CHANGES IN STORM HYDROGRAPHS AFTER ROADBUILDING AND SELECTIVE LOGGING ON A COASTAL WATERSHED IN NORTHERN CALIFORNIA

by

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A Thesis

Presented to

The Faculty of Humboldt State University

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

August, 1985

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85/WM-47/08-23

Natural Resources Graduate Program Number

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ABSTRACT

The effects of road building and selective tractor harvesting on storm peak flows and storm volumes were assessed for a small (424 hectare) coastal watershed in Northern California. Two watersheds, the North and South Fork of Caspar Creek were calibrated from 1962 to 1967 while no treatments took place. Roads were then built on the South Fork, and the two watersheds were monitored until 1971. Between 1971 and 1973 the South Fork was selectively tractor logged, removing 60 percent of the timber volume. The storm flows were monitored until 1976.

Only the very small (566 l/s or less) storm peaks or volumes (121 kiloliters or less) were increased after roadbuilding and logging. Roadbuilding alone significantly ($p < 0.10$) increased the small storm peaks approximately 20 percent, but did not affect the storm volumes. Logging increased both the peaks and volumes of the small storms by about 80 percent and 40 percent respectively. The large storm peaks and volumes were not significantly increased by either roads or logging, even though over 15 percent of the watershed was compacted in roads, skidtrails and landings. The increase in small storm peaks and volumes are not considered significant to the stream's stability or sediment regime.

ACKNOWLEDGEMENTS

This research was part of a joint effort by the Pacific Southwest Forest and Range Experiment Station and the California Department of Forestry. I appreciate being allowed to analyze the data collected during this project and for the use of the computer facilities at PSW's Redwood Sciences Lab. Redwood Sciences Lab allowed me to do a portion of this thesis while under their employment.

I wish to express my sincere thanks to my major advisor, Dr. Raymond M. Rice, to whom I owe much for his advise, guidance, and encouragement to complete this thesis. I thank Ray for his patience and soft-heartedness in allowing me many extensions on this thesis. Ray allowed me to make my own mistakes, but prodded me back on track when I ventured off on tangents, for this I am grateful. I aspire to the directness and clarity of expression he has in reporting research. It has been a rewarding and pleasureful experience being a graduate student under Ray.

I would also like to thank members of my committee Dr. Gerry Allen and Dr. Carl Yee for their guidance and the background that their classes provided for this study and my career in hydrology.

Also to my two and three-year-old daughters, Debbie and Regina, for not helping type this thesis and knowing when it was time for their Daddy to stop working and play. Finally, my thanks to my loving wife Elena who not only provided assistance in preparation of my "little" thesis but also provided support and encouragement.

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INTRODUCTION

The influence of forest management activities on storm flows has been subject to much debate and controversy. One subject of debate is the influence logging and road building may have on increasing storm flows and subsequent cumulative watershed effects. If the magnitude or duration of the large channel-forming flows are increased, the stream power is increased for eroding channel banks, scouring out gravel beds and removing riparian vegetation (Gangmark and Bakkala 1960; Rice 1981; Chamberlin 1982). This could adversely affect the fisheries by reducing the bank cover, scouring out spawning beds, increasing the stream temperature by reducing shade, and decreasing the overall biotic productivity by reducing leaf litter input into the stream system (Chamberlin 1982). Increasing the large channel forming flows can increase sedimentation and channel deposition if the higher flows undermine stream banks and erode the toe portions of unstable slopes, thereby triggering bank failures and landslides into the channel (Farrington and Savina, 1977; Rice 1981). The increased sediment can fill in pools and silt in spawning beds, reducing the streams biotic productivity (Chamberlin 1982).

The effect of forest management on large peak flows is a major issue relating to cumulative watershed effects. If timber management activities do increase the large peak flows, then as more cut units and roads are added to a watershed, their effects on peak flown could cumulate and could change the dynamic equilibrium of the stream.

Federal land management agencies are required to analyze cumulative impacts of their management by the National Environmental Policy Act. Most of the cumulative watershed impact analyses presently being developed by the Forest Service are based on the assumption that the large channel-forming flows are increased as a result of forest management activities (Seidelman 1981; Haskins 1983; Chatoian 1985). For the Pacific Northwest the issue of whether large channel-forming flows are increased in size or duration by forest management has not been fully resolved because the findings have been mixed (Harr et al. 1975; Ziemer 1980; Rothacher 1973; and Harr et al. 1982). The Forest Service has been developing cumulative impact methodologies without adequate information to do so, because of the legal requirements to address cumulative impacts. Until more is known about the effects of roads and logging on stormflows and their subsequent cumulative effects, these issues will continue to be quite controversial.

Objectives

The purpose of this study was to determine the effects of selective harvest and road building on storm flows for a coastal watershed. Specifically, the objectives were to:

1) Determine whether road building and selective harvest altered peak discharge, total storm volume, and quick flow volume.

2) Determine whether road building and selective harvest altered large hydrographs and small hydrographs to the same degree.

3) Develop hypotheses about the effects of road building and selective logging on storm hydrograph parameters.

Ziemer (1981) did an analysis on Caspar Creek, the same site as this study, to determine the effects of roadbuilding and logging on the storm flows. The difference between Ziemer's work and this study is that hydrographs were defined differently and different parameters were developed. The storm hydrograph parameters used in this paper were similar to parameters used on the Alsea watershed study by Harr et al. (1975), Harris (1973), Krygier and Harr (1972), and Hsieh (1970).

Literature Review

The first analysis of the effects of logging on floods in the Pacific Northwest was published by Anderson and Hobba (1959). The study was done by analyzing United States Geological Survey (USGS) gaging records and logging history for sub-watersheds of the Willamette River in Oregon. Anderson and Hobbs (1959) concluded that logging had increased floods, and that both for great storms and small storms the effects of forest cutting on floods were the same. These conclusions were in contrast to more recent paired watershed studies.

On the H.J. Andrews experimental watershed HJ-1, in central Oregon, Rothacher (1973) found that logging had only minor effects on the major peak streamflows, which occurred when soils were thoroughly wet. Exceptions were the early fall storms which in general do not result in major peak streamflows. The early fall stream flows were from 40 to 200 percent higher than was predicted from the control watershed using the pre-logging data. Although some post-logging peaks were increased to relatively high levels, none of the increases exceeded previous high stormflow peaks. Roading another of the H.J. Andrews watersheds (HJA-3) significantly decreased the size of the peak flows; Rothacher (1973) could not explain this observation except for the fact that only two years of data existed with only relatively small storm sizes. Other more recent watershed studies on the H.J. Andrews Experimental Forest (Harr et al. 1982) found that neither the size nor timing of peak flows changed significantly after shelterwood logging (HJA-7 watershed) and after clearcut logging (HJA-6 watershed). On HJA-10 (a 10.2 hectare watershed which was 100 percent clearcut logged by a cable yarding system and left unburned) Harr and McCorison (1979) found the size of annual peak flows caused by rain with snow melt was reduced 36 percent. The peak flows resulting from rainfall alone were not significantly changed.

For the Coyote Creek Experimental Watersheds, in Southern Oregon, (Harr et al. 1979) found that roading and logging did significantly ($p < 0.05$) increase peak flows on two out of the three treated watersheds. Although large stormflow data was lacking for the control period in this study, by extrapolating the control period regression line beyond the data points to the higher flows indicated that logging and road building increased the larger stormflows. Increases in size of peak flow appeared to be related to the amount of watershed area where soils were compacted. Watershed CC-1, which was shelterwood harvested (removing approximately 50 percent of the basal area) and tractor logged, had 15 percent of its area compacted in skid trails and roads. Harr et al. (1979) determined that a nine year return period flow would be increased approximately 48 percent. Watershed CC-3, which was clearcut and tractor logged, had 13 percent of its area compacted from skid trails or roads. The regression showed that a nine year return period flow would be increased approximately 35 percent. Watershed CC-2 had 5 percent of its area heavily compacted and, although not statistically significant, a nine year flood flow would be increased 11 percent. These results should be interpreted with caution because of the lack of high flow data during the control period, causing a need to extrapolate the regressions in order to estimate treatment effects.

On the Alsea experimental watersheds, in the Oregon Coast Ranges, Harr et al. (1975) found that peak flows on Deer Creek 3 were increased significantly when roads, landings and skid trails occupied 12 percent of the watershed. Harr suggests that a 10-year event could be increased to a 25-year event, and a 25-year event could be increased to a 90-year event on watersheds with 12 percent of their area in roads, landings and skidtrails. Significant increases in aid-winter peak flows also occurred on Deer Creek 4 which was clearcut cable logged, and had no roads. Krygier and Harr (1972) were not able to explain the increase in mid-winter. Frequent site trips showed no evidence of overland flow occurring during the storms. On the main Deer Creek watershed and Needle Branch Creek watershed, Harris (1973) found no significant increase in the peak flows exceeding 5.5 1/s-ha, after clear-cutting 26 percent of the main Deer Creek watershed and 82 percent of the Needle Branch watershed. Harr et al.'s (1975) analysis, which included smaller storms, showed that peak stormflows at Needle Branch Creek significantly increased after logging. The greatest increases in peak stormflows occurred during the fall, but the mid-winter storms on Needle Branch Creek also increased. These results should be interpreted with caution because there were very few or no stormflows of significant size after treatment. No peak during the post clear-cutting period on Needle Branch or Deer Creek 4 exceeded the estimated annual peak of 9.2 l/s-ha. The other watersheds in the Alsea study also used approximately the same return period flows (Harr et al. 1975).

On Caspar Creek, in Northern California, Ziemer (1980) found that the roads, which occupied over 5.5 percent of the South Fork Caspar Creek watershed, had no significant effects on peak flow or the duration of the highest one half of the storm flow (HALFQ). Selective tractor harvesting, removing 60 percent of the volume over the entire watershed, did increase both peak flows and HALFQ, but only for flows less than 0.78 1/s-ha. The smaller peaks were increased an average of 107 percent. Over 15 percent of the watershed was compacted in skid trails, landings and roads, but in contrast to the Harr et al. (1979) study on Coyote Creek and the Harr et al. (1975) study on the Alsea watersheds, the large mid-winter flows were not significantly increased (Table 1).

There is some evidence that clearcutting can increase the large stormflows, when a warm rain occurs on a wet snow pack. Harr (1980) and Christner and Harr (1982) evaluated USGS gaging records and harvest records for watersheds in the Willamette River basin and found evidence that logging had increased the large storm flows. They speculate that the increases occurred during rain on snow events where the openings from clear cut logging increased the rate of latent heat transfer which caused rapid melt rates and increased runoff. Anderson and Hobba (1959), also using USGS gaging records, found that both small and large peaks had increased for watershed drainage in the Willamette River.

Table 1. Summary of Paired Watershed Studies on the Effects of Roadbuilding and Logging on Stormflows in the Pacific Northwest.

