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CHANGES IN STREAMFLOW

Following Timber Harvest in Southwestern Oregon

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Contents

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CHANGES IN STREAMFLOW FOLLOWING TIMBER HARVEST IN SOUTHWESTERN OREGON

Reference Abstract

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Changes in size of annual and seasonal yields and instantaneous peak flows were determined on three small, experimental watersheds following three silvicultural methods of timber harvest. Changes are related to changes in forest hydrologic system.

KEYWORDS: Streamflow -)forestry methods, water supply, logging (-hydrology, runoff -)vegetation.

RESEARCH SUMMARY

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Changes in streamflow after complete clearcutting, small patch clearcutting, and shelterwood cutting were determined for three small watersheds in southwestern Oregon. The first year increase in annual yield was 36 cm (39 percent), and increases averaged 29 cm (43 percent) for 5 years in a watershed that was completely clearcut. Increases averaged 6-9 cm (8-14 percent) in the other logged watersheds. Largest absolute increases occurred in winter, whereas largest relative increases generally occurred during fall and summer when maximum differences in soil water content existed between cut and uncut watersheds. Increases in size of instantaneous peak flow appear related to the proportion of a watershed where soil had been compacted during logging and slash disposal. Size of peak flow was increased most in the shelterwood cut watershed where soil was compacted on about 13 percent of the area. Effects of soil disturbance on peak flow may have significance for erosion and for culvert design in headwater areas and for sedimentation downstream, but probably are of little importance for flooding of lowlands downstream. Increases in annual water yield under sustained yield forest management will not augment water supplies appreciably in southwestern Oregon.

Introduction

Shelterwood cutting and small patch clearcutting have been proposed to overcome problems of reforestation in the mixed-conifer zone of southwestern Oregon. In 1962, a study was begun to determine changes in quantity and quality of streamflow following these two harvest methods and to compare them with changes caused by complete clearcutting. Specifically, the objectives of this study are to determine increases in size of annual yield, seasonal yield, and peak streamflow after timber harvest. This report describes changes in streamflow following the first of three phases of timber harvest. Water quality changes will be described in a subsequent report.

That cutting forest vegetation increases streamflow has been known for some time, although the size and duration of increases are known for only a few local areas. Taken collectively, however, water yield improvement studies indicate the range in size of increases that can be expected in various regions (Hibbert 1967). In the maritime climate of western Oregon, two such studies have shown that clearcut logging of entire small watersheds in mountainous topography of the Coast and western Cascade Ranges can cause absolute increases in annual yield that are among the largest in the world (Rothacher 1970, Harris 1973, Harr 1976). Increases in size of peak flows have also been related to timber harvest activities in western Oregon (Rothacher 1973, Harris 1973, Harr et al., 1975). Changes in streamflow have been due to both reduced evapotranspiration which makes more water available for streamflow, increased overland flow caused by soil compaction during roadbuilding, logging, and slash disposal, and interception of subsurface flow by roadcuts and ditches.

Mixed conifer forests cover approximately half of the five-county area making up southwestern Oregon and also extend well into northern California. Old-growth forests contain valuable timber which supports the most economically important industry in the region. These watersheds also yield a major portion of irrigation water for agriculture, the region's number two industry. Streams are also important as spawning and rearing areas for anadromous and resident fish. Natural, low summer streamflow, the demand for irrigation water, and runoff-erosion relationships have made forest-streamflow relations of prime interest and concern to land managers and water resource planners in this region (Hayes 1959, Hayes and Herring 1960).

Study Area

WATERSHED CHARACTERISTICS

The four Coyote Creek Experimental Watersheds are located about 55 km southeast of Roseburg, Oregon, at the head of Coyote Creek, a small tributary of Buckeye Creek which flows into the South Umpqua River. Watersheds range in size from 48.6 to 69.2 ha and generally have well-defined boundaries (fig. 1). Watershed aspect ranges from east-northeast for CC-1 (Watershed 1) to north for CC-3. Elevation of the watersheds ranges from 730 to 1 065 m above mean sea level.

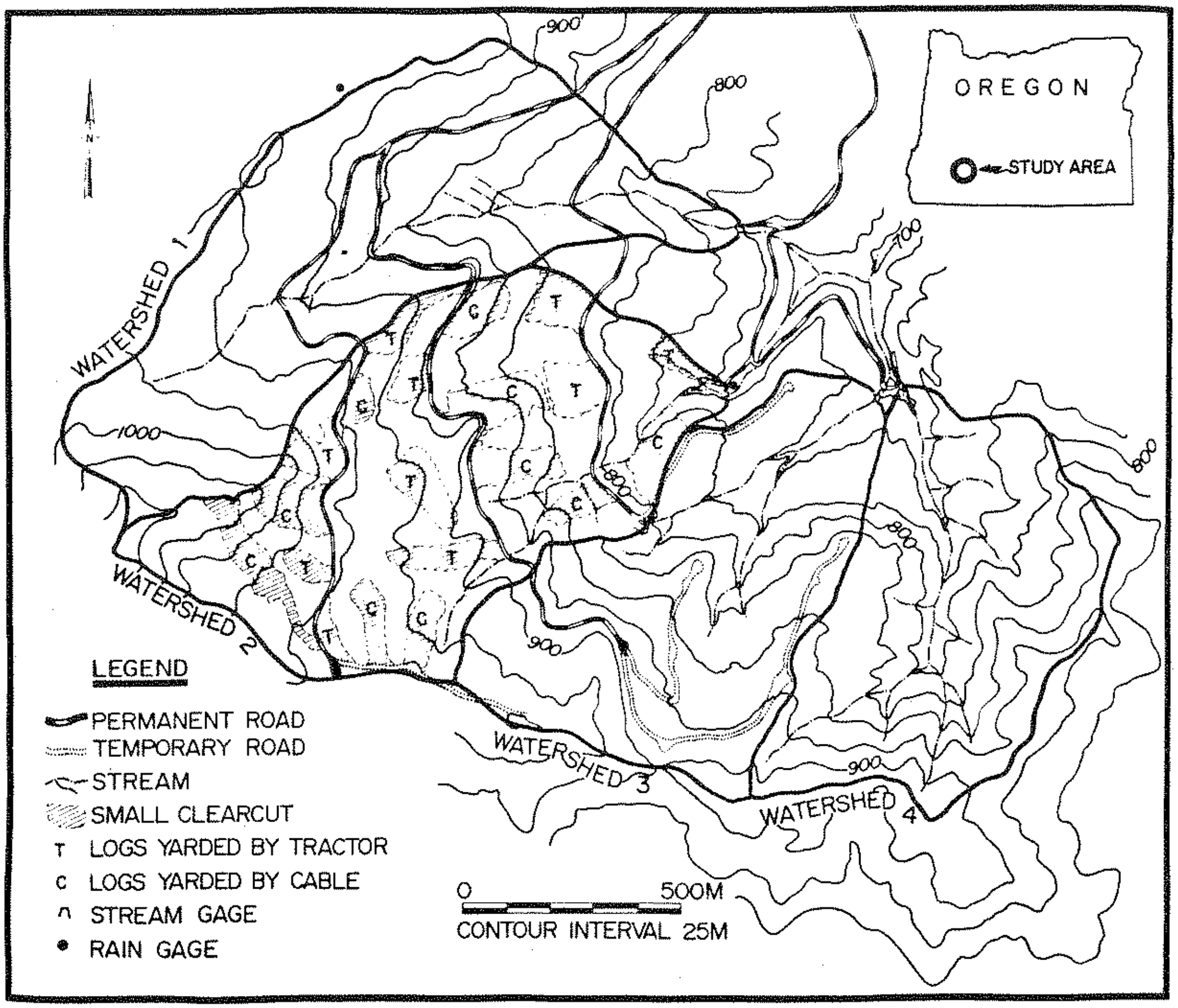


Figure 1.--Map of Coyote Creek Experimental Watersheds.

