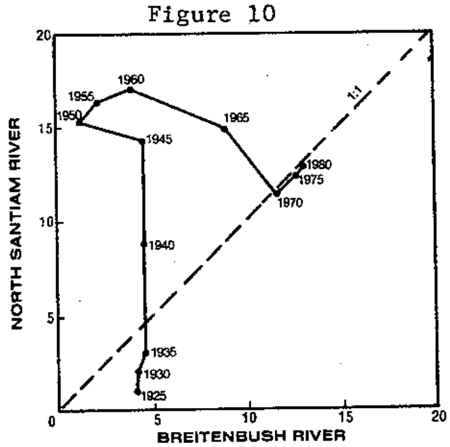


Figure 9

Percent of North Fork Willamette Middle Fork and Salmon Creek watersheds below 1 200-m elevation in forest stands, 25-yr-old or younger.

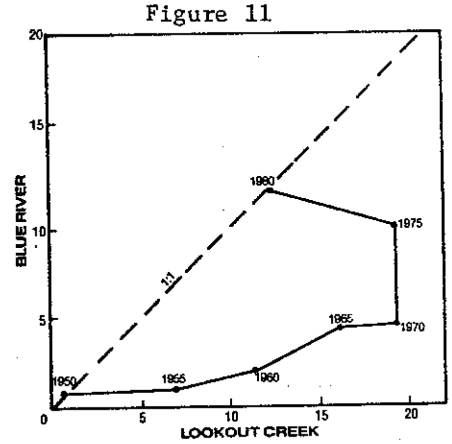
The changes in slope of the double-mass curve of peak flows of the North Santiam and Breitenbush Rivers also appear related to proportion of watersheds in forest stands 25 yr old or younger (Figure 10). Between 1925 and about 1940, percentages of the two watersheds in such a condition were not greatly different. By 1945, however, the percentage of the North Santiam drainage in stands 25 yr old or younger was about three times greater than in the Breitenbush drainage. Figure 5 indicates that peak flows of the North Santiam River were larger between 1945 and the late 1960's, but appear to have decreased to about their former sizes by the early 1970's. We believe the change in slope at about 1945 in Figure 5 reflects increased rate of harvest in the transient snow zone of the North Santiam drainage. Furthermore, we believe the second change in slope at about 1970 does not reflect reduced size of flows in the North Santiam watershed, but rather increased size of flows in the Breitenbush watershed as rate of harvest increased there. It is true the double-mass slope after 1970 is nearly identical to that prior to 1940, but this slope reflects equal percentages of the two watersheds in stands 25 yrs old or younger rather than hydrologic recovery of the North Santiam drainage. Figure 11 supports a similar argument that the change in slope of the Blue River-Lookout Creek peak flow relationship in Figure 6 is the result of not only increased size of peak flows following logging in the Lookout Creek watershed between 1955 and 1970, but also of increased size of flows of Blue River as harvest continues in that watershed.

Figure 10



Percent of North Santiam and Breitenbush River watersheds below 1 200-m elevation in forest stands, 25-yr-old or younger.

Figure 11



Percent of Blue River and Lookout Creek watersheds below 1 200-m elevation in forest stands, 25-yr-old or younger.

A change in the routing of water through a watershed could also account for a portion of the increases in size of peak flows of the six watersheds. Snowpacks in large openings are known to develop more ice lenses due to lower nighttime temperatures than do packs under forest cover (Smith, 1975). During some melt conditions, meltwater may flow over ice lenses to watercourses without entering soil and may contribute to higher rates of streamflow. The frequency of occurrence of ice lenses and their extent within the transient snow zone of western Oregon are not known. The existence of midslope roads has also affected routing of water from managed watersheds. Overland flow from road surfaces and cutbanks and subsurface flow intercepted by ditches are quickly routed to streams through the ditch-culvert system. Although significant increases in size of peak flows in small, experimental watersheds have been detected only where roads, skidtrails, or other compacted soil occupied more than 10 percent of total watershed area (Harr, 1979), this does not mean that small increases in overland flow from many areas of less extensive soil disturbance cannot contribute to higher peak flows in a large watershed of the size dealt with here. Changes in routing of water in subwatersheds can either increase or decrease size of flows in the parent watershed depending on whether the change in routing synchronizes subwatershed flows previously desynchronized or vice versa.

