THESIS

STREAMFLOW RESPONSE TO FOREST MANAGEMENT: A META-ANALYSIS USING PUBLISHED DATA AND FLOW DURATION CURVES

Submitted by

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In partial fulfillment of the requirements

for the Degree of Master of Science

Colorado State University

Fort Collins, Colorado

Fall 1999

COLORADO STATE UNIVERSITY

NOVEMBER 8, 1999

WE HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER OUR SUPERVISION BY STEPHEN A. AUSTIN ENTITLED STREAMFLOW RESPONSE TO FOREST MANAGEMENT: A META-ANALYSIS USING PUBLISHED DATA AND FLOW DURATION CURVES BE ACCEPTED AS FULFILLING IN PART REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE.

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ABSTRACT OF THESIS

STREAMFLOW RESPONSE TO FOREST MANAGEMENT:

A META-ANALYSIS USING PUBLISHED DATA AND FLOW DURATION CURVES

The effects of forest management on streamflow have long been a concern for land managers. A clear understanding of this relationship is difficult because studies on the hydrologic influences of forests are highly variable in their conclusions. This project was undertaken to help reduce the confusion by evaluating results from these studies.

An initial analysis of changes in peak and low flows was conducted using reported results from approximately 160 papers. The effects of logging on peak flows ranged from -36% to 563% relative to pre-treatment flows. Most changes were less than 35% and approximately one-third were reported as not significant. Large relative increases were uncommon and associated with severe site disturbance and smaller peak flows. The largest peak flows were typically little affected by timber harvest. Afforestation studies generally showed a decrease in the size of peak flows as the trees matured. Low flows typically increased after logging and decreased after afforestation.

Mean daily flows from paired basins were used to generate flow duration curves for a second analysis of streamflow changes after forest management. Absolute and relative changes in flow were determined for 11 flow percentiles after adjusting for climatic differences between pre- and post-treatment periods. This consistent methodology was used to minimize variability between studies and to determine the changes in runoff over time due to forest management.

The flow duration curve data showed that the highest flow had the smallest relative increase (median = 12%) while the lowest flow increased the most (59%). Low flows recovered within three to four years after logging while increases for larger flows persisted ten or more years. Afforestation studies again showed streamflow decreasing with regrowth.

There were few strong relationships between the changes in flow after logging and basin characteristics or management activities. Significant basin characteristics included annual precipitation, hydrologic regime, mean elevation, mean basin slope, drainage density, and vegetation type. Significant management activities included percent area harvested, silvicultural method, yarding method, and the use of buffer strips around waterways. Insufficient data precluded a similar analysis using afforestation results.

This study shows the complexity and variability of the hydrologic response to forest management. Despite the lack of strong predictive relationships, the results do show a difference in how high and low flows respond to logging and afforestation. The results also provide an indication of which basin characteristics and management activities influence the observed changes. This information should provide a better basis for determining the effects of forest management on streamflow.

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ACKNOWLEDGMENTS

I would first and foremost like to thank my Lord and Savior for being faithful and making sure that my family and I always had a roof over our heads, plenty of food to eat, clothes to wear, vehicles that ran well, and a loving church family to help meet our spiritual needs. I would also like to thank Him for giving me the strength to see this project through to the end.

I would like to thank Walt Megahan and the National Council of the Paper Industry for Air and Stream Improvement for funding this project and patiently waiting for the final product. Thanks also goes out to the numerous persons and institutions for taking the time and effort to answer my requests for data. Without their help, much of this study would not have been possible.

I am grateful for the direction, insight, and especially the patience of my advisor, Lee MacDonald, who is almost as happy to see this study come to an end as I am. I would also like to thank my committee members Chuck Troendle and Jennifer Hoeting for their guidance and insightful comments.

I am deeply indebted (literally) to my mother-in-law Kay DeVries and my parents Don and Karen Austin for helping out financially over the years while I pursued my degrees. Thank you all for helping make this possible.

Finally, I would like to thank the only person happier than myself that this project is over--my wonderful wife Mary. She has been faithfully by my side since the beginning. In fact, this was all her fault. Little did she know that I would still be a student twelve years after she first suggested that I take some courses with her at a community college. Thank you Mary for working to support me while I pursued my undergraduate degree and, until Alison was

born, while I pursued my graduate degree. Thank you for keeping Alison and Amber away while I worked on my thesis. Thank you for the child who will be joining our family shortly before I graduate. Thank you for understanding when I postponed celebrating our anniversary to finish a draft of this thesis. Thank you for loving me. I love you and dedicate my thesis to you. You no longer have to share me with it--it is finished.

DISCLAIMERS

The following disclaimers were written by those who provided the discharge data and are included as per their request.

H. J. Andrews, Fox Creek, and Coyote Creek data:

> Data sets were provided by the Forest Science Data Bank, a partnership between the Department of Forest Science, Oregon State University, and the U.S. Forest Service Pacific Northwest Research Station, Corvallis, Oregon.
>
> Funding for these data was provided by the Long-Term Ecological Research (LTER) program and other National Science Foundation (NSF) programs, Oregon State University, and U.S. Forest Service Pacific Northwest Research Station.
>
> NSF grants: DEB-7611978, DEB-8012162, DEB-8508356, BSR-8514325.

Hubbard Brook data:

> Some data used in this publication were obtained by scientists of the Hubbard Brook Ecosystem Study; this publication has not been reviewed by those scientists. The Hubbard Brook Experimental Forest is operated and maintained by the Northeastern Forest Experiment Station, U.S. Department of Agriculture, Broomall, Pennsylvania.

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1. INTRODUCTION

> "It is not enough to know *whether* forests influence stream flow; it is necessary to know how much, at what seasons, and under what conditions of climate, soil, and topography, and the variations between different kinds of forest, as well."
>
> --Bates and Henry, 1928

1.1. BACKGROUND

In the United States, the role that forests play in regulating streamflow has been debated since at least the mid-nineteenth century. In 1864, G. P. Marsh theorized in his book "Man and Nature" that the denudation of forests was greatly affecting erosion, floods, climate and water supplies (Hewlett and Doss, 1984). A few years later, several states began investigating the long-term effects of deforestation (Young and Giese, 1990). In 1877, Dr. Franklin B. Hough released the first comprehensive report on forestry for the United States Congress. One of the conclusions he presented regarding the relationship between forests and streamflow is as follows:

> It is a matter of common remark, that our streams diminish as our woodlands are cleared away, so as to materially injure the manufacturing interests depending on hydraulic power, and to require new sources of supply for our State canals, and for the use of cities and large towns. Many streams, once navigable, are now entirely worthless for this use (Hough, 1878 quoted in Satturlund, 1972).

New York became the first state to set aside "forest preserves" in 1885 for the "preservation of the headwaters of chief rivers of the state..." (Satturlund, 1972). At the national level, the first forest reserves were established six years later with the passing of the General Revision Act of 1891

(Young and Giese, 1990). Section 24 (known as the Forest Reserve Act) gave the President the authority to set aside public lands. Less than a month after it passed, President Harrison established the Yellowstone Park Forest Reservation and over the next two years created 14 other forest reserves totaling over 5.3 million hectares (Young and Giese, 1990).

Since there were no provisions in the Forest Reserve Act regarding how the forest reserves were to be used, it was determined that these lands were off limits to logging, mining, or any other activity. When President Cleveland set aside an additional 8.6 million hectares as forest reserves near the end of his term, Congress responded by passing the Organic Act. This act established guidelines regarding which lands could be set aside and for what purposes these lands could be used. One of the primary uses was for water:

> No national forest shall be established, except to improve and protect the forest within the boundaries, or for the purpose of securing favorable conditions of water flows, and to furnish a continuous supply of timber for the use and necessities of citizens of the United States... (16 U.S.C. §§ 475, June 4, 1897).

Up to this point in time, all laws enacted to protect headwaters and maintain streamflow were based primarily on empirical evidence. The strength of this evidence is apparent in Raphael Zon's 1912 report to the U. S. Congress summarizing what was then known of the relationship between forests and water (Zon, 1927). Zon's conclusions were based on many observational studies and some scientific evidence gathered throughout the world. This report showed that Zon's contemporaries in the scientific community had a reasonable understanding of the hydrologic influences of forests. For example, it was understood that groundwater recharge was the primary source of baseflow and that losses to interception, evaporation, transpiration, and surface runoff limited the amount of water available for baseflow. At the same time, however, some scientists held the belief that the presence of forests could increase precipitation by as much as 25% over adjacent, non-forested sites. This suggests that scientific investigation of the forest-water relationship was long overdue. However, by the time that Zon's report was presented, only two controlled experiments were being conducted in the world.

The Swiss began collecting streamflow and climatic data in 1900 from two basins--one completely forested and the other primarily in pastureland (Hibbert, 1966). This was an important first step for the study of forest and streamflow interactions. However, it is difficult to conclude that the differences in discharge between the two basins were primarily due to the differences in land cover. This fact was not lost on the Americans interested in quantifying this relationship: "Without questioning the immense value of the results...it may be freely said that the Swiss experiment leaves a certain want unfilled" (Bates and Henry, 1922). In 1909, a site was chosen in the headwaters of the Rio Grande for the purpose of meeting this "unfilled want".

The Wagon Wheel Gap study was the first to use a paired basin design to investigate the role of forests in regulating streamflow. Two adjacent basins with similar geology, soils, topography, and land cover were selected and monitored for several years prior to forest harvest. The effects of harvesting on streamflow were evaluated by comparing expected discharge on the treated basin--based on the pre-treatment calibration between the two basins--with measured discharge after logging. The difference between the measured and expected discharges was attributed to the treatment. With this study, Bates and Henry (1928) quantitatively showed that forest harvest increased annual water yields along with the size and volume of the spring snowmelt hydrograph.

In the 1930s and 1940s many other studies were initiated to provide more data on the effects of forest cover on streamflow. Up until the 1960s, the primary emphasis of these studies was the potential for increasing water yield by cutting timber. This emphasis continued on into the 1970s and early 1980s, even though results from afforestation studies and long-term logging studies suggested that the increases were short-lived (Hibbert, 1966; Anderson et al., 1976). The longevity of this interest in annual water yield is also surprising considering the large body of environmental legislation passed in the U. S. during the 1960s and 1970s. Legislation such as the Multiple Use-Sustained Yield Act, National Environmental Policy Act, the Wilderness Act, and the National Forest Management Act stressed multiple use management and a need to minimize the cumulative effects of land use activities on public lands. These laws made it impractical, if not illegal, to manage public forests solely for timber production and increasing water yields.

During the late 1970s, it became apparent that annual water yield was not the best indicator of cumulative effects and that other measures of runoff were more directly related to key water resources. As a result, investigations of the relationship between forest management and discharge started to focus on changes in peak and low streamflow. These flows were considered to be better indicators of cumulative effects due to their influence on channel morphology (Heede, 1991), sediment transport (King, 1989), and fish habitat (Hicks et al., 1991). While there is still some interest in annual water yield changes after logging (e.g., Stednick, 1996), most current studies of forest cover and streamflow relationships stress the effects of forest management on peak and low flows.

Several reviews of forest management influences on streamflow have been presented since Zon's 1912 report to Congress (Hibbert, 1966; Anderson et al., 1976; Bosch and Hewlett, 1982; Stednick, 1996). These periodic updates document how knowledge of this relationship has progressed over time. They have also provided improved guidance for resource managers.

The first of these summaries focused on the effects of forest treatment on annual water yield. It was also designed to present "the significance of these results when considered collectively" (Hibbert, 1966). In other words, Hibbert felt that the relationship between forest cover and annual water yield could best be understood by grouping the results of different studies. Hibbert used both timber harvest and afforestation studies in his review, with the latter being used to validate the timber harvest studies (i.e., if decreasing forest cover increases annual water yields, then increasing cover should decrease water yields). From 39 timber harvest and afforestation studies located mostly in the U. S., Hibbert concluded that:

1. Reduction of forest cover increases water yield.
2. Establishment of forest cover on sparsely vegetated land decreases water yield.
3. Response to treatment is highly variable and, for the most part, unpredictable.

Bosch and Hewlett's (1982) review also focused on the relationship between forest management and changes in annual water yields. Their review was intended to give land managers an idea of the "direction and approximate magnitude of past and future changes in streamflow as a function of forestry operations". With the addition of 55 more timber harvest and afforestation studies, Bosch and Hewlett reinforced the first two conclusions presented by Hibbert (1966). They also agreed that the results from different studies were highly variable, but disagreed with Hibbert regarding the predictability of these results. Bosch and Hewlett (1982) were able to show that quantifiable trends could be detected from the combined results of different studies. This was accomplished by relating the changes in annual water yield after logging to different basin characteristics and management activities. By giving land managers a reasonable estimate of changes in streamflow that would occur after logging, Bosch and Hewlett expanded the usefulness of a review. Unfortunately, this expanded usefulness has not been extended to peak and low flows.

No comprehensive review and analysis of the effects of timber harvest on peak and low flows has been presented. The few reviews that have been published have limited usefulness because they are either based on a small number of studies (e.g., Johnson, 1967; Anderson et al., 1976, pp. 42-44), or they are restricted to a specific geographic or climatic region (e.g., Lull and Reinhart, 1972; Wolff, 1984; Bruijnzeel, 1990, pp. 101-115). They also draw general conclusions rather than presenting quantitative trends.

The need for an extensive review of the effects of timber harvest on peak and low flows is readily apparent when published results are compared. There is a paper to support almost any claim, as reported peak flow changes have ranged from increases of 500% or greater (Dietterick and Lynch, 1989; Swindel et al., 1983) to no change (Harr, 1980; Johnston, 1984) or even decreases of 22% (Cheng et al., 1975) and 36% (Harr and McCorison, 1979). Reported low flow changes ranged from an increase of 164% (Hicks et al., 1991) to a decrease of 15-20% (Harr, 1980). If resource managers are to make informed decisions regarding the use of forest lands, then the state of knowledge on the subject of peak and low flows should be disseminated in a clear and consistent manner. Efforts should be made to understand the causes of the variation in reported results so that resource managers can be provided with reasonable estimates of the changes in flow associated with forest management activities.

The wide variety of peak and low flow definitions is one reason for the variability in results and probably the main reason why no comprehensive review of the effects of timber harvest on these flows has been attempted. For example, Ziemer (1981) and Wright et al. (1990) showed that there are many ways to analyze changes in peak flows after logging. Using the same data set, Ziemer (1981) analyzed changes in peak flows by looking at adjusted mean peak flows, double mass curve averages, regressions, and the mean ratio of peak flow differences between treated and control basins to the small and large peak flows on the control basin. These different analysis techniques produced results ranging from no significant change to a 225% increase in the size of peak flows (Ziemer, 1981). More examples of the different types of peak flows investigated in the literature are shown in Table 1.1. Low flow definitions are just as diverse.

Unlike annual water yield, where the differences in definitions are limited primarily to differences in units, the inconsistency in defining both peak and low flows precludes direct comparisons between studies. In several cases, it is difficult to tell what is being investigated because the flows studied are not clearly defined. Hewlett (1982) attempted to tackle this problem in an excellent article, but his call for consistency was either unheard or unheeded.

Some of the variability in the published results may also be caused by differences in study durations and recovery rates. The time that it takes for streamflow to return to pre-treatment levels varies from site to site and depends primarily on the rate of vegetation regrowth. Estimates of hydrologic recovery range from the end of the first post-treatment growing season at Fernow Experimental Forest in West Virginia (M. B. Adams, 1995, personal communication) to 80 years at Fraser Experimental Forest in Colorado (Troendle and Kaufmann, 1987). In most studies, the effects of timber harvest

Table 1.1. Partial list of peak flow definitions used by authors investigating the effects of timber harvest on streamflow.

Peak flow investigated	Reference
Instantaneous peak discharge	Anderson and Hobba (1959); Blackburn et al. (1986)
Instantaneous peaks less base flow	Cheng et al. (1975); Duncan (1986)
Peak mean daily	Troendle and King (1985)
Annual maximum daily flow	Van Haveren (1988); Cheng (1989)
Growing and/or dormant season peaks	Reinhart et al. (1963); Dietterick and Lynch (1989)
Summer, fall, and/or winter peaks	Harr et al. (1975); Gottfried (1991)
Annual instantaneous peak (less base flow) associated with snowmelt	Megahan et al. (1995)
Peak for 1-hour unit hydrograph	Mumeka (1986); Dept. of Drainage and Irrigation, Malaysia (1989)
Peak associated with mean storm	Swank et al. (1988)
Instantaneous peak less base flow for mean maximum 1-hour storm	Hewlett and Helvey (1970)
Percentiles on flood frequency curves	Hsia (1987); King (1989)

on peak and low flows are averaged over the entire post-treatment period for which data are available. However, there is no consistency in the length of this period. Thus, the differences in recovery rates combine with the different post-treatment time periods to increase the variability in the published results. While a comprehensive review of the effects of forest management on peak and low flows will help clear up this confusion by pointing out these inconsistencies, it is not enough by itself. An analysis of the hydrologic impacts of logging using a consistent methodology is also required.

One simple yet effective way to analyze a broad range of flows is by using flow duration curves (FDCs). A FDC is a graphical representation of a streamflow record (Vogel and Fennessey, 1994). It differs from a hydrograph because the data are ranked and plotted as percentiles. Thus, a FDC illustrates the percentage of time less than or equal to a given flow (Figure 1.1). A

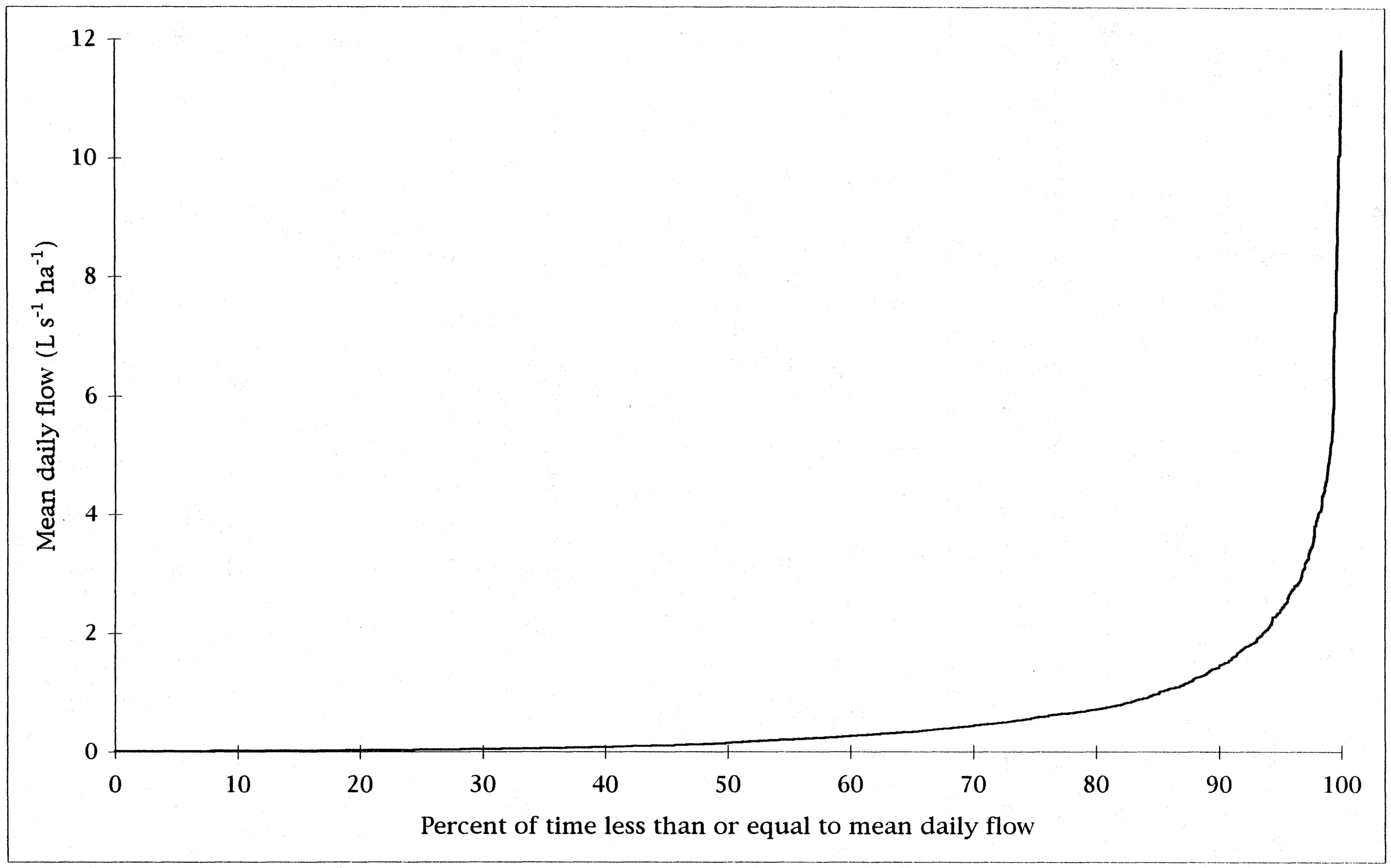


Figure 1.1. Example of a flow duration curve using six years of pre-treatment data from H. J. Andrews watershed 10.

benefit of FDCs is that they can easily be developed from mean daily flows, making them ideal for this project as most data sets are only available at that resolution. More importantly, the effects of land use changes on large and small flows can be analyzed by calculating changes in percentiles taken from pre- and post-treatment FDCs using a paired basin methodology.

The original intent of those who began studying the hydrologic influences of forests was to shed light on the subject so that forest lands could be managed wisely and streams could be protected. A great deal of information has been obtained from the numerous studies conducted since the Swiss first attempted to quantify the relationship between forests and streamflow in 1900. It is the intent of this author to follow in the footsteps of those pioneers by sorting through and analyzing the available information to more clearly define the effects of timber harvest on peak and low flows.

1.2. GOAL AND OBJECTIVES

The purpose of this study is to provide resource managers and researchers with a clear understanding of the relationship between forest management and peak and low streamflows. This includes providing information on the expected changes in peak and low flows after timber harvest or afforestation; the influence of basin characteristics and management activities on these changes; and the persistence of these changes after treatment.

The specific objectives for this study were:

1. Review and summarize the results of existing studies on the effects of timber harvest and afforestation on peak and low flows.
2. Determine if any basin characteristics or management activities are consistently associated with the reported changes in flow.

3. Reanalyze the original flow data from timber harvest and afforestation studies through a pre- and post-treatment comparison of selected flow duration curve percentiles.
4. Determine if any basin characteristics or management activities are consistently associated with observed changes in the selected flow duration curve percentiles.
5. Determine the time to recovery after timber harvest for high, median, and low flows using flow duration curves developed from different post-treatment periods (e.g., first two years, second two years, etc.).
6. Determine the time to the stabilization of streamflow changes after afforestation for high, median, and low flows using flow duration curves developed from different post-treatment periods.

2. METHODS

2.1. LITERATURE SEARCH

The search for studies on the effects of timber removal on streamflow was carried out primarily at Colorado State University (CSU). Key word searches were conducted in *Uncover*, *Water Resources Abstracts*, *Agricultural Abstracts*, and *GeoRef* to develop an initial list of studies. Any studies that reported a change in peak flows associated with timber harvest were photocopied. Additional studies were identified by reviewing the references cited. Studies on low flow changes after timber harvest and afforestation studies were obtained by a similar process. Altogether, almost 350 published studies were reviewed and approximately 160 papers were acquired and read in full.

2.2. STUDY SUMMARIES AND MATRIX DEVELOPMENT

The published studies were first grouped by study site. Three types of data were recorded for each study: general information, basin characteristics, and management activities (Table 2.1). Multiple tables were generated to record and compare data from both the forest harvest and afforestation studies (Appendices I and II, respectively). These tables summarize the effects of forest harvest on streamflow in 135 treated basins from 57 different study sites world-wide. Similarly, afforestation data for 21 treated basins in 6 different countries were recorded.

As the tables were being filled in, it became apparent that the desired information could not all be obtained from the published sources and that

Table 2.1. Summary information collected for each timber harvest study. Similar data were collected for each afforestation study.