The watersheds are underlain by the Little Butte Formation, rhyodacitic pyroclastic rocks consisting of welded and nonwelded ash-flow tuffs with andesite and basalt common on ridges (Kays 1970). Although many slopes are relatively smooth, some have poorly developed external drainage patterns that attest to past and present mass erosion processes (Swanson and Swanston 1977). Ranging from 20 to 80 percent, slope gradients of the experimental watersheds are typical of much of the surrounding region.

Two soil series occupy most of the study area (Richlen 1973). Dumont soils are moderately permeable, well-drained gravelly loams at least 150 cm thick, and derived from reddish breccia parent material. Straight soils are similar to Dumont soils but are only 50-100 cm thick. Surface soils of both series have relatively high permeabilities but may be underlain by denser soil layers that impede vertical movement of soil water.

The study area is in the mixed conifer zone (Franklin and Dyrness 1973). Here, Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) of the more mesic regions to the north and west is intermingled with ponderosa pine (*Pinus ponderosa* Laws.), sugar pine (*Pinus lambertiana* Dougl.), and incense-cedar (*Libocedrus decurrens* Torr.) characteristic of warmer, drier sites. Within the watersheds, more mesic habitats contain western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), grand fir (*Abies grandis* (Dougl.) Lindl.), and big leaf maple (*Acer macrophyllum* Pursh). Before logging, both age class and overstory density varied considerably within a watershed as well as among watersheds.

CLIMATE AND STREAMFLOW

The climate of the study area is influenced by the Pacific Ocean 150 km to the west. Annual precipitation at the climatic station adjacent to CC-2 has averaged 123 cm, ranging from 88 cm to 156 cm (table 1). Winters are cool and wet, and summers are warm and dry. Approximately 89 percent of annual precipitation occurs in the October-March period during long-duration, low intensity frontal storms associated with cyclones which originate over the Pacific Ocean. Locally, precipitation caused by frontal activity is augmented by orographic precipitation when moist, unstable air masses move inland. Average daytime temperatures range from -0.5° to 1-5°C in winter and 15°-20°C in summer (fig. 2).

Table 1--Annual precipitation at the climatic station adjacent to CC-2 and streamflow at control watershed CC-4.

Year	Precipitation	Streamflow at CC-4
	- - - - - Cm	- - - - -
1961	115.2	1/ --
1962	122.1	1/ --
1963	124.7	1/ --
1964	115.7	1/ --
1965	124.4	2/ --
1966	107.8	37.5
1967	118.5	53.2
1968	87.6	18.1
1969	110.9	53.4
1970	116.3	51.6
1971	155.7	89.1
1972	153.3	107.0
1973	89.5	28.9
1974	156.5	106.5
1975	122.6	68.9
1976	145.8	75.8
Mean	122.9	62.7

1/ Streamflow measurement began in December 1, 1963.

2/ Stream gage was inoperative from December 1, 1964 to March 19, 1965.

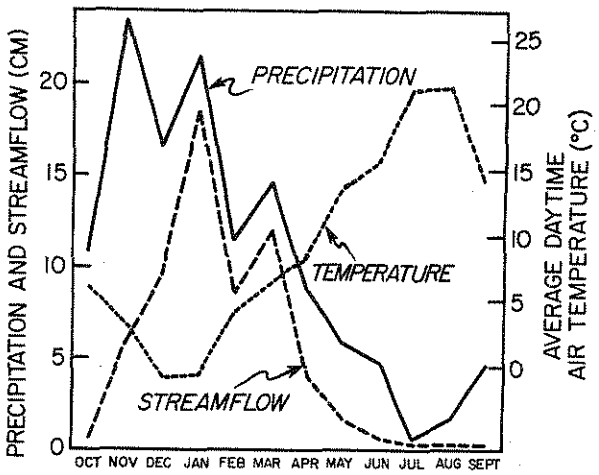


Figure 2.--Monthly precipitation at CC-2 and streamflow at CC-4, 1964-1976, and average monthly daytime air temperature at CC-2, 1970-1973.

Although most precipitation occurs as rain, snow is common, particularly at higher elevations. Occasionally a snowpack may remain for 1-3 months; but in most years, it usually melts within 1-2 weeks. The highest runoff in this region, as in the rest of the Pacific Northwest, has resulted from rapid snowmelt during prolonged heavy rainfall (Waananen et al. 1971, U.S. Army Corps of Engineers 1975).

Streamflow has been measured continuously with 120-degree sharp-crested V-notch weirs (fig. 3) since December 1963. (Streamflow measurements began at CC-1 and CC-2 in 1962, but data prior to December 1963 have been excluded from this study.) Because weir ponds were filled with sediment at CC-1, CC-3, and CC-4 between December 21, 1964 and March 19, 1965, five peak streamflows could not be measured accurately during this period. Data for this period has been excluded from all analyses. An October 1-September 30 water year has been used throughout.

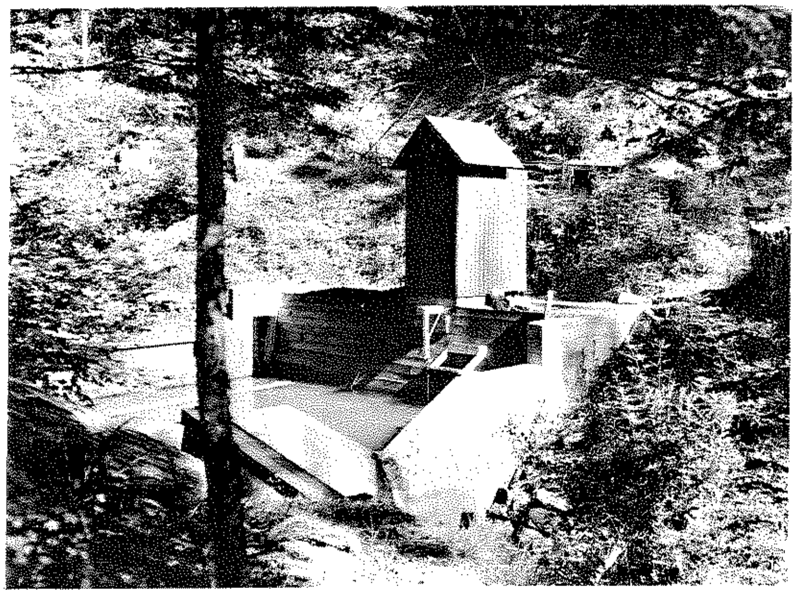


Figure 3.--The 120-degree sharp-crested V-notch weir at CC-1.

During the 1966-1976 period, annual streamflow at CC-4, the control watershed, averaged 63 cm, ranging from 18 to 107 cm. Annual streamflow at this watershed has varied from 21 percent of annual precipitation during 1968, which had the least precipitation of the 11-year period, to about 70 percent during 1972 and 1974, two of the wettest years of the period. Apparent annual evapotranspiration, as estimated from annual precipitation minus annual streamflow adjusted to a unit area basis, has averaged about 61 cm, ranging from 50 cm in 1974 to over 70 cm in 1966. Maximum instantaneous streamflow has been over 4,000 times greater than minimum streamflow.