IMPLICATIONS FOR FOREST MANAGEMENT

Although our knowledge of snow hydrology in the transient snow zone of western Oregon is far from complete, we recognize that certain changes in the snow hydrologic system can occur. The physical basis for increased rate of snowmelt after logging does exist in the components of snowmelt that are dependent on windspeed and turbulence. Increased melt results in increased rate of water delivery to soil, and roads and ditches can route surface and subsurface water to streams faster than in undisturbed watersheds. Increased rate of delivery of water to soil can lead to more or larger landslides in areas susceptible to mass erosion. In addition, surface erosion on disturbed soil can increase during periods of high runoff. Faster delivery of more water to streams can cause higher flows and stream velocities that erode banks and channels and move large organic debris. And, because the flow changes we have been discussing have been detected in streams draining relatively large areas, there is reason to believe that changes in peak flows in some smaller basins within the large watersheds could have been much greater. Smaller watersheds tend to have greater proportions of their areas in an altered condition, and harvesting tends to be concentrated in a shorter period of time.

If logging has increased rate of snowmelt during rainfall enough to have increased size of peak flows in six watersheds in the Willamette National Forest, measures should be taken to minimize the possibility of both on-site damage to soil and water resources and cumulative effects downstream. Such measures which, for the most part, are not foreign to management of National Forest lands, include: (1) limiting amount of watershed area in openings created by clearcutting, particularly in the transient snow zone; (2) promptly reforesting logged areas; (3) promoting rapid growth and maintaining a high degree of site occupancy by trees; (4) managing riparian zones to protect streambanks from erosion during high flows; and (5) carefully locating and constructing roads to minimize interruption of both surface and subsurface drainage patterns. Forest land managers have always attempted to accomplish measures (2) through (4) from the standpoint of making the most efficient use of forest land for growing trees. Such activities are also essential for minimizing damage to soil and water resources that might result from logging in the transient snow zone.

RESEARCH NEEDS

Accomplishing measure (1) above could affect the scheduling of timber harvest, and decisions to minimize the amount of openings in a watershed need to be based on established cause and effect relationships. Before we can be assured that forest management activities are not adversely affecting soil and water resources, we need to learn more about the rain-on-snow phenomenon and under what conditions it might be affected by timber harvest. Pertinent questions to be answered by research include:

(1) What is the difference in rate of snowmelt during rainfall between forested and clearcut areas?

(2) What effect does shelterwood cutting have on rate of snowmelt during rainfall?

(3) How do site and stand characteristics influence rate of snowmelt during rainfall?

(4) What stand characteristics can be used to index degree of hydrologic recovery?

(5) How significant are changes in channel stability, slope stability, water quality, and aquatic habitat associated with increased size of peak flows?

SUMMARY

Streamflow records for six watersheds in Oregon's Willamette National Forest indicate hydrologic conditions of the watersheds have changed over the past 4-5 decades. Increased size of peak flows appears related to cumulative effects of timber harvest activities, primarily clearcut logging in the transient snow zone. There is a strong possibility that higher windspeed and turbulence following clearcutting has increased rate of melt of warm snowpacks during rainfall. More rapid delivery of water to soil and to streams increases the probability of landslides and stream channel erosion in headwater areas as well as channel erosion processes downstream. Timber harvest scheduling should take into account both the possibility for changes in snow accumulation and melt resulting from logging in the transient snow zone and the time required for hydrologic recovery. Major tasks for Forest Service Research include determining differences in melt rate between forest and logged areas in the transient snow zone and determining what stand characteristics can be used to index degree of hydrologic recovery of logged areas.

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