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Changes in Storm Hydrographs due to Roadbuilding and Clearcut Logging on Coastal Watersheds in Oregon

Project Termination Report

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Foreword

The senior author, James Krygier, was responsible for study design, measurements, and direction of graduate students. Supplementary analysis and final reporting were accomplished by both authors.

The work reported here is primarily the results of work by graduate students. The students made a major contribution to the discharge analysis of the experimental watersheds. These men are Dennis Gilleran, Warren C. Harper and Frederic Shu-Kong Hsieh. Their theses are on file at the Oregon State University Library.

Advice and review of original manuscripts was given by Peter C. Klingeman.

The report has not proceeded through the normal process of scientific review, and should not be regarded as a final publication.

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Introduction

The primary purpose of this study was to establish the significance of changes in storm hydrographs occurring as a result of roadbuilding and clearcut logging. Experimental watersheds, including a control, were used to evaluate kinds of hydrograph changes associated with timber harvesting.

Logging by clearcutting methods is common in Oregon. Hundreds of miles of logging roads are constructed each year and several hundred thousand acres are harvested by the clearcut method. The visual impact of the clearcutting practice is high, and as a result there has been continuing speculation concerning the influence of timber harvesting on floods.

Past watershed research has been concentrated on water-yield changes associated with vegetative manipulation or various kinds of watershed treatments. Results have not been generally reported in a form to include the statistical treatment of storm hydrograph response that would lead to a strong inference about the effects of clearcutting in western Oregon. However, some studies indicate increases in peak discharge where cutting has taken place in a watershed (Anderson, 1958; Maruyama, 1952; Reinhart et al., 1963).

Studies of runoff processes do indicate that storm hydrographs may be modified where surface runoff is generated, or where the amount of soil water is increased by a reduction in evapotranspiration. The magnitude of the hydrograph response is related to the extent of soil disturbance that decreases infiltration, the degree of vegetative removal, the existing soil depth, increased runoff efficiency and other variables. To establish that storm hydrographs have been modified, however, requires that the integrated effect on the hydrograph be measured repeatedly before and after timber harvesting on watersheds, and these measurements be compared to measurements on a control watershed.

Concern about the possible influence of logging on aquatic resources in Oregon led to the initiation of the Alsea Watershed Study in 1958 and an opportunity to evaluate storm-runoff response. Oregon State University, in cooperation with the U.S. Geological Survey, installed the stream gages at the outlets of the three small watersheds: Deer Creek, Flynn Creek, and Needle Branch. After a period of calibration in the natural state, Deer Creek was to be patch cut and Needle Branch clearcut while Flynn Creek was to serve as a control.

In 1964 Deer Creek was subdivided into a number of smaller gaged units. Some would be clearcut and others patch cut within the treatment pattern and schedule of the original Alsea Watershed Study. This was done to gain additional treatments for more precise evaluation of logging activities on stream hydrology.

The combined and separate treatments tested among these watersheds were: Roadbuilding on Needle Branch (NB), Deer Creek (DCM) and two subwatersheds of Deer Creek (DC II, DC III); nearly complete clearcutting without burning or roads (DC IV); nearly complete clearcutting with roads and high intensity burning (NB); part of the watersheds clearcut, with roads (DC II, DC III); combined roads and clearcutting on the larger Deer Creek watershed (DCM), to include gaged subwatersheds (DC II, DC III, DC IV) and other roads and a clearcut with a medium intensity burn.

The hydrograph variables of storm response that were evaluated for change were: instantaneous peak discharge, time-to-peak, and quick, delayed and total flow volumes. In addition some of the watersheds were evaluated for induced peak discharge, height-of-rise, and rising and falling limb volumes.

This report summarizes the Alsea Hydrology Study which has been reported in three separate Master's theses, and provides supplemental analysis of the data. Each thesis dealt with a particular part of the overall hydrology study, and this report highlights pertinent information. For more complete information concerning data reduction, statistical analyses, results, and literature reviews, the reader is referred to the following Master's theses on file at the Oregon State University library, and at the Water Resources Research Institute, Corvallis, Oregon:

Gilleran, D. J. 1968. Rapid calibration of coastal streams to detect effects of roadbuilding. 51 p.

Harper, W. G. 1969. Change in storm hydrographs due to clearcut logging of coastal watersheds. 116 p.

Hsieh, F. S. 1970. Storm runoff response from roadbuilding and logging on small watersheds in the Oregon Coast Range. 149 p.

Literature

Water yield studies under almost all environmental conditions have indicated that vegetative manipulation will result in alteration of streamflow response (Bates and Henry, 1928; Hoover, 1944; Wilm and Dunford, 1948; Tennessee Valley Authority, 1955, 1961; Love, 1955; Rich, 1960; Rich and Reynolds, 1961; Reinhart, Eschner, and Trimble, 1963; Rothacher, 1965, 1970; Hibbert, 1967; and many others). These studies, when taken collectively, indicate that reductions in vegetative cover increase water yield. Results of individual treatments vary widely depending on climate and characteristics of individual watersheds.

Vegetation plays an important role in the hydrologic cycle by preventing water from reaching the soil, by removing water stored in the soil profile, and by affecting the rate of travel over and through the soil. Therefore, physical and vegetative factors which might cause changes in individual hydrograph parameters include evapotranspiration (interception, transpiration and evaporation from soil surfaces), and infiltration.

Evapotranspiration

Interception loss is a part of evapotranspiration and is made up of storage capacity and water evaporated from storage during the storm (Leonard, 1967; Krygier, 1971). After storage capacity is satisfied, interception loss is dependent only on evaporation rate, and for large storms interception loss becomes a decreasing percentage of total rainfall.

Interception storage, which is removed in the process of clearcutting, can account for up to 0.4 inches in dense old-growth stands of Douglas-fir (Krygier, 1971). The effect of this variable alone on runoff is not known, but undoubtedly has its greatest influence on the response of watersheds to smaller storms.

Interception loss, including the influence of storage, may account for a large percentage of the total precipitation during short-duration events. However, it is a small percentage of long-duration storms. Rainfall interception for Douglas-fir has been found to range from 19 to 100 percent depending on storm size. Rothacher (1963) found a storm of 0 to 0.5 inches to intercept 100 percent while a storm 1.5 to 2.0 inches intercepted only 19 percent of incoming rainfall.

Transpiration from well-stocked vegetative communities is undoubtedly the most significant process other than infiltration to influence individual hydrograph characteristics. Plants extract water from soil at depths below that affected by surface evaporation, and release it to the atmosphere through the leaf stomata. In a study to determine effects of trees on soil-water removal, Ziemer (1964) found forested areas lost water more rapidly than adjacent areas cleared of trees. Water loss was greater in early summer and then decreased as the quantity of water became limiting. Maximum depletion had occurred by early September with nearly all available soil-water removed from the root zone. The openings, however, still maintained soil-water levels considerably above those found in the forest.

Evaporation from bare soil extracts water from relatively shallow depths, four inches for clays and about eight inches for sands (Veihmeyer, 1964). Therefore, water loss from a vegetated site will generally be much greater than from a bare soil. Because a deep-rooted species extracts water from a greater depth, it will remove more water than a shallow-rooted species, where water is not continually replenished. This relationship lends support to the hypothesis that removal of a forest or replacement with a shallower rooted species will result in an increased quantity of water available for streamflow.

Infiltration and Soil-Water Movement

Logging may cause soil compaction which can lead to reduced infiltration and percolation. Overland flow will result when precipitation intensity is greater than the infiltration rate of the soil (Chow, 1964). When infiltration rates are reduced by road building or logging, increased peak flows and storm volumes may be expected.

A decrease in infiltration rates on road surfaces as compared to natural surfaces is widely accepted. However, the situation on cutover lands is in doubt because of the wide variability of soils and conditions of disturbance (Rothacher, 1953; Dunford, 1954; Chow, 1964; Bullard, 1966). Certain logging practices may compact soil and reduce infiltration capacity While skyline and high lead systems deeply disturb a small percentage of total logged area (Dyrness, 1965, 1967) tractor logging can compact a substantial proportion of total logged area (Wooldridge, 1960; Dyrness, 1965).