Watershed Treatments

In this study we used the paired watershed technique. With this technique, a hydrologic variable in one watershed is compared with that in another watershed during the calibration or pretreatment period to establish a relationship between watersheds over a range of climatic conditions. Then one watershed of a pair is treated or altered in some way while the other is left as an undisturbed control. Post-treatment measurements of the hydrologic variable are compared with a prediction of the variable based on the calibration relationship to evaluate changes caused by treatment. Three pairs of watersheds were used in this study.

Road Construction

During the summer of 1970, a system of permanent roads was constructed to provide access for logging (fig. 1). Roads have 5.5-m-wide subgrades and 3.7-m-wide driving surfaces. After subgrade and surface courses were compacted with a vibrating roller, road cutbanks and fill slopes were seeded, mulched, and fertilized in late September (fig. 4). All road construction operations were completed before October 1, 1970.

Figure 4.--Newly constructed road with mulched cutbanks and fill slopes in CC-2.

During road construction, 6.4 percent, 7.6 percent, and 1.6 percent of CC-1, CC-2, and CC-3, respectively, were cleared (table 2). All but about 2 percent of CC-1 and CC-2 and 0.3 percent of CC-3 were revegetated a year after seeding. In general, seeding was successful in preventing surface erosion from road cutbanks and fill slopes.

Logging

Logging began in May 1971 and was completed before September 30, 1971. In CC-1, individual trees making up about 50 percent of total basal area were marked for a preparatory shelterwood cut. Timber was cut and removed after spur roads were constructed to tractor landings scattered throughout the watershed. Cull logs were yarded to landings, but slash was left where it fell. When logging was completed, spur roads and landings were scarified and water-barred. Slightly less than half of CC-1 was disturbed to some degree; 13 percent was compacted (table 3). In addition, some road cuts and ditches have intercepted subsurface flow.

Table 2--Summary of treatment areas in Coyote Creek Experimental Watershed

Percents and areas	Watersheds			
	CC-1	CC-2	CC-3	CC-4
Total area (ha)	69.2	68.4	49.8	48.6
Area in permanent roads (ha)	1.1	1.2	.1	0
Percent in permanent roads	1.6	1.7	.3	0
Area logged in 1971 (ha)	1/ 69.2	20.5	49.8	0
Percent logged:	1/ 100	30	100	0
by tractor	1/ 100	14	23	0
by high-lead	0	16	77	0
Slash disposal by tractor (percent)	0	14	23	0
Slash disposal by high-lead (percent)	0	16	77	0

1/ A preparatory shelterwood cut was made throughout the watershed. Approximately 50 percent of total basal area was harvested.

Table 3-- Soil disturbance resulting from yarding and slash disposal. Figures are frequencies of occurrence expressed as percentages of total observations made at 3-m intervals along transects

Disturbance 1/	CC-1 (Shelterwood)	CC-2 (Small patch-cut) 2/			CC-3 (Clearcut) 2/		
	Tractor	Tractor	Cable	Composite 3/	Tractor	Cable	Composite
	- - - - - - - - - - - - - - - -	-	-	Percent 4/	-	-	- - - - - - - - - - - -
Undisturbed	52	5	42	25	11	44	34
Slightly disturbed	17	25	39	32	26	29	28
Deeply disturbed	9	30	9	19	25	8	12
Compacted	13	26	6	15	27	7	12
Nonsoil areas	9	13	4	8	11	12	12
Bare soil	11	35	15	24	34	9	15

1/ Slightly disturbed = litter removed and mineral soil exposed, litter and mineral soil mixed, or mineral soil deposited on litter and slash; deeply disturbed = surface soil removed and subsoil exposed; compacted = obvious compaction due to passage of machinery or logs.

2/ "Tractor" and "cable" refer to methods of both yarding and slash removal.

3/ Composite figures were obtained by weighting tractor and cable percentages by percent of logged area where logs were yarded by each method. To obtain composite percentages for the entire watershed, multiply by 0.30, the proportion of the watershed that was logged.

4/ Columns do not add to 100 percent because disturbed areas may also be compacted or bare.

In CC-2, timber was harvested in 20 small clearcut patches ranging in size from 0.7 to 1.4 ha which collectively make up 30 percent of total watershed area. Half the patches, those on more gentle slopes, were logged by tractor whereas other patches were logged with a mobile, high-lead cable system (fig. 1). In the tractor logged units, slash was piled by tractor. Soil was compacted on 26 percent of the tractor logged area; only 5 percent of the tractor logged area remained undisturbed. In the high-lead logged units, soil disturbance was less severe. Soil in 6 percent of logged area was compacted and 42 percent was undisturbed (table 3). Road cuts and ditches have intercepted subsurface flow in several areas in this watershed also.

Timber in CC-3 was completely clearcut after spur roads were constructed across the middle of the watershed and along the central ridge. Several wet areas have been exposed and drained by road cuts and ditches along the uppermost road. Timber on 38 ha (77 percent of the watershed) was clean-logged, i.e. all material >20 cm in diameter and >2.4 m in length was yarded to a high-lead landing (fig. 5). Soil was compacted on only about 7 percent of the clean-logged area and 44 percent was undisturbed (table 3). The use of tractors for yarding and for windrowing slash in the area between the stream and the northwestern boundary of the watershed and in two other smaller areas compacted soil on 27 percent of the area and left only 11 percent undisturbed (fig. 5). Slash piles were burned during the fall of 1973.

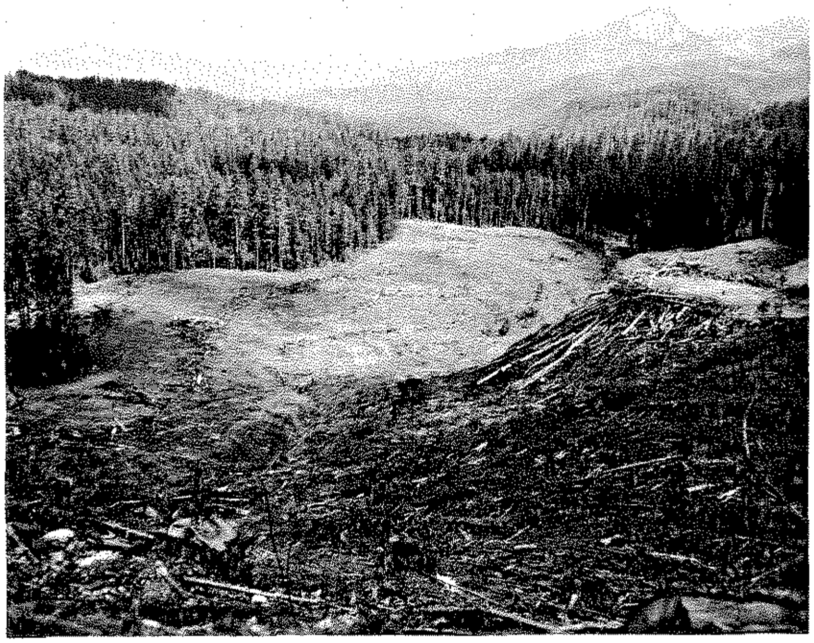


Figure 5.--Seventy-seven percent of CC-3 was clean-logged. All material >20 cm in diameter and >2.4 m in length was yarded to landings one of which is shown at right. Tractor-piled slash on the tractor-yarded northwestern portion of CC-3 is visible in the center of this photograph.

METHODS OF DATA ANALYSIS

Streamflow data were analyzed to determine changes in annual yield, seasonal yields, and instantaneous peak flows after timber harvest. Annual and seasonal yields or flows are total volumes of flow computed for a water year or a season and are expressed as a uniform depth of water over a watershed. Peak flow is the maximum instantaneous streamflow attributable to a particular runoff period and is expressed in liters per second per hectare (liters/sec·ha).