Watershed	Area (ha)	Mean Rainfall (cm)	Logging System	Silvicultural Treatments [a]	Area Compacted	Min Flow Analyzed (1/s/ha)	Roading Effects on Peak Flows	Logging Effects on Peak Flows [b] [flow change in l/s/ha (%)]	Reference
H.J. Andrews Watershed 1	95	233	cable	CC-100% BB-100%	----	1.1	not tested	fall pks increased up to 7 (200%) larger winter pks ns [c]	Rothacher (1973)
H.J. Andrews Watershed 3	101	233	cable	CC-25% BB-25%	10%	1.1	decreased	moan increase 0.33 (10%); date on larger pks lost	Rothacher (1973)
H.J. Andrews Watershed 6	13	219	10% tractor 90% cable	CC-100% BB-100%	----	4.5	not tested	no significant change in peak flows or timing of peak flows	Harr et al. (1982)
H.J. Andrews Watershed 7	21	219	60% tractor 40% cable	SC-60% BB-100%	----	4.5	not tested	no significant change in peak flows or timing of peakflows	Harr et al. (1982)
H.J. Andrews Watershed 10	10	230	cable	CC-100% YUM-100%	19%	2.2	not tested	annual rain on :now pka decreased d 4.4 (36%); annual rein fall pks ns	Harr and McCorison (1979)
Coyote Creek Watershed 1	69	123	tractor	SC-50% UT	13%	2.2	not tested	mean pks Increased .85 (30%); larger pks (9yr rtn pd) increased 3.2 (48%)	Harr et al. (1979)
Coyote Creek Watershed 2	68	123	14% tractor 16% cable	CC-30% TP-14% YUM-16%	5%	2.2	not tested	no significant change in peek flows	Harr et al. (1979)
Coyote Creek Watershed 3	49	123	23% tractor 77% cable	CC-100% TP-23% YUM-77%	12%	2.2	not tested	mean pks increased 1.5 (44%); larger pka (9yr rtn pd) increased 3.0 (35%)	Harr et al. (1979)
Alsee study Needle Branch	70	248	10%tractor 72% cable	CC-82% BB-82%	5%	5.5 and 0.03	ns	large pks > 5.5 ns ; pks > 0.03: -fall pks mean increase 1.7 (50%) - winter pks mean increase 1.1 (19%)	Harris (1973); Harr et al. (1975)
Deer Creek	303	247	cable	CC-26% UT	4%	5.5 and 0.03	ns	no significant change in peak flows	Harris (1973)
Deer Creek Subwatershed 3	40	247	cable	CC-65% UT	12%	0.03	increased 0.55	fall pks mean increase 0.33 (50%) winter pks man increase 1.3 (30%)	Harr et al. (1975)
Deer Creak subwaterahed 4	16	247	cable	CC-90% UT	----	0.03	not tested	fall pks mean increase 3.0 (51%) winter pks mean increase 1.1 (20%)	Krygier and Harr (1972)
South Fork Caspar Creek	424	1010	tractor	SC-60% UT	16%	0.19 and	ns 4.7	pks 0.19-0.78 increased 0.52 (107%) large pks > 4.7 ns	Ziemer (1980)

a) CC-lOO% = Clearcut logged over 100% of the watershed; SC-60% - Shelterwood harvest removing 60% of the basal area; BB-100 - broadcast burned, 100% of the watershed; TP-23% = tractor piled, 23% of the watershed; YUM-77 = slash was cable yarded over 77% of the watershed; end UT = slash not treated.
b) To convert the results in the text from l/s to l/s/ha divide l/s by 508 ha for the North Fork and 424 ha for the South Fork Caspar Creek watershed.
c) ns = no significant change detected.
d) An annual peak flow has a return period of about 2 years.

Caspar Creek

This study analyzed data from the North and South Fork of Caspar Creek. Caspar Creek is located in the Jackson State Forest, about 10 km south of Fort Bragg, California, and about 7 km from the Pacific Ocean (Figure 1). The North and South Forks of Caspar Creek drain watersheds having areas of 508 ha and 424 ha respectively. Soils are mainly Hugo and Mendocino, overlying sedimentary rocks (Rice et al. 1979).

The climate is Mediterranean, having mild summers with fog but little or no rain. Caspar Creek does not receive any appreciable snowfall. The rain fall averages about 120 cm per year (Ziemer 1981).

About 35 percent of both watersheds have slopes less than 30 percent. The South Fork has about one percent of its area in slopes greater than 70 percent, whereas the North Fork has about seven percent of in slopes greater than 70 percent (Ziemer 1981).

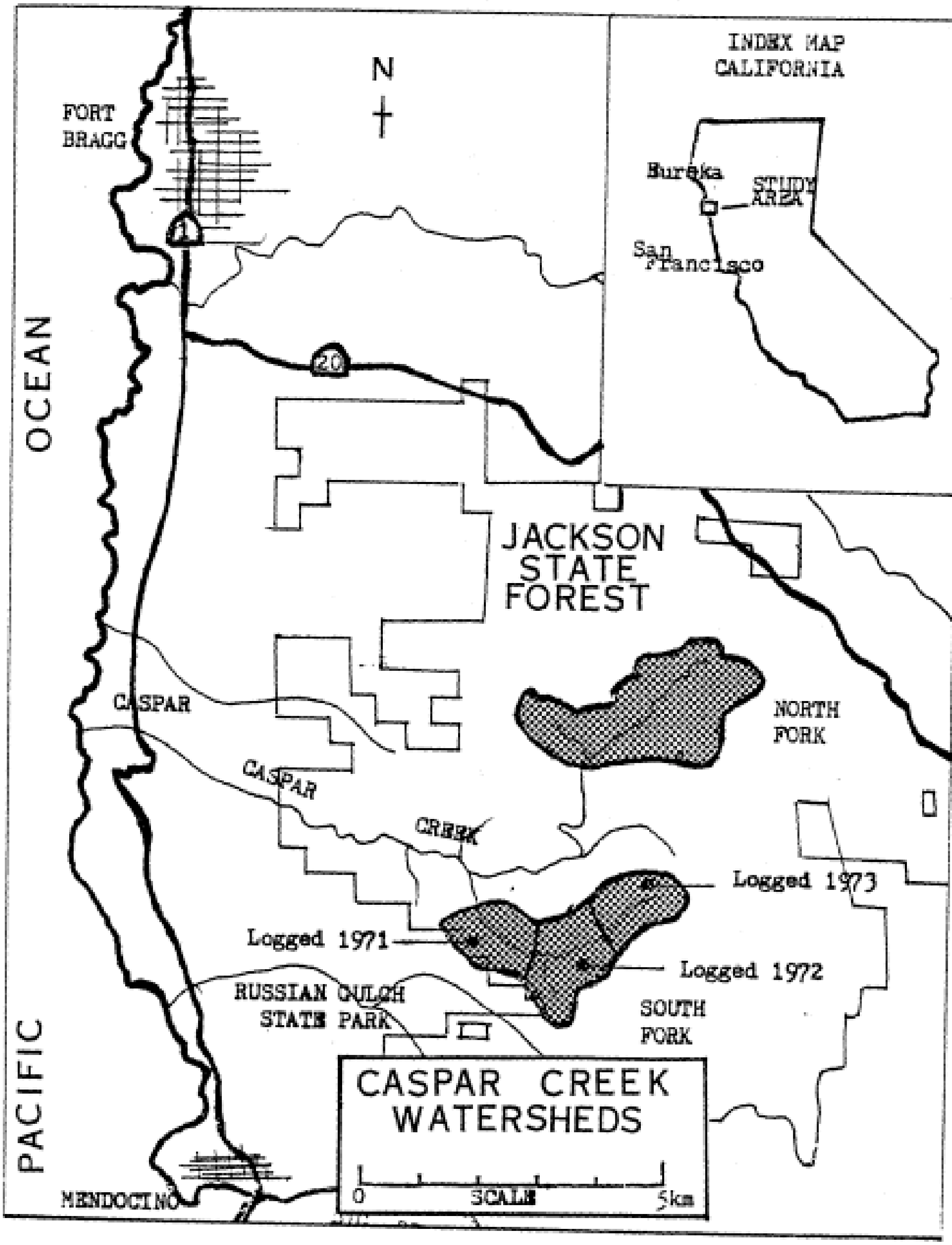

Figure 1.Vicinity Map of Caspar Creek Paired Watersheds.

MATERIALS AND METHODS

The Caspar Creek watershed project was started in 1961, as a cooperative project between the Pacific Southwest Forest and Range Experiment Station, Forest Service U. S. Department of Agriculture and the California State Department of Forestry.

Instrumentation

In November 1962, 120-degree sharp-crested V-notch weirs with rectangular sections for higher flows (over 690 l/s) were installed at the lower end of each watershed, the North and South Forks of Caspar Creek. Water level recorders (Model A-35, Leopold and Stevens Instruments, Beaverton Or.) were also installed on the ponds immediately upstream of the weirs. The ponds were both approximately 0.1 ha in size and also served as debris catch basins for the concurrent sediment study.

Treatment History

The North and South Forks of Caspar Creek were originally clearcut logged and burned in the late 1800's, the North Fork about 20 years after the South Fork (Tilley 1977). When the study began in 1962, both watersheds supported fairly dense stands (700 m^3/ha) of second growth redwood (*Sequoia sempervirens* (D. Don)Endl.), grand fir (*Abies grandis* (Dougl. ex D.Don)Lindl.), western hemlock (*Tsuga heterophylla* (Raf.)Sarg.) and Douglas-fir (*Pseudotsuga menziesii* (Mirb.)Franco). The timber stand on the South Fork watershed was about

85 years old; the timber stand on the North Fork was approximately 65 years old. Because of the age difference, the North Fork was selected as the control and the South Fork as the watershed to be selectively harvested. The road location and construction, and the timber harvest practices were designed to meet standards which in 1971 were considered "state of the art" practices, but also considered commercially acceptable by the local tuber contractors.

Both watersheds were monitored in an undisturbed condition between 1962 through the spring of 1967. During the summer of 1967 about 6.8 km of main-haul logging road and spur roads were constructed fn the South Fork watershed. Most of the logging roads were constructed adjacent to the stream channel. Of the total 6.8 km of road, 6 km were within 61 m of the stream and 2.3 km impinged directly on the stream channel. The coarse debris in the stream and along the channel banks, resulting largely from the road construction, was mostly removed after road construction. The roads (including cut-and-fill slopes) occupied 19 ha. (4.5 percent of the total watershed area) from which 993 m^3/ha (85 MBF/acre) of timber was removed.

About 110 m of stream bed were disturbed by tractor operation directly in the stream. These areas were primarily around bridge crossings, landings, and in a stretch of stream cleared of debris which had been deposited there from the road construction. All fill slopes, landings and mayor areas of soil exposed by the road building activities were fertilized and seeded with annual ryegrass (*Lolium multiflorum*) in September 1967. The grass was well established before the first rains in November (Jackman and Stoneman 1973).

From 1967 through the spring of 1971, stream flow was measured to record the effects of road construction.

Logging began on the South Fork of Caspar Creek during the summer of 1971 and continued over a three year period. The South Fork watershed was divided into three sale areas, the first sale started at the weir and continued a third of the way up the watershed (Figure 1). The lower area (101 ha) was selectively logged, removing 59 percent of the timber volume during the summer of 1971. The middle area (128 ha) was selectively logged during the summer of 1972, removing 69 percent of the timber volume. The remaining area (176 ha) was selectively logged in the summer of 1973, removing about 65 percent of the timber volume (Table 2). All logging was done by tractor. Some of the steeper slopes required that skid trails be constructed. The proportion of the watershed area heavily compacted (area in roads, landings and skid trails) occupied over 15 percent of the watershed (Table 2). Most of the roads and landings were near or adjacent to the streams, and many of the skid trails did not have crossdrains installed.