General information	Basin characteristics	Management activities
References	Area (ha)	Type of silvicultural method
Location	Latitude and longitude	Percent of vegetation cover removed
Name of treated basin(s)	Elevation mean, range, and relief (m)	Use of buffer strips around waterways
Study design	Ecoregion domain	Duration of harvest period (months)
Type and frequency of precipitation data	Vegetation type	Type of yarding
Location of precipitation measurements relative to discharge station	Pre-harvest stand age (years)	Type of site preparation
Discharge record before and after treatment (years)	Soil type and depth (m)	Road density (km km^{-2})
Author's definition of peak or low flow	Geology	Percent of area compacted
Reported changes in flow (percent and L s^{-1} ha^{-1})	Mean slope of the basin (percent)	Season of management activities
Statistical significance of observed changes	Mean slope of the treated area (percent)	
	Drainage density (km km^{-2})	
	Annual precipitation (mm)	
	Annual ET (mm)	
	Dominant hydrologic regime (i.e., cause of runoff)	
	Dominant aspect	
	Rate of regrowth	

some of the referenced publications could not be obtained from CSU or cooperating libraries. In an attempt to fill these gaps, the original authors or institutions most likely to have the missing data were contacted by mail. A second set of letters was sent out to those who did not respond to the first letter within a couple of months. Many gaps in the tables were filled from the responses to these letters.

Additional searches were conducted periodically during the summarization process to identify new studies or studies that had been overlooked in the original search. The tables were then updated as new information and studies became available.

2.3. ANALYSIS OF PUBLISHED DATA

The information summarized in the harvest and afforestation tables became the data set for analyzing the published studies. Due to limited information, the number of basins included in this analysis dropped from 135 to 80. For peak flows, the initial comparisons were between studies that had used similar definitions and analysis procedures. Nine results for the effects of only roads were not included in this analysis. The studies were not stratified according to storm and base flow separation techniques because it often was not specified if and how the separation was determined. The studies on peak flows were placed into eight groups according to the type of high flow that was analyzed: (1) instantaneous peak flows, (2) high flows using daily discharge data, (3) growing season high flows, (4) dormant season high flows, (5) annual maximum high flows, (6) author-defined mean high flows, (7) author-defined large high flows, and (8) all high flows.

Some studies used one data set to determine changes in different types of peak flows. For example, changes in instantaneous peaks may have been calculated for different size classes or different times of the year. When this occurred, the different reported results were placed only in the more specific peak flow categories (e.g., growing season or large peak flows), so that the multiple results from one study were not repeatedly placed in the more general instantaneous category. For the purposes of this paper, the instantaneous category contained results only for all instantaneous peaks averaged over the entire post-treatment period.

The daily category contained results from studies that analyzed the largest mean daily flows over the post-treatment period. Growing season peak flows occurred only during the spring or summer months, while dormant season peaks were from the fall and winter months. The growing and dormant season data were typically averaged over several years and included both daily and instantaneous high flows. Studies that investigated a distinct maximum annual high flow (e.g., snowmelt-dominated hydrographs) were placed in the annual category.

Mean flows were taken from studies where the author compared either the average flow or the flow associated with the average storm before and after treatment. Large flows were author-defined by either size class, percentile, or an arbitrary selection of the highest peaks over the study period.

Each of the peak flow study results were included in the "all" category except one result where the same data were used to analyze the same type of peak flows for two different studies. In this case, the more recent result was used in the analysis. Results that were too unique to be classified were also placed in the "all" category.

The reported changes in peak flows had to be given in relative terms (i.e., percent change) in order to be included in the comparison of peak flow types, as few studies reported changes in absolute terms. Results given only as absolute changes were not used unless relative changes could be determined from the information provided.

The analysis of reported results was greatly complicated by the variations in the use of statistical analyses. Some studies did not evaluate the statistical significance of the observed changes in peak flows. Studies that did evaluate the significance of results often differed in the levels of significance used. Many times p-values were not provided and, in some cases, neither the p-value nor the level of significance was provided. Thus, for the purpose of this study, the actual reported changes were used regardless of their reported significance. In this way, results from different studies could be combined despite the differences in analyses. Studies that reported results as non-significant without specifying the observed changes were not treated as zero in the analysis, but were tabulated separately for each peak flow type. To minimize confusion, the non-significant results from studies that did not report observed changes will be referred to as “NS results”.

None of the categories had sufficient data to warrant more than a simple statistical analysis except the “all” category. Unfortunately, a more detailed analysis of the “all” category was inappropriate since the data set included multiple results for some basins and many different categories of peak flows. Thus, a combination of the different categories was used to develop a more consistent data set (“composite peak flows”) for more detailed analysis.

The following criteria and adjustments were used to create the composite peak flow category. From the original data set, 20 results were excluded because only one result was used from each basin. In each of these cases, the most generically defined peak flow type was chosen. For example, instantaneous peak flow results would be taken over growing season peak flow results if both results had been reported. Similarly, the results with the highest temporal resolution were used when multiple results were available (e.g., instantaneous results would be chosen over daily results).

When peak flows for a given study were broken down by season or size class, the number of events used to calculate each peak flow type were usually provided. The results from these studies were included in the analysis by using a weighted average based on the number of events in each category. For example, if a study had 10 growing season peaks and 25 dormant season peaks, the average change for these peak flow types would be multiplied by 10 and 25, respectively. The sum of these two products would then be divided by 35 to obtain the percent change for that study. This adjustment reduced by another nine the number of results available for analysis.

Eleven more results were excluded from the analysis because the peak flow types were either obscurely defined or the results were questionable. An additional study was eliminated because the extreme increase (500%) after logging was due to the channeling of runoff toward the gaging station along windrows created during site preparation (Swindel et al., 1983). After excluding the 35 NS results and the nine roads-only studies, these constraints reduced the 130 published results to a sample size of 45 for the detailed statistical analysis.

The first step in the detailed analysis was to plot each basin characteristic and management activity against the reported percent change in peak flows. Missing information about basin characteristics and management activities reduced the number of data points in most of these comparisons (Table 2.2). For the continuous data, such as mean annual precipitation or percent area cut, these plots were used in conjunction with correlation tables to determine which characteristics and activities could help explain the magnitude and direction of the observed changes. Regression analysis was then used to test the relationships that appeared most promising. A 0.10 level of significance was used on untransformed data because this was

Table 2.2. Number of observations available for each basin characteristic and management activity by peak flow category. Characteristics or activities without sufficient data for analysis using the composite peak flow category are not presented below.

	Peak flow type								
	Instantaneous	Daily	Growing season	Dormant season	Annual	Mean	Large	All	Composite
Maximum sample size	8	7	4	12	6	11	17	82	45
Basin characteristics									
Area	8	6	4	12	5	11	16	79	44
Latitude	8	7	4	12	6	11	17	82	45
Elevation mean	4	5	4	0	4	1	8	39	30
Elevation range	7	3	4	2	2	6	4	35	22
Ecoregion domain	8	7	4	12	6	11	17	82	45
Vegetation type	8	7	4	12	6	11	17	81	44
Pre-harvest stand age	7	1	4	12	2	8	11	60	32
Soil type	8	6	4	11	6	9	17	77	41
Mean slope of the basin	5	1	3	5	1	8	6	39	22
Drainage density	3	1	0	4	0	7	2	19	13
Annual precipitation	7	7	4	12	6	11	17	81	44
Annual ET	1	2	4	1	1	8	6	32	20
Dominant hydrologic regime	8	7	4	12	6	11	17	82	45
Dominant aspect	6	7	4	10	5	8	15	72	39
Management activities									
Type of silvicultural method	8	7	4	12	6	11	15	80	43
Percent of vegetation cover removed	8	7	4	12	6	11	17	82	45
Use of buffer strips around waterways	7	1	4	11	2	8	8	53	29
Duration of harvest period	6	0	4	5	1	8	13	51	28
Type of yarding	6	5	0	11	6	9	17	70	38
Type of site preparation	6	5	3	5	6	7	16	63	33
Road density	4	3	0	11	4	5	10	48	23
Percent of area compacted	6	5	1	10	5	10	14	63	35

an exploratory study and the data were highly variable. Transformations were not used because the presence of zeros and negative values precluded most common transformations without arbitrarily adjusting, and thus biasing, the data.

Standardized residuals and scatter plots were used to check for outliers and influential observations. Outliers were generally included because either their removal resulted in the appearance of more outliers or removing them did not change the significance of the relationship. When it was apparent from the plots that a single observation was driving the relationship between a basin characteristic or management activity and the reported changes in peak flows, the observation was generally removed and the relationship reassessed. The quality of each significant relationship was determined by evaluating the R^2, the standard error of the regression, the slope of the regression equation, and the role of outliers or influential observations.

For the categorical basin characteristics and management activities, numbers were assigned to each category to facilitate comparisons (Table 2.3). Since the different categories had unequal variances, the nonparametric Kruskal-Wallis test was used instead of analysis of variance to detect differences between categories. If significant differences were observed at $\alpha = 0.10$, then two-sample t-tests assuming unequal variances were performed for each combination of categories within a characteristic or activity. Since 0.10 was the overall error rate for the comparisons within a characteristic or activity, α-values for t-tests were obtained by dividing 0.10 by the number of comparisons made within that characteristic or activity (Ott, 1993).

This project was exploratory in nature, so no multivariate analyses were conducted on these data. The inherent problems and variability in the data meant that it was more appropriate to identify general trends and not to

Table 2.3. Numeric values assigned to each categorical variable.

Value	Categorical variable: Ecoregion domain*	Vegetation type	Pre-harvest stand age	Dominant hydrologic regime	Soil texture	Aspect	Silvicultural method	Use of buffer strips	Type of yarding	Type of site preparation	Season of harvest activities
1	Dry	≥ 90% conifer	< 50 yrs	Rain	Fine	N	Clearcut	Yes	Tractor	Mechanical	Dormant (fall and winter)
2	Humid temperate	60-89% conifer	> 50 yrs	Snow	Coarse	NE	Patch cut	No	Rubber-tired skidder	Fire	Growing (spring and summer)
3	Humid tropical	Mixed	Mixed	Mixed	Mixed	E	Selection cut	Mixed	Fully suspended	Both	Mixed
4		60-89% hardwood				SE	Mixed		Partially suspended	None	
5		≥ 90% hardwood				S			Tractor and cable		
6						SW			None		
7						W					
8						NW					

*Taken from maps produced by Bailey (1989).

develop multivariate models. Thus, no overall adjustment (e.g., Bonferroni adjustment) was made for the large number of statistical tests performed. An overall adjustment was also not used because the differences in available information for each study resulted in different sample sizes and different populations for each univariate analysis.

There were insufficient data to allow a statistical analysis for either the effects of timber harvest on low flows or the effects of afforestation on peak or low flows. Thus, only the general trends for these relationships are presented here.

2.4. FLOW DURATION CURVES

Flow data were obtained in electronic or hard copy format for 32 harvested and four afforested basins and their paired controls. Mean daily flows were used because many sources could not provide higher resolution data and the data sets became unwieldy if higher resolution data were used.

To facilitate comparisons, each set of data was converted to liters per second per hectare ($L\ s^{-1}\ ha^{-1}$). If the data were provided at a higher temporal value, weighted average flows were calculated for each day. In such cases, midnight values were often not available because many data recorders only registered when flows changed by a predetermined amount. When discharge values at midnight were unavailable, linear interpolation was used to determine these values as they were needed to calculate the mean daily flows.

2.4.1. PERCENTILES

The flow duration curves (FDCs) were developed in Microsoft Excel using the rank and percentile tool. This macro ranked all the flow data in descending order for the period of interest. The largest mean daily flow was equal to the 100th percentile and the smallest flow equaled the zero percentile.

Although the FDC procedure could be used to evaluate change for any given percentile, it was not practical to analyze all percentiles on all basins. Limiting the number of percentiles investigated also reduced the potential for Type I statistical errors (Ott, 1993).

Since the flows of most interest were located at either end of the FDC, the percentiles selected for analysis were: 1, 2.5, 5, 10, 25, 50, 75, 90, 95, 97.5, and 99. By analyzing several percentiles at each end of the FDC the consistency of the results could be compared. The zero and 100th percentiles were not analyzed because their results were both highly variable and less reliable due to their dependence on the most extreme climatic conditions over the period of analysis.

It should be noted that the different percentiles are not independent. The data were ranked in order to form the FDCs, so the data in each percentile depend on the data in the percentiles below them. Thus, adjacent percentiles were often highly correlated even though sample sizes sometimes varied between percentiles due to differences in the number of no flow days. The lack of independence between percentiles precluded the use of multivariate analysis to evaluate trends across the FDC.

As with the published data (Section 2.3), an overall adjustment was not used for statistical analyses within a percentile. This is because the differences in available information for each study resulted in different sample sizes and different populations for each univariate analysis. Also, the purpose of this project was to identify general trends and not to develop a statistical model for predictive purposes.

The absolute discharges for all 11 percentiles were obtained from the ranked data using the "percentile" function in Excel. This function was used because it ranked identical values rather than assigning one rank to all flows with the same value.

2.4.2. PAIRED BASIN METHOD

A paired basin approach was used to account for climatic differences between pre- and post-treatment time periods. FDCs were generated before and after treatment for both the control and treated basins. Typically, the FDCs for the control basin differed before and after treatment. In the absence of management activities or natural disturbances, these differences were assumed to be due to climatic differences between time periods. Since the focus of this study is on the hydrologic response to forest management, the differences associated with climatic changes over time had to be taken into account. This was accomplished by assuming that the climatic changes observed on the control basin also occurred on the treated basin. Thus, the pre-treatment FDC for the treated basin was adjusted by the percent change observed in the control basin (Equation 1). Any differences between the post- and adjusted pre-treatment FDCs on the treated basin were then attributed to the treatment.

The following equation was used to determine the percent change on the treated basin for each of the selected percentiles:

$$T_{\%\,change} = \frac{T_{post} - T_{pre}\left[1 + \dfrac{C_{post} - C_{pre}}{C_{pre}}\right]}{T_{pre}\left[1 + \dfrac{C_{post} - C_{pre}}{C_{pre}}\right]} * 100\% \qquad (1)$$

where T and C represent the discharge values on the treated and control basins, respectively. The subscripts pre and post signify pre- and post-treatment, respectively. Absolute changes in flow for the treated basin were obtained by using just the numerator of Equation 1. Changes could not be calculated for percentiles that had zero discharge during the pre-treatment time period. This is why the smaller percentiles have fewer observations than the larger percentiles (e.g., Table 3.5).

To check the validity of the adjustment methodology, a test run was performed using all the data sets containing at least five years of pre-treatment discharge. The "post-treatment" period was defined as the last three years of the pre-treatment record. The "calibration" period was at least two years long and consisted of all data prior to the "post-treatment" data. If the basins were perfectly matched, the adjusted changes in flow on the treated basin should equal zero since no treatment had occurred.

The results from each basin were grouped by percentile and tested for significance from zero using a one-sample sign test. Using the sign test and a median value of zero for no change, a p-value of 1.00 would be associated with percentiles that had an equal number of negative and positive results, while a p-value of 0.00 would be associated with percentiles consisting of either all positive or all negative results. This non-parametric test was used because high skew in the data prevented the use of tests with more power. If the median change for a given percentile was not significantly different from zero ($\alpha = 0.05$), then the adjustment method was considered valid.

After the FDC methodology was validated, the adjustment procedure was carried out on the full data set for each paired basin. The results obtained from each study were once again grouped by percentile. A one-sample sign test using $\alpha = 0.05$ was used to test whether the median value for each percentile was significantly different from zero.

In order to maintain consistency for the two significance from zero tests, the same level of significance was selected. The 0.05 level of significance was used because it represented a compromise between α-values of 0.01 and 0.10. An α-value of 0.01 would make it difficult to find any changes in flow due to treatment, but validation of the methodology would be highly likely. On the other hand, an α-value of 0.10 would provide less rigorous proof of the validity of the adjustment methodology. An α-value of 0.10 would also increase the likelihood that the post-treatment change in flow would be significantly different from zero.

2.4.3. TIME PERIODS

The pre-treatment time period consisted of all available discharge data prior to any management activities on the treated basin. This period ranged from 1.5 to 16 years depending on the study (Appendices I and II).

In most cases the post-treatment time period began the first water year after treatments ceased. October 1 to September 30 and April 1 to March 31 were used to define water years in the northern and southern hemispheres, respectively. In two cases (Caspar Creek and Hubbard Brook-4), logging was carried out over three treatment periods that were each separated by two years. For these studies, the post-treatment period was assumed to begin after the second treatment as this included most of the forest harvest while minimizing the effects of regrowth.

The regrowth issue also arose when deciding the length of the post-treatment time period after logging that would be used for the analysis of basin characteristics and management activities. After analyzing the combined results from each basin for post-treatment time periods of 2, 3, 4, 5, and 6-10 years, it was decided that three years of post-treatment data would be used. Three years represented the best compromise between the variability associated with shorter time periods and the decreasing changes in flow over time due to regrowth. This post-treatment interval reduced the number of basins available for analysis using the FDC method to 26 since six post-treatment data sets were less than three years long.

2.4.4. HIGH RESOLUTION DATA

The effect of analyzing mean daily rather than mean hourly flows was evaluated by comparing the results from one pair of basins (HJA-1 and HJA-2) where the raw data allowed the calculation of mean flows for multiple temporal resolutions. For each percentile, differences between the calculated changes in flow were compared along with ratios of mean hourly and mean daily flows using the three year post-treatment time period. The statistical significance of the differences between the hourly and daily data could not be tested because they were developed from the same data set and, thus, not independent of each other.

Since the amount of data necessary to create hourly FDCs was more than Excel functions could handle, the following formula was developed to obtain the percentiles for mean hourly flows:

$$\text{percentile} = \frac{(\text{rank} - 1)}{(n - 1)} \qquad (2)$$

where mean hourly values were ranked from smallest to largest with the smallest given a rank of 1 and n is the total number of discharge values. In order to rank the large hourly data set, the data were split into smaller groups and sorted. Similar values from these individual groups were then combined and resorted. This was repeated until all data were effectively sorted and ranked. When interpolation was necessary to determine a discharge value for a desired percentile, the following equation was used:

$$Q = \frac{(P - P_b)}{(P_a - P_b)}(Q_a - Q_b) + Q_b \qquad (3)$$

where Q and P are the desired discharge and percentile, respectively, and the subscripts a and b represent the respective values above and below the desired values.

2.5. ANALYSIS OF FLOW DURATION CURVE DATA

Once the flow duration curves were generated and the discharge values associated with each percentile were obtained, the analysis of the FDC data began. All analyses were performed using both absolute (L s^{-1} ha^{-1}) and percent changes. Results were grouped by percentile and the significance of the changes was checked by testing for differences from zero using an α-value of 0.05 as discussed above (Section 2.4.2).

2.5.1. ANALYSIS OF BASIN CHARACTERISTICS AND MANAGEMENT ACTIVITIES

The changes in each percentile were related to the basin characteristics and management activities in a similar fashion as the analysis of the published peak flow results (Section 2.3). Univariate plots provided an initial indication as to which characteristics and activities were most likely related to the changes in flow for each percentile. Correlation tables, regression analysis, and residual analysis were used to evaluate the continuous data. Kruskal-Wallis tests and t-tests were used to analyze the categorical data.

The categorical analysis was limited by the small number of FDC results. The most results possible for any given characteristic or activity was 26, or slightly more than half the maximum number of data points available for the published results. Since the number of categories for a given characteristic or activity ranged from three to eight (Table 2.2), comparisons were often limited by the number of data points in a given category. In order to make reasonable comparisons, categories with less than three data points were excluded from Kruskal-Wallis tests. If only two categories within a characteristic or activity had three or more results, then a t-test was the only analysis performed for that characteristic or activity. When possible, similar categories with limited data were grouped and tested for differences from other categories (e.g., clearcut vs. selection and patch cuts).

The large number of statistical tests needed to analyze these relationships raised the possibility of spurious statistical results. Even though few comparisons were made using exactly the same data sets due to differences in the available data for each study, the number of tests performed was minimized to reduce the potential for Type I errors. Thus only the highest, median, and lowest flows (99th, 50th, and 1st percentiles, respectively) were analyzed initially. A basin characteristic or management activity that was significantly associated with the calculated changes in flow at one of these percentiles was then tested for significance with changes in flow at the adjacent percentiles.

The adjacent percentiles for large flows were considered to be the 97.5 and 95th percentiles. For median flows, the 25th and 75th percentiles were used. The 2.5 and 5th percentiles were the adjacent percentiles for the 1st percentile. If a basin characteristic or management activity was found to be significant with the adjacent percentiles, then each of the closest percentiles would be successively tested until the characteristic or activity was no longer significant. By identifying unique and potentially spurious results, this procedure increased the reliability of the more general trends for both absolute and percent changes in flow.

2.5.2. RECOVERY OF STREAMFLOW OVER TIME

Post-treatment recovery rates were assessed by evaluating how each percentile changed over time. Median values for each percentile were used in the comparisons because the presence of extremely high percent change values severely skewed some of the results.

The post-treatment data from each study were grouped into two-year intervals after treatment for the recovery analysis. If there were sufficient post-treatment data, up to five intervals were calculated for each study. By grouping the results from different sites and time periods, it was assumed that any undue influence from studies affected by abnormal post-treatment precipitation patterns would be minimized. It was also assumed that most of the post-treatment differences due to abnormally wet or dry years were accounted for by the paired basin adjustments (Section 2.4.2).

Although the use of two-year intervals increased the variability between periods, these intervals also increased the temporal resolution of the recovery curves. At the same time, the use of two-year periods helped increase the sample size of each percentile. For example, a study with only five years of post-treatment data would have two post-treatment time periods, but the same study would only have one post-treatment period if three- or four-year intervals were used.

Only the 1st, 50th, and 99th percentiles were statistically evaluated for recovery over time after logging. Non-parametric sign tests were used to determine if the median for each of these three percentiles differed significantly from zero ($\alpha = 0.05$) for each time period. Means were also determined for each percentile over time to evaluate the skew of each data set. Recovery rates for the other eight percentiles were used to confirm the general trends observed for the 1st, 50th, and 99th percentiles.

2.5.3. AFFORESTATION ANALYSIS

Flow data were available for four paired basins in two afforestation study areas. As with the timber harvest data, the FDCs for the first three years after treatment were compared to the adjusted FDCs prior to treatment. Only the 50th to 99th percentiles were evaluated because one of the basins had zero flow more than 50% of the time and two others had no flow at least 25 percent of the time. The limited sample size precluded any effort to relate the observed changes in flows to basin characteristics or specific management practices.

The effect of afforestation on streamflow over time was also evaluated. Since the post-treatment data sets ranged from 14 to 20 years, these effects were analyzed using three-year time intervals instead of the two-year intervals used in the timber harvest data sets. This helped reduce the variability while still allowing five post-treatment time periods. The 50th to 99th percentiles were evaluated, but none were statistically analyzed due to the small number of afforestation studies.

One of the four afforestation studies (Shackham Brook in New York) did not have any pre-treatment data. While the treated basin was gaged immediately after planting, the control basin was not gaged until several years later. Fortunately, the initiation of data collection on the control basin coincided with the end of a second round of planting on the treated basin. This second planting was due to the poor survival rate of the original planted trees, so the effects of tree growth were assumed to be minimal during the first three years after the second round of planting. This three-year period was therefore used to calibrate the two basins. All data after the first three-year period were considered to be post-treatment data. Thus, the second through sixth three-year intervals from Shackham Brook were respectively grouped with the first through fifth intervals from the other studies.

3. RESULTS

3.1. PUBLISHED DATA

The literature search for the effects of timber harvest on peak flows yielded results from 80 basins in 39 different study sites world-wide (Appendix I). These studies were typically conducted in temperate zones on basins less than 100 hectares in size. Twenty-eight of these basins from 13 sites were also used to investigate low flows. None of the basins were investigated only for low flows.

Afforestation studies were conducted primarily outside of the United States. Data were obtained for 21 basins at 13 different sites (Appendix II).

3.1.1. EFFECTS OF LOGGING ON PEAK FLOWS

3.1.1.1. GENERAL ANALYSIS OF REPORTED RESULTS

The reported changes show that peak flows usually increase after timber harvest (Figure 3.1, Table 3.1). Mean increases for most of the peak flow categories were between 24 and 50%, while the median increases were between 20 and 50%. Two of the three largest mean changes were more than twice their respective median changes. This strong skew indicates that few studies have documented large changes in the size of peak flows. The similarity and small size of the means and medians for most of the peak flow categories also support this general conclusion.