Burning of slash and other surface debris can decrease infiltration capacity on some soils. The development of a hydrophobic layer in southern California was shown to reduce infiltration capacity (De Bano *et al*., 1967). The response of some soils to this phenomenon has been observed in the Cascades of western Oregon, but no information is available for the Coast Range.

Overland flow is not a common occurrence on natural forested watersheds. Infiltration is modified little or not at all where the forest floor is kept intact, or the soils are highly permeable (Dils, 1957; Rothacher, 1965). The lack of overland flow suggests that quick flow is a result of subsurface flow (Whipkey, 1965; Hewlett and Hibbert, 1967). The rapid response of a watershed to precipitation, when assuming no overland flow, may be explained by the variable source concept presented by Hewlett and Hibbert (1967). A temporary water table may also develop at a less permeable layer, or along the wetting front in a dry soil, permitting water to flow laterally under saturated conditions (Whipkey, 1965).

Changes in Peak Flows

Increases in peak discharge associated with forest cutting have been found in a number of studies. Reinhart et al. (1963) found peak discharge increased by 21 percent during the growing season following clearcutting at Fernow, West Virginia. Increases were thought to be a direct result of reduced evapo-transpiration. Following logging, less water was required to replenish that removed by vegetation making more water available for streamflow.

Two studies in Japan showed increases in peak discharge following logging. Maruyama (1952) found average peaks increased more than 20 percent following clearcutting. Nakano (1967) found increases in peak flow of 69 to 114 percent following logging.

The experiments at Wagon Wheel Gap (Bates and Henry, 1928) and Fraser, Colorado (Goodell, 1958) both indicate increased peak flow in the spring following logging. Goodell found the rise during the spring freshet more rapid than formerly and the spring peak higher. Peak flows were similarly increased in the White River experiment where the timber was killed by the Englemann spruce beetle (Love, 1955).

No significant increase was found in peak discharge from roadbuilding or logging of old-growth Douglas-fir stands in Oregon (Rothacher, 1965).

Eight percent of the watershed had been roaded, and 25 percent of the watershed clearcut.

Thus, there is an apparent difference in the expected change in peak discharge among several studies.

Description of Study Area

The watersheds selected for experimental comparisons of runoff characteristics are Deer Creek, Needle Branch and Flynn Creek, all with stream-gaging stations at their outlets. Deer Creek was divided into subwatersheds that were also gaged. All watersheds are tributary to Drift Creek, a stream which enters the Alsea River near Waldport, Oregon. The area is about ten miles from the Pacific Ocean (Figure 1).

Climate

These watersheds have a marine climate, typical of the Oregon coastal region. This type of climate produces cool wet winters and warm dry summers. Rainfall is the principal precipitation type with at least 90 percent occurring during the winter months of October through May. Snow is uncommon. Average annual precipitation from 1959 to 1968 for the area is 95 inches. Storm intensities are low and areal extent is generally quite wide, especially during the winter period. This type of rainfall is the result of a large number of frontal systems moving in from the Pacific Ocean, especially during the winter period.

Temperatures are generally mild with monthly averages approximately 35°F during the colder winter months and 50°F during the summer months. During the winter period average daily maximum is 45°F and average daily minimum is 30°F. For the summer period average maximum and minimum temperatures are 75°F and 45°F respectively.

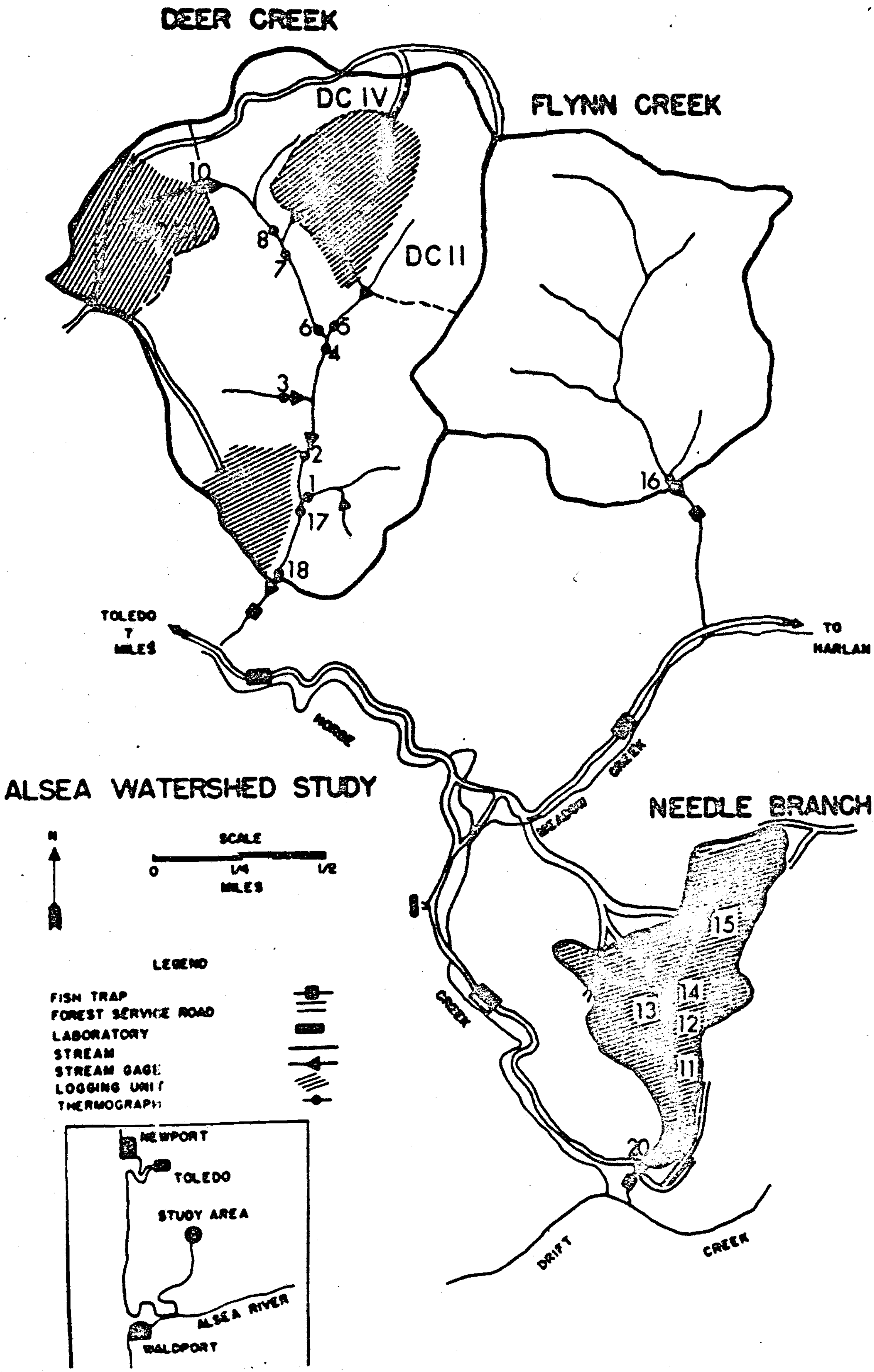

Figure 1. Map of study watersheds.

Geology and Soils

Soils were developed from the Tyee formation, which consists of arkosic sandstone and siltstone. Both of these rock types are sedimentary, of estuarine and marine origin. The two dominant soil types making up the soil complex of the study watersheds are Bohannon and Slickrock. These are generally found in association, with Bohannon on the steeper slopes and Slickrock on the more moderate slopes (U. S. Soil Conservation Service, 1964).

The Slickrock soil series comprises 75 to 80 percent of the soils on Flynn Creek. Needle Branch is 65-75 percent Bohannon. Ninety percent of Deer Creek is made up of the Bohannon soil.

Bohannon soils are well-drained, medium-textured, shallow, gravelly and stony, and are found on moderate to steep slopes. The A and B horizons are typically 11 and 13 inches thick respectively, and total soil depth to bedrock is about 24 inches. Percolation rate is moderately rapid and storage capacity is low.