The selection cutting removed single trees and small groups of trees with the objectives of reserving healthy, fast-growing stands of the more desirable species and providing openings to encourage regeneration. Most of the scattered old-growth timber was removed. Near the county roads and the boundary of Russian Gulch State Park, cutting was reduced and some old growth trees were left for aesthetic reasons.

Table 2. Summary of Treatments in the South Fork of Caspar Creek.

Parameter	Year 1967	1971	1972	1973	Average	Total
Area harvested (ha)	19[a]	101	128	176		424
Ave Stand Volume						
(m^3/ha)	993	815	731	598	708	
(MBF/acre)	85.1	69.9	62.7	51.3	61.3	
Volume harvested						
(m^3/ha)	993	483	502	386	471	
(MBF/acre)	85.1	41.4	43.0	33.1	40.3	
Road construction						
Kilometers	6.7	0.71	0.18	0.24		4.9
hectares	19.0	2.0	0.5	0.7		22.2
Skid Trails (ha)	0	8.8	11.2	15.4		35.4
Landings (ha)	0	3.5	1.3	3.6		8.4
Area Compacted (%)	4.5	7.8	10.9	15.6		15.6
(roads, landings,						
and skid trails)						

[a] Road construction right-of-way acreage.

Selection of Hydrographs

The criteria used to select the hydrographs for analysis were the following: 1) All hydrographs roust have an induced peak flow of at least 28.3 l/s (0.056 l/s•ha) on the North Fork; 2) The storm had to have complete records for both the control and treated watershed for the parameter being measured; 3) Store pairs had to correspond in tine; and 4) Story flows had to posses an initial rise greater than 0.0055 l/s•ha•hr. Precipitation records in each watershed were also examined when selecting the hydrographs, to prevent selecting hydrographs which were different because of localized differences in stores. No significant differences in precipitation between the watersheds could be identified.

The data were taken from the water level recording charts and converted to discharge for each time interval using the rating equation for the weirs. For each storm hydrograph I determined the initial, peak and ending flow, and calculated the tine-to-peak, storm duration, total volume, and quick volume.

Hydrograph Separation

Hydrograph separation into quick volume (that part of runoff which enters the stress promptly after the rainfall or snow melt) and delayed volume (the sustained fair-weather component of the runoff) was based on the method described by Hewlett and Hibbert (1967). A line projected from the initial rise, at a slope of 0.0055 l/s•ha•hr, until it intersected the falling limb of the hydrograph, divided the storm hydrograph into quick volume and delayed volume. Time-to-peak, peak discharge, and total volume were also determined for each of the hydrographs selected. Precipitation variables and ratio variables were also determined for each of the hydrograph (Figure 2 and Table 3). The hydrograph parameters were abbreviated and a prefix added (N or S) to indicate the which fork the parameter measured, for example, NTVOL would be North Fork total store volume and STVOL would be the South Fork total story volume.

The hydrograph parameters used in this analysis were originally developed on the Alsea watershed study and described by Krygier and Harr (1972), and Hsieh (1970). The ratio variables and the other variables listed in Table 3 were developed after or taken from variables described by Ziemer (1981). The precipitation variables are the ease data used in Ziemer's (1981) analysis of Caspar Creek.

Data Analysis

Determining Affects of Roadbuilding and Logging on Three Hydrograph Parameters

A least-squared multiple regression and Chow's test.(Chow 1960) were used to determine if the peak flow, total volume or quick volume were altered after road building or logging. These hydrograph parameters are the sort significant hydrograph parameters in terse of management implications. The highest flows and the volume of the highest flows most effect channel erosion and sediment deposition (Megahan 1979; Rice 1981). Rice et al. C1979) estimated that discharges greater than 1273 l/s, on the South Fork of Caspar Creek, occur approximately one percent of the time, but carry 26 percent of the volume of water end 81 percent of the suspended sediment.

Table 3. Description of Hydrograph Parameters and Other Variables Used in the, Analysis.

Variable	Definition
Hydrograph Parameters	
Peak Flow (PFLOW)	The maximum rate of flow of a storm event. If multiple peaks usually the first and largest peak which is comparable in time with the other fork is picked, in l/s.
Total Volume (TVOL)	The total water volume passing the weir between the initial response of the stream and the intersection by the hydrograph separation line, in kiloliters.
Quick Volume (QVOL)	That portion of total volume above the hydrograph separation line, in kiloliters.
Delayed Volume (DVOL)	That portion of total volume below the hydrograph separation line, in kiloliters.
Base Flow (BFLOW)	The initial flow on the North Fork before the storm, in l/s.
Time to Peak (PDUR)	The time between the initial response of the stream to a storm event and the peak flow, in hours.
Storm Duration (DUR)	The time between the initial response of the stream to a storm event and the intersection by the hydrograph separation line, in hours.
Ratio Variables	
PFLOWSFT	Ratio of the change in peak flow between the South and North Forks ([SPFLOW-NPFLOW]/NPFLOW).
TVOLSFT	Ratio of the change in total volume between the South and North Forks ([STVOL-NTVOL]/NTVOL).
QVOLSFT	Ratio of the change in quick volume between the South and North Fork ([SQVOL-NQVOL]/NQVOL).
Other Variables	
STORM	Sequential storm number within a year, beginning with the first storm with a induced peak flow greater than 28.3 l/s.

Table 3. Description of Hydrograph Parameters and Other Variables Used in the Analysis (continued)

Variable	Definition
Other Variables	
LOGGED	Percent of the total watershed area logged or partially cutover.
PPTDAY	Precipitation within 24 hours prior to the peak, in cm.
PPTWK	Precipitation between 24 hours prior to the peak and 7 days prior to the peak, in cm.
PPTMO	Precipitation between 7 days and 30 days prior to the peak, in cm.
API2	0.7 * PPTWK + 0.2 * PPTMO + 1
LOGSEQ	LOGGED/STORM
LOGBFLOW	LOGGED/(Base Flow)
LOGAPI2	LOGGED/API2

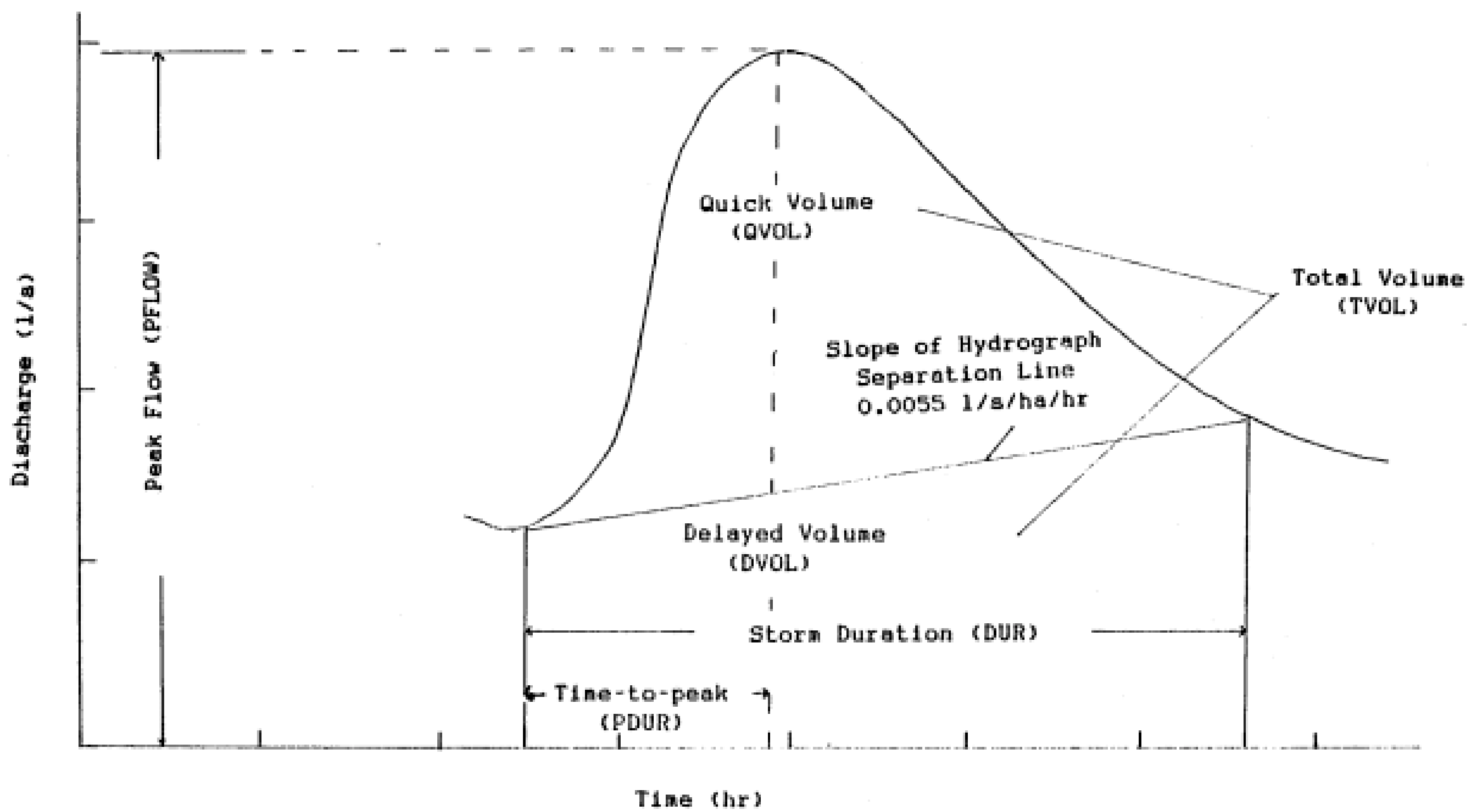

Figure 2. Diagram of the Hydrograph Parameters (Adapted from Krygier and Harr, 1972).

A stepwise multiple regression model (Dixon and Jennrich 1981) was used to developed regression equations for the calibration period. Using the same model forms developed from the calibration period data, regression equations were developed for the combined calibration and roaded period data sets, and the combined calibration and logged period data sets. The South Fork treatment watershed parameters were used as dependent variables and the North Fork control watershed parameters as independent variables.

For a given dependent variable an the South Fork, I limited the independent variables the regression model could select to the corresponding variable on the North Fork, its logarithm, and its square. This prevented the model from becoming overly complex and including too many variables. Hill (1979) determined that when performing multiple F-tests for entering variables into the equation, it is possible to have too many significant variables. The more variables you are selecting from to enter the equation, the more likely that the computed F-value will erroneously suggest that one of them is significant. For example, using regression coefficients of ten uncorrelated independent variables, the probability that one or more of the ten will, by chance, exceed a 5 percent value is 0.40, not 0.05. The subsequent predictor equation with too many variables may not perform as well on a new sample of data as an equation with fewer variables. For my analysis this would have increased the chance of a type I error occurring. Limiting the number of independent variables also allowed me to plot all data and regression lines so to examine the relationship of the data points and relationship of the regression lines.