The instantaneous peaks had the greatest range of results (-22 to 500%) and the most results (17) reported only as "not significant" (NS results). The mean change of 97% for instantaneous peak flows was nearly three times as

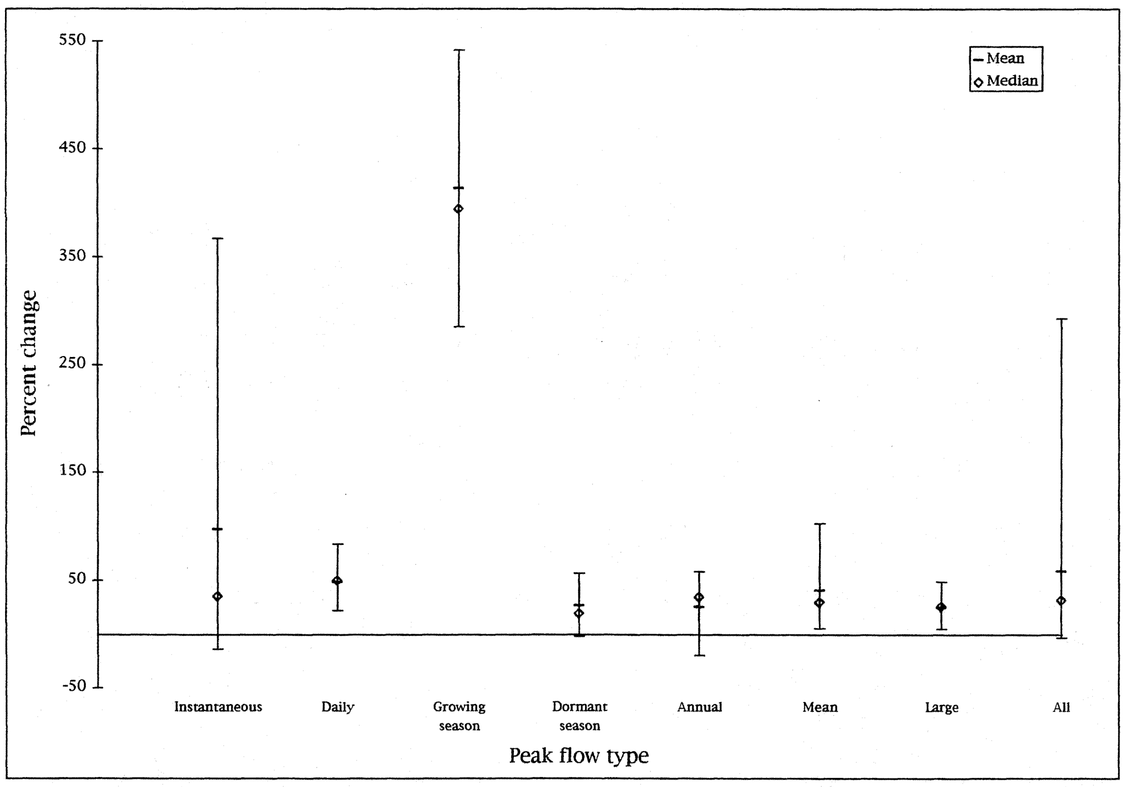


Figure 3.1. Mean, median, 5th percentile, and 95th percentile for percent change in peak flow by peak flow type.

Table 3.1. Summary statistics by peak flow category for the reported percent change in peak flows associated with timber harvest. Appendix III lists all of the results grouped by peak flow category.

Peak flow category	N*	NS results	Mean	Median	Min	Max
Instantaneous	8	17	97	35	-22	500
Daily	7	0	48	50	21	87
Growing season	4	3	413	395	300	563
Dormant season	12	2	26	20	-11	60
Annual	6	1	25	35	-32	65
Mean	11	0	40	30	0	150
Large	17	1	24	26	2	50
All	82	35	59	32	-36	563

* N is the total number of studies that reported a percent change; only these studies were used when calculating the summary statistics.

large as the median change of 35%. This mean was also the second largest change among the eight categories of peak flows in Figure 3.1 and Table 3.1. This suggests that the results for instantaneous peaks were strongly skewed towards larger changes. Even after removing the maximum observed increase of 500%, the instantaneous peak flows still showed a relatively large range (-22 to 118%). The large range and the large number of NS results show that the effects of timber harvest on instantaneous peak flows are highly variable.

In contrast, the reported changes in daily peak flows were relatively consistent. The difference between the minimum (21%) and maximum (87%) changes was among the smallest for the peak flow categories. At the same time, there were no NS results for daily peak flows. The respective mean and median changes of 48 and 50% indicate that there is only a slight skew in the combined daily flow results. The results suggest that daily peak flows are not as variable as instantaneous peak flows and daily peak flows may be more useful when evaluating the effects of timber harvest on high flows.

All but one of the reported changes greater than 150% were for growing season peak flows (Dietterick and Lynch, 1989; Patric and Reinhart, 1971). The other large change was a 500% increase in instantaneous peak flows reported for a severely disturbed site (Swindel et al., 1983). The change in growing season peak flows ranged from 300 to 563% for the four studies that reported a value, while three other studies reported NS results after treatment.

The four reported increases in growing season peak flows were all from studies that used herbicides to inhibit regrowth. In contrast, only one of the three NS results was from a site where herbicide treatments were used. This difference in treatment may partially explain the extreme results. However, additional analyses suggest that the large percent increases in growing season peak flows are probably caused by a combination of the size of flows investigated and seasonal climatic influences (see Section 3.1.1.2).

Increases for dormant season peak flows were among the smallest after logging. This peak flow category had the smallest median change of 20%, while the mean change of 26% was essentially identical to the smallest mean increases (Table 3.1). Even though the data were slightly skewed toward large changes, the maximum reported increase in dormant season peak flows was only 60%.

Seven studies investigated the effects of timber harvest on annual peak flows. The six reported changes ranged from -32 to 65%. The mean (25%) and median (35%) were among the smallest increases for the eight different categories of peak flows. The difference between the mean and median was caused primarily by the decrease of 32% observed at watershed 10 in the H. J. Andrews Experimental Forest in Oregon (Harr and McCorison, 1979).

Mean and median changes for the mean peak flow category were 40 and 30%, respectively. The results from this peak flow category were skewed because one study reported an increase of 150%. None of the other 10 studies reported a change in mean peak flows greater than 60%. There were no NS results.

The large peak flow category showed little skew or variability and consistently had some of the smallest changes. This category had the smallest mean change (24%) and nearly the smallest median change (26%) (Table 3.1). The maximum change was the smallest of the eight peak flow categories and the range was only 2 to 50%. Only 1 of the 20 studies that investigated the large peak flow category reported a NS result. These results indicate that large peak flows do increase after logging, but the relative change associated with timber harvest is not as large as the other categories of peak flows. All the data on peak flows are compiled in Appendix III.

3.1.1.2. PEAK FLOW CHANGES BY SIZE AND SEASON

The changes in peak flows were separated into different size classes for four basins in three different study areas. Three of these basins showed an inverse relationship between peak flow size and the percent increase after logging (Figure 3.2). The fourth basin, North Creek in Queensland, Australia, had mixed results (Gilmour, 1977). Larger flows had larger relative increases than smaller peak flows after logging on North Creek. However, this same basin showed little difference between small and large peak flow increases when the vegetation that remained after logging was cleared from 67% of the area for conversion to pastureland (Figure 3.2).

The inverse relationship between peak flow size and relative increases after logging can also be seen on a seasonal basis. Relative increases associated with typically small growing season flows are larger than increases for typically large dormant season flows (Table 3.1). This is probably due in part to the difference in peak flow response to precipitation resulting from differences in soil moisture conditions.

In rain-dominated temperate areas, soil moisture levels are generally lowest during the growing season. This is due to the greater loss of water to evapotranspiration (ET) and interception that occurs during the late spring, summer, and early fall. Once vegetation is removed in these areas, some of the precipitation that usually would be lost to ET and interception is used for soil moisture recharge and increased runoff. This extra runoff may be small in absolute terms, but a small absolute increase in growing season peak flows can

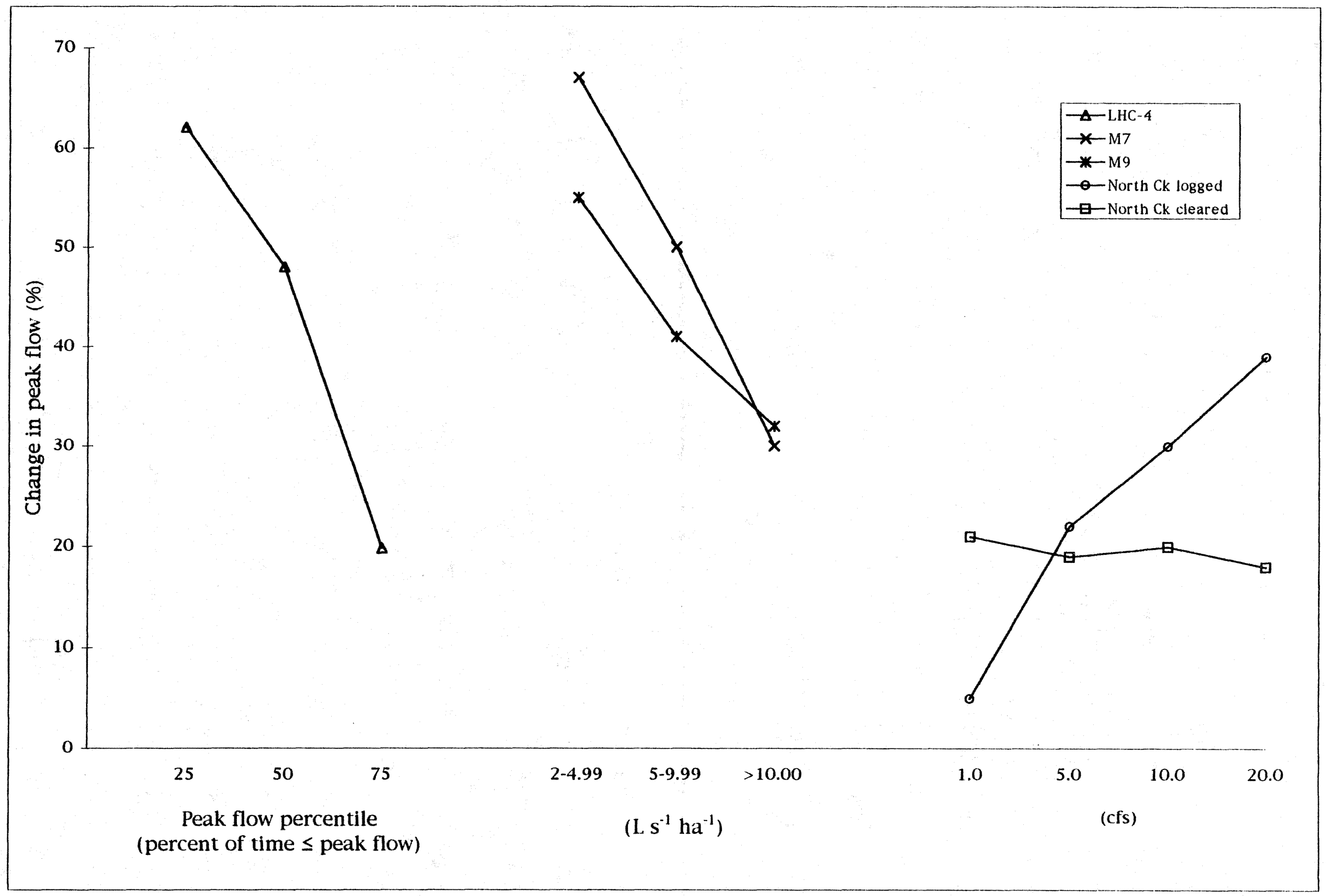


Figure 3.2. Reported results for studies that investigated multiple peak flow size classes. LHC-4 is in the Lien-Hua-Chi experimental basins of Taiwan (study number 26). M7 and M9 are part of the Mai Mai experimental area of New Zealand (study number 37). North Ck is located in Queensland, Australia (study number 58).

result in large percent increases (e.g., Dietterick and Lynch, 1989; Patric and Reinhart, 1971).

Peak flows are generally largest during the dormant season because soil moisture levels are high and a higher proportion of the rain or snowmelt becomes runoff. The high soil moisture levels are due to lower ET and interception losses during the late fall, winter, and early spring. When trees are removed, the proportion of rain or snowmelt becoming runoff does not change as dramatically in the dormant season as in the growing season because there is relatively little difference between pre- and post-harvest soil moisture levels during the dormant season. Thus, the dormant season peak flows increase by relatively small amounts after logging (Table 3.1).

The peak flow response to timber harvest associated with seasonal variations of soil moisture and precipitation described above is not universal. For example, in areas where little precipitation falls during the growing season, no changes in peak flow were detected (Cheng, 1989; Gottfried, 1991). Also, Harr et al. (1975) found that early dormant season peak flows increased more after logging than peak flows later in the dormant season because of differences in soil moisture levels. They separated the dormant season at their study site in Oregon into periods of "recharging" and "recharged" soil moisture conditions (Harr et al., 1975). These periods were based on both an arbitrary date separation (e.g., September to November was the recharge period for two of the basins) and a sharp rise in base flow level. The recharging and recharged periods roughly coincided with fall and winter, respectively. After logging, the median increase for the smaller fall peak flows was 50%, while the median increase for the larger winter peak flows was only 19%. Thus, while the pattern of smaller peak flows increasing by larger relative amounts still held true for these Oregon basins, the differences between small and large peak flow increases were not apparent for growing and dormant season flows.

3.1.1.3. DECREASES IN PEAK FLOW

Five of the 82 results in the all peak flow category were decreases. Although decreases in peak flow were not common, the observed declines are of interest because they are the opposite of what might normally be expected after logging. The decreases were typically attributed to a change in the timing of the processes that generated peak flows. Cheng et al. (1975) suggested that the compaction of macropores after logging slowed the subsurface flow of water to streams. The greater travel time through the soil resulted in peak flows decreasing by 22%.

In another study, Harr and McCorison (1979) suggested that a reduction in interception after logging was the cause of a 32% decrease in peak flows on H. J. Andrews watershed 10 in Oregon. Their study site was in a transitional zone with relatively little snow accumulation prior to logging. Cutting the trees reduced interception and increased snow accumulation on the ground. As this snow had a smaller surface area, it melted more slowly than the intercepted snow in the canopy. Harr and McCorison (1979) hypothesized that slower melt in cleared areas desynchronized runoff from different parts of the basin, resulting in the reduced peak flows.

3.1.1.4. STATISTICAL ANALYSIS OF PEAK FLOWS

The 45 results composited for the detailed statistical analysis of published changes were less variable than the 82 results pooled for the "all" peak flow category. The median increase of 30% for the data analyzed in detail (Table 3.2) is essentially the same as the median for all peaks (Table 3.1). However, the mean change for all peaks is nearly twice the size of the mean

3.2. Descriptive statistics of peak flow results used in detailed analysis.

Statistic	Value
Number of results used	45
Mean (%)	35
Median (%)	30
Standard deviation (%)	35
Minimum (%)	-32
Maximum (%)	150
Skew	1.3

increase for the peak flows used in the detailed analysis (59 and 35%, respectively). This difference is due to the exclusion of the growing season peaks and the severely disturbed site that had a 500% increase. The skew of 1.3 and the difference between the mean and the median suggest that the data used for the detailed analysis were skewed toward the higher percent changes. However, this skew was not as strong as for all peak flows.

The percent change in peak flows was significantly related to four continuous basin characteristics (Table 3.3). As annual precipitation increased, the increases in peak flows decreased (Figure 3.3 (a)). Since areas with higher precipitation typically have larger peak flows, this relationship supports the concept that larger flows are less affected by logging (Section 3.1.1.2).

Increases in annual ET and drainage density were significantly related to increased changes in the size of peak flows. This was unexpected as higher annual ET rates and higher drainage densities both typically occur in areas with high annual precipitation rates and thus high peak flows. However, both relationships were driven by influential observations (Figures 3.3 (b) and (c)) and neither relationship was significant without these observations.

Table 3.3. Significant results from the regression analysis of percent change in peak flow vs. basin characteristics and management activities using the published data.

Variable	N	Coefficients y-int	Coefficients slope	Standard error	R^2	p-value	Comments
Basin characteristics							
Annual precipitation (mm)	44	58	-0.015	34	0.08	0.065	two outliers included
Annual ET (mm)	20	5.2	0.060	39	0.17	0.075	one outlier included; driven by one observation
Drainage density (km km^{-2})	12	15	1.5	15	0.44	0.019	one outlier removed; driven by one observation
Latitude (degrees)	44	98	-1.6	32	0.08	0.060	one influential observation removed; two outliers included
Management activities							
Area compacted (%)	35	21	1.1	31	0.13	0.035	one outlier included; driven by one observation

Latitude was the only other basin characteristic significantly related to a percent change in peak flows. There was a weak tendency for peak flows to increase less after harvesting with increasing latitude (Figure 3.3 (d)), but it is unclear why this relationship was significant. None of the categorical basin variables were significantly related to published changes in peak flows (Appendix IV).

Area compacted was the only continuous management variable significantly related to the reported changes in peak flows (Table 3.3). Although this relationship showed the expected positive correlation, it was significant only because of one influential observation (Figure 3.4). Part of

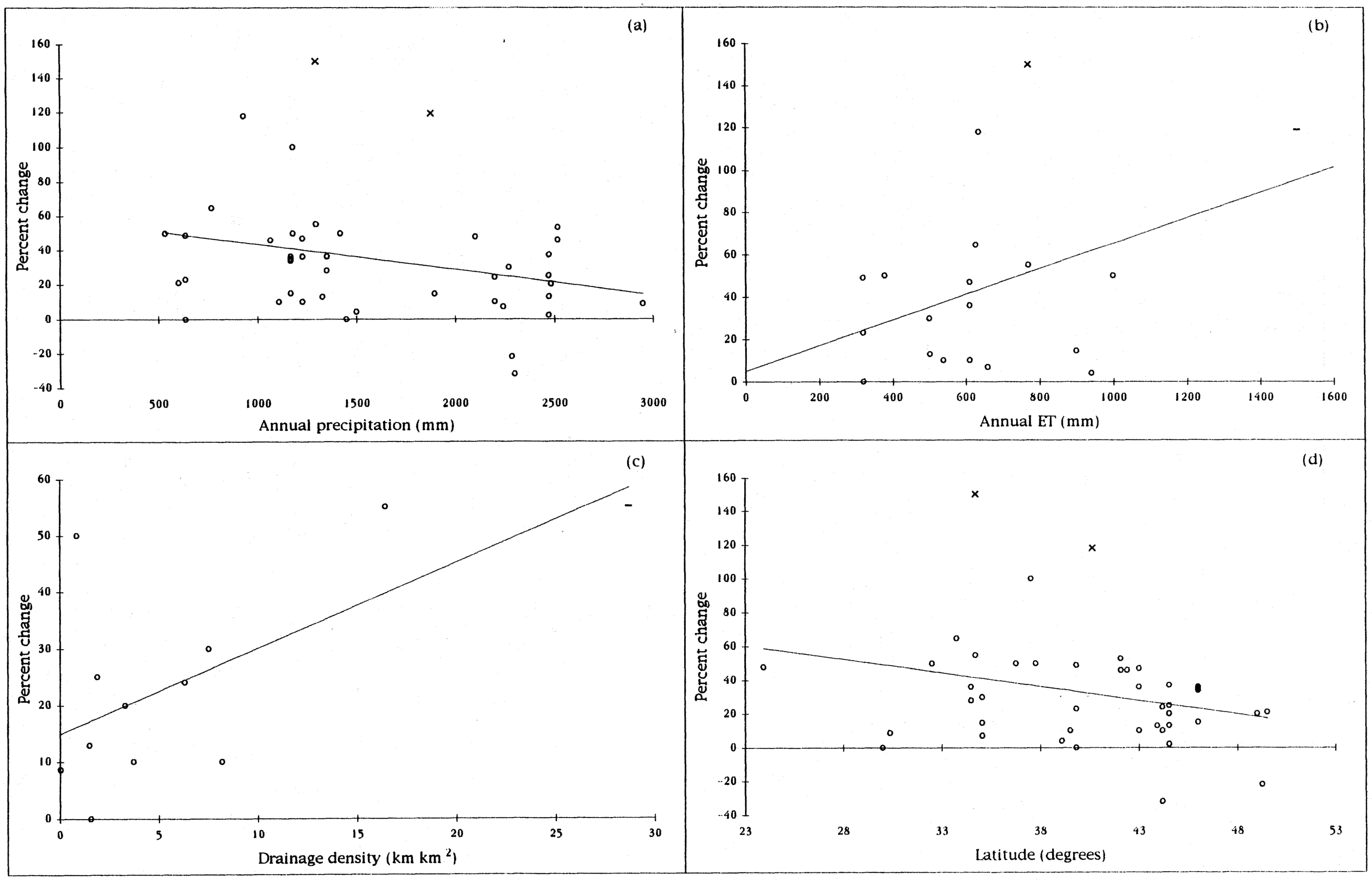


Figure 3.3. Plots of percent change in peak flows vs. annual precipitation (a), evapotranspiration (b), drainage density (c), and latitude (d), respectively. Plots include outliers and influential observations as described in Table 3.3. Outliers and influential observations are represented by "x" and "-", respectively.

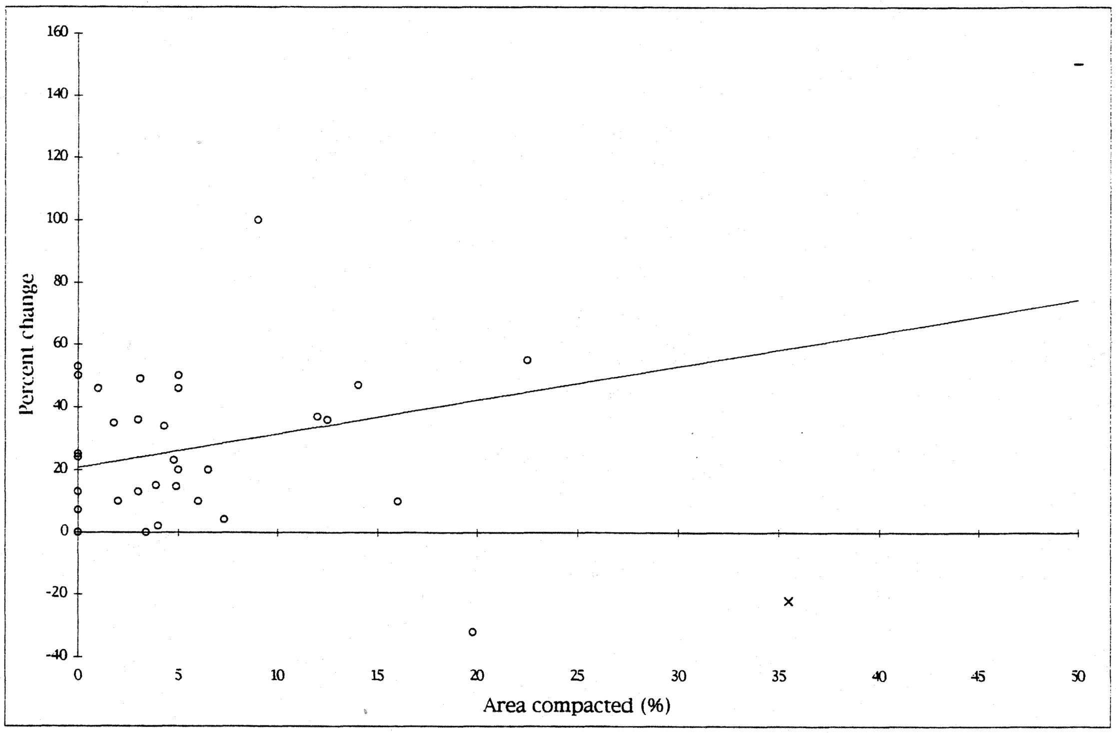


Figure 3.4. Plot of area compacted versus percent change in peak flow. Outliers and influential observations are included as described in Table 3.3. Outliers and influential observations are represented by "x" and "-", respectively.

the observed variability in this relationship may be due to differences in how the amount of compacted area was determined for different studies. Some authors (e.g., Swank et al., 1982) only considered the total area in roads as compacted, while others included skid trails and landings as well (e.g., Ziemer, 1981). The variability may also be attributed to differences in the way that compaction affects flow paths. In some cases, compaction reportedly increased peak flows by reducing infiltration rates and allowing Horton overland flow to occur (Blackburn et al., 1990). However, compaction has also been reported to decrease peak flows by slowing subsurface stormflow through macropores (Cheng et al., 1975).

The only categorical management activity that was significantly associated with a change in peak flow was the type of yarding ($p = 0.028$). The mean increase (49%) for sites where only tractors or rubber-tired skidders were used was more than twice the mean for sites where only a cable system was used (16%) or where both cable and tractor systems were used (22%) (Table 3.4). There was no significant difference between the percent area cut in basins that were yarded using tractors or rubber-tired skidders and basins that were yarded using cable ($p = 0.764$) or mixed systems ($p = 0.564$). As cable systems are less intrusive and thus less disturbing to forest soils than tractors or skidders (Young and Giese, 1990), these results suggest that more site disturbance and compaction will tend to result in greater percent changes in peak flows.

The mean percent change in peak flow for the tractor and rubber-tired skidder category was not significantly different from the mean change for the no yarding category. This lack of significance is probably due to the small number of cases (4) where yarding was not carried out. No significant differences were found between any of the three other yarding categories listed in Table 3.4.