We used simple linear regression to obtain prelogging prediction equations and, for some analyses, postlogging prediction equations. Annual and seasonal flows and instantaneous peak flows at CC-1, CC-2, and CC-3 each were regressed against corresponding flows at CC-4, the control watershed. Each regression analysis is based on the assumption that individual values of a hydrologic variable--either annual flow, seasonal flow, or peak flows--are independent and random. We recognize, however, that independence may not always occur in this type of study.

In the case of annual and seasonal yields, the significance of the difference between prelogging and postlogging data was determined by computing a prediction limit for prelogging conditions. Because timber harvest was expected to increase water yields, we used a one-tailed test for significance of changes in yield at the 0.05 level of probability. Thus, prediction limit is given by $(t_{0.10})(S_Y)$ where S_Y is sample standard deviation of predicted Y, and

$$S_Y = S_{y \cdot x} \sqrt{1 + \frac{1}{n} + \frac{x^2}{\Sigma x^2}}$$

and $S_{y \cdot x}$ = sample standard deviation from prelogging regression, n = number of observations in prelogging regression, and $x = X - \bar{X}$ (Snedecor and Cochran 1956, p. 135-140). The hypothesis was that there is no difference between prelogging yield and postlogging yield. If a particular postlogging annual or seasonal yield exceeded the prediction limit, the hypothesis was rejected in favor of the alternate hypothesis that the yields are significantly greater than prelogging yields.

The significance of the difference between prelogging and postlogging peak flow data was determined by the principle of "extra sum of squares" (Draper and Smith 1966, p. 67-69). This principle tested the hypothesis that there is no difference between prelogging and postlogging 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 periods, respectively (Harr et al. 1975).

Changes in Streamflow

ANNUAL YIELD

In the analysis of annual yields, the calibration period consists of water years 1964 and 1966-70. Because several stream gages were inoperative during part of the 1965 water year owing to bedload filling weir ponds, 1965 data have been excluded from the analysis of annual yield. In addition, data from 1971 have been omitted from the calibration and post-treatment periods because logging was underway during this year and watersheds were in neither an unlogged nor logged condition the entire year.

Prelogging correlation between annual streamflow at the control watershed and annual streamflow at each of the other watersheds used in this study was good. Prediction equations for the 5-year calibration period explain at least 98 percent of the variance in annual yield as indicated by r^2 values in table 4.

Logging operations significantly increased annual yield in all three logged watersheds (fig. 6). Because hydrologic changes caused by timber

Table 4--Summary of annual and seasonal streamflow relationships between logged watersheds CC-1, CC-2, and CC-3 (Y) and control watershed CC-4 (X)

Season	CC-1			CC-2			CC-3		
	$Y = \alpha + \beta X$			$Y = \alpha + \beta X$			$Y = \alpha + \beta X$		
	α	β	r^2	α	β	r^2	α	β	r^2
Full year	-1.93	1.00	0.982	-2.77	0.88	0.990	1.54	0.86	0.991
Fall	-.15	.86	.975	-.58	.89	.987	.04	.93	.997
Winter	22.5	.87	.978	.67	.80	.994	.70	.85	.995
Spring	1.24	.99	.904	-.33	.97	.972	.22	1.04	.980
Summer	.21	1.18	.694	-.16	.49	.771	.05	.98	.605

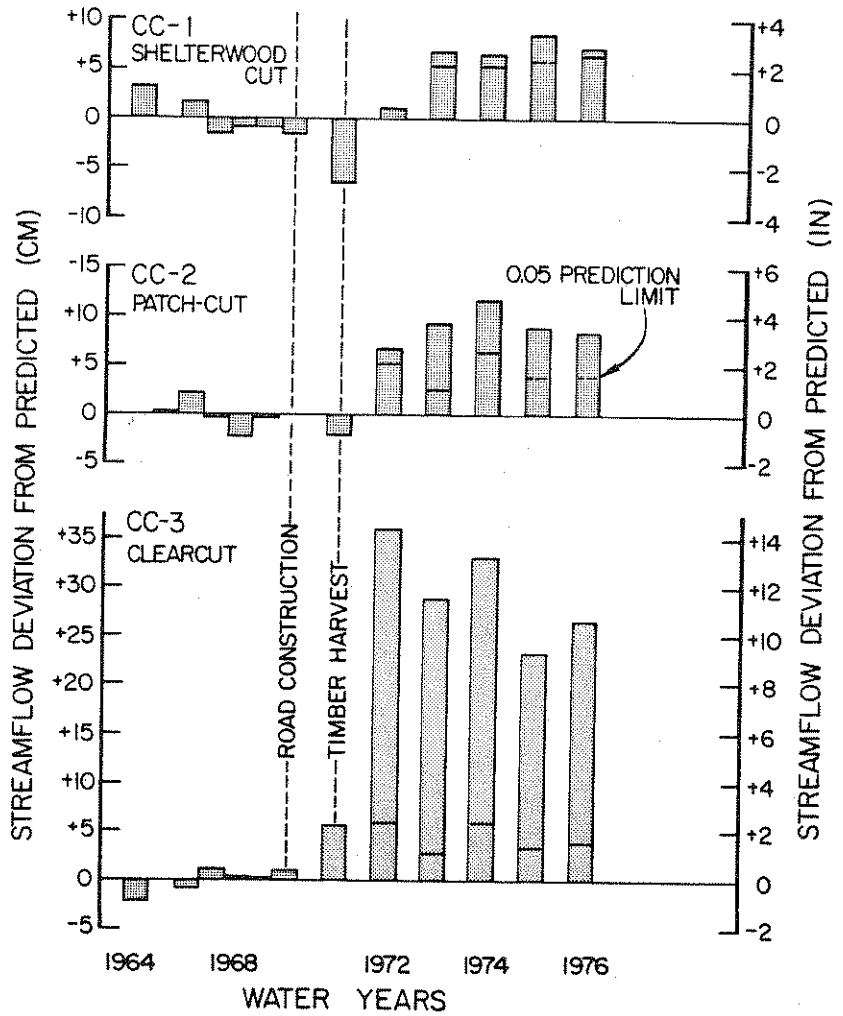


Figure 6.--Changes in annual streamflow after road construction and logging.

harvest cannot be separated from those caused by road building, the "treatment" evaluated here necessarily consists of timber cutting, soil disturbance associated with felling, yarding, and slash disposal, and the presence of roads. Increases in annual yield were largest at CC-3, the clearcut watershed. At CC-3 the first year increase was 36 cm (29 percent), and increases averaged about 29 cm (43 percent) during the first 5 years after logging. Increases averaged about 9.0 cm (14 percent) at CC-2 where small clearcuts and road rights-of-way occupy about 38 percent of the watershed. All post-treatment increases at CC-3 and CC-2 are statistically significant. At CC-1 where about 50 percent of total basal area of timber was harvested in a preparatory shelterwood cut and road rights-of-way occupy about 8 percent of the watershed, increases are significant for all years except 1972, the first year after logging. Increases at CC-1 have averaged 6 cm (8 percent).

Slight downward trends in increases of annual yield are apparent at CC-3 and CC-2 (fig. 6). Several additional years data, however, will be necessary to evaluate these apparent trends. At CC-1, the expected downward trend may be masked by the hydrologic effects of continuing deterioration of the residual forest in this watershed. By 1973 many trees, particularly those adjacent to skid roads and landings, were dead or dying, and additional trees died in subsequent years. Although the causes of death are not known, they appear to be related at least indirectly to damage the trees sustained during shelterwood cutting and to windthrow after logging.