The hypothesis that the regression equation for the calibration period is still valid for the combined calibration period plus the treated period was tested (p = 0.10) utilizing a procedure described by Chow (1960). The 10 percent significance level was chosen (a five percent significance level is standard) to reduce the risk of committing a type II error (ie. where the test would not show a change in storm flows or storm volumes when there actually was a change). With the potential impacts that could occur from increasing storm flows or volumes, I preferred to take a higher risk of committing a type I error (ie. determining that storm flows or volumes were increased when in fact they were not).

Another test that could have been used to test the hypothesis that the regression equations were the same was analysis of covariance (Wilson 1978). Analysis of covariance is a common method used in paired watershed studies (Ziemer 1981; Harr et al. 1975). Wilson (1978), compared Chow's F-test and analysis of covariance F-test and found Chow's test uniformly more powerful when regression models were not of identical form. Analysis of covariance was uniformly more powerful when the two data sets were of a linear combination of the same set of predictor variables, eg. when the model form (predictor variables or the number of significant predictor variables) did not change, but only the coefficients changed. In my analyses the model form did change, therefore I used Chow's test:

$$F_1(n_2,\ n_1-p) = \frac{n_1-P}{n_2} \quad * \quad \frac{S_3-S_1}{S_1} \tag{1}$$

Where, F_1 is the Chow's F value, n_1 is the number of observations of the calibration period data set, n_2 is the number of observations of the treated period data set, p is the number of parameters estimated in each regression (must be the same for all regressions), S_1 is the residual sum of squares of the calibration period data set, and S_3 is the residual sum of squares for the combined data set.

Determining the Treatment Effects on Large Versus Small Flows

In order to examine how large flows were affected by logging or road building versus how smaller flows were affected, I followed a procedure used by Ziemer (1981). The flows were divided into three flow classes, less than 566 l/s, greater than 1416 l/s and 566 to 1416 l/s. The ratio between the South Fork minus the North Fork and the North Fork ([South Fork-North Fork]/North Fork) were computed for the hydrograph parameters (peak flow, total volume, and quick volume). The resulting ratios were abbreviated PFLOWSFT, TVOLSFT and QVOLSFT respectively. The ratios were used to provide a measure of relative change between the treatment and control watersheds after road building and after logging. The means of the variables (PFLOWSFT, TVOLSFT and QVOLSFT) for the calibration period were compared to the roaded period and logged period ratio means for each flow class, using a two-tailed Student t-test for unequal sample sizes (Dixon and Jennrich 1981). The t-values were computed using pooled variances when the variances were equal or separate variances when the variances were unequal (Steel and Torrie 1960). An F-test was used to determine equality of variances.

Determining Variations in Treatment Effects with Antecedent Moisture

To determine if changes in stormflows after road building or logging occurred only when watershed antecedent moisture was low, I divided the hydrographs into two categories based on the base flow (greater than or less than 28.3 l/s). Base flow was used as an direct indicator of the watersheds antecedent soil moisture condition. The means of the variables (PFLOWSFT, TVOLSFT and QVOLSFT) for the calibration period were compared to the roaded and logged period variable means for each base flow category using the same t-test procedure as above for comparing flow classes.

Determining Significant Variables in Logging Effects

To better understand the differences between the North and South Fork watersheds after logging, an all possible subset regression (Dixon and Jennrich 1981) was performed on PFLOWSFT, and TVOLSFT for the logged period. The-regression model for PFLOWSFT was allowed to choose from nine independent variables (STORM, BFLOW, NDUR, NTVOL, PPTWK6, LOGGED, LOGSEQ, API2, and LOGBFL) and the best subset of these variables were choosen for the regression using Mallows' Cp (Daniel and Wood 1979). To limit the number of variables selected in the final equation, a penalty number of three was used. The penalty number adds a penalty for each variable added to the model (Frane 1981). For STVOLSFT, I allowed the model to choose from 14 variables (NPDUR, NPFLOW, BFLOW, NDUR, NTVOL, LOGGED, LGBFLOW, LGNRVOL, NQVOL, API2, LOGAPI, LOGAPI2, LOGBFL, and COMP3) to determine the best subset regression for predicting STVOLSFT.

RESULTS

Effects of Roadbuilding and Logging on Three Hydrograph Parameters

The peak flow and volume regression equations for the calibration period were fit to a logarithmic form because the logarithmic model best met the assumption of homoschedasticity (having uniform variance over the range of the regression) and gave the best distribution of data points along the entire range of the regression (Daniel and Wood, 1971). The subsequent regressions for the calibration and roaded period, and calibration and logged period were fit to the same form so that Chow's F-values could be determined. The logarithmic form of the regression equation was

$$\text{Log(SFpar)} = b_o + b_1 \text{ Log(NFpar)} \qquad (2)$$

where SFpar was the South Fork hydrograph parameter, NFpar represents the same parameter on the North Fork, and b_o and b_1 were the regression coefficients.

The regression coefficients, residual sum of squares, R-squared values, F-ratios, and Chow's F-test values comparing the calibration period regression to roaded period and to the logged period, are shown in Table 4. The computed Chow's F-values showed that the regression equations for peak flow, total volume and quick volume were not significantly different ($p \geq 0.10$) after road building. The computed Chow's F-values showed that the regressions for all of the hydrograph parameters were significantly different ($p < 0.01$) after logging (Table 4).

Table 4. Regression Coefficients, R-Squared, Residual Sum of Squares, F-values, and Chow's F-test Showing which Regressions were Significantly Different from the Calibration Period Regression, for each Hydrograph Parameter.

Regression	n	Regression Coefficients[b] b_o	b_1	R^2	Sum of Squares Residual	F-value	Degrees of Freedom	Chow's F-Test[c]
Peak Flow								
Calib[a]	49	0.241	0.951	0.968	0.492	1444		
Calib & Road	86	0.299	0.933	0.968	0.856	2544	37 46	0.92 ns
Calib & Log	92	0.476	0.886	0.927	2.074	1151	43 46	3.44 ***
Total Volume								
Calib	49	0.258	0.883	0.983	0.466	2677		
Calib & Road	86	0.263	0.882	0.984	0.728	5176	37 46	0.70 ns
Calib & Log	91	0.424	0.817	0.953	2.112	1819	42 46	3.87 ***
Quick Volume								
Calib	49	0.393	0.834	0.973	0.936	1691		
Calib & Road	86	0.386	0.841	0.975	1.392	3307	37 46	0.61 ns
Calib & Log	91	0.531	0.778	0.945	3.075	1544	42 46	2.50 ***

a) Calib = calibration period; Road = roaded period and; Log = logged period.

b) The b coefficients represent regressions of the form:
Log(SFpar)= bo * b1 Log(NFpar)

c) *** = Significant ($p < 0.01$). ** = Significant ($p < 0.05$).
* = Significant ($p < 0.10$). ns = Not significant at ($p \geq 0.10$).

Comparing the calibration and logged period regressions in regards to peak flow (Figure 3), the smaller peak flows were increased after logging. However, with the larger peak flows the regression lines converge and cross. As the peak flows become larger the difference between the logged and calibration periods diminish.

Comparing the calibration and logged regressions for total volume and quick volume (Figures 4 and 5), the same pattern emerged as the peak flow regressions had shown. The smaller storm volumes were increased after logging, but for the larger storm volumes the regression lines converge and cross.

Large Storm Flows Versus Small Storm Flows

To determine if the hydrograph parameters were increased after road building and after logging, on both small stormflows and large stormflows, the hydrograph parameters were divided into three classes based on the North Fork peak flow (less than 566 l/s, 566-1416 l/s, and greater than 1416 l/s). The means of the ratio variables (PFLOWSFT, TVOLSFT and QVOLSFT) were tested by flow class to determine if their means had changed from the calibration period after roading (Table 5), or after logging (Table 6).

Roaded Period

No significant ($p \geq 0.10$) differences in the means of the ratios for the calibration period and the roaded period were detected, except for PFLOWSFT in the peak flow class of less than 566 l/s (Table 5). The mean value for PFLOWSFT during the calibration period was approximately 0.35 and after roading the mean value increased to 0.55,

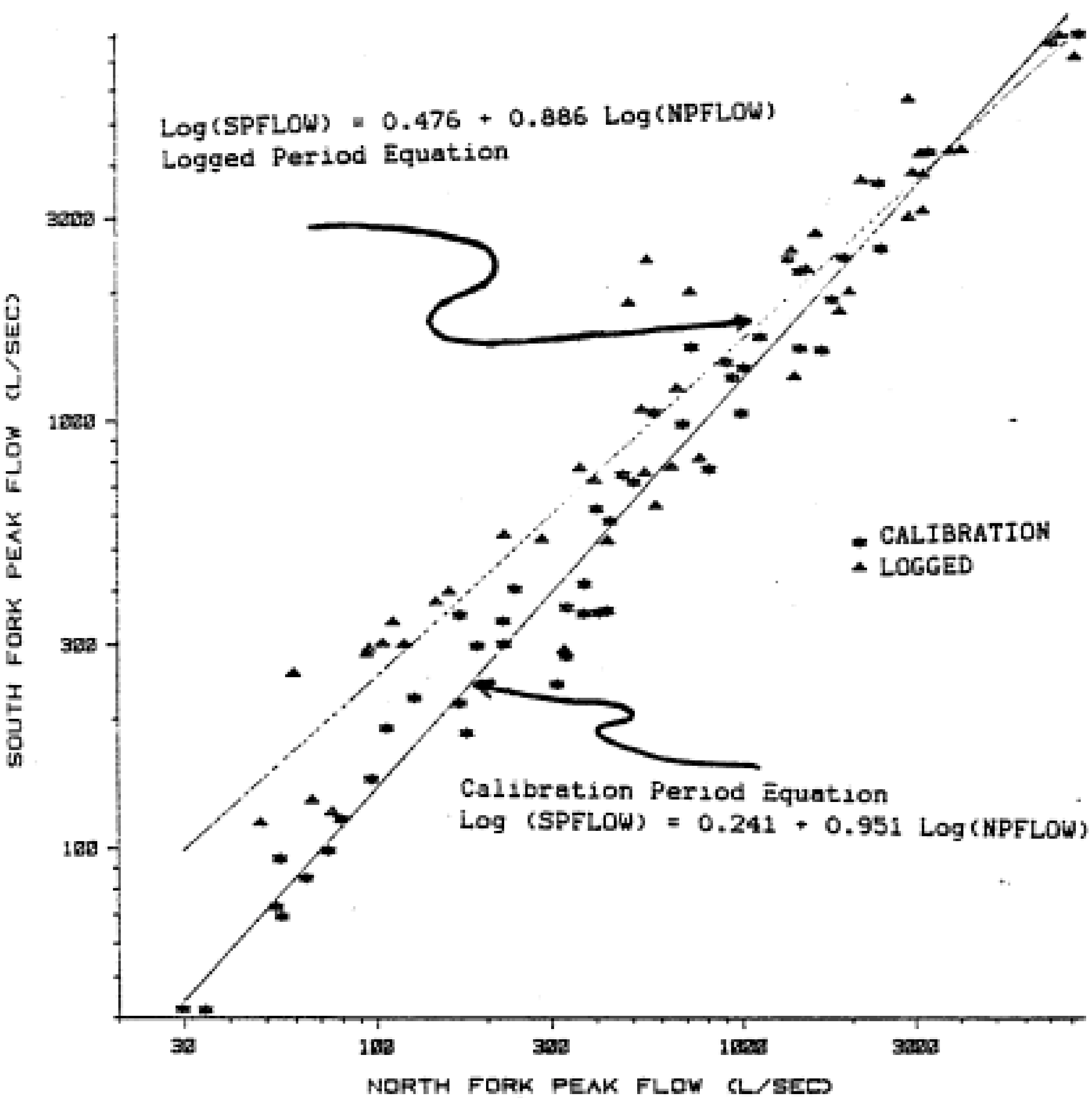

Figure 3. Relationship Between Peak Flows on the North (NPFLOW) and South Fork (SPFLOW) of Caspar Creek during the Calibration Period and the Logged Period.