The results of all statistical tests can be found in Appendix IV. Plots of each basin characteristic and management activity versus reported change in peak flow are in Appendix V.

3.1.2. EFFECTS OF LOGGING ON LOW FLOWS

Twenty-eight studies evaluated the change in low flows due to forest harvest. Unlike peak flows, only general post-treatment trends are presented for low flows because the diversity of low flow definitions (Appendix I) prevented any meaningful grouping of results in a manner similar to the published peak flow results (Table 3.1). In 16 cases there was an increase in low flows, in 10 cases there was no significant change, and in only 2 cases was

Table 3.4. Percent change in peak flow by yarding category. Overall p = 0.028. Given that α = 0.10 overall, significance for individual comparisons equals $\alpha/6$ or 0.017. P-values are for two-tailed two-sample t-tests.

Category	N	Mean change in peak flow (%)	P-values for each comparison with tractors and rubber-tired skidders
Tractor and rubber-tired skidders	17	49	
Cable systems	12	16	0.007
Mixed tractor and cable	5	22	0.012
None (i.e., trees left on site)	4	21	0.022

there a decrease in low flows. These results indicate that, just like peak flows, low flows: 1) will typically increase after logging; 2) are hard to statistically analyze due to their highly variable nature; and 3) will, on rare occasions, decrease.

Low flows typically occur when evapotranspiration (ET) demands are the greatest. When the trees are removed from a basin, more water is available for streamflow and thus, low flows are likely to show a similar response to timber harvest as the small peak flows of the growing season and recharge periods (Section 3.1.1.2). This similarity of response means that low flows should have large percent increases after logging. In fact, intermittent or ephemeral streams that became perennial after harvest would have infinitely large percent increases in low flow.

The diversity of low flow definitions likely grew out of the large relative increases in flow observed after logging. To avoid reporting problems, many authors simply reported a change in the number of days per year with mean daily flows below some arbitrary discharge. While this approach solved one problem--especially in areas with periods of no flow--it created two others. First, this type of result precludes direct comparisons between studies because the low flow thresholds are site-specific. Second, the reported changes can be confusing as a decrease in low flow days actually means an increase in low flows.

The two cases where low flows decreased were from the same site in northwestern Oregon. Harr (1980) surmised that fog drip in this area played an important role in maintaining summer flows. As the fog passed through the forest, moisture condensed on the trees and dripped to the ground. Without the trees, this unexpectedly large source of water was lost and low flows decreased.

Another interesting result was how the low flows changed over time. After initially finding an increase in low flows for two basins in western Oregon, Hicks et al. (1991) reported that one basin had no significant change by the 15th year after logging while the other decreased significantly by the eighth year post-treatment. They suggested that this reduction in low flows may have been due to a change in riparian vegetation from conifers to hardwood species that used more water. Keppeler and Ziemer (1990) saw a similar decrease in total summer volume 10 years after logging. They suggested that reduced competition for light and nutrients may have increased growth and water use by the remaining trees in the partially harvested basin that they studied. Both of these studies indicate that low flows are very sensitive to changes in ET rates.

3.1.3. EFFECTS OF AFFORESTATION ON PEAK AND LOW FLOWS

Most of the 22 afforestation studies were conducted in New Zealand and South Africa where native grasslands and brushlands were converted to exotic timber species. Only four basins were investigated in the United States (Appendix II).

Definitions for changes in peak flow associated with afforestation were more diverse and obscure than for the timber harvest studies. Nevertheless, 11 of the 15 peak flow studies reported decreases in peak flows after afforestation. Two studies were inconclusive while a third found no change after afforestation. Reported decreases in peak flows ranged from 11 to 73%.

Twelve of the 14 low flow studies reported decreases after afforestation. Reported decreases ranged from 26 to 100%, with eight of the nine reported changes being decreases of 50% or more. Low flow definitions were more consistent for afforestation studies than for timber harvest studies.

The reported results indicate that less water was available for streamflow after afforestation since both peak and low flows typically decreased as the trees approached maturity. The observed declines in flow are probably due to increased evapotranspiration and interception, as sites severely impacted by planting and erosion control activities had decreases in both peak and low flows once the trees were at or near maturity (e.g., TVA, 1961 and 1962). This suggests that the rate and magnitude of changes in evapotranspiration and interception will play a major role in determining what changes will occur when vegetation is manipulated.

3.2. FLOW DURATION CURVE DATA

3.2.1. VALIDATION OF ADJUSTMENT METHODOLOGY

The adjustment procedure for the FDC analysis was tested by comparing the changes in flow generated from a split set of calibration data (Section 2.4.2). As the "post-treatment" data set was generated from calibration period data, any differences between periods were due to the inherent variability in the data and any bias in the methodology.

Table 3.5. Summary statistics for absolute changes in flow calculated using pre-treatment data. P-values are from non-parametric sign tests of the significance of each median value from zero. Values are in L s^{-1} ha^{-1}.

Percentile	N	Mean	Median	Std. dev.	Min.	Max.	p-value
1.0	16	0.0020	0.00080	0.0059	-0.0080	0.020	0.302
2.5	16	-0.0012	-0.00085	0.011	-0.034	0.023	0.455
5.0	17	-0.0024	-0.000018	0.014	-0.048	0.023	1.000
10.0	19	0.000017	-0.000041	0.0085	-0.016	0.028	1.000
25.0	20	0.00030	0.00013	0.015	-0.037	0.047	0.824
50.0	21	-0.0048	-0.0011	0.021	-0.070	0.034	0.383
75.0	23	-0.013	-0.0055	0.033	-0.10	0.029	0.678
90.0	23	-0.014	-0.013	0.053	-0.13	0.12	0.405
95.0	23	0.016	0.024	0.077	-0.19	0.14	0.093
97.5	23	0.041	0.014	0.11	-0.13	0.44	0.093
99.0	23	-0.017	0.028	0.28	-0.60	0.51	0.405

None of the differences were significant and only two percentiles had p-values less than 0.3 (Table 3.5). Both the 95th and 97.5 percentiles had p-values of 0.093 because each had more than twice as many positive than negative changes in flow. Nevertheless, these results indicate that the adjustment methodology does not generate significant ($\alpha = 0.05$) changes in absolute flows.

As might be expected, the absolute changes were very close to zero for the median and smaller flows, while the larger flows showed a greater range of changes (Figure 3.5, Table 3.5). The greatest median difference from zero was 0.028 L s^{-1} ha^{-1} for the data from the 99th percentile.

A comparison of the means and medians for each percentile showed that the distribution of absolute change in flow for 10 of the 11 percentiles were at least slightly skewed (Table 3.5). Since four means were greater and six means were less than their respective medians, the adjustment procedure did not result in a systematic bias towards either higher or lower values.

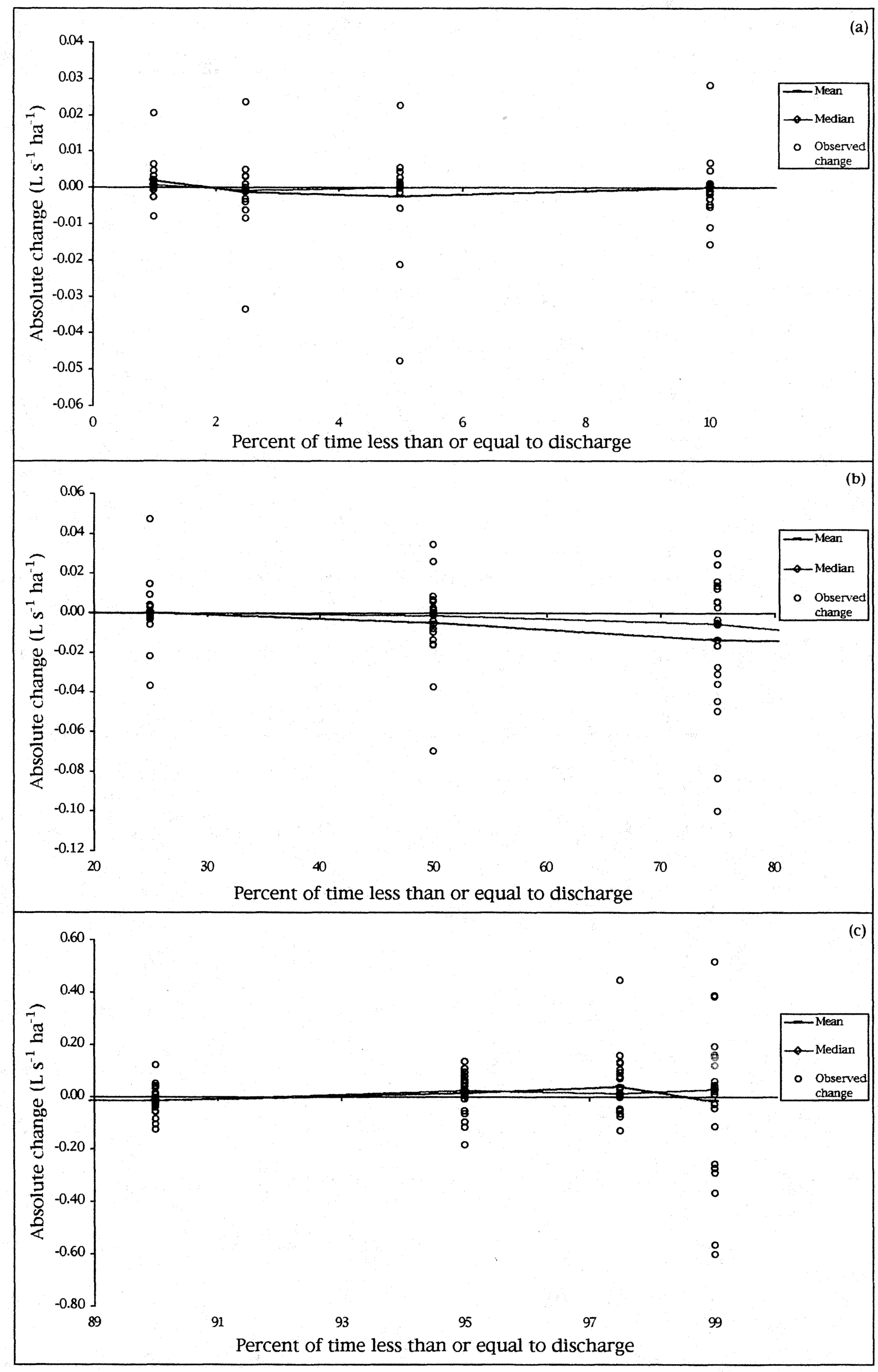


Figure 3.5. Means, medians, and absolute changes in flow calculated using pre-treatment data. The results are presented by the (a) 1st to 10th, (b) 25th to 75th, and (c) 90th to 99th percentiles to reflect the differences in the range of data for each group of percentiles.

Though the non-parametric sign test is not sensitive to outliers, an outlier analysis was conducted to determine the potential sources of variability. This analysis showed that only the data from the 90th, 95th, and 99th percentiles did not have outliers. Though it was not clear why, the greatest absolute change in flow for each of the seven percentiles that had outliers was recorded at either Fox Creek 1 in Oregon or Coweeta 6 in North Carolina. Removing these outliers greatly reduced the variability for each percentile.

The adjustment methodology was also tested for its validity in determining relative changes in flow (Figure 3.6). As with the absolute values, none of the differences were significant ($\alpha = 0.05$). Only one percentile (2.5) had a median change greater than ± 5% (Table 3.6).

The variation in percent change was much greater for low flows than for high flows (Figure 3.6). This is due to the fact that a small absolute change in low flows can be a very large change in percent terms. The median for the 95th percentile was the only median larger than its respective mean, suggesting that all other percentiles were skewed toward higher flows. This skew was most evident for flows less than the 50th percentile and is probably due to the inherent bias in calculating percent change, as the smallest possible decrease is -100%, while there is no limit on the percent increase.

As with the absolute values, an outlier analysis was conducted to determine the potential sources of variability. Only the data for the 1st and 2.5 percentiles did not have outliers. The greatest percent change in flow for seven of the nine percentiles with outliers was from Thomas Creek in Arizona and S4S in Marcell, Minnesota. Removing outliers greatly reduced the variability in each case.

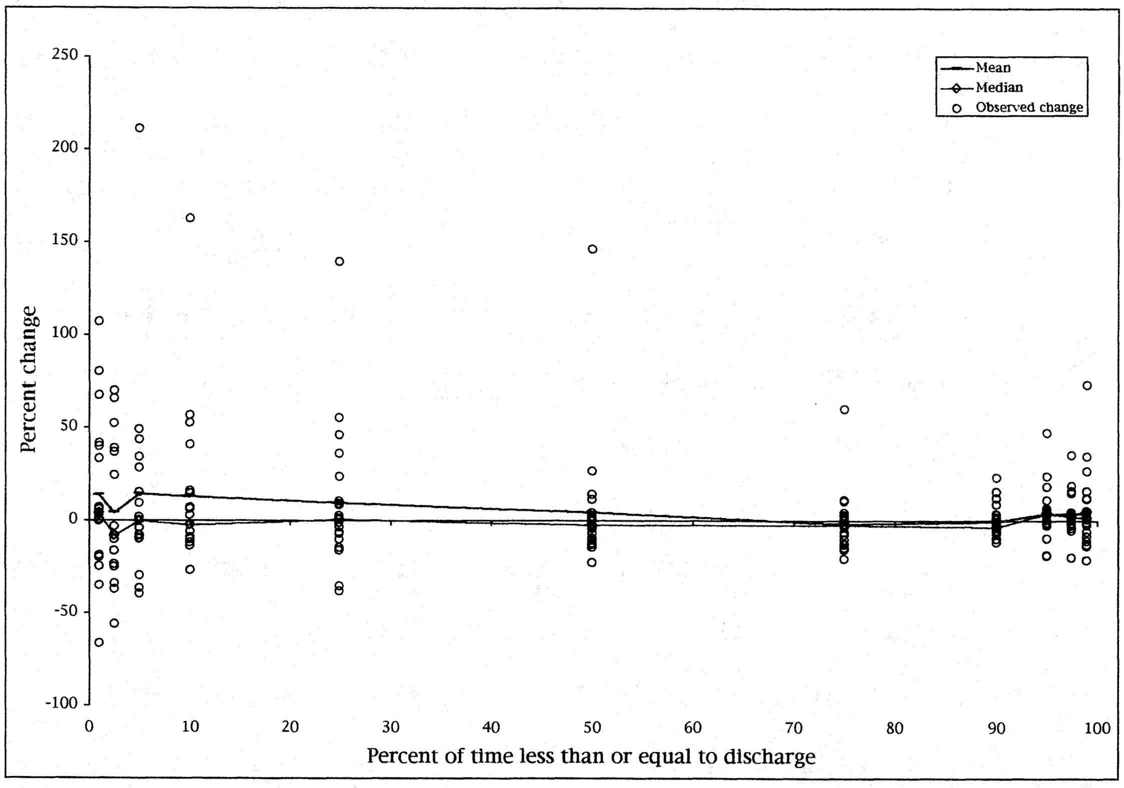


Figure 3.6. Means, medians, and relative changes in flow by percentile calculated using pre-treatment data.

Table 3.6. Summary statistics for percent changes in flow calculated using pre-treatment data. P-values are from non-parametric sign tests of the significance of each median value from zero.

Percentile	N	Mean	Median	Std. dev.	Min.	Max.	p-value
1.0	16	13.7	4.3	45.4	-66.5	107.0	0.455
2.5	16	4.0	-8.4	38.7	-56.2	69.5	0.455
5.0	17	14.5	-0.1	56.8	-39.5	211.1	1.000
10.0	19	13.2	-2.3	42.7	-26.8	162.5	1.000
25.0	20	9.8	0.7	38.5	-38.4	139.3	0.824
50.0	21	4.6	-2.4	34.2	-22.7	146.2	0.383
75.0	23	-1.7	-2.4	16.2	-20.5	59.9	0.678
90.0	23	-0.3	-3.3	8.4	-11.8	23.2	0.405
95.0	23	4.0	4.3	13.4	-18.8	47.3	0.093
97.5	23	3.5	2.2	10.3	-20.0	35.1	0.093
99.0	23	4.8	1.7	19.6	-21.4	73.0	0.405

The lack of significant differences between "calibration" and "post-treatment" data for $\alpha = 0.05$ indicates that the adjustment methodology is valid for determining both absolute and relative changes in flows associated with timber harvest (Tables 3.5 and 3.6).

3.2.2. DAILY VS. HOURLY FLOWS

There were no systematic differences between mean daily and mean hourly absolute changes in flow calculated using three years of post-treatment data from H. J. Andrews watershed 1 (Table 3.7). The greatest absolute difference between daily and hourly flows was 0.059 L s^{-1} ha^{-1} for the 99th percentile, while the smallest difference was 0.00016 L s^{-1} ha^{-1} for the 10th percentile.

The ratios of daily to hourly flows showed that the absolute changes for median and smaller flows were most similar, ranging from 0.97 to 1.03. The ratios were somewhat less consistent for larger flows, ranging from 0.86 to 1.09. The greater variability at the high end of the FDC may be due to the greater sensitivity of higher resolution data to storm flows in these small basins. The divergence from a ratio of 1.0 was typically less than ± 0.1 and there were no systematic biases for high flows. Thus, it is difficult to interpret or determine the importance of the observed differences between absolute changes in flow for the mean daily and mean hourly flows at the high end of the FDC. At least for this pair of basins, it seems that absolute changes in median and lower percentile flows may be reliably determined using mean daily flows, whereas higher resolution data may determine the absolute changes in higher flows more accurately.

There were no consistent patterns in the differences between daily and hourly relative changes in flow (Table 3.8). For 10 of 11 percentiles, the

Table 3.7. Difference between mean daily and mean hourly absolute changes in flow ($L\ s^{-1}\ ha^{-1}$) for each percentile at H. J. Andrews watershed 1.

Percentile	Daily	Hourly	Difference	Ratio
1.0	0.01235	0.01265	-0.00030	0.98
2.5	0.01002	0.01029	-0.00028	0.97
5.0	0.01053	0.01028	0.00025	1.02
10.0	0.01688	0.01672	0.00016	1.01
25.0	0.04120	0.04185	-0.00065	0.98
50.0	0.0798	0.0772	0.0026	1.03
75.0	0.1775	0.1682	0.0093	1.06
90.0	0.363	0.395	-0.033	0.92
95.0	0.260	0.302	-0.042	0.86
97.5	0.601	0.572	0.029	1.05
99.0	0.683	0.625	0.059	1.09

Table 3.8. Difference between mean daily and mean hourly percent changes in flow for each percentile at H. J. Andrews watershed 1.

Percentile	Daily	Hourly	Difference	Ratio
1.0	347.4	433.9	-86.5	0.80
2.5	109.1	115.7	-6.5	0.94
5.0	103.3	100.1	3.2	1.03
10.0	131.1	131.9	-0.8	0.99
25.0	144.9	150.6	-5.7	0.96
50.0	63.0	61.6	1.4	1.02
75.0	50.0	48.2	1.8	1.04
90.0	43.3	48.1	-4.8	0.90
95.0	17.8	20.9	-3.0	0.85
97.5	30.5	28.4	2.1	1.07
99.0	22.4	19.3	3.1	1.16

differences in calculated percent change were within ± 6.5%. The large percent difference observed for the first percentile is almost certainly due to the fact that a small difference in a small number can yield a very large relative difference.

Overall, the ratios for percent change did show a greater divergence from 1.0 than the ratios for the absolute changes. The variation from one was greatest at the two extremes of the flow duration curve. For the two lowest percentiles, the ratio of daily to hourly percent change was less than one (i.e., daily flows underestimated the treatment effect relative to the hourly flows), while the reverse was true for the two highest percentiles. This indicates that the use of daily flows may slightly overestimate the calculated percent changes in peak flows presented in this study. However, even for these relatively small basins, there does not appear to be any consistent bias in using daily rather than hourly flow data.

3.2.3. ANALYSIS OF FLOW DURATION CURVE PERCENTILES

3.2.3.1. TIMBER HARVEST

3.2.3.1.1. CHANGES IN FLOW

The comparison of pre-treatment and adjusted post-treatment FDCs showed that flows increased significantly ($\alpha = 0.05$) after timber harvest for each of the 11 percentiles investigated (Table 3.9). There was a consistent increase for the median absolute change in flow from the 2.5 percentile (0.0041 L s^{-1} ha^{-1}) through the 99th percentile (0.21 L s^{-1} ha^{-1}) (Table 3.9). The much larger absolute increases in the higher flows mean that most of the increased water yield associated with timber harvest occurs at the upper end of the FDC.

A comparison of mean and median increases shows that the data for nine of the percentiles were at least slightly skewed toward larger flows (Table 3.9, Figure 3.7). The data for the 25th and 50th percentiles were slightly skewed toward smaller flows. An outlier analysis showed that only the data for the 2.5 percentile did not have an outlier and that the data for each of the 5th

Table 3.9. Summary statistics for the absolute changes in selected flow percentiles following timber harvest. Values are in L s^{-1} ha^{-1}. P-values are from non-parametric sign tests of the significance ($\alpha = 0.05$) of each median value from zero.

Percentile	N	Mean	Median	Std. dev.	Min.	Max.	p-value
1.0	17	0.0066	0.0057	0.010	-0.015	0.028	0.021
2.5	18	0.0065	0.0041	0.012	-0.021	0.028	0.001
5.0	19	0.010	0.0058	0.017	-0.021	0.061	0.001
10.0	20	0.014	0.010	0.018	-0.018	0.071	0.000
25.0	22	0.010	0.016	0.038	-0.12	0.073	0.001
50.0	23	0.022	0.026	0.045	-0.14	0.080	0.000
75.0	25	0.053	0.036	0.068	-0.06	0.21	0.004
90.0	26	0.099	0.061	0.14	-0.11	0.52	0.001
95.0	26	0.15	0.098	0.16	-0.15	0.53	0.000
97.5	26	0.20	0.15	0.22	-0.08	1.0	0.000
99.0	26	0.29	0.21	0.46	-0.66	1.6	0.009

to 99th percentiles had at least one outlier greater than three standard deviations from the mean. These outliers and skew did not influence the significance of the increases, however, because the non-parametric sign test is not sensitive to outliers or skew.

The largest absolute increases for the 90th to 99th percentiles occurred on the Needle Branch basin at Alsea, Oregon. The largest increase was 1.6 L s^{-1} ha^{-1} for the 99th percentile. These increases were 20 to 80% larger than the next largest increase in flow for these percentiles. Several of the treatments on the Needle Branch basin were associated with larger increases in high flows in the variable analysis (Section 3.2.3.1.2), possibly explaining the large increases observed on this basin.

Decreases in flow were not uncommon as each percentile had at least two and as many as six decreases in flow for the three-year period after logging. Eleven of the 26 basins analyzed had absolute decreases in at least one percentile. However, the greatest decreases in flow all occurred in

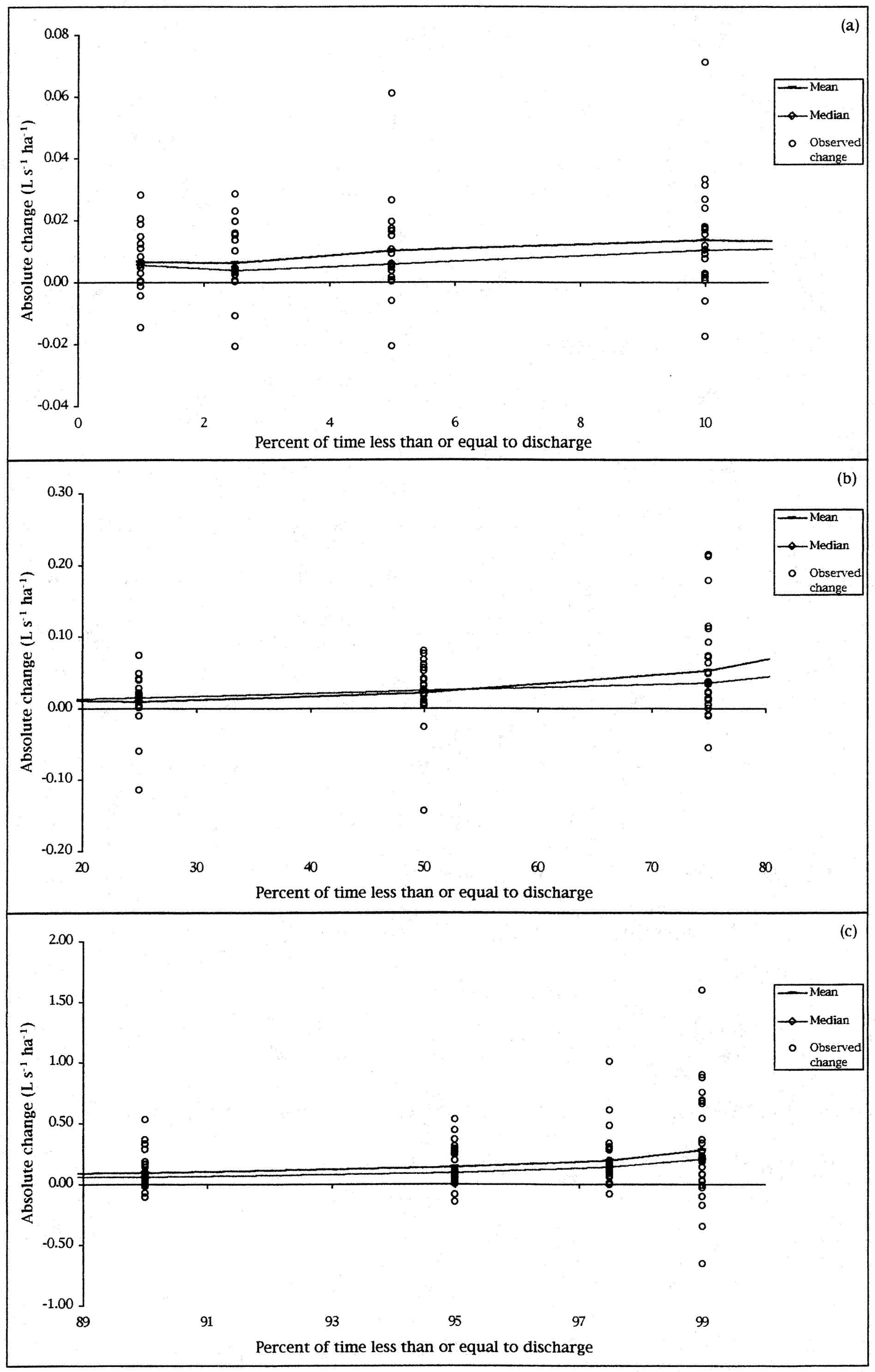


Figure 3.7. Means, medians, and absolute changes in flow associated with timber harvest. The results are presented by the (a) 1st to 10th, (b) 25th to 75th, and (c) 90th to 99th percentiles to reflect the differences in the range of data for each group of percentiles.