Slickrock soils occupy gentle undulating slopes, are moderately well-drained, deep, moderately gravelly and cobbly, and are moderately fine textured. The A and B horizons are often seven inches and 40 inches, respectively, with a total soil depth near 55 inches. Percolation rate is moderately rapid and water storage capacity is high.

Topography

Relative shape of each of the study watersheds may be noted in Figure 1. Average slope on Needle Branch, Flynn Creek, and Deer Creek is 37 percent, 34 percent and 30 percent, respectively. Valleys on Needle Branch are narrow and steep-sided with some slopes approaching 70 percent. Hillsides are less steep on Flynn Creek and Deer Creek with a large portion of the area between 35 and 40 percent.

Elevation at the outlets of the three large watersheds is 600-700 feet above sea level. Main streams flow from north to south and the drainage pattern is dendritic. Drainage density of all watersheds is about three miles of stream channel per square mile of drainage area.

Vegetation

Two dominant species, Douglas-fir (about 100 years-old) and red alder, provided the primary forest cover. In Deer Creek, about 60% of the overstory was Douglas-fir and 40% was red alder; Needle Branch was nearly a pure stand of Douglas-fir; and Flynn Creek had an overstory composed of 70% alder and 30% Douglas-fir. A heavy understory in the watersheds consisted of salmonberry, sword fern and scattered vinemaple.

Methods

Watershed Selection

The three large watersheds, Needle Branch, Deer Creek, and Flynn Creek were selected for the broader goals of the study which had to include criteria associated with anticipated fishery studies. However, the watersheds were also selected on the basis of: (1) no previous major land-use; (2) extensive coverage by timber stands; (3) similarity in geology, soils and climate; (4) opportunity to reach agreement with landowners on the timing and kind of treatment.

Treatment History

All watersheds remained untreated through the winter of 1965. The calibration period was from 1958 to 1965 for Deer Creek, Needle Branch and Flynn Creek, and from 1962 to 1965 for the subwatersheds. Calibration and treatment histories are outlined in Figure 2.

Roadbuilding was undertaken in the spring of 1965, and completed on all watersheds by late fall of that year. Therefore, the roads were separated from logging and other practices as a treatment effect for one storm season. Clearcut logging began in March 1966 and was primarily completed by October of 1966; some minor yarding occurred up to early December of that year. Slash burning occurred in October of 1966 on the Needle Branch, and a clearcut in Deer Creek, unmeasured by subwatershed gages, was burned in the spring of 1967.

Areal coverage of treatments, and size of watersheds are shown in Table 1.

Layout of clearcuts, roads and instrumentation are shown in Figure 1.

The final test of watershed selection is the degree of correlation in flow parameters in the calibration period between the control (Flynn

Table 1. Summary of treatment areas.

	DCM	DC II	DC III	DC IV	Needle Branch	Flynn Creek
Total area (acres)	750	138	100	39	175	502
Road length (ft)	26,000	4,700	9,100	---	34,000[1]	---
Roaded area and landings (acres)	27.8	4.3	12.1	---	16.0[1]	---
Percentage of total area in roads and landings	3.7	3.1	12.1	---	9.0[1]	---
Logged area (acres)	195	27	72	39	175	---
Percentage of total area logged	26	20	72	100	100	---
Burned area (acres)	58	-----	-----	---	175	---
Percentage of total area burned	7.7	-----	-----	---	100	---

[1]Includes tractor skid trails on one segment of watershed.

Creek) and the watersheds to be treated. Almost all watersheds and parameters tested had r (correlation coefficient) values greater than 0.9, which can be considered good to excellent correlations (Appendix Tables 1-4).

Instrumentation

Streamflow measurement for each of the three major study watersheds began in 1958 with broadcrested concrete V-notch weirs. Each gaging site was equipped with both a strip-chart recorder and a punch-tape recorder. Control sections were not constructed to any theoretical model so field rating curves were necessary. Such rating curves were periodically checked and adjusted by the U.S. Geological Survey.

In 1962 subwatersheds DC II and DC III were instrumented with venturi-trapezoidal flumes. In addition, a 60° V-notch plate was installed on each flume to accurately measure low flows during summer months. Strip-chart water level recorders were installed in October 1962 but were replaced by punch-tape recorders in 1965. Subwatershed DC IV had an H-type flume installed in 1963 with a strip-chart water-level recorder. The flumes were also rated.

Recording rain gages were located near the outlet of each major watershed until 1966. Measurements from a central weather station overlapped the latter years of these measurements, and were continued alone after 1966.

Definition of Hydrograph Parameters

Each streamflow rise was considered as an independent event. In order to determine and evaluate hydrologic changes following logging activities, hydrograph parameters were selected which would define the hydrograph shape as completely as possible. Time-to-peak, peak discharge, total volume, and quick- and delayed-flow volumes were determined for each of the selected events for all watersheds. In addition, induced peak discharge, and rising-limb, and falling-limb flows were examined for the Deer Creek subwatersheds. These stream-rise parameters are shown in Figure 3, and described in Table 2.

Hydrograph Separation

Three methods (Chow, 1964) are traditionally used to separate direct runoff (surface and subsurface) from base (ground water) flow. In each method, flood flow is terminated at that point where the base flow line intersects the recession of the hydrograph. However, it is almost impossible to separate direct flow from base flow on a physical basis. It is necessary, however, for purposes of hydrograph analysis, to separate flow that runs quickly from a watershed from that which is delayed, or is well controlled. As pointed out by Hewlett and Hibbert (1967), the problem with elaborate separation methods is that an aribtrary classification for rate of flow is added to an arbitrary classification for source of flow. A decision is made concerning what rates are considered storm flows and these rates are arbitrarily divided into direct runoff and base flow. Because the decision is arbitrary in any case, it would seem logical to base the separation on one arbitrary decision rather than two and base the classification on a fixed, universal method applicable to all hydrographs on small watersheds.

Based on the above ideas, Hewlett suggests a line on constant slope that could be readily adapted to a computer system. After analysis of about 200 water-years of record collected on 15 small forested watersheds in the Appalachian-Piedmont region, he decided on a line projected from the initial rise, at a slope of 0.05 cubic feet per second per square mile (csm) per hour, until it intersected the falling limb of the hydrograph.