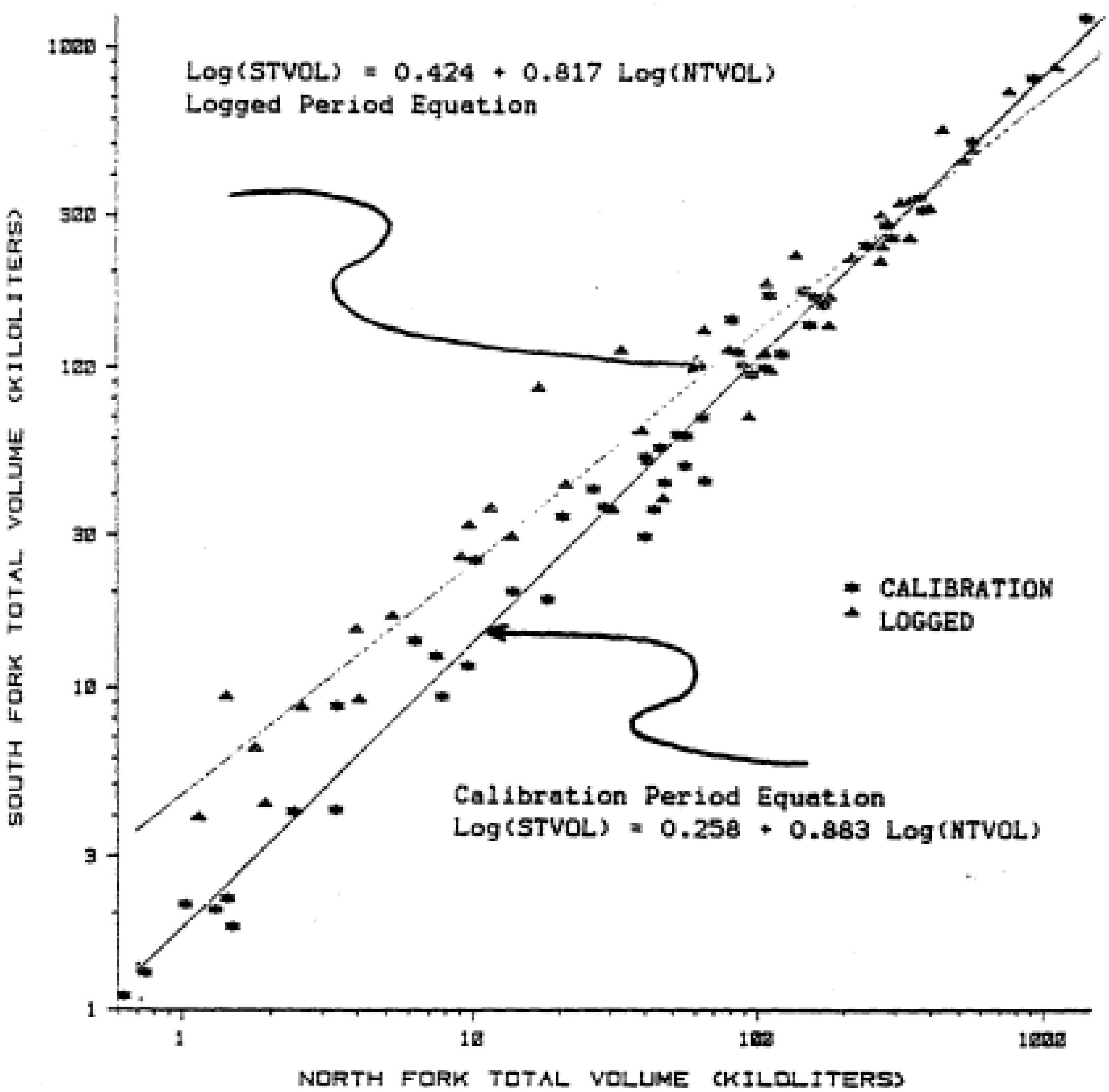

Figure 4. Relationship Between Total Storm Volumes on the North (NTVOL) and South Fork (STOVL) of Caspar Creek during the Calibration Period and the Logged Period.

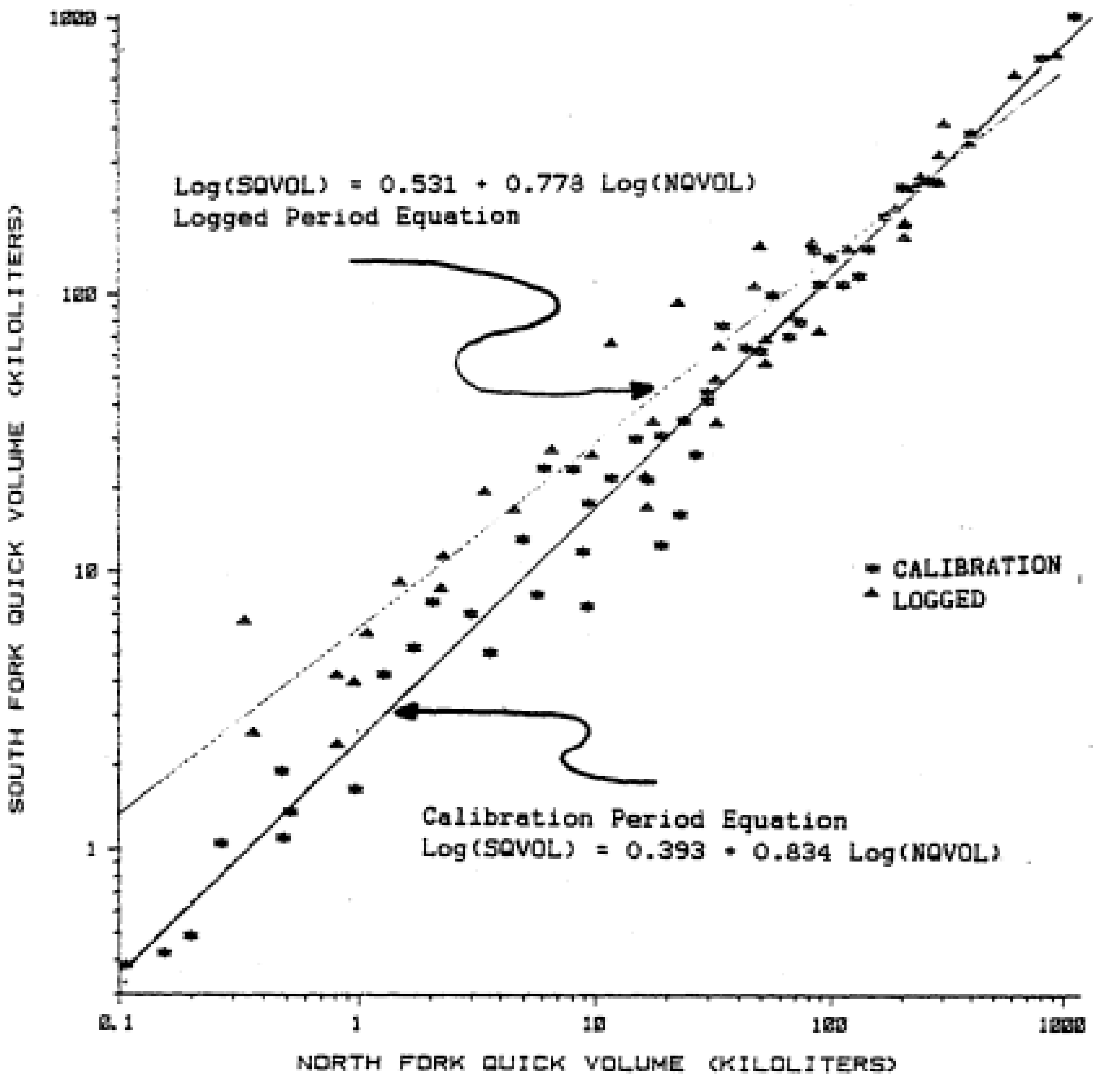

Figure 5. Relationship Between Storm Quick Volumes on the North (NQVOL) and South Fork (SQVOL) of Caspar Creek during the Calibration Period and the Logged Period.

Table 5. Difference in PFLOWSFT, TVOLSFT and QVOLSFT Before and After Road Building for High, Medium and Low Storm Flows.

Variable	Calibration Period (1963-1967)			Roaded Period (1968-1971)			Calibration versus Roaded Period		
	No. of Storms	Mean	Standard Deviation	No. of Storms	Mean	Standard Deviation	Rd-Ca[a] Means	d.f.[b]	t-statistic[c]
Peak Flows Greater Than 1416 1/s									
PFLOWSFT	9	0.153	0.23	13	0.147	0.17	-0.005	20	0.83 ns
TVOLSFT	9	-0.082	0.14	13	-0.053	0.11	0.028	20	0.53 ns
QVOLSFT	9	0.108	0.42	13	0.062	0.17	-0.047	20	0.36 ns
Peak Flows 566 to 1416 1/s									
PFLOWSFT	10	0.451	0.33	10	0.460	0.37	0.009	18	0.06 ns
TVOLSFT	10	0.181	0.31	10	0.127	0.29	-0.055	18	0.40 ns
QVOLSFT	10	0.353	0.35	10	0.364	0.35	0.011	18	0.07 ns
Peak Flows Less Than 566 1/s									
PFLOWSFT	29	0.350	0.31	14	0.549	0.37	0.200	41	1.81
TVOLSFT	29	0.398	0.48	14	0.442	0.48	0.045	41	0.28 ns
QVOLSFT	29	1.766	1.03	14	1.025	0.93	-0.742	41	0.47 ns

a) Ca = Calibration period data. Rd = Roaded period data.
b) d.f. = degrees of freedom.
c) ns = Not significant ($p \geq 0.10$). * Different from calibration mean ($p < 0.10$).

Table 6. Difference in PFLOWSFT, TVOLSFT and QVOLSFT Before and After Logging and Road Building for High, Medium, and Low Storm Flows.