Oregon, where the two Fox Creek basins accounted for more than half of the 34 cases where decreases occurred. The minimum values for the two largest percentiles occurred on H. J. Andrews watershed 10 (HJA-10), with the greatest decrease in flow of -0.66 L s^{-1} ha^{-1} occurring at the 99th percentile (Table 3.9). The calculated decreases in low flows at Fox Creek and high flows at HJA-10 are consistent with the published results for each of these basins (Harr, 1980; Harr and McCorison, 1979).

The percent increases in flow were also significantly different from zero for each of the 11 percentiles analyzed (Table 3.10). The greatest median increases were for the 1st to 25th percentiles, with the largest increase of 59% occurring at the 1st percentile. In contrast, the median increases in flow for the 90th to 99th percentiles were only 12 to 14%. This trend is consistent with the published data, where the smaller peak flows typically had the largest relative increases (Section 3.1.1.2).

Both an examination of the plotted data (Figure 3.8) and a comparison of means and medians (Table 3.10) indicate that the data in each percentile was at least slightly skewed towards large increases. This is probably due to the inherent bias in calculating percent change that was noted earlier (Section 3.2.1). The skew was most notable for the data from the 5th percentile, where the maximum increase of 30,200% drove the mean change in flows up to 1680% as compared to a median change of 39%.

The data for each percentile had at least one outlier. These outliers were greater than 4 standard deviations from the mean for the 5th through the 75th percentiles, illustrating the extreme relative changes that are possible for low to moderate flows.

The most extreme percent changes were for low flows on basins where very small pre-treatment flows were increased by small to moderate absolute

Table 3.10. Summary statistics for the percent changes in selected flow percentiles following timber harvest. P-values are from non-parametric sign tests of the significance ($\alpha = 0.05$) of each median value from zero.

Percentile	N	Mean	Median	Std. dev.	Min.	Max.	p-value
1.0	17	186	59	340	-36	1330	0.021
2.5	18	224	51	463	-40	1820	0.001
5.0	19	1680	39	6900	-35	30200	0.001
10.0	20	427	53	1390	-20	6270	0.000
25.0	22	100	57	187	-38	886	0.001
50.0	23	52	22	88	-20	416	0.000
75.0	25	27	20	31	-5	139	0.002
90.0	26	16	14	16	-5	43	0.001
95.0	26	17	12	17	-9	60	0.000
97.5	26	15	13	12	-3	40	0.000
99.0	26	14	12	17	-14	52	0.009

amounts. For example, on watershed 2 at Hubbard Brook (HB-2), the adjusted pre-treatment flow of 0.0002 L s^{-1} ha^{-1} for the 5th percentile increased by more than 30,000% to 0.061 L s^{-1} ha^{-1}. Also, for the 2.5 to 75th percentiles, the maximum percent changes all occurred on basins that had no flow for part of the year. In each case, the maximum percent change was for the smallest percentile with flow prior to logging (e.g., HB-2). These extreme increases are a result of the relative change approaching infinity as pre-treatment flows approach zero. For this reason, the percent increase may not be very meaningful for small to moderate flows in basins with intermittent or ephemeral streams. In such cases, the absolute change in flow will generally be a more useful indicator of the effects of timber harvest.

3.2.3.1.2. ANALYSIS OF BASIN CHARACTERISTICS AND MANAGEMENT ACTIVITIES

Six continuous basin characteristics were significantly related to the absolute changes in flow for at least one percentile (Table 3.11). However, there was little consistency between percentiles and most significant results

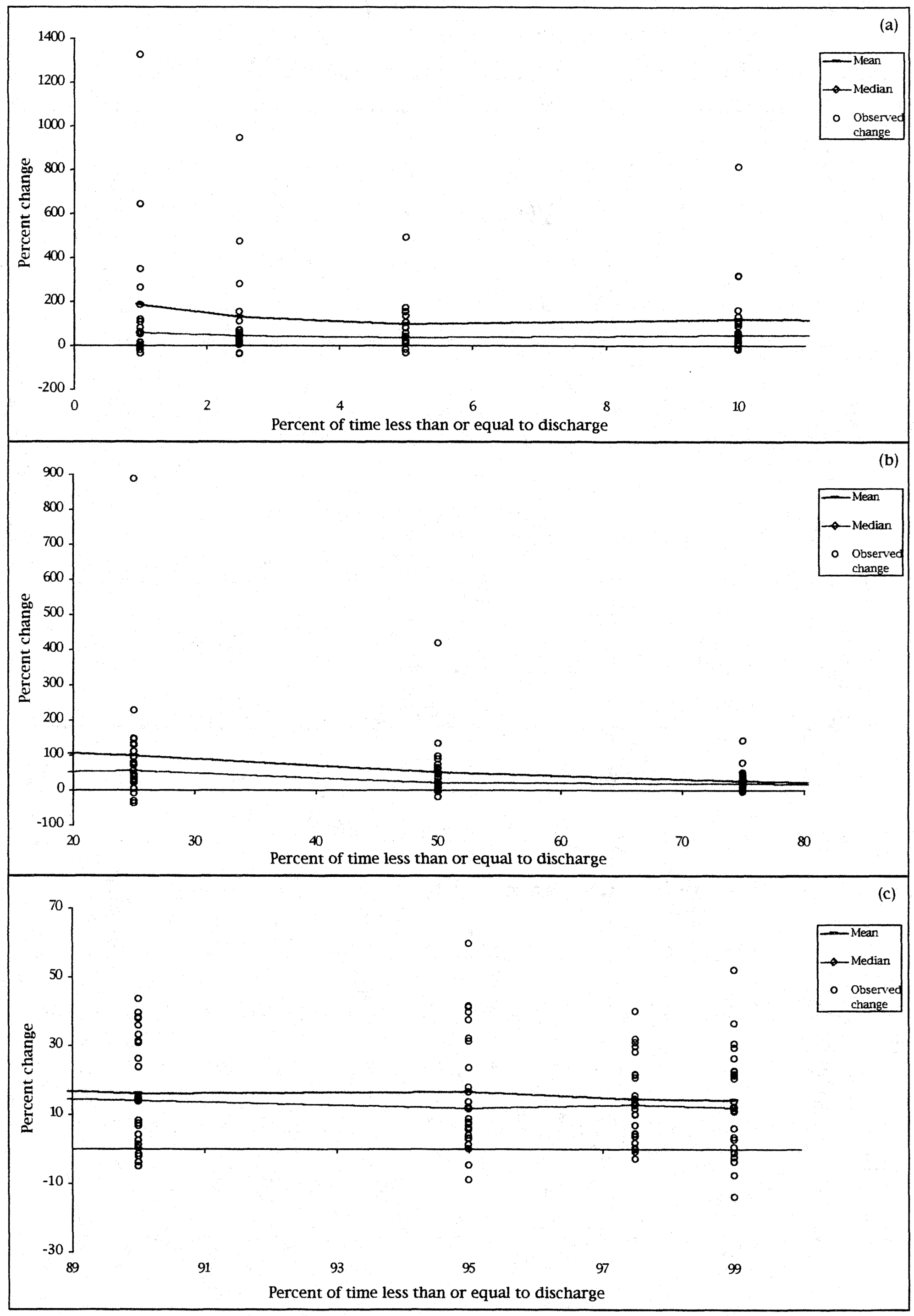


Figure 3.8. Means, medians, and percent changes in flow associated with timber harvest. The results are presented by the (a) 1st to 10th, (b) 25th to 75th, and (c) 90th to 99th percentiles to reflect the differences in the range of data for each group of percentiles. Extreme values of 1800%, 30,000%, and 6300% are not shown for the 2.5, 5th, and 10th percentiles, respectively.

Table 3.11. Continuous basin characteristics significantly related to absolute and relative changes for at least one percentile. R^2 values are provided when the relationship is significant. The symbols "ns" and "--" represent relationships that were non-significant ($\alpha = 0.10$) and not tested, respectively.

Basin characteristic	Percentile										
	1.0	2.5	5.0	10.0	25.0	50.0	75.0	90.0	95.0	97.5	99.0
Absolute changes in flow (L s^{-1} ha^{-1})											
Mean basin slope	0.83	0.74	0.63	0.58	0.37	0.23	0.38	0.45	ns	ns	ns
Drainage density	0.88	0.86	ns	--	--	ns	--	--	--	--	ns
Latitude	0.18	0.16	ns	--	--	ns	--	--	--	--	ns
Area	ns	--	--	--	--	ns	--	--	ns	ns	0.18
Mean elevation	ns	--	--	--	--	ns	--	--	ns	ns	0.21
Percent changes in flow											
Drainage density	0.91	0.72	ns	--	--	ns	--	--	--	--	ns

proved to be questionable when the scatter plots were examined. Only one continuous basin characteristic was significantly related to relative changes in flow. Details of all the statistical analyses are provided in Appendix VI.

Mean basin slope was the only continuous basin characteristic that was consistently and significantly ($\alpha = 0.10$) related to absolute changes in flow. The relationship was always positive, with mean basin slope explaining 23 to 83% of the variability in the data for the 1st through 90th percentiles. The higher R^2 values associated with the smaller percentiles suggests that a higher gradient may be more important for lower flows. In contrast, mean basin slope was not significantly associated with the calculated changes in flow for the larger percentiles.

The lowest values in each of the mean basin slope scatter plots (e.g., Figure 3.9) were decreases in flow from the Fox Creek study in Oregon. These decreases in low flows were attributed to a loss of fog drip in the original study (Section 3.1.2). Thus, the changes in flow on the Fox Creek basins may not have been associated with their respective mean basin slopes. However, while

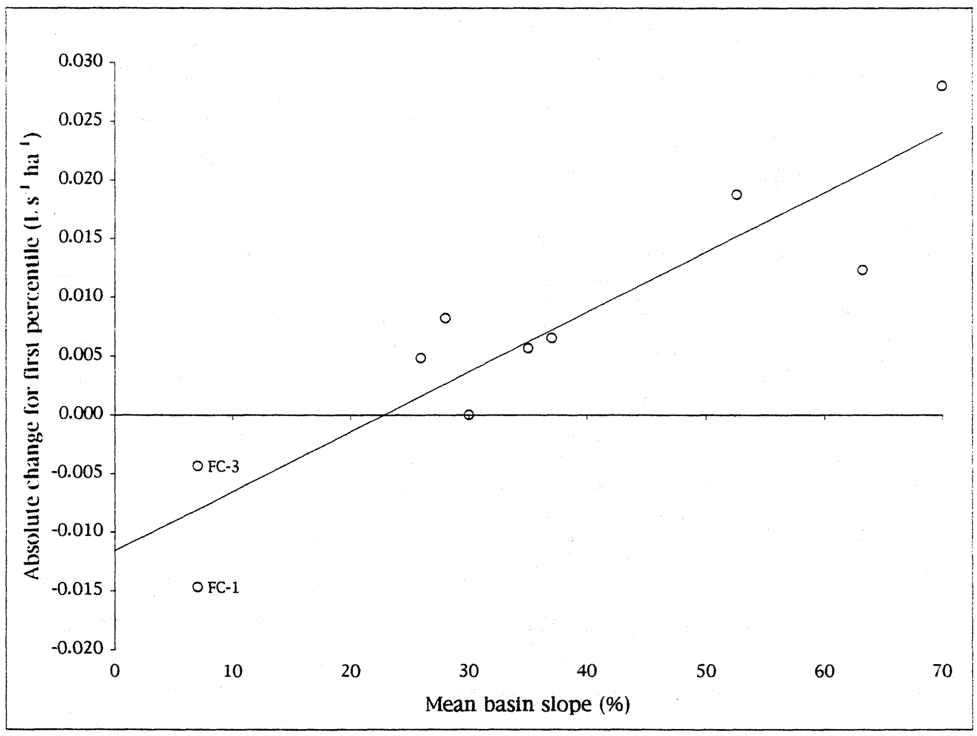


Figure 3.9. Relationship between absolute change in discharge and mean basin slope for the first percentile.

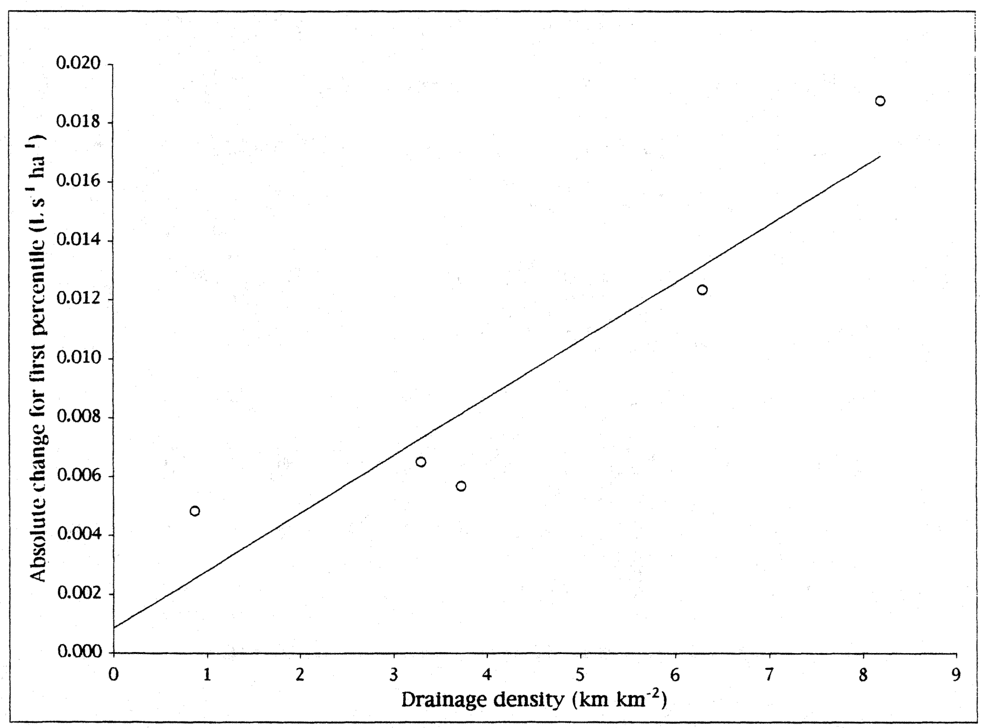


Figure 3.10. Relationship between absolute change in discharge and drainage density for the first percentile.

these observations helped support the positive trends that were observed, Figure 3.9 shows that they were not the sole cause of these trends.

Drainage density had a strong positive relationship with both absolute and relative increases in flow for the 1st and 2.5 percentiles. In each case, however, there were only five observations and drainage density was not significantly related to the changes in flow for any other percentile. Scatter plots showed that the observed trends were not driven by influential observations and that the regression line fit the data well (e.g., Figure 3.10). This suggests that higher drainage densities may contribute to higher low flows after logging. The greater opportunity for soil water to drain from the hillslopes into the streams at higher drainage densities may explain this association.

Latitude was only significantly related with the absolute change in flow for the 1st and 2.5 percentiles (Table 3.11). However, without the largest increase in flow, the p-value changed from 0.086 to 0.495 for the first percentile and from 0.099 to 0.548 for the 2.5 percentile. It is unclear whether a greater range of latitudes would affect the significance of this relationship as the variability for latitudes greater than 42 degrees is very high (Figure 3.11 (a)).

The relationship between absolute change in flow and basin area was only significant for the 99th percentile. This negative relationship was driven by a 0.35 L s^{-1} ha^{-1} decrease in flow on Caspar Creek South, the largest basin analyzed (Figure 3.11 (b)). Without this observation, the relationship was not significant ($p = 0.273$).

Mean elevation had a significant relationship with absolute changes in flow only for the 99th percentile (Table 3.11, Figure 3.11 (c)). Higher mean elevations were associated with smaller increases in flow. The three highest

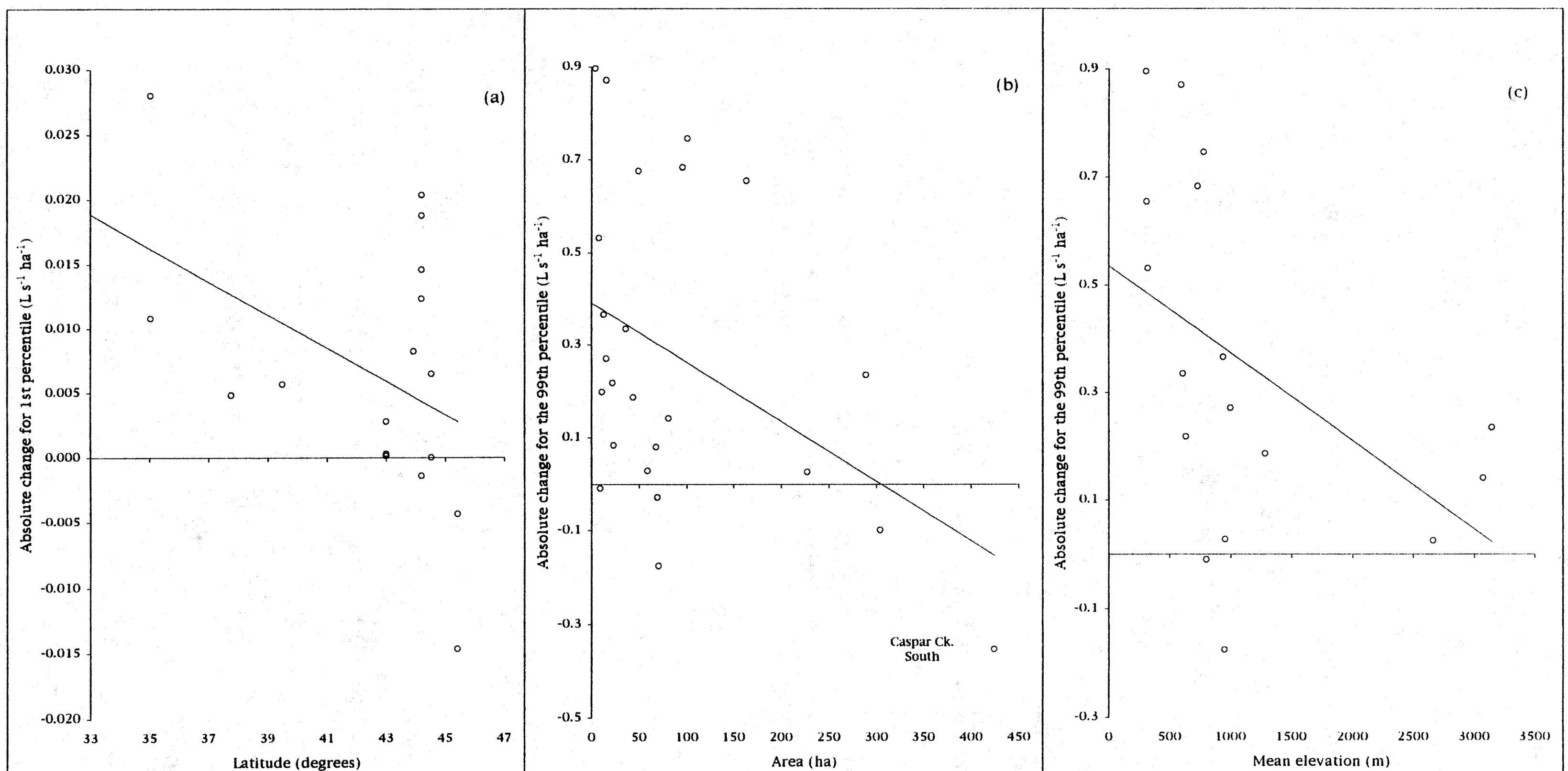


Figure 3.11. Relationships between (a) latitude and absolute change for the 1st percentile; (b) area and absolute change for the 99th percentile; and (c) mean elevation and absolute change for the 99th percentile.

elevation basins were separated from the rest of the data by about 1500 m. Each of these high-elevation basins had only small increases in flow after logging. Even though they appeared to be driving this relationship, the relationship was still significant ($p = 0.018$) without the three high-elevation observations.

The observed trend of decreasing changes in flow with increasing mean elevation may be due in part to changes in both precipitation and ET as elevation increases. Precipitation generally increases with increasing elevation. As larger flows are generally associated with higher precipitation levels, the high elevation flows would probably be less affected by forest management (Section 3.1.1.2). At the same time, proportionately smaller ET losses at higher elevations would contribute to smaller differences between pre- and post-treatment soil moisture levels during the high flow periods. If soil moisture differences are small, less "extra" water would be available for runoff and thus the changes due to harvest would be small.

Hydrologic regime and vegetation type were the only basin characteristics with significant differences between categories. For hydrologic regime, it was only possible to compare rain with mixed results for the 10th through 75th percentiles, as only two snowmelt-dominated basins had pre- and post-treatment flows in these percentiles. Data from a third snowmelt-dominated basin allowed a comparison of all three categories for the highest flows. For the 25th and 50th percentiles, the mixed snow-and-rain basins had significantly higher mean relative increases in flow than the rain-dominated basins (Table 3.12). In each case, the mean for the mixed regime more than doubled the mean increase for the rainfall regime.

For the larger flow percentiles, there were no significant differences between the different hydrologic regimes. This was unexpected, as each snow

Table 3.12. Mean percent changes in flow for the percentiles where hydrologic regime was a significant variable. Sample sizes are provided in parentheses.

	Hydrologic regime			
Percentile	Rain (N)	vs.	Mixed (N)	p-value
25.0	35 (6)		78 (14)	0.087
50.0	19 (6)		44 (15)	0.053

dominated basin was also a high-elevation basin and there was a significant negative relationship between elevation and the absolute change in 99th percentile flows (Table 3.11, Figure 3.11 (c)). This lack of a significant difference may be due to the limited number of results from snow-dominated basins.

Vegetation type was the other categorical basin characteristic with a significant difference between classes. The mean increase at the 99th percentile for conifer and mostly conifer basins was 9.7%, as compared to 22.5% for hardwood and mostly hardwood sites ($p = 0.097$). It was not clear why this difference was observed.

Three continuous management variables were significantly related to the calculated changes in flow for at least one percentile each (Table 3.13). Two of these variables were associated with both absolute and relative changes. As with the basin characteristics, however, there was little consistency between percentiles and scatter plots showed that some results were questionable.

Percent area cut was positively and significantly related to absolute changes for eight percentiles (Table 3.13), explaining 15 to 45% of the variability in the observed changes (e.g., Figure 3.12 (a)). Percent area cut was also positively related ($p = 0.078$) to the percent changes in flow for the first percentile (Figure 3.12 (b)), although it was not significant ($p = 0.398$) when two outliers were included.

Table 3.13. Continuous management variables significantly related to absolute and relative changes for at least one percentile. R^2 values are provided when the relationship is significant. The symbols "ns" and "--" represent relationships that were non-significant ($\alpha = 0.10$) and not tested, respectively.