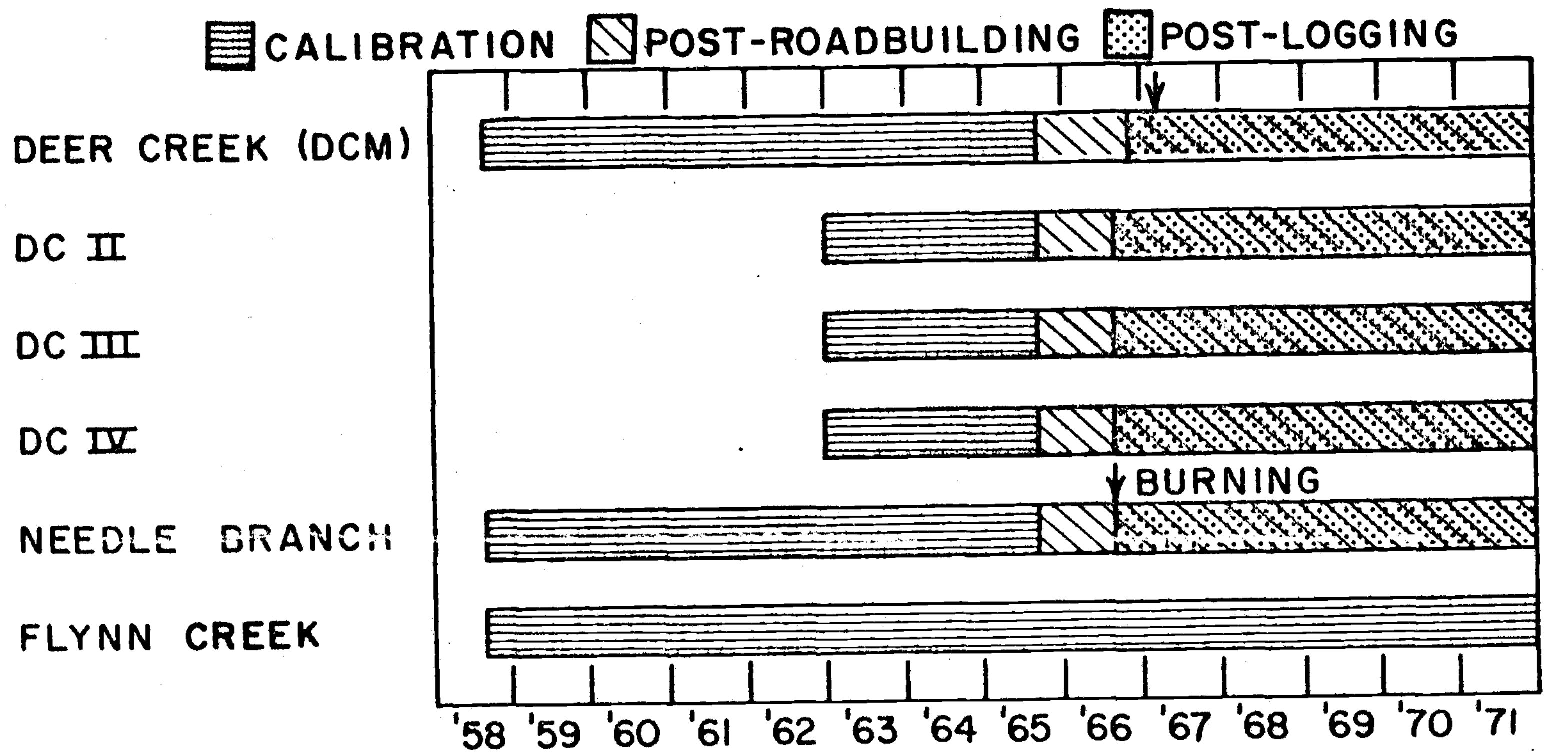

Figure 2. Treatment history of the experimental watersheds.

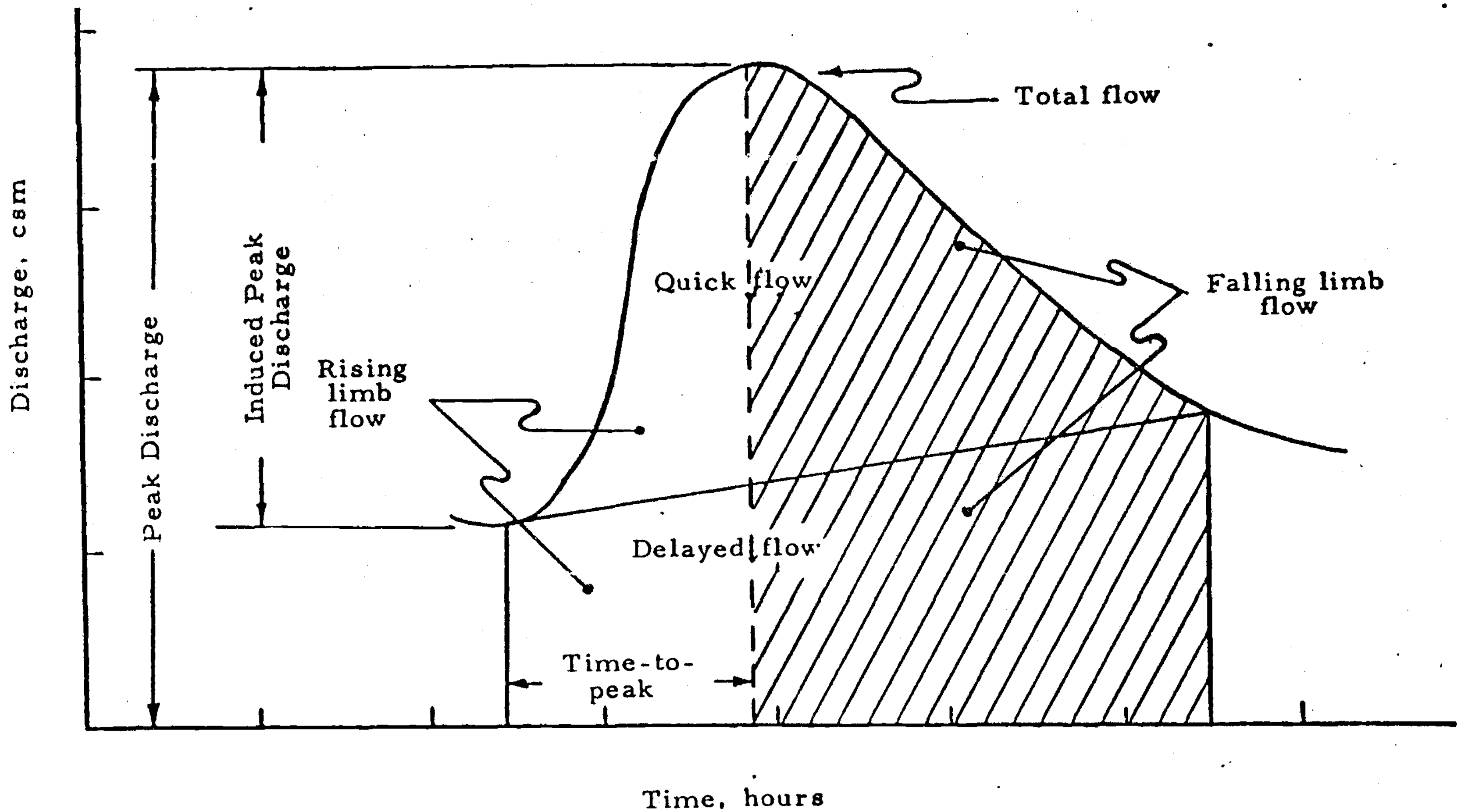

Figure 3. Diagram of the parameters of stream flow.

Table 2. Description of parameters analysed.

Hydrologic Parameters	Definition	Method of Calculation
Time-to-peak	The time between initial response of a stream to a storm event and maximum water stage.	Taken directly from time-stage record
Peak discharge	Maximum rate of flow of a storm event	Stream gage rating curve applied to maximum water stages
Induced peak discharge	That portion of peak discharge attributable solely to a storm event.	Peak discharge minus initial base flow
Height-of-rise	Rise in water stage from the beginning of storm runoff to the time of peak.	Maximum stage minus initial stage
Total volume	Integrated discharge of a stream in time period between initial response and the intersection by hydrograph separation line.	Hydrograph separation line of constant slope of 0.05 csm per hour
Quick flow	That portion of total flow above the hydrograph separation line.	Total flow minus quick flow
Delayed flow	That portion of total flow below the hydrograph separation line	Total flow minus quick flow
Rising limb flow	Integrated flow between times of initial response and time of peak.	By definition
Falling limb flow	Integrated flow between time of peak and intersection by hydrograph separation line.	By definition

Hewlett refers to the flow thus divided as "quick flow" and "delayed flow". The controversial idea of source is thus avoided, and therefore this method was used in determining these volumes.

Selection of Events

One essential criterion of selection for all the parameters is that the particular storm had to appear in the flow records of both the control and the treated watershed and be comparable in time. The reasons for this restriction are: (1) paired samples are necessary for later regression analyses; (2) only when both the control and the treated watershed were subjected to the same storm could meaningful comparisons be achieved. Therefore, the same runoff event was not always usable for each parameter, and with additional restrictions for some parameters the number of observations varied by watershed and by parameter.

Picking runoff events for the height-of-rise parameter required clearly defined points of runoff initiation. The latter was also required for induced peak discharge and the volume parameters. Time-to-peak required clearly defined peaks since broad crests left exact time in doubt.

Single-peaked events were the principal runoff events selected for peak and induced peak discharge. However, a number of complex hydrographs were used particularly since only a two-year period existed for determining effects following logging, and because the pre-calibration period was short for the subwatersheds. Where it was doubtful that peaks of complex hydrographs were independent, the highest peak was used on DC IV and Needle Branch, and for the other watersheds the first major distinctive peak was used.