Variable	Calibration Period (1963-1967)			Logged Period (1972-1976)			Calibration versus Logged Period		
	No. of Storms	Mean	Standard Deviation	No. of Storms	Mean	Standard Deviation	Lg-Ca[a] Means	d.f.[b]	t-statistic[c]
Peak Flows Greater Than 1416 1/s									
PFLOWSFT	9	0.15	0.24	15	0.25	0.33	0.10	22	0.83 ns
TVOLSFT	9	-0.08	0.14	15	-0.03	0.25	0.05	22	0.55 ns
QVOLSFT	9	0.11	0.42	15	0.03	0.28	-0.08	22	0.54 ns
Peak Flows 566 to 1416 1/s									
PFLOWSFT	10	0.45	0.33	7	0.51	0.65	0.06	15	0.27 ns
TVOLSFT	10	0.18	0.31	7	0.16	0.45	-0.02	15	0.11 ns
QVOLSFT	10	0.35	0.36	7	0.56	0.76	0.21	8	0.79 ns
Peak Flows Less Than 566 1/s									
PFLOWSFT	29	0.35	0.31	21	1.46	1.93	1.11	23	5.29 ***
TVOLSFT	29	0.39	0.48	21	1.72	1.45	1.32	24	4.04 ***
QVOLSFT	29	1.76	1.03	21	3.46	3.91	1.70	22	2.62 **

a) Ca = Calibration period data. Lg = Logged period data.
b) d.f. = degrees of freedom.
c) ns =Not significant ($p \geq 0.10$). ** Different from calibration mean ($p < 0.10$).
*** Different from calibration mean ($p < 0.01$).

a significant ($p < 0.10$) increase of 0.20 over the calibration period. This represents a 20 percent increase in the small peak flows (less than 566 l/s) after road building relative to control watershed.

Logged Period

In comparing the means of the ratios (PFLOWSFT, TVOLSFT and QVOLSFT) between the calibration and logged period, no significant differences ($p \geq 0.10$) were detected in the largest two peak flow classes (over 566 l/s). In the smallest peak flow class (less than 566 l/s) all the ratio variables were significantly higher ($p < 0.05$) after logging (Table 6).

The South Fork peak flows, in the flow class of less than 566 l/s, averaged 35 percent higher than the North Fork peak flows during the calibration period. After logging they averaged 146 percent higher, a relative increase of 112 percent. The South Fork total storm volumes and quick volumes, in the flow class of less than 566 l/s, also increased relative to the North Fork by 133 percent and 170 percent respectively after logging.

Variation of effects with Antecedent Moisture Conditions

To determine if the antecedent moisture of the watershed affected the storm flow response after road building or after logging, I grouped the storm hydrograph parameters into two categories based on base flow (greater than or less than 28.3 l/s). Base flow was determined by the stream flow of the North Fork at the time of storm initiation. This parameter was selected as a direct indicator of antecedent moisture condition of the North Fork watershed.

No significant differences ($p \geq 0.10$> were found for the calibration versus the roaded period in either base flow category.

In comparing the weans of the ratios (PFLOWSFT, TVOLSFT, and GVOLSFT) for the calibration period and the logged period, the means were not significantly different ($p \geq 0.10$) for the base flow category greater than 28.3 l/s. The ratio weans were all significantly ($p < 0.05$) higher after logging for the base flow category less than 28.3 l/s. The increases in store flows, relative to the North Fork, ranged from 110 percent for peak flows to 254 percent for quick volumes after logging (Table 7).

Significant Variables in Logging Effects

To determine the significant variables which predict the changes between the North and South Fork hydrograph parameters after logging, I conducted an all possible subsets regression using the logged period data on PFLOWSFT, and TVOLSFT. This analysis uses the same approach Ziemer (1981) took in analyzing the data except that Ziemer used the entire data set and performed the test only on PFLOWSFT.

The variables which were significant in explaining the differences in the North and South Fork were BFLOW, NDUR, and LOGGED (Table 8). The most important variable was a negative coefficient of NDUR. The standardized coefficient had a value of -0.573. Ziemer (1981), using this sane analysis procedure, explained that standardized coefficients were regression coefficients that have been scaled so that the absolute value of the coefficient indicates the relative importance of that variable in the regression. As the duration of the storm

Table 7. Difference in PFLOWSFT, TVOLSFT and QVOLSFT, Before and After Logging for Base Flows Greater than and Less than 28.3 1/s (High and Low Antecedent Soil Moisture Conditions).

Variable	Calibration Period (1963-1967)			Roaded Period (1972-1976)			Calibration versus Logged Period		
	No. of Storms	Mean	Standard Deviation	No. of Storms	Mean	Standard Deviation	Lg-Ca[a] Means	d.f.[b]	t-statistic
Base Flow Category Greater Than 28.3 1/s									[c]
PFLOWSFT	23	0.18	0.32	24	0.35	0.45	0.17	45	1.53 ns
TVOLSFT	23	0.05	0.37	24	0.04	0.95	-0.01	45	0.23 ns
QVOLSFT	23	0.42	0.79	24	0.31	0.88	-0.11	45	0.57 ns
Base Flow category Less Than or Equal to 28.3 1/s									
PFLOWSFT	25	0.48	0.25	19	1.57	0.92	1.10	21	5.06 ***
TVOLSFT	25	0.46	0.42	19	1.90	1.38	1.44	21	4.39 ***
QVOLSFT	25	1.16	0.97	19	3.71	3.98	2.55	20	2.73 **

a) Ca = Calibration period data. Lg = logged period data.
b) d.f. = degrees of freedom.
c) ns = Not significant ($p \geq 0.10$). ** Different from calibration mean ($p < 0.10$).
*** Different from calibration mean ($p < 0.01$).

Table 8. Best Regression (as determined by Mallows' Cp) of All Possible Subset Regressions for PFLOWSFT Using Logged Period Data.[a]

Regression Variables[b]	Regression Coefficient	Standard Error	Standardized Coefficient
INTERCEPT	1.0795	0.26832	1.175
NDUR	-0.0115	0.00222	-0.573
BFLOW	-0.0063	0.00165	-0.419
LOGGED	0.0129	0.00334	0.402

a) R2 = 0.63, Standard error estimate is 0.577, n=43 and F= 22.51
b) Other variables considered were STORM, NTVOL, PPTWK, LOGSEQ, API2, LOGBFL.

increased the predicted difference between the South Fork peak flow and North Fork decreased or became sore negative.

The next cost important variable in estimating the PFLOWSFT was BFLOW, its standardized coefficient was -0.419. BFLOW is the stream flow rate on the North Fork before each storm. It is an indicator of the watershed's antecedent moisture condition. When BFLOW was high the differences between the peak flow on the South and North Fork were small or negative and as it decreased the predicted differences became more positive. The least significant variable in the regression was LOGGED, its standardized coefficient was 0.402. This variable was the percent timber volume removed from the South Fork. As the area logged increased, the predicted peak flows on the South Fork increased relative to the North Fork.

The results of the regression analysis for TVOLSFT using the logged period data is shown in Table 9. The most significant variable in predicting TVOLSFT was a negative coefficient of the log of NTVOL. The greater the storm runoff volume, the less the predicted difference or more negative the predicted difference between TVOL on the South Fork and the North Fork. A positive coefficient of LOGAPI2, the percent volume logged divided by the rain fall from one to 30 days before the measured storm flow, was also significant in predicting TVOLSFT. In other words, the greater the volume logged and the less the amount of rainfall the previous month, the greater the predicted value of TVOLSFT. The next two variables are API2 and BFLOW. API2, the precipitation from one day to 30 days prior to the peak flow, and BFLOW is the flow rate of the North Fork before the storm started. They both can be used as indicators of the antecedent moisture condition of the watershed. They are highly correlated, having a 0.70 correlation coefficient. The API2 coefficient is positive and the BFLOW coefficient is negative.

Table 9. Best Regression (as determined by Mallows' Cp) of All Possible Subset Regressions for TVOLSFT Using Logged Period Data.[a]

Regression Variable[b]	Regression Coefficient	Standard Error	Standardized Coefficient
INTERCEPT	0.99122	0.42063	0.742
LOG(NTVOL)	-1.04299	0.14481	-0.661
LOGAPI2	0.03480	0.00623	0.493
API2	0.28248	0.09937	0.337
BFLOW	-0.15596	0.46285	-0.252

a) R2 = 0.82, Standard error estimate is 0.591, n=43 and F= 44.0.
b) Other variables considered were NPDUR, NPFLOW, NDUR, NTVOL, LOGGED, LGBFLOW, LOG(NRVOL), NQVOL, LOGAPI, LOGBFL, and COMP3.

DISCUSSION

The larger peak flows and storm volumes (total volume and quick volume) were not significantly increased after either road building or logging. Significiant ($p < 0.10$) increases in storm peaks and storm volumes occurred only in the smallest storm flows (those having peak flows $\leq$ 566 l/s) after logging. After road building the small store peaks were significantly increased but storm volumes were not.

The increases in the smaller peak flows or storm volumes after road building or logging could have been caused by either reduced evapotranspiration and reduced interception from the removal of the trees, or from compaction by the roads, skid trails and landings.

Evapotranspiration and Interception Effects

Logging can modify the soil moisture depletion by reducing evapotranspiration (Ziemer 1981). Evapotranspiration during the growing season can produce substantial soil moisture differences between logged and unlogged watersheds, which in turn, can cause increased storm runoff in the wetter, logged watershed. After the North Fork (control) watershed received a number of storms and the soil moisture was recharged, the North and South Fork responded similar to the calibration period. Evapotranspiration is reduced during the winter months and the interval between storms are short, therefore the watershed soil moisture differences generally do not become significant again until spring or summer (Ziemer 1981).

The North Fork base flow provided an indicator of antecedent moisture or recharged condition of the North Fork. As the base flow increased, the North Fork soil water became recharged and the difference between the two hydrographs diminished (Figure 6). The stores occurring during low antecedent moisture conditions were up to 240 percent higher than predicted. With increasing base flow the increases in the South Fork peak flows became insignificant. The same trend also occurred for the South Fork total volume and quick volume parameters.

Interception is another variable which was changed by timber harvesting and could affect storm runoff. Rothacher (1973) found on the H. J. Andrews Experimental Forest that interception during storms of 50-100 mm, averaged 6 to 12 mm in old growth Douglas-fir. Assuming the redwood canopy on Caspar Creek had similar water holding capacities, interception would have been significant for only the small storms. Many of the small storm flows on Caspar Creek were in response to less than 25 mm of rainfall. Assuming that the logging removed 60 percent of the canopy, the storm volume from a 25 mm rainfall event could have been increased by approximately 20 percent due to the reduced interception. For larger storms interception was less significant because the canopy would quickly reach its water holding capacity of 6 to 12 mm. The largest storm flows on the North Fork were in response to over 220 mm of rainfall. Removal of 60 percent of the canopy could have increase the total storm runoff volume by only about two percent over the untreated watershed.