Continuous variable	Percentile 1.0	2.5	5.0	10.0	25.0	50.0	75.0	90.0	95.0	97.5	99.0
Absolute changes in flow ($L\ s^{-1}\ ha^{-1}$)											
Percent area cut	0.38	0.32	0.38	0.45	ns	0.20	0.17	0.15	ns	ns	0.17
Road density	ns	--	--	--	--	ns	0.37	0.46	0.61	0.53	0.37
Percent area compacted	ns	--	--	--	--	ns	--	--	ns	ns	0.35
Percent changes in flow											
Percent area cut	0.26	ns	ns	--	--	ns	--	--	--	--	ns
Percent area compacted	ns	--	--	--	--	ns	--	--	ns	ns	0.20

The relationship between percent area cut and the changes in flow were stronger for the lower percentiles ($R^2 = 0.32$ to 0.45) than the median and higher percentiles ($R^2 = 0.15$ to 0.20). This difference in R^2 values may be due in part to the smaller sample sizes associated with the lower percentiles. However, the difference in R^2 values may also be due to the fact that higher flows are less sensitive to timber management (Section 3.1.1.2) and lower flows are more sensitive to the reduction in ET and interception associated with greater percent area cut (Section 3.1.2).

The consistent relationship between percent area cut and absolute changes in flow for the 1st to 90th percentiles was influenced by the large decreases in flow on basins that had only a small percent area cut (Figure 3.12). Without these decreases, none of the relationships between absolute change in flow and percent area cut were significant. These decreases were probably not as influential for the relative changes in flow because of the bias towards increases inherent when calculating relative changes (Section 3.2.1). In contrast, there is no bias in calculating the absolute changes in flow. Though this bias in the relative data will not always be important, the results

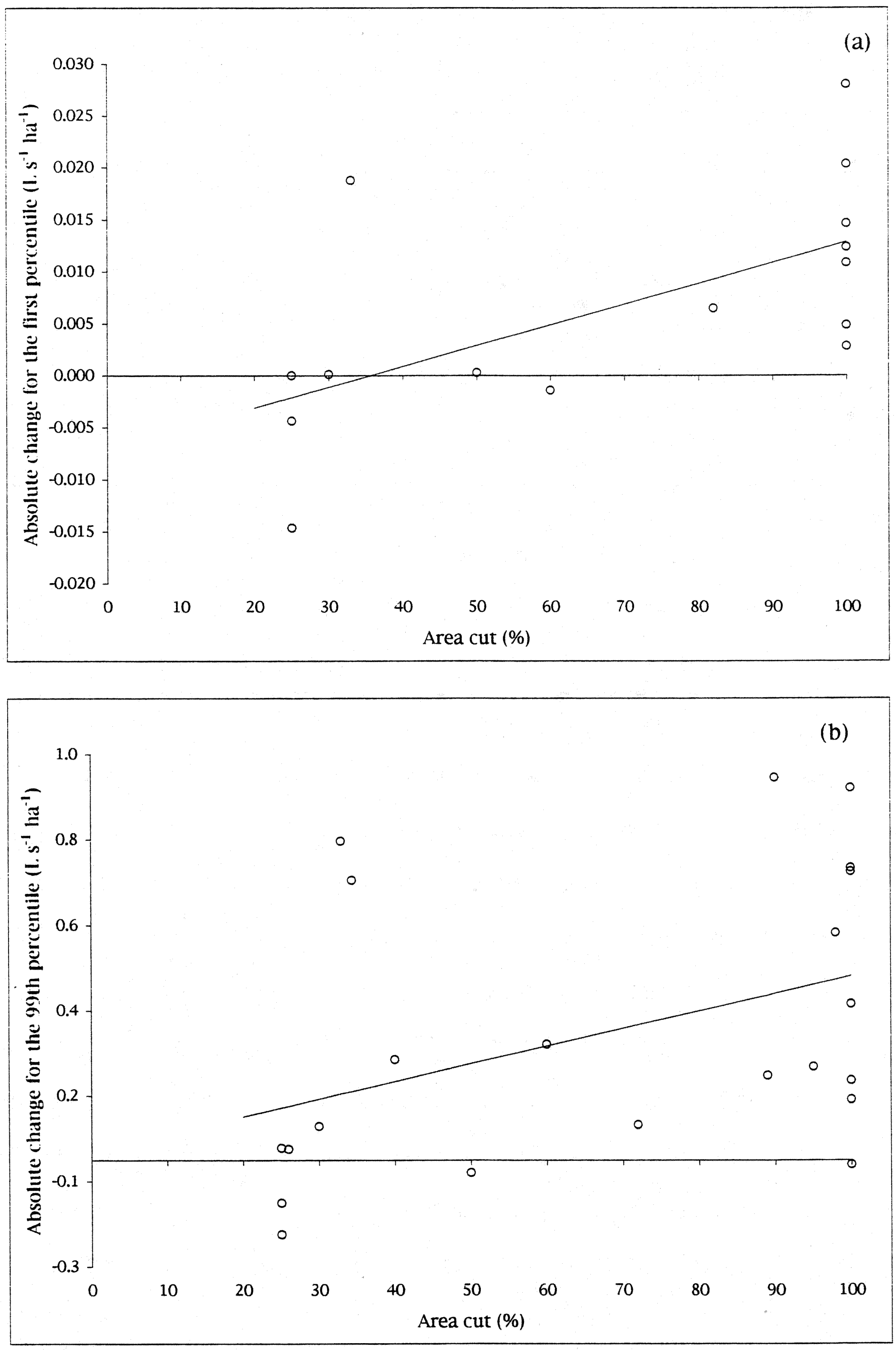


Figure 3.12. Relationship between absolute change in discharge and percent of the area cut for the 1st (a) and 99th (b) percentiles.

associated with this analysis of percent area cut illustrate the problems of using only relative changes to characterize the hydrologic effects of logging. Because there was no consistent relationship between percent area cut and the observed changes in flow, the flow data were not normalized to 100% area cut in order to further analyze the role of specific basin characteristics or management activities.

Road density explained 40 to 60% of the variability in absolute flow changes for the five highest percentiles (Table 3.13). However, scatter plots revealed that each relationship was driven by one influential observation (e.g., Figure 3.13). The largest road density of 14.6 km km^{-2} occurred on the Needle Branch basin in Oregon. This road density was more than five times greater than any other basin. Though hydrologic principles suggest that a greater area in roads can lead to higher peak flows as the strength of this relationship suggests (Table 3.13), these road density results have to be regarded as inconclusive. More observations are necessary to fill the gap between road densities of 3 and 14 km km^{-2} (Figure 3.13) and more studies need to be conducted on the hydrologic effects of roads without the confounding influence of other forest management activities.

The percent area compacted was significantly related to both absolute and percent changes in flow at the 99th percentile (Table 3.13). However, the relationship was opposite to what was expected, as basins with greater compacted area were associated with lower increases in peak flows (e.g., Figure 3.14). Scatter plots of the data showed that there was high variability for basins with little compaction and only four observations for basins with more than six percent compacted area.

H. J. Andrews watershed 10 (HJA-10) had the largest percent area compacted and the greatest decrease in flow for the 99th percentile. Since the

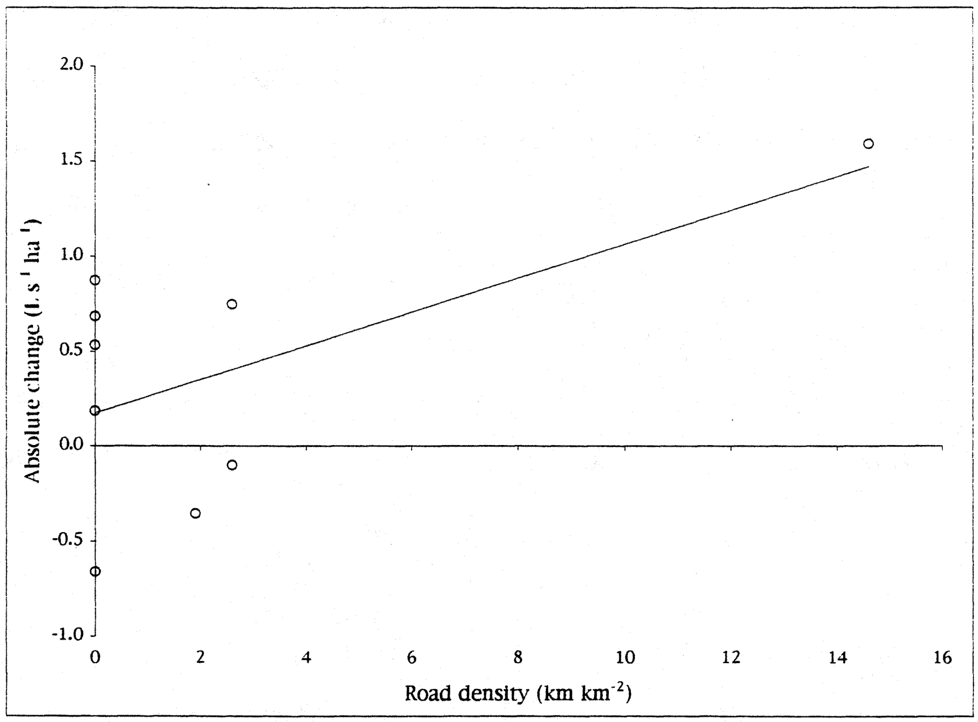


Figure 3.13. Relationship between absolute change in discharge and road density for the 99th percentile.

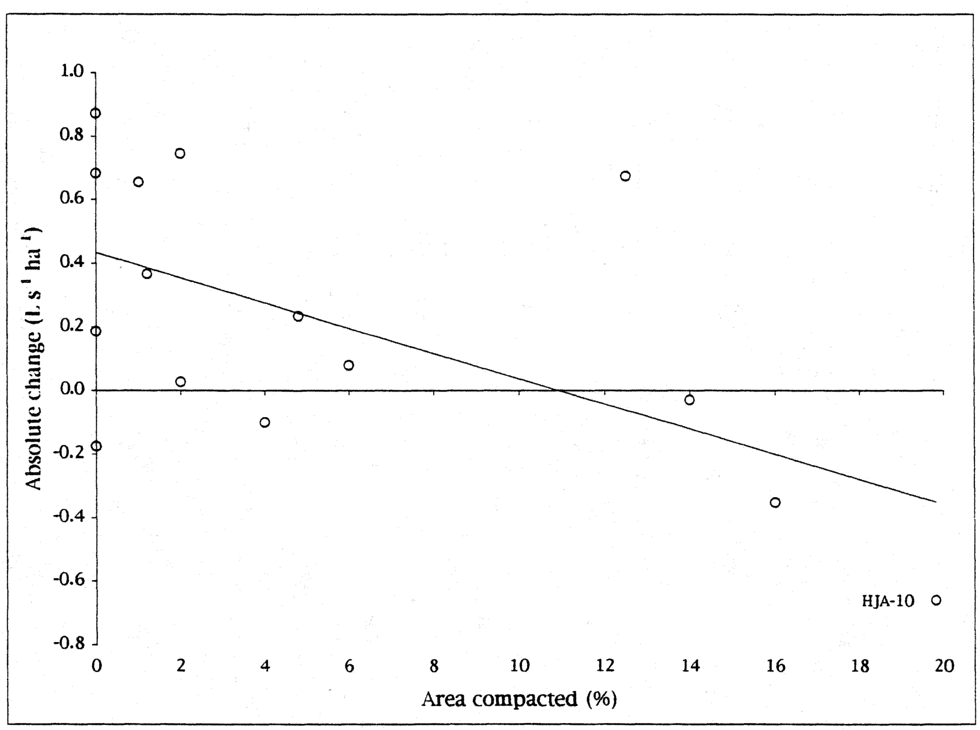


Figure 3.14. Relationship between absolute change in discharge and percent area compacted for the 99th percentile.

original authors attributed this decrease to a desynchronization of peak flows instead of compaction (Section 3.1.1.3), this point was removed. Regression analysis showed that removal of the HJA-10 observation eliminated the significant relationships between percent area compacted and both absolute and relative changes in flow at the 99th percentile ($p = 0.159$ and 0.305, respectively).

Interactions between continuous variables were considered significant if the absolute value of the correlation was greater than or equal to 0.5. Using this criteria, each significant basin characteristic was correlated with at least one other significant basin characteristic or management activity. Percent area cut was the only significant management activity correlated with the significant basin characteristics. However, these interactions were either driven by influential observations or based on limited data, as missing information resulted in small sample sizes for some correlations. Interactions for characteristics or activities typically associated with changes in flow (e.g., annual precipitation and percent area cut) were also due to influential observations or limited data. For example, mean elevation and annual precipitation were correlated ($r = -0.529$) only because the three high elevation observations were all located in dry climates (Figure 3.15). Also, the high absolute correlations (0.524 to 0.994) between drainage density and seven other basin characteristics and management activities may be spurious because only six studies reported drainage density.

Significant differences between classes were found for three categorical management activities. These were type of silvicultural method, use of buffer strips, and season of harvest activities.

Basins subject to clearcutting had significantly larger mean absolute changes in flow for the 1st through 10th percentiles than basins that had

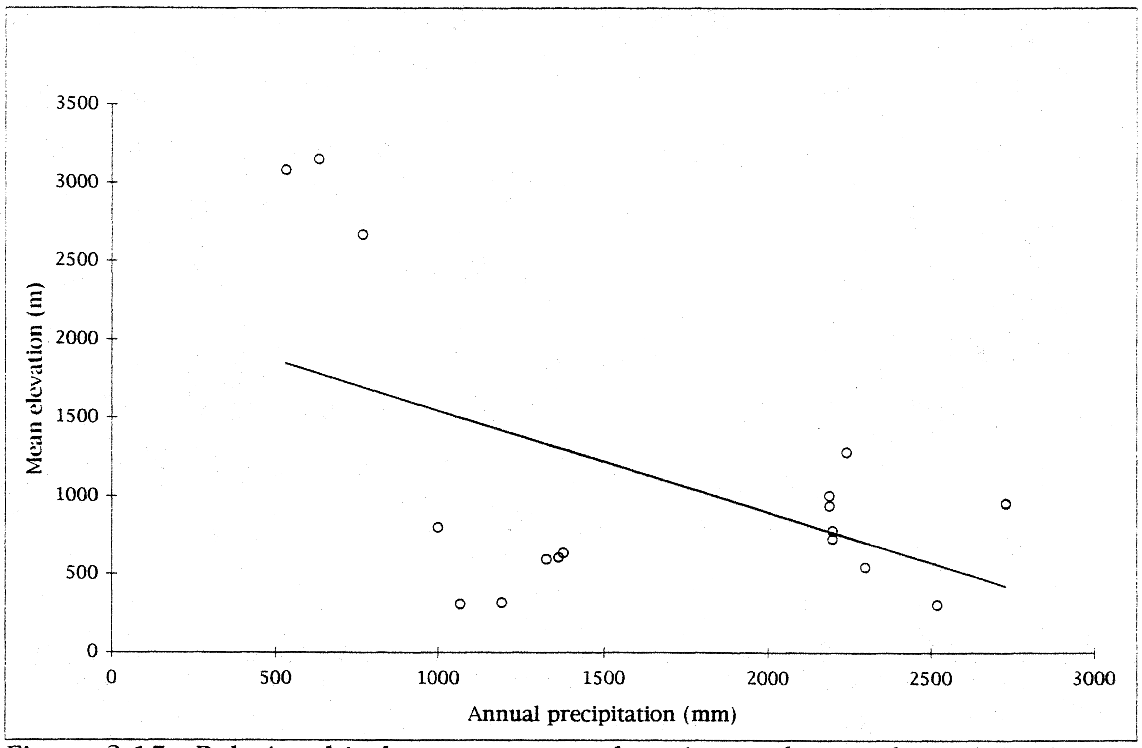


Figure 3.15. Relationship between mean elevation and annual precipitation (r = -0.529).

been selection cut (Table 3.14). The absolute changes for clearcut sites were significantly higher than the combined results for selection and patch cut sites for the 1st through 25th and the 99th percentiles.

For mean relative changes, the only significant differences between silvicultural methods occurred at the 99th percentile. The mean change in flow for clearcut basins (18%) was greater than the changes for both the selection cut basins (2%) and the combined results from selection and patch cut basins (5%). There were no significant differences for the mean change in flow between the patch cut basins and the basins subject to selection cuts.

The observed effect of silvicultural method is difficult to interpret because it is confounded by the percent area cut. On average, 95% of the vegetation was removed from basins that were clearcut. In contrast, only 35%

Table 3.14. Mean absolute changes in flow (L s^{-1} ha^{-1}) for the percentiles where silvicultural method was a significant variable. Sample sizes are in parentheses. The symbol "ns" means that any difference between categories was not significant.

	Type of silvicultural method used					
Percentile	Clearcut (N)	vs.	Selection cut (N)	Clearcut (N)	vs.	Selection and patch cuts (N)
1.0	0.012 (9)		0.0015 (3)	0.012 (9)		0.00056 (8)
2.5	0.012 (10)		0.0017 (3)	0.012 (10)		-0.00036 (8)
5.0	0.018 (11)		0.0019 (3)	0.018 (11)		0.000017 (8)
10.0	0.023 (11)		0.0041 (3)	0.023 (11)		0.00086 (8)
25.0	0.025 (12)		0.0069 (4)	0.025 (12)		-0.012 (9)
99.0		ns		0.41 (15)		0.072 (10)

of the vegetation was removed on average for basins that were patch or selection cut. Also, at least 72% of the vegetation was removed in the clearcut basins, while none of the basins subject to selection or patch cuts had more than 60% of the forest cover removed. This correlation between percent area cut and silvicultural method suggests that percent area cut may play an important role in determining the expected changes in flow after logging, even though the scatter plots did not show a clear and consistent relationship between percent area cut and the observed changes in flow (e.g., Figure 3.12).

Most of the significant differences between silvicultural methods were associated with low flows. Given the association between silvicultural method and percent area cut, these differences are probably due to the higher reduction in interception and ET in the clearcut basins, as this would explain why more water was available during the drier parts of the year.

The significant differences observed between silvicultural methods for the data from the 99th percentile were due to the decreases in flow associated with several of the selection and patch cut basins. The data show that 4 of the 10 basins that were selection or patch cut had a decrease in flow at the 99th percentile, while the same basins had only one or two decreases in flow for the

90th through 97.5 percentiles. Since flow decreases were more common at the 99th percentile for the selection and patch cut basins, the silvicultural method yielded significant differences at this percentile. However, it is not clear why more decreases in flow occurred for the 99th percentile than for other percentiles.

The observed changes in flow were generally less in basins where buffer strips were used. Basins with buffer strips around all waterways (fully buffered) had significantly lower mean absolute changes in flow than basins without buffers for the 1st, 10th, and 25th percentiles (Table 3.15). Similarly, for the 50th to 95th percentiles, basins with buffers around only some of the waterways (mixed buffer use) had lower absolute changes in flow than basins without buffers (Table 3.15). Fully buffered basins also had smaller relative changes in flow at the 97.5 and 99th percentiles than basins with mixed buffer use (Table 3.16). Note that the comparisons between mixed and other buffer use categories were limited to the 50th through 99th percentiles, as only two basins with mixed buffer use had streamflow below the 50th percentile.

These results suggest that the area immediately adjacent to the stream channel plays an important role in moderating the changes in stream flow associated with forest management activities. In the case of low flows, this makes sense, as the trees left in the undisturbed areas adjacent to the stream may minimize low flow increases by utilizing some of the additional water generated in upslope areas.

The smaller changes in high flows associated with buffered sites may be explained by two processes. The variable source area concept suggests that the area immediately adjacent to the stream provides most of the water for runoff (Hewlett and Hibbert, 1966). As more water is required to saturate these areas when trees are present, a smaller proportion of the precipitation becomes

Table 3.15. Mean absolute changes in flow (L s^{-1} ha^{-1}) for the percentiles where the use of buffer strips was a significant variable. Sample sizes are in parentheses. The symbol "ns" means that any difference between categories was not significant. Note that the mean decreases were not significantly different from zero.

	Use of buffers				
Percentile	Fully (N)	vs. Without (N)	Mixed (N)	vs. Without (N)	p-value
1.0	-0.0027 (4)	0.013 (9)	insufficient data		0.039
10.0	-0.00084 (4)	0.023 (10)	insufficient data		0.044
25.0	-0.025 (6)	0.030 (10)	insufficient data		0.052
50.0	ns		0.012 (3)	0.047 (10)	0.003
75.0	ns		0.027 (5)	0.098 (10)	0.020
90.0	ns		0.037 (5)	0.19 (10)	0.022
95.0	ns		0.074 (5)	0.20 (10)	0.058

Table 3.16. Mean percent change in flow for percentiles where the use of buffer strips was a significant variable. Sample sizes are in parentheses.

	Use of buffers		
Percentile	Fully (N)	vs. Mixed (N)	p-value
97.5	9 (6)	23 (5)	0.036
99.0	5 (6)	32 (5)	0.024

runoff. Thus, peak flow increases are reduced when streamside areas are buffered. Buffers may also minimize the increase in high flows by providing an undisturbed zone through which overland flow would have to pass before it reaches the stream. Since undisturbed forest soils typically are very permeable, any overland flow from upslope harvested areas may infiltrate back into the ground upon reaching the streamside buffer. In basins without buffers, this upslope runoff may be able to reach the channel because harvest activities can reduce the permeability (Huang et al., 1996).

Sites that were harvested during just the growing season had significantly smaller absolute changes in flow for the 99th percentile than sites where harvesting occurred during both growing and dormant seasons (mean = -0.019 and 0.42 L s^{-1} ha^{-1}, respectively). As this relationship was not significant for any other percentiles or for relative changes in flow, it is difficult to draw any clear conclusions from this result.

3.2.3.1.3. RECOVERY OF STREAMFLOW

Recovery of streamflow after logging was determined for the same flow percentiles that were used to evaluate the absolute and relative changes in flow (Section 3.2.3.1.1). However, the statistical significance of changes in flow for each time period were only evaluated for the 1st, 50th, and 99th percentiles (Section 2.5.2). The absolute and relative changes in streamflow after logging by two-year interval for each study can be found in Appendix VII along with summary statistics for each percentile.

In general, the absolute increases in flow after logging dropped off rapidly except at the higher flow percentiles (Figure 3.16). Similar trends were evident for the relative changes in flow (Figure 3.17), although the data were not quite as consistent for the lowest percentiles because of the bias and greater variability associated with calculating percent changes in flow.

Mean and median changes in flow for the first percentile decreased steadily towards zero over the first three post-treatment intervals (Figure 3.18). Over this time period, the median change decreased from 0.0049 to -0.0001 L s^{-1} ha^{-1} and from 78 to -1%. Statistical analysis indicates that recovery occurred by the second post-treatment interval (Table 3.17, Figure 3.18). By the last post-treatment period, there is some evidence of a decrease in flow at the first percentile, but the values were not statistically different from zero.

The data from the 2.5 and 5th percentiles also showed a marked decrease in the change in flow over the first two post-treatment intervals (Figure 3.17). However, the median changes in flow then appeared to stabilize around 0.0008 L s^{-1} ha^{-1} and 25% for each of these percentiles.