Selection of runoff events for volume required intersection of the falling limb. When intersection did not occur the event was eliminated.

An additional problem was encountered with data from Deer Creek IV. Leakage flow occurs through the very deep alluvial deposits under the flume. When flow did not exist prior to initial rise it was impossible to determine the time or volume of runoff necessary to produce surface flow in the channel. Therefore, events were not considered unless flow existed prior to the intial streamflow rise, i.e., events starting at zero flow were not considered.

Data Reduction

The reduced raw data were composed of paired values of each parameter for the control and the treated watersheds. These were subsequently used in various statistical analyses. General steps in reducing the raw data were as follows:

1. Selection of events from stage-time records.
2. Adjustment of records for various mechanical and technical data collection errors.
3. Tabulation of parameters in the form of times and stages.
4. Development of computer programs to convert the crest stages and the point-of-rise stages of individual storm hydrographs into peak and induced peak discharges, using the various rating curves and tables.

The reduction of flow volume parameters included, in addition to the above steps, the tabulation of enough data points to define the complete hydrograph. Rating tables and equations were internally applied within the computer according to time periods and watersheds. Two subroutines served to integrate and separate the hydrographs into various components and convert the final flow volumes to areal inches.

Two methods of separating data between a recharging condition and the winter wet condition were used in this study. An arbitrary date of

November 30 was used; September through November comprised the fall season and December through March the winter season for Needle Branch and Deer Creek IV. A less arbitrary separation was suggested for subsequent analysis. Therefore a method of separation based on antecedent moisture conditions was used for the other Deer Creek watersheds.

In this latter method, antecedent base flows were plotted over month of the year. The resulting curves showed a gradual rise in baseflow to 3 or 5 csm following several storms in October and November with a sharp rise occurring in November or December. A baseflow value of 3.5 csm were selected to separate recharging and recharged periods. These correspond closely to fall and winter periods of the Needle Branch and Deer Creek IV analyses.

Flood Frequency Analysis

Storm-runoff data utilized in the analyses govern the extrapolation to larger floods. In order to set limits on the return period to where the study may apply, a flood-frequency analysis was undertaken.

Because the Alsea experimental watersheds have a streamflow gaging record of only nine years, three approaches were tried in order to obtain an accurate flood-frequency relation. The first two, streamflow correlation between Flynn Creek and the Alsea River near Tidewater and precipitation correlation were abandoned because correlations were poor.

A third approach, flood frequency analysis, is considered the best approach available. A single-station Gumbel flood frequency analysis was performed on Flynn Creek (the control watershed). The computation of recurrence interval by the Gumbel method is illustrated in Table 3. Annual peak discharges versus recurrence intervals were plotted on Gumbel distribution paper. Peak discharges corresponding to return intervals

Table 3. Partial duration series of single-station Gumbel flood frequency analysis of Flynn Creek, 1959-1967.

Water year	Date and hour	Flood peak (csm)	Order number (m)	Recurrence interval $TR = \frac{n+1}{m}$ [1]
1959	1- 9-0400	68	10	1.40
1960	2- 9-0400	55	13	1.08
1961	11-24-0800	100	3	4.67
	2-10-1100	82	7	2.00
1962	11-22-0800	59	12	1.17
1963	11-26-0100	83	6	2.33
1964	1-19-1700	81	8	1.75
1965	12-22-1130	115	2	7.00
	1-28-1030	176	1	14.00[2]
1966	12-27-2400	67	11	1.27
	1- 3-2400	72	9	1.56
	3- 9-1100	94	4	3.50
1967	1-27-2330	90	5	2.80

[1]n = number of flood peaks (= 13).

[2]The 1965 January flood was estimated to be close to a 100-year flood on watersheds of longer records.

of 2.33 years, 10 years and 25 years were estimated to be 85, 120, and 149 csm respectively.

Regression Analysis

Regression techniques were used in this study to obtain the pre- and post-treatment prediction equations for every parameter. Stepwise and simple linear regression programs from the Oregon State University Computer Center Library were utilized to determine the calibration and post-treatment prediction equations. Examinations of the regression coefficients, and the adjusted means (mean of means) were made to justify the significance of the changes due to the different treatments.

Before any test of change could be made among the parameters of the control and the treated watersheds, correlation coefficients had to be established as reasonable in magnitude, and the validity of a linear model determined.

A stepwise regression program was utilized to determine the best prediction equations, including curvilinear models. For example, the peak discharge of Flynn Creek, as the independent variable, was regressed on four dependent variables of Deer Creek III: the first power, square and the cube of the peak discharge; and the ratio of the initial base flow discharges prior to storms between Flynn Creek and Deer Creek III. The results showed r to be greater than 0.98 for the correlation between the first power of the peak discharges of Flynn Creek and Deer Creek III. The other dependent variables did not improve the correlation significantly enough to be included in the prediction equation. The same conclusion resulted from using a stepwise approach on induced peak discharge and time-to-peak for the treated watersheds. Therefore, the linear regression was used for all correlations, including runoff-volume parameters where only a very limited number of observations was available for analyses.

Tests for Change

Further statistical tests were used on the linear relationships to determine the statistical equality of the pre- and post-logging relationships, i.e., tests were used to determine whether these two lines were actually different, or whether the difference that occurred could have happened by chance. In this study a change was considered significant at the 95 percent level.

Any indicated change in the regression for a particular parameter as a result of treatment was subjected to two tests: a test for change in slope and a test for change in vertical position.

Change in Slope

This test compared differences in slope between pre- and post-logging regressions for each parameter. A change in slope implies that the effect of the treatment varied with increasing values of the parameter. The coefficient under consideration is b_1 in the expression:

$$y = b_0 + b_1 x.$$

The hypothesis tested is that $b_{11} = b_{12}$, i.e., the slope prior to logging is equal to the slope following logging. The second subscript (1 or 2) designated pre-logging (1) or post-logging (2) period. Student's t-test for slope (Li, 1957) may be stated as

$$t_s = \frac{b_{11} - b_{12}}{\left(\left(\frac{ResSS_1 + ResSS_2}{n_1 + n_2 - 4} \right) \left(\frac{1}{SSX_1} \quad \frac{1}{SSX_2} \right) \right)^{\frac{1}{2}}}$$

in which b_{11} and b_{12}, $ResSS_1$ and $ResSS_2$, n_1 and n_2, and SSX_1 and SSX_2 are slopes, residual sums of squares, number of observations, and sum of squares corrected for the mean for the pre- and post-treatment regressions of the control-watershed, respectively. The computed t_s has $(n_1 + n_2 - 4)$ degrees of freedom which is based on the degrees of freedom of the estimated variance.

The test for change in slope yields a computed value of "t" which must be compared with the critical value of t. The critical value of t is dependent on the level of significance selected and the degrees of freedom involved. If the computed value of t is greater than the critical value of t, the hypothesis is rejected in favor of the alternate hypothesis that the slopes are in fact different.

Change in Vertical Position

For this analysis it was necessarily assumed that slopes not statistically different are equal. A change in vertical position implies that the effect is the same over the full range of values. The test for change in vertical position, which is given the name "mean of means" or "adjusted means", is a modification of the test for change in intercept given by Draper and Smith (1968), i.e., the change in b_0, as in the expression:

$$y = b_0 + b_1 x.$$

The student's t-test for the adjusted means (Li, 1957) is:

$$t_m = \frac{Y_{X_0 1} - Y_{X_0 2}}{\left(\left(\frac{\text{ResSS}_1 + \text{ResSS}_2}{n_1 + n_2} \right) \left(\frac{\Sigma (X_{i1} - X_0)^2}{n_1 (SSX_1)} + \frac{\Sigma (X_{i2} - X_0)^2}{{}_2 (SSX_2)} \right) \right)^{1/2}}$$

in which $Y_{X_0 1}$ and $Y_{X_0 2}$ are vertical positions of the treated watershed regression line estimated at the mean of means X_0 of the control watershed for the pre-and post-treatment periods. X_{i1} and X_{i2} are the individual data points for the pre- and post-treatment periods. All other terms in this equation are the same as those used in the test of slopes. The degrees of freedom are also equal to $(n_1 + n_2 - 4)$.