SEASONAL STREAMFLOW

Seasonal streamflow data were analyzed to determine the time of year increases in yield occurred and to help identify the hydrologic processes most likely altered by timber harvesting activities. Monthly streamflow data were placed in four seasonal groups:

10% 1. fall (October - November)
79% 2. winter (December - March)
10% 3. spring (April - June)
1% 4. summer (July - September)

These periods roughly correspond to the major hydrologic seasons. During the fall period, soil water storage is being recharged; on the average, only about 6 cm (10 percent) of annual streamflow occurs in this period. As the winter storm season progresses, soil water storage becomes filled, transpiration decreases, and interception losses become an increasingly small percentage of gross precipitation of individual storms. Monthly streamflow becomes an increasingly large proportion of monthly precipitation. About 49 cm (79 percent) of annual streamflow occurs during the winter period. In spring, monthly precipitation is less, storms are smaller so that greater percentages of gross precipitation are lost to interception, and soil water content decreases as transpiration increases. On the average, spring accounts for only 6 cm (10 percent) of total annual streamflow. In summer, evapotranspiration is at its maximum, rainfall is infrequent, and streamflow generally decreases to annual minimums. Less than 1 cm (1 percent) of annual streamflow occurs during the summer period.

Results of seasonal yield analyses are shown in figure 7. Increases which exceed the 0.05 prediction limit occurred initially during the summer of 1971 when the watersheds were being logged. At CC-3, the totally clearcut watershed, 1971 summer flow was increased 2.2 cm (196 percent). Increases were more modest at the shelterwood cut and patch-cut watersheds. Largest

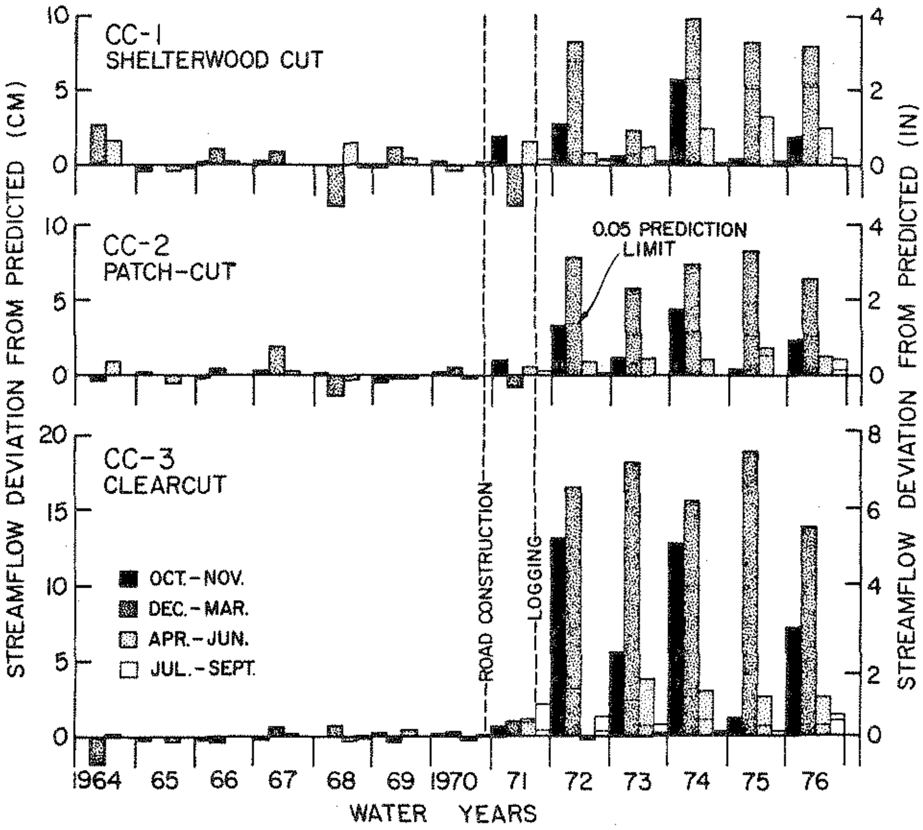


Figure 7.--Changes in seasonal streamflow after road construction and logging.

absolute increases in all postlogging years have occurred in the winter season at all watersheds. Of these, the winter increases at CC-3 have been the largest, averaging about 17 cm (33 percent) the first 5 postlogging years. Winter increases at CC-1 and CC-2 have averaged about 7 cm (14 percent). At all watersheds, fall has been the season of second largest increases, followed by spring and summer. Because of the small size of some increases at CC-1 and CC-2 and because of natural variation in seasonal flows, some increases at these two watersheds are not statistically significant (table 5). All increases at CC-3, however, are statistically significant at the 0.05 level.

Winter increases are large in absolute terms but in many years are smaller in relative terms than increases in other seasons. For example, the winter increase at CC-3 in 1975 was about 19 cm (fig. 7), much larger than the fall increase of 1.2 cm. The fall streamflow, however, was 166 percent greater than predicted flow, whereas winter streamflow was only 37 percent greater than predicted. Relative increases in all seasons are summarized in table 5.

INSTANTANEOUS PEAK FLOW

Instantaneous peak flows greater than 2.2 liters/sec·ha at CC-4, the control watershed, and corresponding peak flows at treated watersheds were tabulated by water year. Postlogging data were then compared with prelogging data to determine if peak flow relationships between treated and control watersheds had changed after logging.

Table 5--Percentage increases in observed seasonal flows after roadbuilding and logging relative to predicted seasonal flows in watersheds CC-1, CC-2, and CC-3

Water year	Fall			Winter			Spring			Summer		
	CC-1	CC-2	CC-3	CC-1	CC-2	CC-3	CC-1	CC-2	CC-3	CC-1	CC-2	CC-3
1971	[1] 25	[1] 13	[1] 8	[2] --	[2] --	[2] --	[3] 17	[3] 7	13	26	65	195
1972	34	39	135	11	11	23	9	11	[4] --	44	[3] 20	134
1973	[3] 55	150	400	16	34	100	[3] 17	[3] 20	59	37	[3] 19	109
1974	34	24	63	16	13	26	[3] 19	[3] 9	24	[3] 19	[3] 5	43
1975	80	200	150	15	17	37	[3] 37	23	30	42	40	46
1976	45	57	138	15	17	27	[3] 29	[3] 17	32	[3] 21	126	70

1/ Increases occurred after roadbuilding.

2/ Winter of 1971 is included in the prelogging period.

3/ The increase is not significant at the 0.05 level of probability.

4/ Measured flow was less than predicted.

As evidenced by the relative positions of the prelogging and postlogging regression lines, size of peak flow was increased substantially after logging in CC-1 and CC-3, but only slightly in CC-2 (fig. 8). In addition, prelogging and postlogging regressions are significantly different only at CC-1 and CC-3 (table 6). For a peak flow of 10.9 liters/sec·ha at CC-4, a peak with a return period of about 9 years, size of corresponding peak flows at CC-1 and CC-3 were increased 48 percent and 35 percent, respectively. At CC-2, the increase was about 11 percent. Relative increases at other flow rates in each watershed may be obtained by comparing prelogging and postlogging regressions at those flow rates.