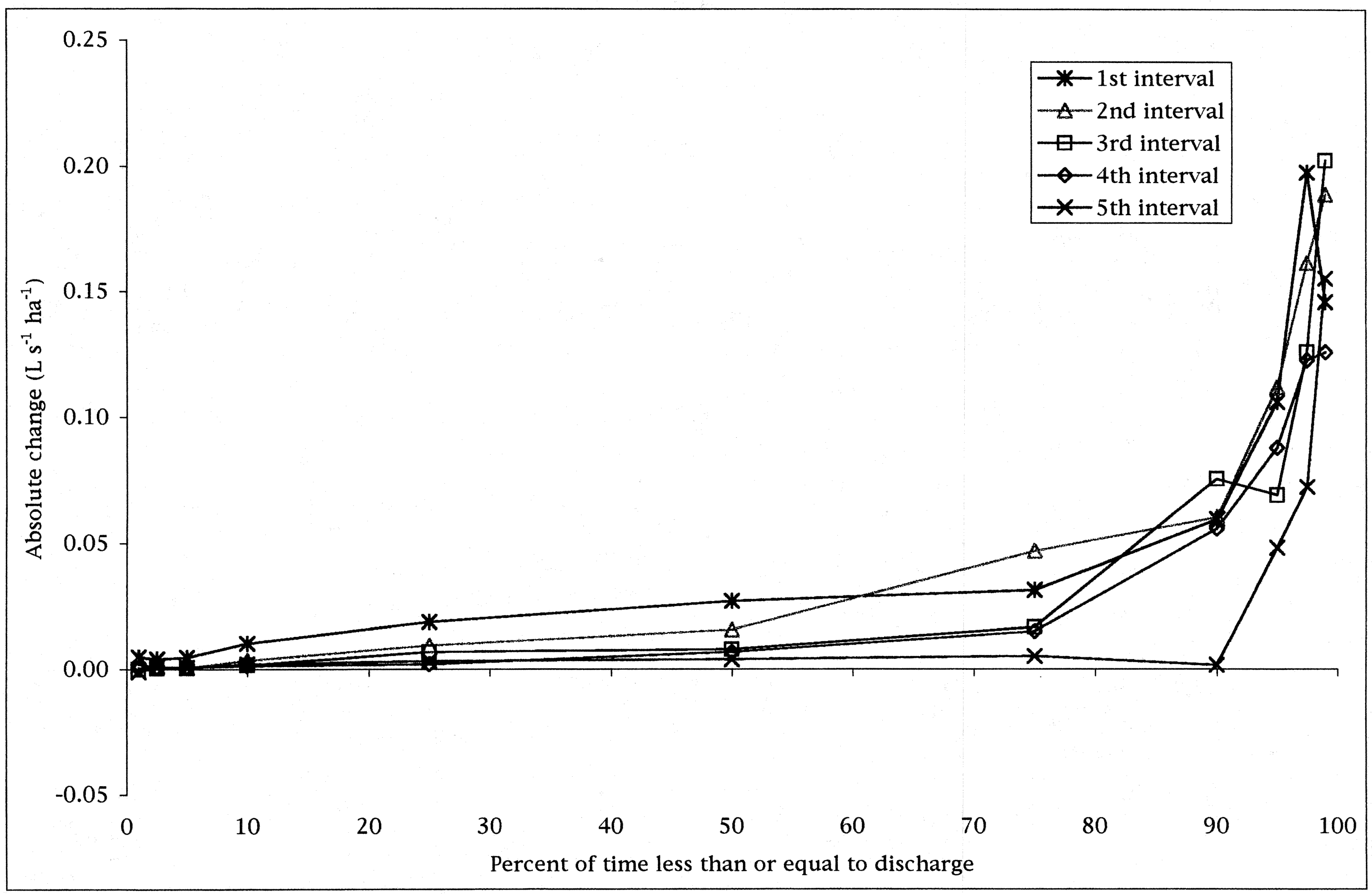


Figure 3.16. Median absolute change in flow over time. Each line represents a two-year time period after logging.

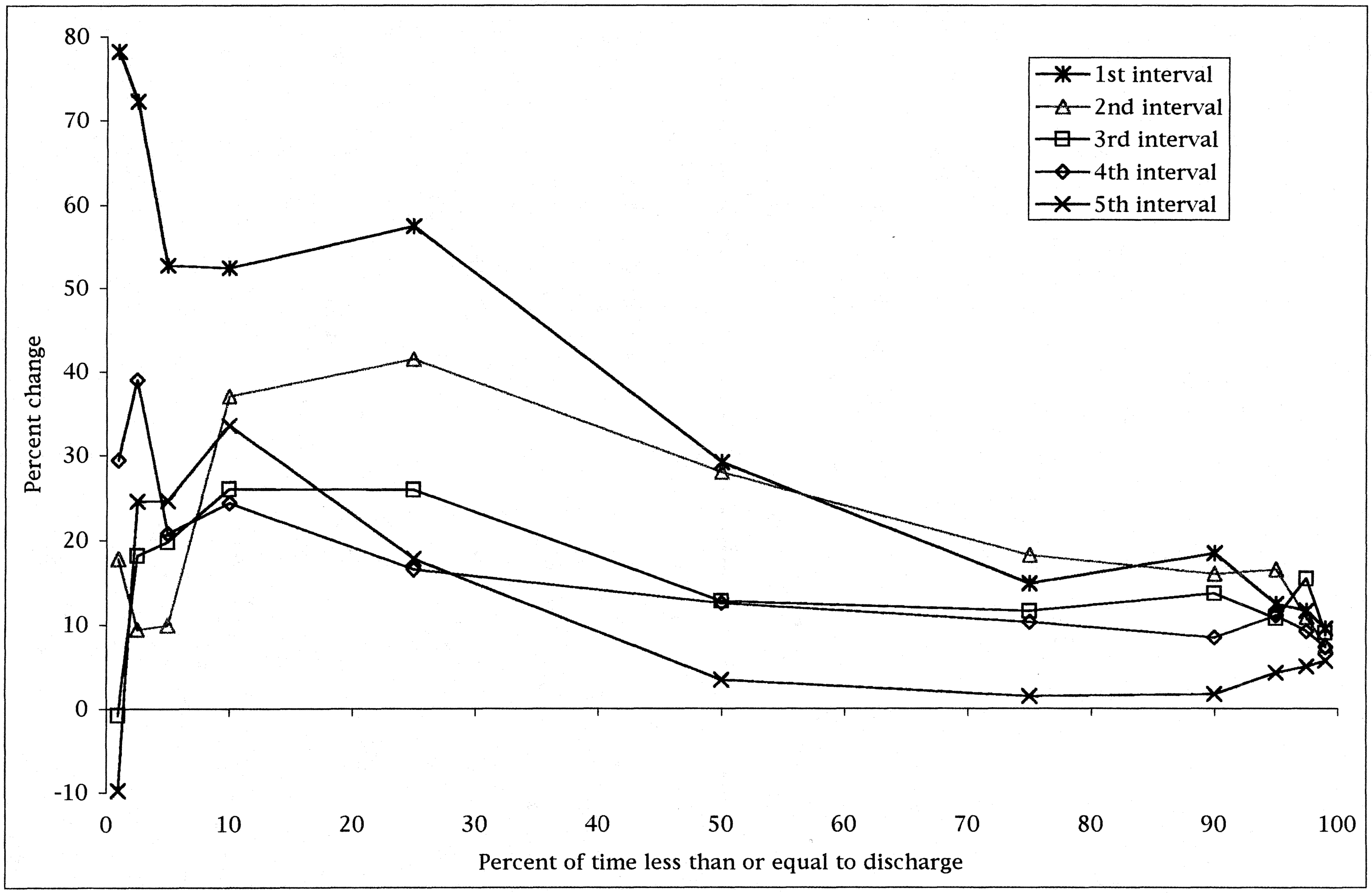


Figure 3.17. Median percent change in flow over time. Each line represents a two-year time period after logging.

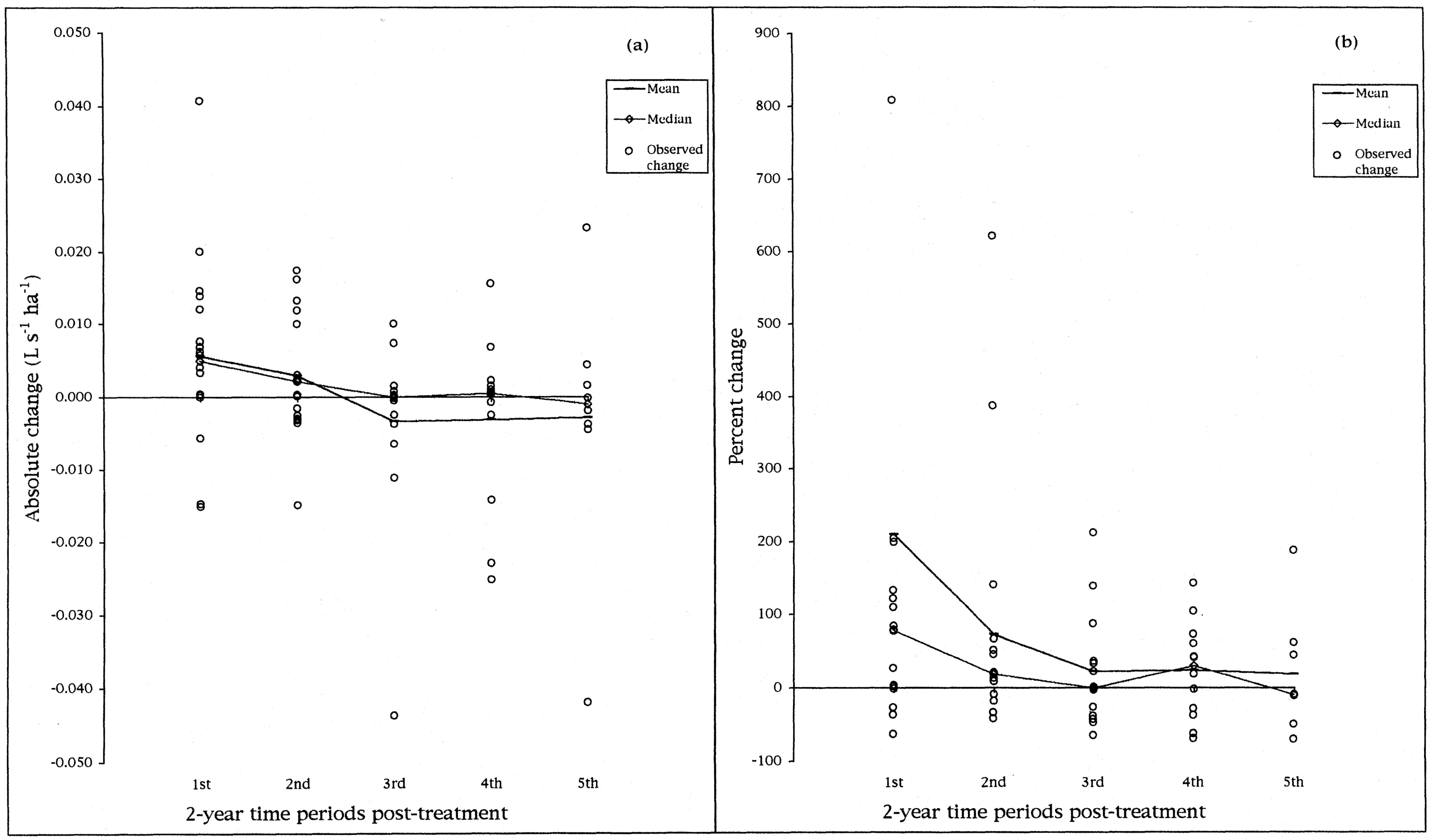


Figure 3.18. Mean, median, and observed changes in flow for the first percentile over time. Absolute and relative changes are shown in (a) and (b), respectively. A 2000% increase during the first time period is not shown in (b).

Table 3.17. Mean and median values for absolute and relative changes in first percentile flows by two-year time periods. P-values are from non-parametric sign tests of the significance ($\alpha = 0.05$) of each median value from zero.

Time period	N	1st ($L\ s^{-1}\ ha^{-1}$) Mean	Median	p-value	1st (%) Mean	Median	p-value
1st	18	0.0055	0.0049	0.013	210.0	78.2	0.031
2nd	17	0.0029	0.0021	0.332	72.9	17.7	0.332
3rd	14	-0.0034	-0.000087	1.000	21.5	-0.8	1.000
4th	12	-0.0031	0.00047	0.774	23.1	29.4	0.774
5th	8	-0.0029	-0.0010	0.727	17.8	-9.8	0.727

The median flow increases associated with the 10th and 25th percentiles declined sharply over the first three post-treatment periods, but then declined only slightly between the third and fourth periods (Figure 3.17). However, the median change for both of these percentiles was larger for the fifth interval than for the fourth. The 10th percentile appeared to be stabilizing around median changes of about 0.0016 $L\ s^{-1}\ ha^{-1}$ and 28% during the last three intervals. For the last two intervals, the median change for the 25th percentile was higher than the median change for the 10th percentile in absolute terms (0.0026 $L\ s^{-1}\ ha^{-1}$) and lower in relative terms (17%).

The relatively rapid recovery rates for the 1st to 25th percentile flows suggest that low flows are controlled by processes that recover quickly after logging. Most of the authors that reported regrowth considered it to be rapid (e.g., Hsia, 1987; Langford et al., 1982; Miller, 1984). Rapid regrowth would suggest a rapid increase in interception and transpiration. The increase in transpiration is probably the major cause of the rapid recovery, as the lowest flows typically occur during periods when transpiration rates are high and precipitation inputs--and thus interception rates--are low. Since younger stands tend to transpire at higher rates than older, mature stands (Bosch, 1979), the increasing transpiration may also account for the decreases in flow observed at the first percentile during the fifth time period (Figure 3.17).

Median absolute and relative changes associated with the 50th percentile decreased each time period after logging (Figures 3.16 and 3.17). By the fifth interval, the increases in flow had returned nearly to pre-treatment levels. Absolute changes decreased by a factor of seven (from 0.027 to 0.0038 $L\ s^{-1}\ ha^{-1}$) and relative increases dropped from 29 to 3% over the post-treatment period (Table 3.18).

Though the 50th percentile flows decreased consistently after logging (Figure 3.19), statistical analysis of the timing of flow recovery produced mixed results (Table 3.18). Using a 0.05 level of significance, the change in flow was not significantly different from zero for the third two-year interval ($p = 0.064$), but was just significant for the fourth interval ($p = 0.049$). The absolute and relative changes in flow for the fifth interval were not significantly different from zero ($p = 0.774$).

The extreme skew evident for the relative changes in flow during the first two post-treatment periods (Figure 3.19 (b)) was caused by the basins with near zero pre-treatment flow at the 50th percentile. As noted before (Section 3.2.1), these extreme values are caused by relative increases in flow approaching infinity when pre-treatment flows approach zero. This skew did not influence the significance, however, as the data were tested using the non-parametric sign test.

In general, the median increases in flow over time for the 75th and 90th percentiles behaved similarly to the 50th percentile. The median increases for the 75th and 90th percentile flows varied over the first four intervals, but then showed a marked decline in the fifth post-logging period (Figures 3.16 and 3.17). The changes in flow for each percentile dropped from a high of

Table 3.18. Mean and median values for absolute and relative changes in 50th percentile flows by two-year time periods. P-values are from non-parametric sign tests of the significance ($\alpha = 0.05$) of each median value from zero.

Time period	N	50th (L s^{-1} ha^{-1}) Mean	Median	p-value	50th (%) Mean	Median	p-value
1st	27	0.025	0.027	0.000	84.9	29.1	0.000
2nd	23	0.017	0.016	0.003	83.8	27.9	0.003
3rd	19	-0.0083	0.0078	0.064	16.1	12.8	0.064
4th	17	0.0078	0.0066	0.049	26.4	12.5	0.049
5th	12	-0.0030	0.0038	0.774	10.1	3.3	0.774

18% during the first or second interval to lows of one or two percent over the post-treatment period. During the same time period, the absolute changes for the 75th and 90th percentiles dropped from 0.047 to 0.0050 L s^{-1} ha^{-1} and from 0.075 to 0.0015 L s^{-1} ha^{-1}, respectively (Appendix VII). As the median changes were nearly zero by the fifth two-year interval (Figures 3.16 and 3.17), the 75th and 90th percentiles recovered more rapidly than the higher flow percentiles.

The data from the 95th and 97.5 percentiles indicated less rapid recovery than the percentiles lower on the FDC. However, during the fifth post-treatment interval, the changes in flow for the 95th and 97.5 percentiles dropped markedly (Figures 3.16 and 3.17). Median changes during the final period were 0.048 L s^{-1} ha^{-1} and 4% for the 95th percentile and 0.072 L s^{-1} ha^{-1} and 5% for the 97.5 percentile.

The median change in flow for the 99th percentile was more persistent than for the other high flow percentiles (Figure 3.20). Absolute increases for the 99th percentile were consistently between 0.1 and 0.2 L s^{-1} ha^{-1} during the first five two-year intervals (Table 3.19). At the same time, median relative increases associated with the 99th percentile were reduced by nearly half, from 10 to 6% over the post-treatment time period. The relative increases are

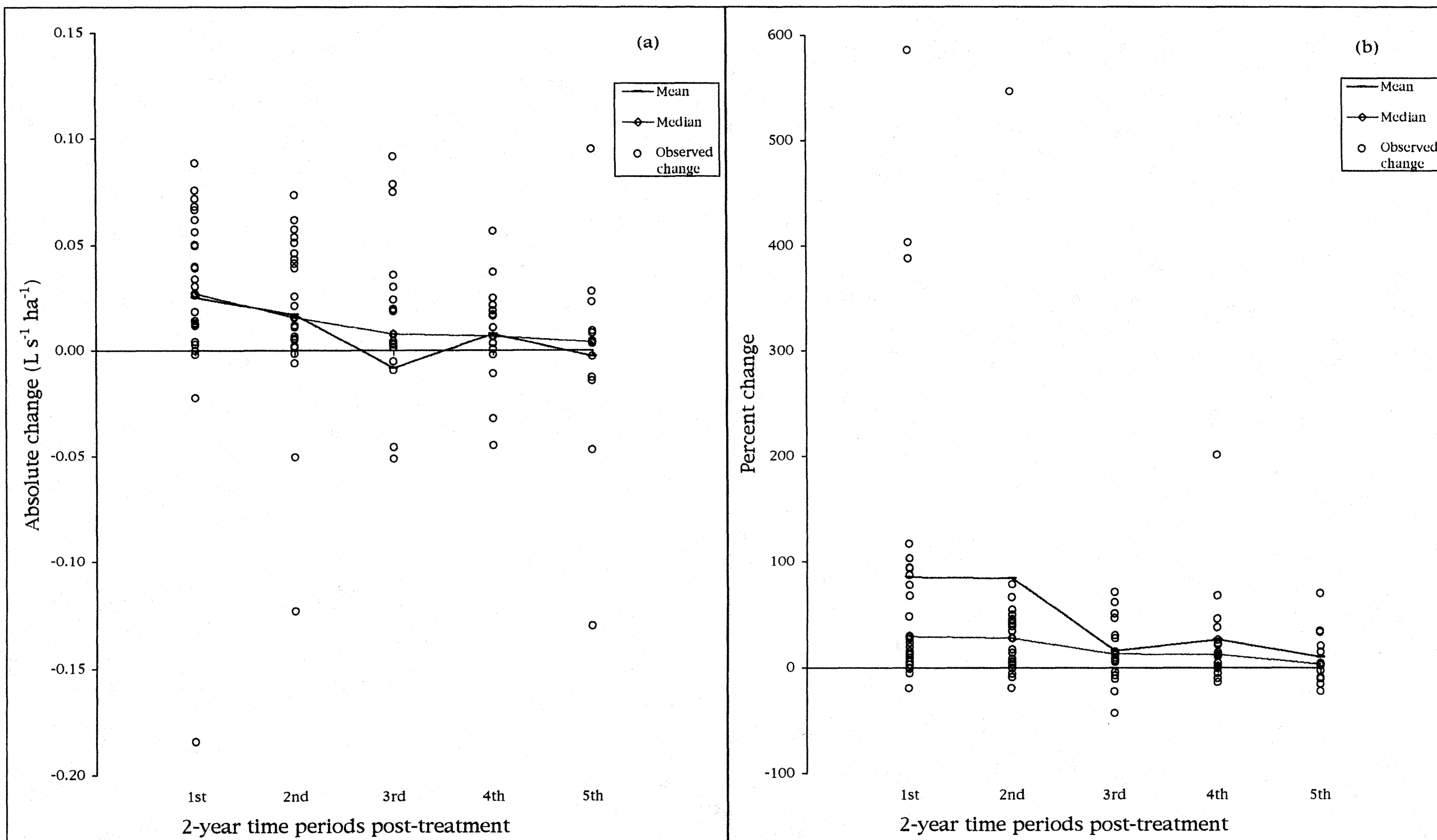


Figure 3.19. Mean, median, and observed changes in flow for the 50th percentile over time. Absolute and relative changes are shown in (a) and (b), respectively. A 0.46 L s^{-1} ha^{-1} decrease during the third interval is not shown in (a) and an increase of over 850% during the second interval is not shown in (b).

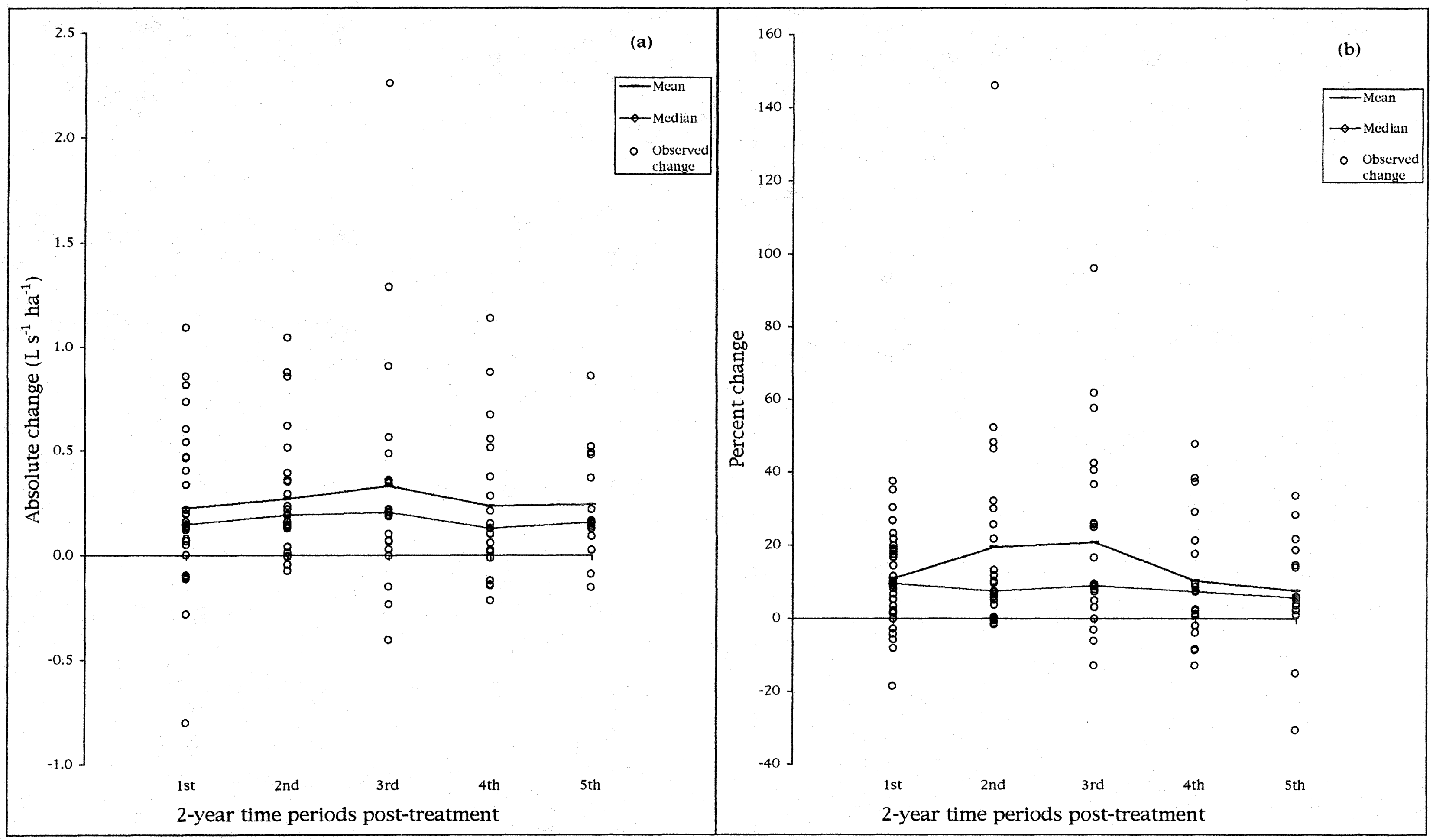


Figure 3.20. Mean, median, and observed changes in flow for the 99th percentile over time. Absolute and relative changes are shown in (a) and (b), respectively.

Table 3.19. Mean and median values for absolute and relative changes in 99th percentile flows by two-year time periods. P-values are from non-parametric sign tests of the significance ($\alpha = 0.05$) of each median value from zero.

Time period	N	99th (L s^{-1} ha^{-1}) Mean	Median	p-value	99th (%) Mean	Median	p-value
1st	30	0.22	0.15	0.001	10.9	9.5	0.001
2nd	25	0.27	0.19	0.004	19.4	7.5	0.004
3rd	22	0.33	0.20	0.004	20.7	8.9	0.004
4th	19	0.23	0.13	0.064	10.2	7.3	0.064
5th	14	0.24	0.16	0.013	7.6	5.6	0.013

slightly less than the median increase of 12% for the three-year post-treatment analysis (Table 3.10) because slightly different data sets were used (Section 2.5.2).

Statistical analysis indicated that absolute and relative changes in flow did not recover at the 99th percentile until the fourth post-treatment period (Table 3.19). However, the changes in flow were again significantly different from zero for the fifth interval ($p = 0.013$). This apparent inconsistency is because 5 of the 19 basins had decreases in flow during the fourth interval, while only 2 of the 14 basins showed a decrease in flow during the fifth interval. This again illustrates how data availability can affect the results, particularly when there is such variability in the observed flow changes between study basins.