Results

Subsequent emphasis is given to changes among hydrograph parameters that were significant in the regression analysis. Statistical results are given in the appendix tables. Graphical plots of data, or final data lists, and regressions have been omitted. These are located in the theses listed in the introduction.

Given percentages represent changes at the mean of means of the pre- and post-treatment regressions and will have an undetermined plus and minus error associated with the variances of the regressions.

Peak Discharge

The overall influence of roads and logging was to cause changes in peak discharge from watersheds where the roadbuilding or logging was most extensive.

Roads were isolated from the subsequent logging in the first treatment year. The roaded areas caused a highly significant increase in peak discharge from only one watershed, Deer Creek III, for both fall and winter analytical periods (Appendix Tables 1 and 5). This watershed had the largest proportion of roads constructed within its boundaries. The increase in peak discharge was 50 percent in the fall recharging period and 21 percent in the winter recharged period.

There was no change in peak discharge following roadbuilding in Needle Branch or Deer Creek II. The effect of roadbuilding on peak discharge at Deer Creek main station was negative and inconsequential.

Clearcutting resulted in significantly increased peak discharges from three watersheds, DC III, DC IV, and Needle Branch, which were at least 70 percent clearcut. A fourth watershed, Deer Creek II, had a significant increase only during the winter period. Largest increases in peak discharge from the two completely clearcut watersheds occurred in the fall period; increases at Deer Creek IV and Needle Branch were 128 and 90 percent, respectively. Winter increases in peak discharge from these two watersheds were 22 and 28 percent, respectively. Peak discharge at Deer Creek II increased 19 percent during winter.

Clearcutting on the densely roaded watershed, DC III, sustained the significance of the discharge increases that had occurred in the fall and winter after roadbuilding. After clearcutting the increases in peak were 36 percent for the fall and 45 percent for the winter.

Peak discharge had a 20 percent increase on Deer Creek II for only the recharged winter period.

Induced Peak Discharge

Except for a significant increase in induced peak discharge during the winter following roadbuilding on Deer Creek II, results were similar to those found in the analyses of peak discharge. After logging in Deer Creek II, the increase in induced peak discharge that had been significant for the roaded period was not sustained.

Height-of-Rise

No change was found in height-of-rise for the two completely clearcut watersheds examined, Deer Creek IV and Needle Branch.

Time-to-Peak

No significant change in time-to-peak was recorded among the watersheds, except for a change in slope on Deer Creek IV (Appendix, Table 3). For time-to-peak of less than 10 hours, time was reduced. This isolated change is considered to be of little consequence.

Runoff Volumes--Roads

No change occurred in total, quick, delayed rising limb or falling limb volumes on DCM, DC II or DC III (Appendix, Table 4). Few flow events were available for analysis because of only one year of observation. For this reason flow volumes for the fully clearcut watersheds (Deer Creek IV and Needle Branch) were not analyzed during the roaded period.

Runoff Volumes--Clearcutting

Analysis of the influence of clearcutting in fall and winter was undertaken only for the flow volumes at Needle Branch; there were few usable observations for this analysis. Consequently, except for this station, results are for the combined fall and winter periods (full year).

Total Flow. Total volume was unaffected except at Needle Branch where statistically significant increases were noted for the fall and winter runoff periods (Appendix Table IV). The largest increase in peak volume occurred in the fall (138 percent); however, this increase is based on only three observations. The increase in volume for the winter was 15 percent.

Quick Flow. Quick flow volume for the full year was reduced 13 percent at Deer Creek main station (DCM). Quick flow volume at Needle Branch was increased 120 percent during the fall; there was no increase during the winter. Quick flow volume was unaffected at all other watersheds (Appendix Table 4).

Delayed Flow. The same watersheds having altered quick-flow volumes also had changes in delayed-flow volumes. Delayed flow increased 10 percent at Deer Creek main station (DCM), while Needle Branch had an increase of 186 percent in the fall and 29 percent in winter.

Rising and Falling Limb Flows. Peak flow hydrographs were divided into rising and falling limb flows on the DCM, DC II and DC III watersheds. These flow volumes were not analyzed at other gaging stations. Rising limb flows were increased by 10 percent at Deer Creek Main station and by 36 percent on Deer Creek III. These parameters of flow volume remained unchanged at Deer Creek II.

Discussion

Clearcutting of forests has frequently been labeled as the cause of flood exacerbation. However, floods are stream discharges above levels that usually have special meaning, especially some degree of damage, as they occur at a given location on a stream or river. The definition of a flood on a small mountain stream is not clear. Therefore, stormflow hydrographs that were produced in the experimental streams of the coastal Alsea watersheds during the period of the study were substituted for the less definitive "flood".

Parameters of the hydrograph were analysed for change following varying degrees of clearcutting and associated roadbuilding and slash burning. These hydrograph parameters were peak discharge, induced peak discharge, time to peak, and several divisions of hydrograph volume. The magnitude of change was determined by comparing the parameters to a control watershed prior to treatment, and also after the land-use practice had been applied to the watersheds.

Changes in the hydrographs of the study watersheds cannot be extended to hydrographs of low frequency and large magnitude. All large storm events were included in the analyses, including two events during the calibration period that approached a 100-year recurrence interval. A Gumbel flood-frequency analysis of peak discharge on the control watershed indicated principal data grouping less than a 10-year return period; and for the fall period the data limits are less. Extension of watershed treatment effects to include the range of the largest run-off events is questionable.

Roads

The establishment of roads prior to the fall and winter runoff periods of 1965-1966 were expected to produce an effect of unknown magnitude on the hydrograph. Roads modify the runoff process. A compacted surface reduces infiltration and excess water is carried by a more efficient distribution system--the road surface, ditches, and culverts. The cut slope can interrupt downslope movement of subsurface water converting it to surface flow. Finally, the removal of trees from the right-of-way reduces transpirational extraction, providing a soil mass that is more moist and responsive to precipitation.

The proportion of a watershed in roads should govern the degree of hydrograph change. Among the four watersheds roaded, only one, Deer Creek III, had a definite increase in peak discharge for both fall and winter periods. Twelve percent of this watershed was roaded; this percentage is well above larger areas clearcut in patches. The subwatershed, Deer Creek II, with 3.1 percent in roads had a significant response in winter to the presumably more sensitive induced peak parameter, suggesting that total peak discharge was increased. Comparison of the induced peaks on both watersheds (28 and 20 percent) suggests a smaller change with a lower density road network. The lack of a significant change in peak at Needle Branch and at the main Deer Creek station, both with an extent of roaded areas between the two watersheds above, suggest that roaded area may interact with other variables, such as watershed size, road placement and drainage, and time of travel from source areas. The statistical variation and consequent precision may have also contributed to this treatment response of the watersheds.

A check of precision of yearly peaks (csm) during the roaded periods at the five percent level of probability, resulted in these percentages:

main Deer Creek, 6 percent; Deer Creek II, 16 percent, and Deer Creek III, 10 percent. Since the change in flow at DC III represents an approximate three percent change at main Deer Creek (based on regression means), it is obvious why the increase within Deer Creek would escape detection. Furthermore, there is the potential for redistribution of upstream volume increases within the hydrograph at main Deer Creek, which for smaller storms may not increase the peak of the larger stream. There is sketchy evidence of this phenomenon where delayed flow and rising limb flows had 9 and 10 percent increases (statistically nonsignificant) at main Deer Creek. Thus downstream effects of roads may be quite unimportant, depending on the degree of dilution by unaffected waters and the time of travel to the location of interest.

In order to detect changes with certainty, a higher degree of experimental precision--more observations of storm-runoff events--will be required to determine the impact of roads on the peak hydrograph. The same would be true of volume changes in the hydrograph where no significant influence of roads was detected among the watersheds analysed.