The larger storms occurred during midwinter when the uncut watershed had a high antecedent soil moisture. This, combined with the

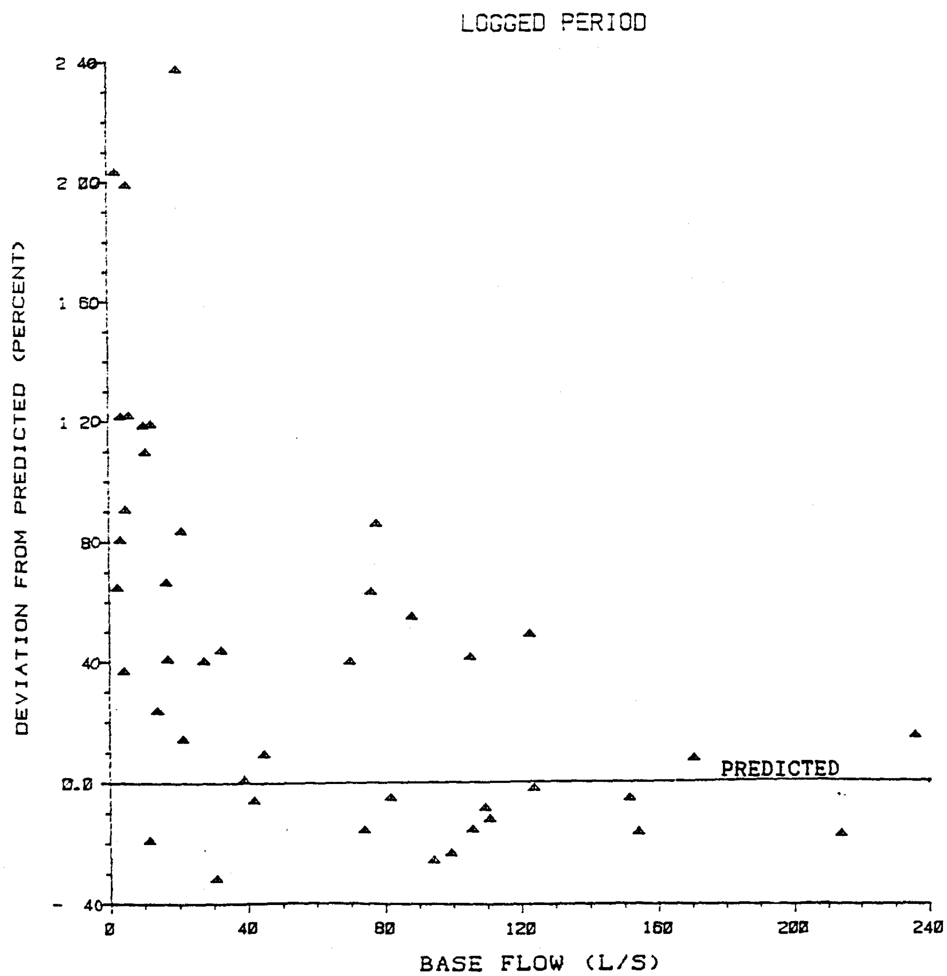

Figure 6. Relationship of Base Flow (Antecedent Soil Moisture) to Percentage Deviation of Post-Logging Peak Flows from Predicted Pretreatment Flows.

reduced effects of interception for larger mid-winter storms, caused the logging effects to be insignificant in increasing large storm peaks or volumes. The increases from logging decreased as the storm size increased (Figure 7 and 8). The smaller peak flows were increased up to 240 percent after logging and the very largest storms were not increased. The storm volumes were also increased up to 290 percent for the smaller storms after logging but again not for the larger storms.

Compaction Effects

Compaction of the watershed may have also contributed to the increase in the peak flow, total volume, and quick volume for the smaller storms on the South Fork. In general the soils of the Pacific Northwest have high infiltration rates so overland flow on a natural forest floor rarely occurs (Harr 1980). Skid trails, landings, cable corridors and roads can compact the soil so surface runoff may occur. This runoff can be concentrated creating a direct, more efficient route for water to reach the stream. All areas of compacted and disturbed soil do not contribute equally to increased runoff. Runoff on a ridge top road that is outsloped would more likely be dispersed and then infiltrate into the soil. A road with controlled drainage near a stream would more likely concentrate the runoff into the channel. Factors which are important in determining the significance of compaction and soil disturbance on increasing storm-flows are 1) the proximity of the compacted areas to the stream channel, 2) continuity or alignment of the compacted areas so that overland flow can reach the streams, 3) interception of subsurface water by road cuts and ditches,

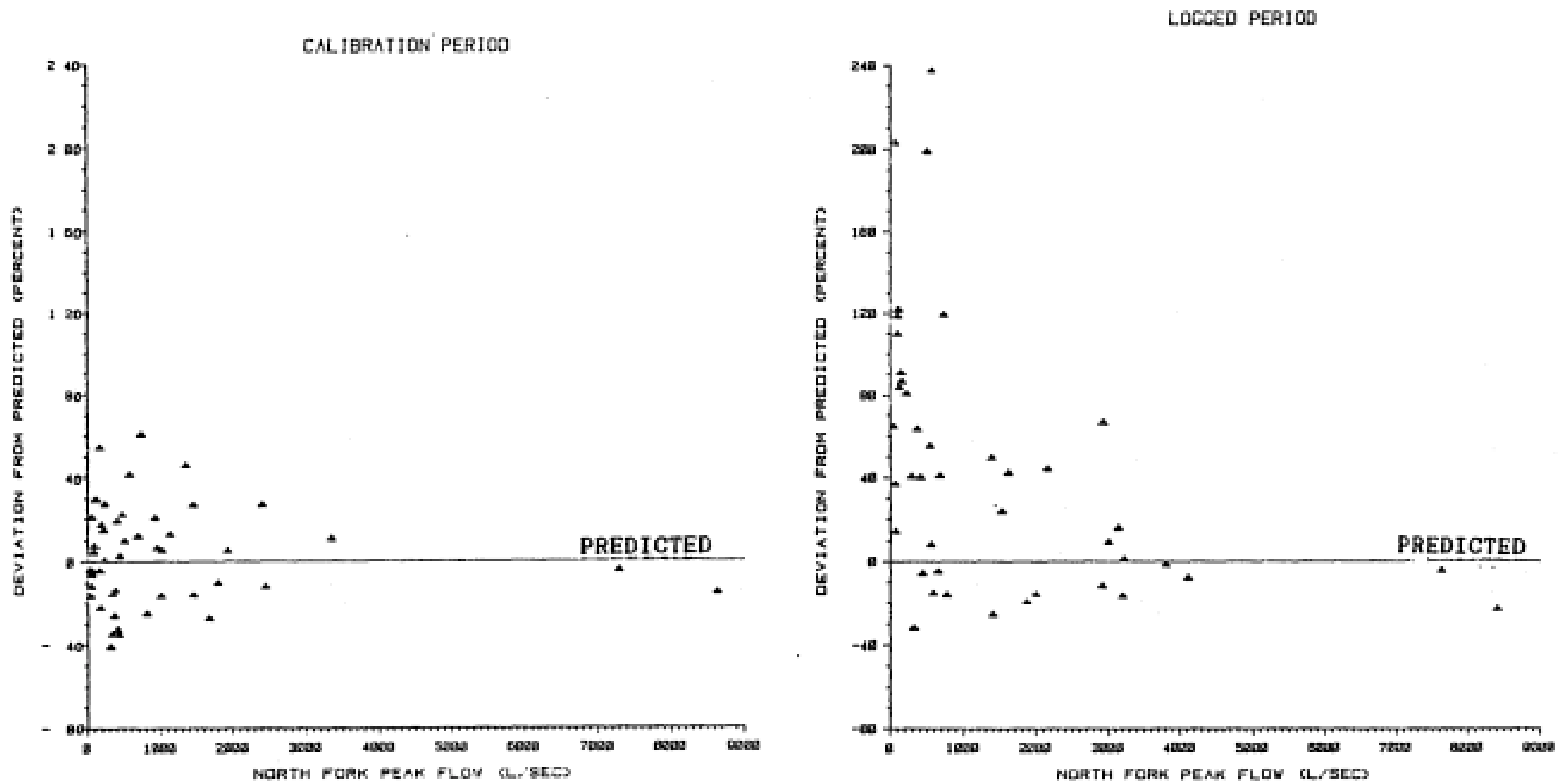

Figure 7. Relationship of North Fork Peak Flows to Percentage Deviation of South Fork Peak Flows from Predicted Pretreatment Flows, During Calibration and Logged Period.

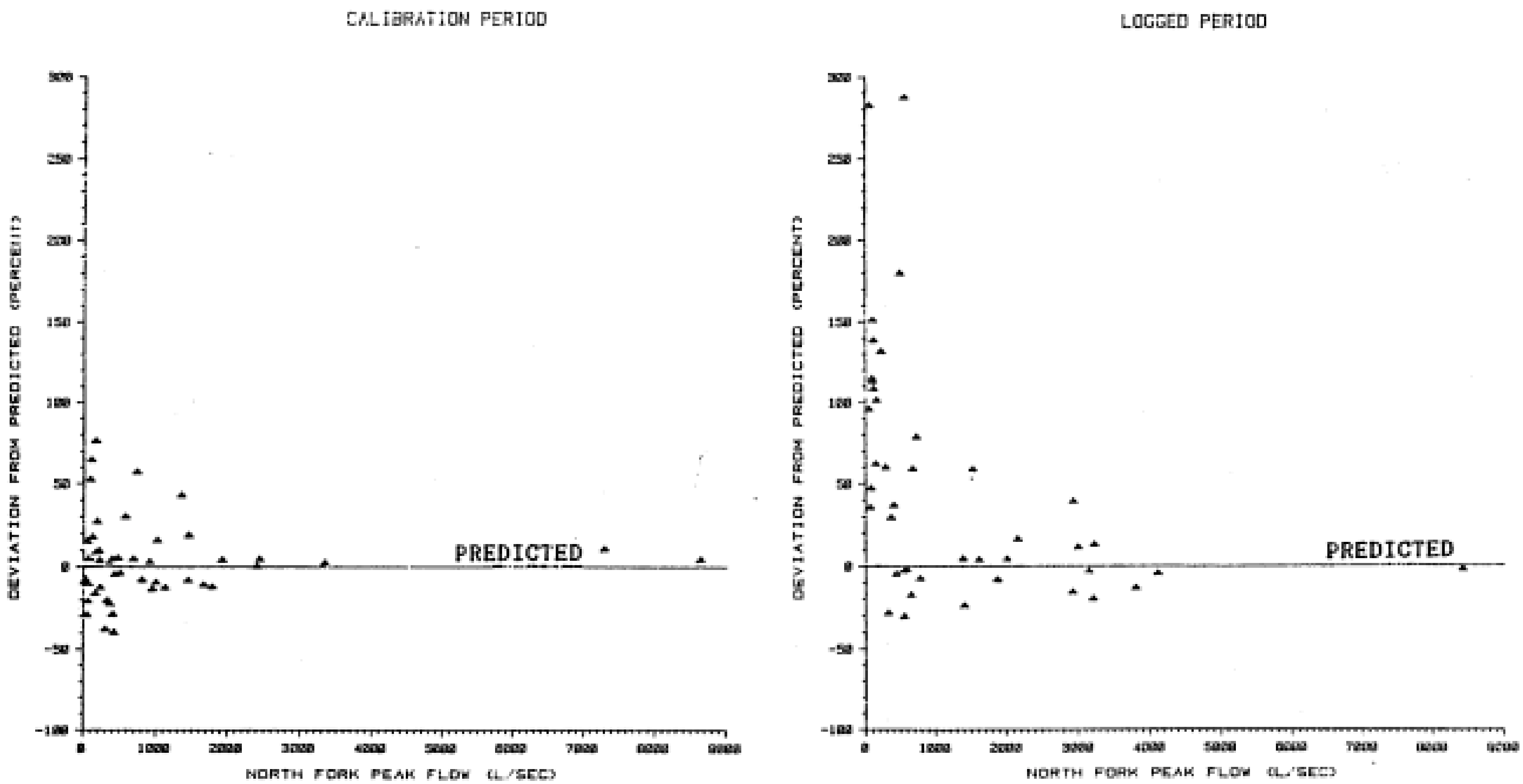

Figure 8. Relationship of North Fork Peak Flows to Percentage Deviation of South Fork Storm Volume from Predicted Pretreatment Volumes, During Calibration and Logged Period.

and 4) watershed soil and physiographic characteristics (eg. soil infiltration rate, depth, slope, and topography) (Harr 1980).