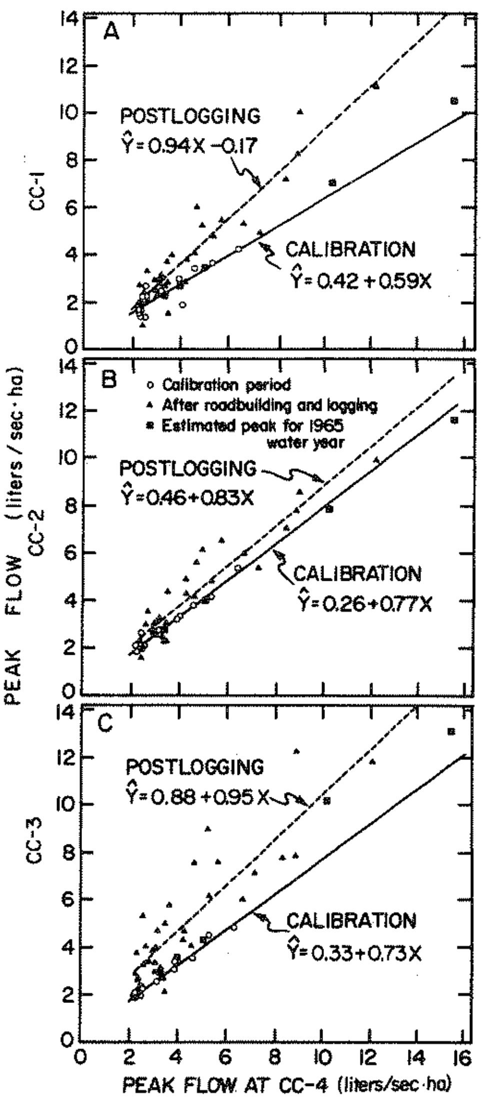


Figure 8.--Changes in peak flow relationships after road construction and logging in (A) *shelterwood cut,* (B) *patch-cut, and* (C) *clearcut watersheds.*

Table 6--Summary of changes in peak flow relationships between control and treated watersheds

Watershed and period	Number of peaks > 2.2 liter/sec·ha	Mean size of peak flow		$\hat{Y} = \alpha + \beta x$			Change at 10.9 liter/sec·ha	F statistic
		Treated	Control	α	β	r^2		
		Liter/sec. ha					Percent	
CC-1								
Calibration	14	2.39	3.34	0.42	0.59	0.77	47	1/ 5.86
Postlogging	32	4.00	4.44	-.17	.94	.89		
CC-2								
Calibration	14	2.82	3.34	.26	.77	.97	10	2.26
Postlogging	31	4.20	4.49	.46	.83	.89		
CC-3								
Calibration	14	2.77	3.34	.33	.73	.98	36	1/ 9.92
Postlogging	33	5.02	4.38	.88	.95	.76		

1/ Calibration and postlogging regressions are significantly different at 0.05 level of probability.

Discussion

WATER YIELD

Diminishing Increases

Although increases in annual and seasonal yields from forested watersheds in the South Umpqua region do occur, they are relatively small in comparison with both natural flows and total water needs for agricultural, domestic, and other users in the region. Such increases are as permanent as the changes in the forest hydrologic system that cause them. In most headwater basins, increases result primarily from reductions in evapotranspiration; both interception losses and soil moisture withdrawals by forest vegetation are drastically reduced so that more water is available for streamflow. But as reforestation proceeds, increases in streamflow will diminish and streamflow should eventually return to prelogging levels. In areas with compacted soil or where subsurface flow is intercepted by road cuts and ditches, increased overland flow may result in reduced soil moisture for evapotranspiration. In addition, these impacts on the hydrologic system may be more persistent than changes in evapotranspiration resulting from timber cutting. With only 5 years of postlogging streamflow data, we cannot accurately determine the rate at which increased annual yield will return to prelogging levels in southwestern Oregon. Studies elsewhere, however, suggest 30-35 years are necessary for yield increases to become negligible (Kovner 1956;

Swank and Helvey 1970). Predicting decline of yield increases is further complicated because we do not know how much of observed increase in yield has resulted from changes in evapotranspiration and how much from soil disturbance.

By using the following example, we can speculate that relatively large increases in water yield from small headwater basins will cause only very small increases in annual yield downstream. Similar examples have been used previously by Rothacher (1970) and Bethlahmy (1974). Consider a 100-km^2 forested watershed that yields 75 cm of water per year--a typical annual flow for this size watershed in the South Umpqua region. Assume that yield increases result entirely from reductions in evapotranspiration and that these increases diminish according to the hypothetical curve in figure 9 which conforms in general to results of other similar experiments (Swank and Helvey 1970). The equation for this curve is:

$$Q_t = Q_1 K^{t-1} \quad (1)$$

where Q_t = increase in annual yield t years after clearcutting; Q_1 = 36 cm, the observed first year increase in yield at CC-3; and $K = 0.9$, a constant which represents the rate of change toward prelogging water yield. (When $K = 0.9$, equation (1) fits the data in fig. 9 reasonably well. Subsequent data will be necessary to determine the true value of K.) If the large, forested watershed is managed with a 100-year rotation and equal areas are clearcut each year, then 1 percent of the watershed will be in a freshly cut condition each year and, according to equation (1), will yield 36 cm more water than if it were uncut. Also, 1 percent of the large basin will yield, Q_2 = 32.4 cm more, 1 percent will yield Q_3 = 29.2 cm more, and so on.

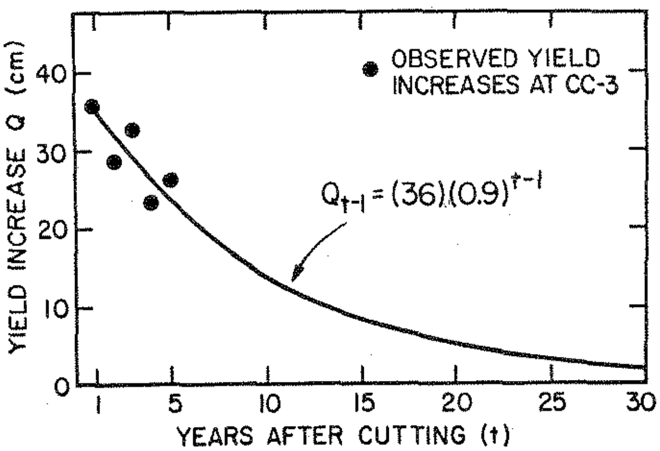


Figure 9.--Diminishing increases in annual yield.

If we assume that yield increases become negligible 30 years after timber cutting, then an area's total yield increase Q_t over 30 years is given by

$$Q_t = \int_1^{30} Q_1 K^{t-1} dt = 343 \text{ cm.} \quad (2)$$

This amounts to an average of 11 cm each year for 30 years. In other words, 30 percent of the large watershed (30 years of a 100-year rotation) would yield 86 cm (75 cm + 11 cm), while 70 percent, having recovered hydrologically or never having been altered, would yield 75 cm. Annual yield for the large basin would be (0.30)(86) + (0.70)(75) = 78 cm, an increase of only 4 percent.

In many cases, increases in annual yield derived from forest cutting in headwater regions of large watersheds could not be detected at the mouth of the watershed. Excellent streamflow records have an error of ± 5 percent which would be about 4 cm for the large basin described above--about the same size of probable increases in annual yield for that basin. Thus, in many years, the increases in annual streamflow could be within the error associated with measurement of annual streamflow and therefore unmeasurable themselves.

A second portion of flow increases detected in the Coyote Creek watersheds resulted from surface soil disturbance and reduced soil permeability caused by roadbuilding, logging, and slash disposal and interception of subsurface water by road cuts and ditches. The hydrologic changes in a watershed caused by permanent roads are permanent. In addition, areas severely compacted by building temporary roads, tractor skidding of logs, and windrowing of slash may not recover fully for many years so that increased flow caused by reduced permeability may exist for a decade or longer. Compaction has persisted 40 and 55 years at two sites in western Oregon (Power 1974). Evaluation of flow increases caused only by soil disturbance, however, is impossible because such increases have occurred concurrently with those caused by reductions in evapotranspiration.