Clearcutting and Associated Treatments

Clearcutting was done in the spring, summer and fall of 1966. Hydrographs from two subsequent years of fall and winter storms were analyzed for the impact on the hydrograph. Clearcutting, without the confounding effect of previously constructed roads, or the influence of slash burning, was clearly interpretable only on Deer Creek IV. Slash burning occurred on an ungaged section of the Deer Creek watershed, and Needle Branch was heavily burned following clearcut logging. Roads were present with the clearcut in DC II, DC III, DCM, and Needle Branch.

Lack of studies on condition and processes within each of the watersheds makos assessment of cause difficult, except as related to inferences from known treatments or combination of treatments within and among the watersheds.

The intensity of the combined treatments, generally, but not consistently, governed the level of hydrograph response. Fall peak discharges were highest on the two clearcut watersheds. Deer Creek III, which was 72 percent clearcut, was next; Deer Creek III next with 20 percent cutover; and Deer Creek main station (DCM) was last (not statistically significant) with 26 percent of the area cut. Winter peaks followed the same order except that Deer Creek III had the largest change (45 percent increase) in winter peaks. The high density of roads and their probable influence on surface runoff undoubtedly caused the largest increase in peaks at DC III for the winter condition.

The two fully clearcut watersheds (Deer Creek IV and Needle Branch) had reasonably similar increases in peak discharge during fall and winter although Needle Branch was roaded and burned. It might be assumed that the roads and burning had no major impact on the hydrograph at Needle Branch, but changes in volume took place at Needle Branch, and not at DC IV. The weaker volume analysis as a result of pooling both seasons at Deer Creek IV does not permit a completely valid comparison of the two watersheds: Yet the lack of an increase in quick flow during the winter months on Needle Branch implies that rapid runoff processes were not significantly influenced when the watershed was recharged. Burning may have had an influence on the fall hydrograph when quick flow increases did take place on Needle Branch.

The substantial change in peak discharges during the fall recharging period as compared to the winter recharged period was most evident on the two fully clearcut watersheds. The greater changes in fall were not unexpected. That higher levels of soil moisture exist through the summer and into the fall following clearcutting have been well documented. A moderately well recharged soil profile in a recent clearcut should respond more quickly to incoming precipitation than the pre-existing fully stocked stand in which soil moisture content in the root zone would be at a lower level.

Why significant increases in peak response occurred on the clearcut without roads (DC IV) in the winter recharged period is unclear. The soils have a high infiltration rate and evidence of overland flow has not been observed. The existence of surface runoff associated with only a cutting disturbance cannot be ruled out because no grid survey was made. However, frequent site visits revealed nothing to indicate that overland flow was occurring from a logging disturbance without the influence of roads or burning.

The development of an increased peak in winter from clearcutting without burning or road effects suggests two causes. First, the definition of the recharged condition was an arbitrary date in late November for Deer Creek IV and Needle Branch, the fully clearcut watersheds. This was later refined for other watersheds as the change to a high base-flow level as fall recharge progressed. Since an arbitrary late fall date does not provide an index of soil moisture status, a number of non-recharged runoff events may have been included in the regression for the recharged condition. Secondly, interception is decreased by vegetation removal, and the loss between storms could account for an increased volume reaching the stream. This volume is a larger proportion of smaller storms which are more representative of the data of this study.

The volume changes that took place provide some slight evidence of hydrograph reformation following cutting. Deer Creek III had a larger volume in the rising limb. The large increases in delayed flow in the fall at Needle Branch would indicate the influence of a recharged draining soil profile. Why increases in the same parameter occurred during winter months is unclear. The changes at Deer Creek were compensating, e.g., a decrease in quick flow was accompanied by an increase in delayed flow. Thus, some form of error is apparent.

CONCLUSIONS

1. Construction of roads in the Alsea forested watersheds, when occupying a large proportion of a watershed, lead to an increase in peak discharge as much as 50 percent in the fall months and 21 percent in winter.
2. No volume changes from road construction were detected among the watersheds.
3. The influence of roads on peak discharge at the outlet of a larger watershed was not detectable although the statistical precision at this location could be considered high for such a study.
4. Clearcutting without effects of roads and slash burning induced changes in peak discharge with substantial differences between fall and winter months. Increases were 128 percent for fall months and 22 percent for the winter "recharged" period.
5. A fully clearcut watershed, roaded and burned, had no apparent change in peak discharge associated with roads, or effect of burning on quick flow in winter, but a possible influence of slash burning on peaks and volume during fall months. Clearcutting increased peaks by 90 percent in fall and 28 percent in winter.
7. Associated volume changes were mixed, due in part to necessary pooling of data for some watersheds. Total flows were increased in fall and winter in one watershed clearcut and burned.
8. Precision of the experiment did not permit the detection of small and in some cases large changes. It will be difficult to conduct such experiments since larger numbers of observations will be required to increase precision, and this will lead to the use of ever smaller peaks or extend the study into periods confounded by a change in watershed conditions.

9. The results of this study cannot be extrapolated to peak discharges beyond a 10-year return period. Most of the data of regressions utilized for inference have a lesser return period. Thus inferences about large floods of more general interest are questionable.

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APPENDIX

Table 1. Summary of statistics for effect of treatments on peak discharge.

Table 2. Summary of statistics for effect of treatments on induced peak discharge.

Table 3. Summary of statistics for effect of treatments on time-to-peak.

Table 4. Summary of statistics for effect of treatments on runoff volume.

Table 5. Significant effects of treatments on peak discharge at the mean of means.

Table 6. Significant effects of treatments on induced peak discharge at the mean of means.

Table 7. Significant effects of treatments on runoff volume at the mean of means.

Table 8. Summary of statistical results for test to determine difference between fall and winter data, including number of observations (n), r, t for slope (t_s), and t for vertical position (t_v), as tested against the control.

Table 1. Summary of statistics for effect of treatments on peak discharge.

	Pre		Road		Log		Road		Log	
	n	r	n	r	n	r	t_s[1]	t_v[1]	t_s	t_v
					DCM					
Yearly	103	.994	17	.997	26	.991	1.20	0.37	0.83	0.79
Recharging	29	.996	8	.981	9	.995	-3.14**[2]	-1.60	0.47	0.87
Recharged	64	.993	9	.997	17	.989	1.28	-0.51	0.63	0.50
					DC II					
Yearly	46	.979	18	.992	26	.996	2.68**	1.31	1.07	0.64
Recharging	9	.961	11	.928	9	.995	0.75	0.28	1.38	0.98
Recharged	35	.997	7	.992	17	.954	1.98	1.11	0.35	2.11*
					DC III					
Yearly	45	.996	19	.989	23	.993	4.85**	4.88**	10.62**	10.83**
Recharging	10	.998	11	.938	7	.946	4.25**	3.82**	2.91**	2.76**
Recharged	37	.996	8	.999	16	.994	5.91**	4.53**	7.98**	11.58**
					DC IV					
Yearly	21	.975	[3]	[3]	20	.894	[3]	[3]	0.32	3.27**
Fall	3	.964			3	.985			1.85	4.43**
Winter	18	.975			17	.949			0.67	2.65**
					NEEDLE BRANCH					
Yearly	101	.970	[3]	[3]	29	.894	[3]	[3]	2.72**	5.22**
Fall	44	.975			9	.990			6.58**	7.62**
Winter	49	.970			17	.911			2.68**	4.15**

[1] t_s is the t value for a change in slope; t_v is the t value for a change in vertical position of the regression.

[2] **Significant at the 99 percent level; * significant at the 95 percent level.

[3] Roads found not to be significant, and automatically pooled with calibration data.

Table 2. Summary of statistics for effect of treatments on induced peak discharge.