The roads and landings in the South Fork watershed were generally adjacent to the stream, and runoff from the compacted areas could directly enter the stream. Compacted skid trails could also transmit water to the stream. Skid trails usually converged downhill allowing the water to concentrate. The effects of skid trails on increasing storm runoff would be less than the roads, since the infiltration was higher on skid trails.

Generally, compaction would affect all but the largest storm flows. When the soils are wet, less rainfall is required to recharge soil water so that more rainfall can be translated into storm runoff, (Harr 1980). In very large storms the watershed approaches saturation and nearly all the rainfall runs off the watershed as storm runoff. For the largest three storm flows on the South Fork, over 90 percent of the rainfall ran off. This is in contrast to the smaller, mid-winter storms of less than 25 mm, where less than ten percent of the rainfall ran off. Although little overland flow occurred during the major storms the translatory flow or flow by displacement through the soil becomes more efficient as the soil approaches saturation (Harr 1975). This can be analogous to a wet sponge. When water is added to the top of the sponge, displaced water would quickly drip out the bottom. If the sponge was dryer it would take longer for the displaced water to drip out the bottom of the sponge or no water would drip out at all.

As a watershed approaches saturated conditions the effects of compaction on the hydrograph parameters would decreased. When the soil becomes wet the quicker delivery of water to the streams from the roads would be masked by the more efficient translatory flow from the recharged watershed. As the watershed approached saturation the saturated watershed would react more like a compacted watershed in that the stormflow response would be quicker and more efficient. The very largest stormflows in this study were not increased by compaction, whereas the smaller storms may have been.

Comparison with Other Studies

My results were contrary to Harr et al. (1975) and Harr et al. (1979) studies on the Alsea watersheds and Coyote Creek watersheds, where Harr determined that logging and roadbuilding increased the largest storm flows as well as the small storm flows when over 12 percent of the watershed was compacted in roads, landings and skid trails. The South Fork of Caspar Creek had over 15 percent of its area compacted, in roads landings and skid trails, but the largest storm flows were not significantly increased. The roads and landings were near the streams and the skid trails were orientated such that they would be effective in delivering the water to the stream if runoff occurred.

On Coyote Creek watershed 1, the treatments were very similar to that on Caspar Creek fn that they both were shelterwood cut removing approximately the same percentage of the volume by tractor (Table 1). Coyote Creek watershed 3 and Deer Creek subwatershed 3 were both clearcut (23 percent) and cable yarded (77 percent) (Harr et al. 1979).

One of the problems common to watershed studies has been in obtaining storm flows that were well distributed, particularly in the larger flow classes. The distribution of the large storm flows were a problem on all three of the watershed studies (Coyote Creek, Alsea and

Caspar Creek). The Coyote Creek study did not have any large storm flow data for the calibration period. The large storms that occurred during the calibration period filled the weir ponds with sediment so they could not be measured accurately (Harr et al. 1979). On the Alsea study no peak during the post clear-cutting period on Needle Branch or Deer Creek 4 exceeded the estimated annual peak of 9.2 l/s/ha. The other watersheds in the Alsea study also used approximately the same return period flows (Harr et al. 1975). Caspar Creek had four large stormflows all fairly close in size (ranging from an estimated 12 to 25 year return period). Two occurred during the calibration period and two occurred during the logged period. Caspar Creek had the best distribution of storm flows among the three studies because it had large storm flows in both calibration periods and logged periods.

To test if the results from this study differed from Harr et al.'s (1979) study because of the additional data for large storm flows, I omitted the two largest peaks during the logged period from the regressions (Figure 9). The regressions were then more like the regressions for the Alsea and Coyote Creek studies. The regressions showed both small and large peak flows increased after logging. Conclusions based on these regressions would be similar to the conclusions made in the Alsea and Coyote Creek studies. Therefore the differences in the results from this study and the Alsea and Coyote Creek studies may be caused by the lack of large flow data on the Alsea and Coyote Creek studies creating a need to extrapolate the regressions to estimate treatment effects.

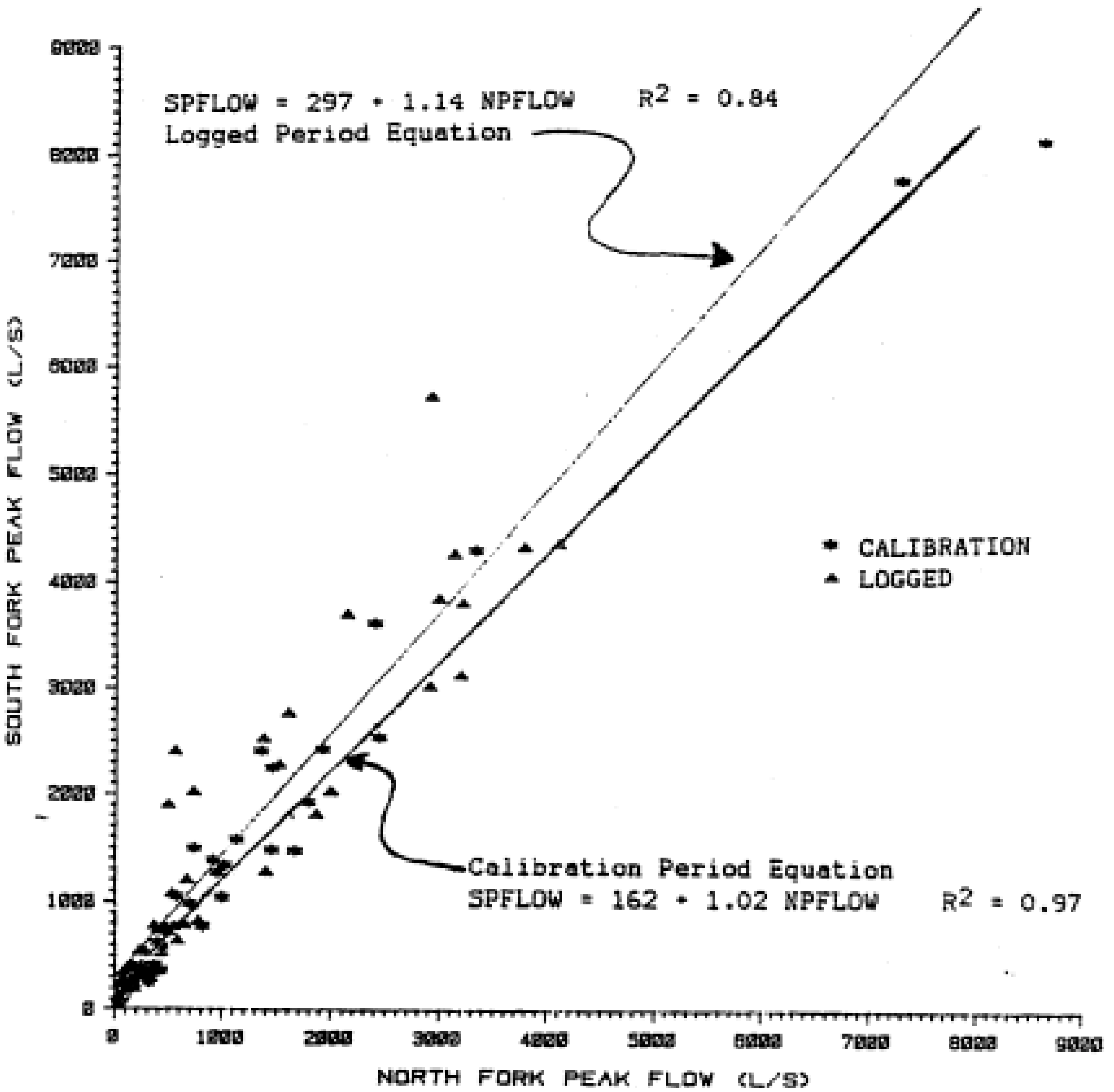

Figure 9. Relationship Between Peak Flows on the North (NPFLOW) and South Fork (SPFLOW) of Caspar Creek During the Calibration Period and the Logged Period After Removing the Two Largest Peak Flows for the Logged Period.

Management Implications

The major management implication of increasing peak flow or storm volume is the potential for increasing erosion and scour from the increased stream power. Increased peak flows and storm volumes resulting from logging and road building are one of the proposed mechanisms of cumulative effects (Grant et al. 1984; Harr 1981). If the magnitude or duration of the large channel forming flows are increased, the channel banks and bed can start eroding or scouring, destabilizing the stream until a new dynamic equilibrium becomes established.

A stream channel is formed in response to flow rates that are large enough to cause significant bedload sediment transport and occur often enough to have a major effect on channel form (Megahan, 1979). A flow rate equivalent to bankfull discharge meets these criteria. Leopold et al. (1964) found that the return frequency for instantaneous bankfull flows was about 1.5 years using data from a number of streams throughout the United States. A 1.5 year return period storm was approximately 2600 l/s on the North Fork and 3600 l/s on the South Fork.

The only peak flows and storm volumes that increased significantly (0.10 level) were the smallest flows (less than 566 l/s. The mean of the peak flows for this class is approximately 330 l/s which is less than 1/10 of the estimated bank full discharge rate of 3600 l/s for the South Fork. The percentage of the suspended sediment transported by this flow class is estimated at about seven percent, using a suspended sediment discharge rating curve developed by Rice et al. (1979). No bedload is transported by this flow class. Lisle (personal communication) in measuring bed load on the North Fork of Caspar Creek found that bed load transport did not begin until flows exceeded 1960 l/s. Consequently, the peak flows and volumes which were significantly changed by logging were not channel forming flows. Therefore increasing these flows would not be likely to cause a cumulative effect since channel scour would not be increased, and bedload is not transported at these flows.

Rice et al (1979) found that the Caspar Creek sediment regime was supply dependent, i.e. the amount of sediment transported was more dependent on the amount of sediment input into the stream than the streams ability to transport that sediment. Increasing the smaller stream flows, where existing channel banks or beds are not scoured out, would also not appreciably increase sediment transport.

SUMMARY AND CONCLUSIONS

In summary, road building on five percent of the watershed and selectively removing 60 percent of timber volume by tractor logging, significantly increased peak flows and runoff volumes only in the very smallest storms (those with peaks $\leq$ 566 l/s). The large flows in this study were not increased even though over 15 percent of the watershed was compacted in skid trails, landings, and roads. From these results it is concluded that the road building and logging caused no significant adverse effects due to increasing the peak flows or storm volumes. It is also concluded that there was no adverse cumulative effects due to increasing the peak flows or storm volumes, because the larger channel scouring flows were not significantly increased.

Developing a cumulative effect methodology on the assumption that the large channel-forming flows are increased by timber management based on compaction effects may be tenuous. Other studies have reported increases in the larger peak flows from roading and logging related compaction, where compaction exceeded 12 percent of the watershed area (Harr et al. 1975; Harr et al. 1979). But these studies have generally been lacking in data for the higher flows either during the calibration period or during the treatment period. In this study, with a reasonable distribution of data in the higher flows in both periods and with over 15 percent of the watershed compacted, no significant increase in the major channel-forming flows were detected.

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