Timing of Increases

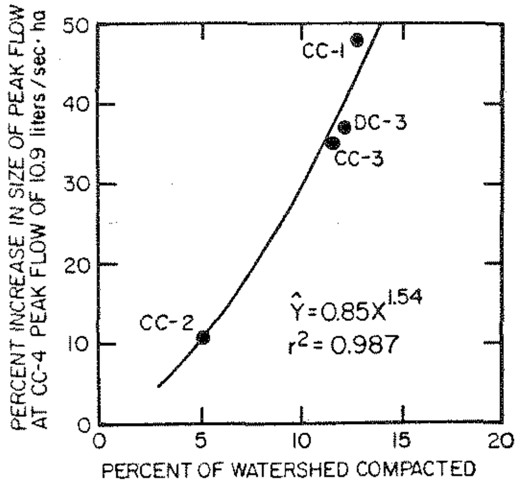
Another important factor that bears on the availability of streamflow increases for use in the South Umpqua watershed is the timing of these increases relative to the timing of water demand. Major increases have occurred during the December through March period when there is an abundance of streamflow but no agricultural demand for water. Conversely, when demand is high in summer, flow increases in that season are of little consequence compared to total demand for irrigation water. Therefore, without storage facilities, water yield increases appear to be of little economic benefit downstream. In addition, largest increases tend to occur during the wettest years when an increase in annual yield would be of least benefit to downstream users (Bethlahmy 1974).

PEAK FLOW

Relation to Soil Disturbance

Increases in size of peak flow appear to be related to amount of watershed area where soils were compacted (figs. 8 and 10). Data for the Deer Creek 3 watershed in the Oregon Coast Ranges also is included in figure 10. The relationship between peak flow and soil disturbance shown in figure 10, however, is oversimplified. This may be misleading because it ignores other factors such as proximity of compacted areas to streams, continuity of compacted areas such that overland flow can reach streams, interception of subsurface water by road cuts and ditches, and watershed soil and physiographic characteristics. In other words, all areas of compacted soil do not contribute toward increased runoff to the same degree. Nevertheless, percentage of compacted soil in a watershed appears to be a good indicator of increased size of peak flows.

Figure 10.--Apparent relationship between soil compaction and increase in size of peak flow. DC-3 is Deer Creek 3 of the Alsea Watershed Study (Harr et al. 1975).



Soil disturbance can affect size of peak flows in several ways, and the relative importance of each depends on the severity and the location of the disturbance. The most easily observed hydrologic effect of disturbance occurs where soil compaction has been sufficient to restrict infiltration and produce overland flow. If this surface water flows directly to a watercourse, for example, road drainage water entering a stream at a culvert where the road crosses a stream, the effect on streamflow is obvious. The size of the watershed's drainage network is increased, the runoff process becomes more efficient, and a greater amount of water arrives at the watershed outlet than would otherwise be the case. Even overland flow not directly reaching a watercourse, i.e., water flowing from severely compacted soil onto undisturbed soil where it infiltrates, should have an effect on storm runoff and size of peak flows. Although we do not know the exact nature of the movement of subsurface water in these experimental watersheds, it should be similar to that studied elsewhere in the western Cascade Range where soils are similar (Harr 1977). The infiltrating overland flow has the same effect as increased rate of rainfall. Unsaturated conductivities, which are dependent on soil water content, are higher than they would be without the addition of overland flow water. Thus, overland flow that infiltrates can increase runoff, but to a lesser degree than overland flow flowing directly into streams.

In CC-1, overland flow from many sections of roads has reached streams directly as has water from several skidroads and water from wet areas intersected by road cuts. In CC-3, overland flow from parts of both permanent and temporary roads in the upper part of the watershed has reached streams. These roads have also exposed and drained two wet areas. With the exception of some areas close to the stream in the lower part of CC-3, overland flow originating on soil compacted during tractor windrowing of slash has eventually infiltrated before reaching a stream. In CC-2, generally only water from some sections of road has reached streams directly; because of the location of the tractor-logged patch-cuts relative to streams, little overland flow from these areas appears to have entered streams.

Although they are also as difficult to detect downstream as are increases in annual yield described earlier (Rothacher 1970, Bethlahmy 1974), increases in peak flow caused by logging activities are of concern both locally and downstream. Overland flow and attendant surface erosion may increase sediment supply to streams, increased peak flows may erode streambanks and beds, and increased sediment may affect downstream aquatic resources.

Trends After Logging

Increases in size of peak flow must be examined in terms of their permanence as well as the size of peak flows that are increased. A double-mass analysis (Searcy and Hardison 1960) of peak flow data was used to detect trends in the peak flow relationships shown in figure 8. Cumulative measured peak flow (cumulations of all instantaneous peak flows, 2.2 liters/sec·ha) at each watershed was plotted over cumulative predicted peak flow at each watershed. An increase in the slope of a line fitted through the plotted points indicates increased size of peak flow at the logged watershed relative to size of peak flows during the calibration period.

Double-mass curves are shown in figure 11. The occurrence of major runoff events and the times of completion of road building and logging are also shown. At each of the three watersheds, the slope of the double-mass curve increased slightly after roadbuilding and considerably after logging. Five years after logging, there are no definite trends toward calibration peak flow relationships in any watershed.

Frequency Analysis

A peak flow frequency analysis was made to set the limits on the return period to which results of this study apply. A peak flow frequency relationship was obtained by fitting 1964-1976 peak flow data at CC-4 to a log-Pearson Type III distribution (U.S. Water Resources Council 1976) (fig. 12). Using this analysis, we estimate peak flows with return periods of 5, 10, and 25 years to be 8.2, 11.5, and 16.9 liters/sec·ha respectively. We emphasize that these are crude estimates because of the short-term record and because the peak flow of December 22, 1964, the largest of record, was estimated at the CC-4 stream gage by correlation with peak flow at the CC-2 gage, the only gage to function properly during that extreme runoff.

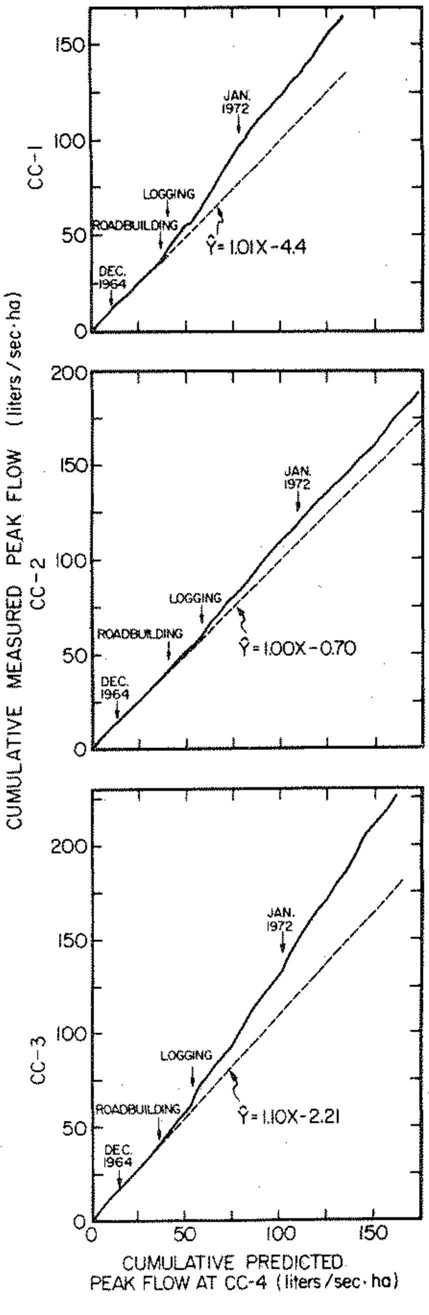


Figure 11.--Double-mass analysis of changes in peak flow after roadbuilding and logging, 1972-1976.