	Calibration		Road		Log		Road		Log	
	n	r	n	r	n	r	t_s	t_v	t_s	t_v
					DCM					
Yearly	103	.992	17	.995	26	.989	1.54	-0.01	1.29	-0.99
Recharging	29	.996	8	.978	9	.999	-2.70*	-1.00	-0.21	-0.33
Recharged	64	.992	9	.996	17	.987	1.32	0.70	1.06	-0.22
					DC II					
Yearly	46	.976	18	.990	26	.971	3.33**	1.27	1.07	1.10
Recharging	9	.885	11	.916	9	.994	0.92	0.89	1.83	1.16
Recharged	35	.975	7	.992	17	.967	2.21*	2.21*	.47	1.29
					DC III					
Yearly	45	.995	19	.992	23	.991	6.20**	4.65**	8.90**	5.62**
Recharging	10	.992	11	.966	7	.976	4.51**	4.51**	3.64**	2.41**
Recharged	37	.995	8	.999	16	.990	4.22**	4.22**	7.19**	6.10**

Table 3. Summary of statistics for effect of treatments on time-to-peak.

	Calibration		Road		Log		Road		Log	
	n	r	n	r	n	r	t_s	t_v	t_s	t_v
					DCM					
Yearly	103	.999	17	.999	26	.999	-1.24	-0.76	0.24	-1.40
Recharging[1]	29	.997	8	1.000	9	.998	-1.53	1.18	-0.86	-1.17
Recharged[1]	64	.999	9	.999	17	1.000	-0.90	-1.63	0.22	-1.02
					DC II					
Yearly	46	.997	18	.922	26	.996	0.92	1.36	1.97	1.26
Recharging[1]	9	.991	11	.992	9	.999	0.31	1.26	0.42	0.33
Recharged[1]	35	.996	7	.994	17	.994	0.14	.56	1.41	1.30
					DC III					
Yearly	51	.996	19	.993	23	.991	-1.00	-1.73	0.45	-0.65
Recharging[1]	8	.954	11	.991	7	.996	-1.00	-0.95	-1.04	-0.88
Recharged[1]	41	.997	8	.998	16	.989	-1.21	-1.75	0.49	-0.27
					DC IV					
Yearly	10	.967			9	.985			2.93*[3]	0.03
					NEEDLE BRANCH					
Yearly	99	.933			26	.990			0.89	-0.57
Fall[2]	44	.894			8	1.000			1.50	0.28
Winter[2]	47	.985			15	.980			.41	-0.78

[1]Seasonal separation by antecedent baseflow.

[2]Seasonal separation by month.

[3]Significant at 95 percent level.

Table 4. Summary of statistics for effect of treatments on runoff volume.

	Pre		Road		Log		Road		Log	
	n	r	n	r	n	r	t_s	t_v	t_s	t_v
					DCM					
Total	20	.995	6	.995	10	.992	1.21	0.85	-1.15	-1.18
Quick	20	.996	6	.992	10	.978	0.80	.08	-2.06*	-3.09*
Delayed	20	.987	6	.997	10	.984	1.77	1.86	2.24*	2.16*
Rising Limb	20	.985	6	.997	10	.989	0.43	0.06	1.91*	1.78*
Falling Limb	20	.984	6	.986	10	.980	0.32	1.19	-1.29	-1.09
					DC II					
Total	5	.995	3	.992	9	.976	0.04	-2.17	0.16	-1.33
Quick	5	.952	3	.991	9	.989	-0.45	-1.03	-0.94	-0.88
Delayed	5	.932	3	.984	9	.921	0.46	-0.57	0.94	0.30
Rising Limb	5	.993	3	.999	9	.985	-0.51	-0.98	1.44	0.32
Falling Limb	5	.970	3	.983	9	.971	1.12	-1.56	1.22	-1.07
					DC III					
Total	4	.720	4	.972	6	.990	0.54	-0.31	0.78	1.56
Quick	4	.971	4	.978	6	.994	-0.08	-0.14	-0.42	1.00
Delayed	4	.751	4	.970	6	.916	0.25	0.26	0.69	1.54
Rising Limb	4	.867	4	.971	6	.990	1.33	-0.38	4.17**	3.16**
Falling Limb	4	.775	4	.960	6	.978	-0.13	-0.25	-0.22	-0.18
					DC IV					
Total	10	.995			7	.990			-1.27	1.07
Quick	10	.985			7	.980			-0.96	0.33
Delayed	10	.608			7	.837			1.07	1.21
					NEEDLE BRANCH					
Total										
Yearly	32	.990			12	.933			0.48	3.31**
Fall	14	.995			3	.949			3.14**	5.15**
Winter	18	.990			9	.911			1.00	2.49*
Quick										
Yearly	32	.985			12	.933			0.08	2.17*
Fall	14	.990			3	.954			2.29*	3.77**
Winter	18	.980			9	.917			0.31	1.25
Delayed										
Yearly	32	.911			12	.922			1.71	2.60**
Fall	14	.990			3	.949			3.22**	5.07**
Winter	18	.812			9	.922			2.41*	2.45*

Table 5. Significant effects of treatments on peak discharge at the mean of means.[1]

	Estimated Value in csm					
	Calibration	Road	% Change	Calibration	Logging	% Change
			DC III			
Yearly	18.3	23.5	28.4**	20.0	28.7	43.5**
Recharging	9.7	14.6	50.5**	7.6	10.3	35.7**
Recharged	25.7	31.0	20.6**	25.4	36.9	45.3**
			DC IV			
Yearly				49.2	62.9	27.9**
Fall				19.4	44.5	127.9**
Winter				54.5	66.1	21.6**
			NEEDLE BRANCH			
Yearly				30.3	41.0	35.0**
Fall				19.3	36.6	89.9**
Winter				44.0	56.3	28.5**

[1]Based on predicted values at the mean of pretreatment and post-treatment regression.

Table 6. Significant effects of treatments on induced peak discharge at the mean of means.

	Estimated Values in csm					
	Calibration	Road	% Change	Calibration	Logging	% Change
			DC II			
Recharged	25.9	31.2	20.5*	23.6	26.8	13.5
			DC III			
Yearly	13.7	17.8	29.9**	16.4	21.2	29.3**
Recharging	7.0	11.8	68.6**	6.0	8.4	40.0*
Recharged	18.3	23.5	28.4**	20.6	27.3	32.5**

Table 7. Significant effects of treatments on runoff volume at the mean of means.

Flow	Calibration	Road	% Change	Calibration	Log	% Change
	Estimated Values in Inches					
			DCM			
Quick	2.23	2.34	0.1	2.20	1.91	-13.1*
Delayed	1.60	1.74	8.7	1.56	1.71	9.6*
Rising Limb	1.24	1.24	0	1.09	1.19	9.5*
Falling Limb	2.64	2.91	10.2	2.63	2.44	- 7.2
			NEEDLE BRANCH			
Total						
Yearly				4.71	5.60	18.9**
Fall				2.59	6.17	138.2**
Winter				6.37	7.35	15.4*
Quick						
Yearly				3.16	3.67	16.1*
Fall				1.73	3.80	119.6**
Delayed						
Yearly				1.56	1.98	27.6**
Fall				.86	2.46	186.0**
Winter				2.12	2.73	28.8*

Table 8. Summary of statistical results for test to determine difference between fall and winter data, including number of observations (n), r, t for slope (t_s), and t for vertical position (t_v), as tested against the control.

Watershed	Variable	Period	n Winter/Fall	r Winter/Fall	t_s [1]	t_v [2]
Needle Branch	Peak Discharge	Pre	49/44	.933/.975	4.88**[3]	
		Post	17/9	.911/.990	3.10**	
Needle Branch	Quick Flow	Pre	18/14	.980/.990	0.81	-0.13
		Post	9/3	.917/.954	0.89	0.97
Needle Branch	Delayed Flow	Pre	18/14	.812/.990	2.21*[4]	
		Post	9/3	.922/.949	0.89	1.51
Needle Branch	Total Flow	Pre	18/14	.990/.995	2.30*	
		Post	9/3	.911/.949	1.01	1.21
Deer Creek IV	Peak Discharge	Pre	17/3	.975/.964	0.24	0.33
		Post	16/3	.964/.985	2.22*	

[1] t_s is the computed t value for change in slope

[2] t_v is the computed t value for change in vertical position

[3] ** significance at the 99 percent level

[4] * significance at the 95 percent level