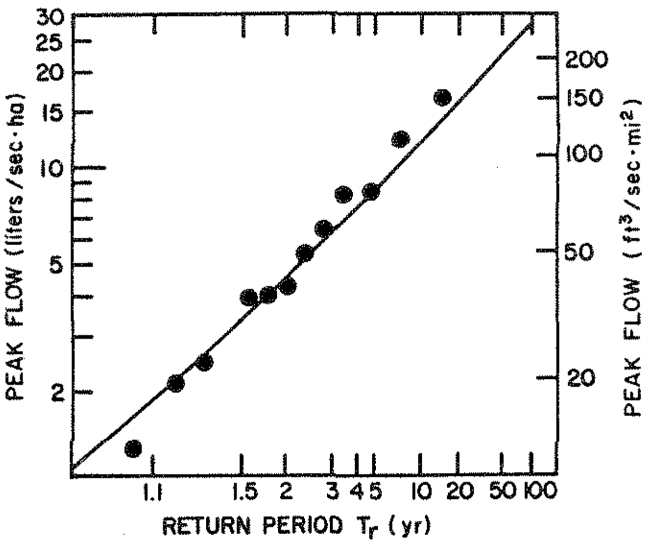


Figure 12--Log-Pearson Type III frequency curve for peak flows at CC-4, Coyote Creek Experimental Watersheds, 1964-1976.

During the calibration period of this study, size of peaks 2.2 liters/sec·ha averaged only 3.3 liters/sec·ha at CC-4, less than the mean annual peak flow of 4.4 liters/sec·ha estimated by the frequency analysis. (By definition, mean annual peak flow has a 50-percent chance of being equaled or exceeded in any 1 year or has a return period of about 2 years.) In the postlogging period, peak flows at CC-4 have averaged 4.4 liters/sec·ha. Of the 32 postlogging peaks, 11 have been larger than the mean annual peak flow estimated from the frequency analysis.

Because of the preponderance of small peaks in both prelogging and postlogging periods, extrapolation of results to large infrequent peak flows is tenuous. If estimated peak flows during water year 1965, which are plotted in figure 8, are included in the peak flow analyses, the position of the CC-1 and CC-3 calibration regression lines would be moved slightly upward causing the predicted increases in large peaks to be smaller than described earlier. For CC-2, the calibration regression would be lowered slightly and would cause the predicted increase in larger peak flows at this watershed to be greater than described earlier. We believe, however, that the estimated peaks of water year 1965 are not accurate enough to be included in the calibration data and that the best estimates of changes in larger peak flows are given by the difference in calibration and postlogging regressions as plotted in figure 8 and summarized in table 5.

Culvert Design

In headwater areas of National Forests of western Oregon, culverts for stream crossings are designed to accommodate flows of certain return periods. Changes in the size of peak flows after soil disturbance caused by logging and slash disposal could influence the success of these culverts.

If the peak flow frequency analysis for CC-4 (figure 12) is applied to the data in figure 8, size of peak flows would be increased, and return periods for given peak flows would be reduced substantially at CC-1 and CC-3. For example, a peak flow with an estimated return period of 35 years before logging could have a return period of about 15 years after extensive soil disturbance thus more than doubling the chance of occurrence in any given year. The size of a 35-year peak flow in an undisturbed watershed could be increased to the size of a 100-year peak flow in a disturbed but otherwise identical watershed.

Although the foregoing is only a rough estimate of changes in return period which could occur after soil disturbance, this estimate can be used in a simple risk analysis to further illustrate possible effects of soil disturbance on size of peak flow. The probability of p_n of a peak flow being equaled or exceeded in the next n years is:

$$p_n = 1 - \left[\frac{T_r - 1}{T_r}\right]^n \qquad 1 - \left[\frac{35-1}{34}\right]^{25} = 0.52 \qquad (3) \qquad 1 - \left[\frac{15-1}{15}\right]^{25} = 0.82$$

where T_r is the return period of the peak flow in years (Linsley et al. 1958). According to equation (3), there is a 52-percent chance that a peak flow with a return period of 35 years will be equaled or exceeded in the first 25 years of culvert use. But if logging operations upstream cause soil disturbance similar to that observed in CC-1 and CC-3, the 35-year peak flow would have an 82-percent chance of being equaled or exceeded in the first 25 years of culvert use after logging. To have only a 52-percent chance of being equaled or exceeded after logging, the culvert would have to be designed to accommodate a peak flow with a return period of 100 years. In terms of culvert size, a 61-cm (30-in) diameter culvert, for example, would be required after soil disturbance to provide at least the same risk of exceedance provided by a 45.7-cm (18-in) diameter culvert before soil disturbance.

We emphasize that the foregoing example is based only on changes in runoff and does not take into account both natural and logging-caused debris. Such debris has been a common reason for failure of culverts which should have accommodated any increased size of peak flows caused by logging activities (Rothacher and Glazebrook 1968).

RELATION TO MASS EROSION

Changes in the forest hydrologic system responsible for changes in streamflow after timber harvest may also adversely affect certain types of mass erosion in southwestern Oregon. Much of the downslope movement of soil masses in creep and earthflow terrain occurs during the fall and winter when maximum soil water levels occur (Swanson and Swanston 1977). Reduced interception and transpiration after logging, by increasing the amount of water entering the soil and decreasing its rate of withdrawal from the soil, may cause higher soil water levels or result in longer periods of time soil water remains at a level conducive for acceleration of soil creep or earthflow. Prolonged periods of active creep or earthflow movement during a single rainy season or reactivation of dormant creep and earthflow terrain may be the result (Swanston and Swanson 1976).

Increases in size of peak flow can increase rates of mass erosion also by changing erosion processes in streams. By removing lateral support for soil masses upslope from stream channels, higher peak flows can cause bank slumping which supplies large volumes of sediment and organic debris to channels.

Together, increased soil water content and higher peak flows may help explain increases in bedload export from CC-3 after logging (Swanson and Swanston 1977).

Summary

1. By reducing evapotranspiration and increasing overland flow, three types of timber harvest increased annual water yield up to 36 cm. For 5 years after logging, yield increases averaged 29 cm (43 percent) at CC-3, the completely clearcut watershed; 9 cm (14 percent) at CC-2, where timber was harvested in 20 small clearcuts; and 6 cm (8 percent) at CC-1, where timber was shelterwood cut.

2. Largest absolute increases in yield occurred during the winter at all watersheds. Largest relative increases occurred in fall and summer.

3. Sizable regional increases in water yield do not appear to be a product of sustained yield forest management practiced by the U.S. Forest Service in southwestern Oregon. Yield increases are as permanent as the changes in the forest hydrologic system that cause them. Large yield increases in recently logged headwater basins appear to be overshadowed by normal water yield from uncut or reforested basins so that yield increases for a large parent watershed probably amount to only about 4-6 percent.

4. After logging, size of peak flow corresponding to a peak flow of 10.9 liters/sec·ha at CC-4 was increased about 48 percent at CC-1, 35 percent at CC-3, and 11 percent at CC-2.

5. Increases in size of peak flow appear to be related to amount of watershed area where soils were severely disturbed. Soil disturbance and interception of subsurface water by roadcuts and ditches may affect surface erosion, stream channel erosion in headwater areas, and peak flows used to select culvert sites.

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