The greater persistence of the observed changes in high flows suggests that the hydrologic processes that generate these changes do not recover as rapidly after logging as the processes that control the lower flows. A review of the individual studies did not reveal any direct evidence for one specific factor or process. However, most of the studies that had increases in flow throughout the post-treatment period had several characteristics in common that may explain the persistence of the increases.

Twenty-one basins that were not harvested over multiple time periods had at least six years of post-treatment data. Twelve of these basins had an increase in flow at the 99th percentile over the entire post-treatment period, while the other nine studies fluctuated between increases and decreases. Most of the 12 studies with persistent increases in flow had several or all of the following characteristics: 1) greater than 50% of the basin was cut; 2) the silvicultural method was clearcutting; 3) no buffer strips were used; and 4) some tractors or rubber-tired skidders were used in the yarding process (Table 3.20).

Each of the management practices in Table 3.20 was associated with larger increases in high flows than similar, less disturbing practices (Sections 3.1.1.4 and 3.2.3.1.2). These practices also tend to be associated with a higher degree of site disturbance. Since greater site disturbance is usually linked with greater soil exposure and compaction (Rice et al, 1972), the association between high site disturbance and higher increases in flow may partly explain why recovery was so slow at the 99th percentile.

The primary source of runoff during precipitation or snowmelt events in many undisturbed forested environments is subsurface flow (Mosley, 1979; Troendle, 1987). After logging, infiltration rates of disturbed soils may decrease and cause overland flow to become more common (Bruijnzeel, 1991). As water typically travels quicker overland than through subsurface routes, it is able to concentrate in the streams more readily and possibly increase high flows.

There are at least two possible causes for a decrease in infiltration rates after logging. First, removal of the litter exposes soils to raindrop impact (Heede and King, 1990). The impacts dislodge smaller particles that can clog pores at the surface, reducing infiltration. For example, peak flow increases

Table 3.20. Proportion of basin cut and selected management practices in the 12 basins that had an increase in flow at the 99th percentile throughout the post-treatment period. "NA" indicates that data were not available.

Basin	Percent of basin cut	Silvicultural method	Use of buffers	Yarding method
Needle Branch, OR	82	clearcut	none	tractor and cable
Cadwell Creek, MA	34	mixed	partial	tractor
Coyote Creek 2, OR	30	patch	NA	tractor and cable
Coyote Creek 3, OR	100	clearcut	NA	tractor and cable
Fool Creek, CO	40	patch	NA	NA
H. J. Andrews 1, OR	100	clearcut	none	fully suspended
H. J. Andrews 3, OR	33	patch	none	partially suspended
H. J. Andrews 6, OR	100	clearcut	none	tractor and cable
H. J. Andrews 7, OR	60	selection	none	tractor and cable
Hubbard Brook 2, NH	100	clearcut	none	none
Mai Mai 8, N. Z.	90	clearcut	complete	partially suspended
Wagon Wheel Gap B, CO	100	clearcut	partial	tractor

on an unlogged basin in Japan were attributed to this process after surface litter was removed by hand (Tsukamoto, 1975). While this source of reduced infiltration may increase peak flows, the effects of litter removal are typically short lived because herbaceous vegetation usually covers a disturbed forest site quickly (e.g., Adams et al., 1991).

A second cause of decreased infiltration rates is compaction. Compaction decreases infiltration by reducing the number of macropores present in a soil (Huang et al., 1996; Bruijnzeel, 1991; Dickerson, 1976). Compaction also reduces the total amount of water that can infiltrate into the soil by reducing the soil moisture storage capacity. Compacted soils can take 10 or more years to return to pre-logging bulk densities and infiltration rates (Dickerson, 1976; unpublished data by van der Plas and Bruijnzeel referenced in Bruijnzeel, 1991). Since compacted soils take a long time to recover after logging and they can contribute to increases in high flows, soil compaction may play an important role in determining the size and persistence of high flow increases after logging, even though there was insufficient data to directly link the observed increases in high percentile flows to percent area compacted (Section 3.2.3.1.2).

Nine basins showed both positive and negative changes in flow at the 99th percentile over time. Only four of these basins had more than one of the four characteristics mentioned in Table 3.20. One of these four basins has already been noted as an exception (HJA-10). Two other basins (S4N and S4S) were from a site in Minnesota that appeared to have highly variable precipitation amounts based on large fluctuations in post-treatment flows on the control basin (S5). Such extreme climatic variability may have affected the changes observed on the treated basins, even after using the data from the control basin to adjust for these climatic differences.

It should be noted that the number of studies for each percentile decreased with each successive two-year interval (Table 3.21). In each case, the number of studies for the last two-year interval was less than half the number of studies used for the first interval.

An analysis using only the studies with data for each two-year post-treatment time interval (i.e., those studies with 10 years of post-treatment data) was conducted to determine if the results for the last post-treatment interval were biased by only having data from basins that took longer to recover. This analysis was designed to address the concern that long-term data existed only because flow recovery had not yet been detected on these basins.

Table 3.21. The total number of results used for each percentile by post-treatment interval.

	Number of studies by two-year post-treatment interval				
Percentile	1st	2nd	3rd	4th	5th
1.0	18	17	14	12	8
2.5	19	18	15	13	9
5.0	20	19	16	14	10
10.0	22	20	17	15	11
25.0	24	22	19	16	11
50.0	27	23	19	17	12
75.0	29	24	21	18	14
90.0	30	25	22	19	14
95.0	30	25	22	19	14
97.5	30	25	22	19	14
99.0	30	25	22	19	14

The recovery analysis using only the studies with 10 years of post-treatment data did not show any significant differences from zero for either absolute or relative changes in flow at the 1st and 50th percentiles. Only the first and fifth post-treatment intervals were significantly different from zero ($p = 0.023$ in each case) for absolute and relative changes in flow at the 99th percentile. The reason why these recovery results for the long-term data sets differ from the results that included all available data (Tables 3.17 to 3.19) is because a greater percentage of the long-term studies had changes that fluctuated around zero. If the long-term data were biased towards studies where recovery had not been detected by 10 years post-treatment, then most of the results would have been consistently greater than zero instead of alternating between increases and decreases in flow over time. These results indicate that the recovery analysis data were not biased and that, once again, data availability can affect the results.

3.2.3.2. AFFORESTATION

Three of the four afforested basins had increases in flow for each percentile during the first three-year period after treatment (Table 3.22), while the fourth basin (Shackham Brook) had a decrease in flow for each percentile. The three basins that recorded an initial increase in flow (C8, C13, and C14) were all located at Moutere Hills in New Zealand. Changes in flow were not calculated for the smaller percentiles because there were periods with no flow (Section 2.5.3). All of the afforestation data can be found in Appendix VIII.

As with the logging results (Section 3.2.3.1.1), the lowest flows exhibited the greatest relative change while the highest flows showed the greatest absolute change. The 50th percentile had the largest relative increase of 531%, while the 97.5 percentile had the smallest relative increase of 79%. Mean absolute changes for all basins ranged from -0.0023 L s^{-1} ha^{-1} for the 50th percentile to 0.51 L s^{-1} ha^{-1} for the 99th percentile (Table 3.22). This absolute increase for the 99th percentile is more than twice the median increase following timber harvest (Section 3.2.3.1.1).

The larger increases for C8 and C13 as compared to C14 (Table 3.22) and the timber harvest studies were probably caused by the more intensive site disturbance on C8 and C13. During the conversion from dense gorse to pine, both of these basins were burned (Duncan, 1995). The C8 basin was also line dozed, while the C13 basin was root-raked and cultivated before planting. This high degree of soil disturbance, when combined with the lower ET and interception losses after removing the dense gorse, may explain the large relative increases in streamflow immediately after planting.

Mean flows rapidly decreased over time after afforestation (Tables 3.23 and 3.24). By the fifth post-treatment period, flow for the 50th and 75th

Table 3.22. Absolute and relative changes in selected flow percentiles for each basin during the first three-year interval following afforestation. "NA" indicates that data were not available.

Percentile	Basin C8	C13	C14	Shackham Brook	Mean
Absolute changes in flow (L s^{-1} ha^{-1})					
50.0	NA	0.0038	0.0014	-0.012	-0.0023
75.0	0.054	0.021	0.0083	-0.0063	0.019
90.0	0.19	0.071	0.017	-0.024	0.062
95.0	0.36	0.16	0.030	-0.046	0.13
97.5	0.60	0.48	0.031	-0.15	0.24
99.0	1.2	0.95	0.25	-0.32	0.51
Percent changes in flow					
50.0	NA	1470	133	-11	531
75.0	370	367	69	-2	201
90.0	303	181	32	-4	128
95.0	227	123	20	-5	91
97.5	145	176	7	-11	79
99.0	179	172	36	-16	93

Table 3.23. Mean absolute change for 50th to 99th percentile flows associated with three-year post-treatment time intervals. The sample sizes are provided in the parentheses for the 50th and 75th to 99th percentiles, respectively.

Percentile	Mean absolute change in flow by post-treatment interval 1st (3, 4)	2nd (3, 4)	3rd (3, 4)	4th (3, 4)	5th (2, 3)
50.0	-0.0023	-0.016	-0.014	-0.0090	-0.029
75.0	0.019	-0.016	-0.011	-0.017	-0.042
90.0	0.062	-0.019	-0.039	-0.043	-0.080
95.0	0.13	-0.029	-0.065	-0.095	-0.16
97.5	0.24	-0.057	-0.16	-0.17	-0.32
99.0	0.51	0.28	-0.26	-0.12	-0.42

Table 3.24. Mean relative change for 50th to 99th percentile flows associated with three-year post-treatment time intervals. The sample sizes are provided in the parentheses for the 50th and 75th to 99th percentiles, respectively.

Percentile	Mean relative change in flow by post-treatment interval 1st (3, 4)	2nd (3, 4)	3rd (3, 4)	4th (3, 4)	5th (2, 3)
50.0	531	-17	-38	1	-66
75.0	201	-13	-49	-26	-64
90.0	128	-1	-48	-38	-49
95.0	91	-7	-46	-43	-46
97.5	79	-5	-50	-41	-45
99.0	93	36	-46	-18	-30

percentiles had dropped by nearly two-thirds relative to the pre-treatment flows (Table 3.24). At the same time, mean flows for the 90th to 97.5 percentiles had decreased by nearly 50% from pre-treatment levels, while the 99th percentile flows had decreased by an average of 30% (Table 3.23).

The decreases in flow after afforestation (Table 3.23) are probably due to changes in the same processes that control hydrologic recovery after logging (Section 3.2.3.1.3). The large relative decrease in flow at the 50th percentile for the New Zealand basins was probably due to increasing interception and transpiration, as Duncan (1990) reported rapid pine growth on these basins and almost complete crown closure on the C14 basin after just five years. The much lower soil moisture levels observed in the planted basins--as compared to the pasture-covered control basins--were attributed to the greater rooting depth of pines (Duncan, 1995). This suggests that transpiration is the most probable cause of the large decreases in 50th percentile flows (Table 3.23).

While the cause of the decreases in higher flows cannot be determined from the data, increased infiltration and interception may be important factors. For example, the pasture on the C14 basin was noted to be in poor condition and heavily grazed prior to planting (Duncan, 1990). Conversion of the C14 basin to pines resulted in a 57% decrease in the 99th percentile flows during the fifth three-year interval after planting. This large decrease in flow on the C14 basin is likely due in part to increased infiltration after conversion, as Horton overland flow was observed during intense rainfall events on pasture-covered areas, but it was considered to be "probably less important in pine- and gorse-covered catchments" (Duncan, 1995).

Interception may also be contributing to the observed decreases in higher flows, as interception losses on two New Zealand basins planted with pines equaled 31% of annual precipitation (Fahey and Watson, 1991). Fahey and Watson (1991) also cited several other studies that showed interception rates ranged from 18 to 48% for pine-covered basins throughout New Zealand and Australia. The potentially large increase in interception and the difference in runoff pathways after afforestation could easily explain the observed decreases in higher percentile flows. These factors may also explain why the mean absolute and relative afforestation changes for the 99th percentile were larger than the corresponding changes for the forest harvest studies (Section 3.2.3.1.1).

4. DISCUSSION

4.1. DIFFICULTIES ENCOUNTERED DURING THIS STUDY

One of the major goals of this study was to assess the relationships between basin characteristics and management activities and observed changes in peak or low flows. We did not want to limit the scope of the project by ruling out potentially important variables before the analysis was conducted, so we tried to obtain as much information as possible about each study. Unfortunately, one of the major difficulties with this study was missing data for both basin characteristics and the specific management activities conducted on each basin.

By asking for a great deal of information, we inevitably ended up with numerous gaps in our data. Many authors did not have the time to track down all of the information we requested. In addition, few studies collected all of the potentially relevant data (e.g., percent area compacted). In a few cases, we were not able to obtain any information beyond what was published because we could not locate anyone associated with the study.

Missing data limited the statistical analysis by limiting the number of relationships that could be tested, by allowing influential observations to drive relationships with few observations, and by precluding the use of multivariate analysis. The missing data also limited the applicability of some results because the range of observations was relatively narrow.

Another important difficulty in this study is the high variability in the changes in flow, basin characteristics, and management activities. Since a major goal of this project was to limit the variability between studies, two approaches were used to minimize this variability: grouping the published data by similar peak and low flow definitions (Section 3.1) and recalculating changes in flow using a consistent methodology (Section 3.2). By removing the effect of different methodologies, it was hoped that the causes of flow changes associated with timber harvest would become more evident. However, a great deal of variability between sites was still apparent in both the composited published results (Section 3.1.1.4) and the flow duration curve data (Sections 3.2.1 and 3.2.3.1.1). This is consistent with the findings of other authors, as Harr (1976) wrote:

> If there is a term that can most appropriately be applied to the hydrology of small, forested streams, it is "variability", not only in streamflow and hydraulic characteristics but also over time and space. Variability is the rule rather than the exception.

This variability makes it very difficult to find consistent and significant relationships between changes in flow after logging and either basin characteristics or management activities.

There were many factors unrelated to flow definitions and flow analysis techniques that contributed to the variability in results between sites. The variable analysis showed that at least nine basin characteristics and seven management activities contributed to the observed variability in flow changes after logging (Sections 3.1.1.4 and 3.2.3.1.2). Though some of these relationships had limited statistical validity (e.g., road density), both hydrologic theory and individual studies indicate that a larger data set might confirm the significance of most of these relationships.

In addition to the factors studied, there are many other sources of variability that were not analyzed. For example, factors such as depth to water table, hydraulic conductivity, soil depth, soil texture, and geologic features can all influence the change in flow after logging or afforestation. Such factors were not analyzed because they were either too difficult to characterize or too little information was available. Other sources of variability included factors such as the length of the pre-treatment record, the strength of the relationship between paired basins, the accuracy of the measured flow, and the varying definitions of key characteristics or management activities (e.g., compacted area). Another source of variability was the limitations of accuracy and precision associated with the constraints of time and funds.

There are many more factors that can contribute to the observed variability that have not been mentioned and still others that have not been considered. Several recommendations for limiting the variability in future studies are provided below in Section 4.3 so that we can hopefully have a better understanding of the characteristics and activities most likely to influence changes in streamflow after forest management.

An important limitation of this study is a lack of knowledge about the magnitude and frequency of peak flows evaluated for each study. It was not always clear if the peak flows that were evaluated were important for sediment transport or other channel forming processes. Knowing the magnitude and frequency of the peak flows observed in each study would provide some useful guidance with respect to the geomorphic significance of the observed changes. Information about the recurrence intervals may also provide a better framework for analyzing the published results and possibly reduce the variability in observed changes between studies. This information was requested for each study (Section 2.2), but the limited response indicated that the information was either not available or, more likely, the request was poorly worded.

The implications of the FDC data were also limited because the percentiles investigated could not be directly related to sediment transport rates or geomorphic indicators such as bankfull. Since I did not know the geomorphic significance of key flows such as the 99th percentile, I could not predict how the observed changes in flows would affect channel stability, fish habitat, or sediment transport. Knowing the geomorphic significance of the high percentile flows would strengthen the interpretation and application of the FDC results.

4.2. IMPLICATIONS OF FOREST MANAGEMENT EFFECTS ON HIGH AND LOW FLOWS

The results present strong evidence that both high and low flows increase after logging. Low flow increases tend to be relatively large, but short-lived. In contrast, the increases in higher flows are relatively small, but larger in absolute terms and more persistent.

Resource managers need to evaluate the applicability of these results to their particular situation. This requires an understanding of the local hydrologic processes and available management activities. Resource managers can then determine which studies are most applicable to their situation and what changes in flow they can expect after forest management activities. For example, peak flow increases after logging were smallest in areas with larger annual precipitation. Thus, if an area scheduled for logging is located in a dry climate, then the resource manager might expect larger increases in peak flows and plan stream crossings accordingly.

Many of the studies utilized for this study were conducted when high impact management activities such as clearcutting and tractor yarding were more widely applied. Even though these high impact activities are often limited to smaller areas, they are still used. Thus, the relationships between management activities and changes in flow provided in this study can still be utilized by resource managers when making planning decisions. However, resource managers must also evaluate the results from more recent studies, as these may better reflect current practices.

Knowledge of the probable changes in flow may not be sufficient, as resource managers also need to understand how a given increase in high flows might affect their resource concerns. For example, changes in channel morphology have been associated with peak flow increases after logging. This is because the increased flows can erode banks and channels, move large organic debris, and transport more sediment (Harr, 1986; Christner and Harr, 1982). In the Rocky Mountains of Colorado, increases in peak flows were shown to increase sediment transport (Troendle and Olsen, 1994). The source of this increased sediment was shown to be from within the channel rather than from increased sediment inputs associated with upslope site disturbances. Heede (1991) also found significant changes in channel morphology associated with increases in annual yields and peak flows after timber harvest. His results showed a 10% increase in mean cross-sectional area, a 285% increase in knickpoints, and a 46% decrease in natural control structures (e.g., log steps and gravel bars) for an ephemeral stream in the White Mountains of Arizona. These changes in channel morphology can have detrimental impacts on water quality and fish habitat, and should be taken into account when evaluating the effects of timber harvest on streamflow.

Resource managers also need to consider the potential additive effect of increased peak flows in higher order channels. Though flows would likely be reduced downstream on larger streams and rivers by differences in lag times, spatial and temporal rainfall patterns, and the extent of logging operations between basins (Bruijnzeel, 1986), increases in flows downstream from multiple basins that have been harvested may occur. A spatial model such as the one developed by Bevers et al. (1996) can help minimize downstream increases by scheduling forest management activities to desynchronize flows from different sub-basins.

Another important implication of forest management effects on peak flow increases relates to public perception. It is generally believed that logging results in severe flooding. However, the published data indicated that large peak flows typically increase by 26% (Section 3.1.1.1), while the FDC analysis showed that the median increase for 99th percentile flows was only 12% (Section 3.2.3.1.1). In addition, these small, localized increases in peak and 99th percentile flows would likely be even smaller in higher order waterways downstream from the harvested areas (Bruijnzeel, 1986). Thus, in the absence of large-scale and severe site disturbance, the general perception about forests and severe flooding is largely unfounded.

The effects of low flow increases on resource concerns should also be understood by land managers. For example, increases in low flows may provide important benefits for fisheries and agricultural resources during the drier seasons. Hicks (1990 M. S. thesis cited in Hicks et al., 1991) found an inverse relationship between oxygen depletion and streamflow during dry conditions at H. J. Andrews in Oregon. Increased water flow during dry seasons would likely benefit cold-water fisheries by increasing dissolved oxygen, maintaining lower water temperatures, and slightly increasing habitat. Low flow increases may also benefit agricultural interests by providing more water when crops and livestock need it the most. However, unless regrowth is inhibited, the low flow increases should not be expected to last more than three to four years after logging (Section 3.2.3.1.3).

4.3. RECOMMENDATIONS FOR FUTURE RESEARCH

My first recommendation is that future studies build on the foundation laid by this study. The missing information that hindered this study should be sought out and those who have access to the missing data should work to fill in the gaps identified here (e.g., Appendices I and II). More information should also be obtained from tropical studies, as they were poorly represented in this data set and they could help broaden the range of information regarding basin characteristics. The extra data from each of these sources would allow others to perform more rigorous statistical analyses of the relationships investigated in this study and begin to look at the interactions of multiple variables. Further analysis using a larger data set will hopefully provide more specific guidance to land managers and thereby improve resource planning.

Future studies should also look at the geomorphic significance of the flows investigated. There are several ways that this can be accomplished. The initial focus should be on obtaining this information from the original authors or institutions, since they are most likely to know the geomorphic significance of the flows evaluated for each study. If this information is not available, then the original flow data should be obtained so that the magnitude and frequency of the pre- and post-treatment flows could be calculated. Mean daily flows should be sufficient for determining changes in low flows, but instantaneous flow data should be used to more accurately characterize the larger flows. Though instantaneous data are more difficult to work with, an important benefit is that one could relate the observed flows to bankfull and sediment transport rates. Knowledge of the geomorphic relationships might also help to reduce the variability of a meta-analysis by providing a more accurate means of grouping similar data.

If the instantaneous data cannot be obtained, it is possible to determine the recurrence intervals of select percentiles from flow duration curves developed from mean daily flows. Vogel and Fennessey (1994 and 1995) suggested that means and confidence intervals could be developed for each percentile on a FDC by creating FDCs for each year analyzed. This would allow statistical tests to be performed on pre- and post-treatment data. If there are enough years of data, this could also allow for the development of recurrence intervals for any given percentile using the same ranking procedures that are used to develop flood frequency curves. The recurrence intervals can then be used to determine the relative magnitude of each percentile, thereby providing a rough estimate of the geomorphic significance of the high percentile flows evaluated for each study. No matter how the geomorphic significance is obtained, it will enhance the results of each study by providing perspective on the type of events investigated.

There is a strong need to improve how future paired-basin studies are reported. First, each researcher should provide as much information as possible about each paired-basin study. If the information cannot be published due to space limitations, they should at least make sure that the details of the study are readily available from the internet or the institution sponsoring the study. This additional information would minimize confusion by allowing other researchers or land use managers to better assess the applicability and implications of the main results. The availability of these data would also facilitate future meta-analyses by reducing the difficulties associated with collecting additional information and analyzing incomplete data sets (Section 4.1).

The additional data provided for each study should focus on the basin characteristics, management activities, and methods used to collect and analyze the data. Was the annual precipitation measured on site? Were the calibration or post-treatment periods drier or wetter than normal? What are the recurrence intervals for the flow events studied? How was the drainage density determined? What criteria were used for determining the total area compacted? In a clearcut, were all trees cut or were smaller trees left standing? Was the baseflow separated out of stormflows and if so, how? Were there any missing flow data? Not only will this kind of information enhance a study, but it will provide a better basis for determining the reliability of the results.

Authors should report the changes that were observed along with the significance of the results instead of simply stating that the changes were not significant. This will serve two important purposes. First, providing p-values will prevent the confusion encountered in this study when results from different studies were combined and it was unclear whether or not to consider non-significant results as zeros (Section 2.3). Second, and more importantly, providing p-values lets the resource managers decide the relative reliability and significance of a given result.

The high variability for natural systems evident in the results indicates that a level of significance of 0.05 or even 0.10 may be unrealistic. For example, Heede (1991) found no significant change ($p = 0.11$) in the annual maximum instantaneous flows after logging. However, there were substantial changes in stream morphology after treatment. This was not due to logging activities in the stream because extra care was taken to minimize streamside disturbances and the stream appeared undisturbed immediately after logging. Thus, even though Heede (1991) could not show with 90% certainty that changes in flow occurred, the physical evidence for those changes was apparent in the stream channels.

Authors should also report the pre- and post-treatment flow values along with the percent changes in flow. The absolute values allow the reader to see the size of events that are being investigated along with the absolute changes that were observed. For example, the 2.5 percentile flow at Hubbard Brook Watershed 5 increased 1800% from 0.00018 to 0.0033 L s^{-1} ha^{-1} after logging. By providing the flow values, it is readily apparent to the reader that this was a near zero flow that increased by a very small amount in absolute terms. Reporting only the relative change could be misleading without the context provided by the absolute flow values. Also, when data are grouped together to perform a meta-analysis, the use of only relative changes results in greater variability and a bias towards increases in flow due to the basic mathematics associated with the determination of relative changes (Section 3.2.1).

Another problem with relative changes is that simple differences in mathematical techniques can lead to large differences in results. For example, Dietterick and Lynch (1989) reported an average peak flow increase of 419% during the first growing season after logging for a basin in Pennsylvania. This value was obtained by calculating the percent increase in peak flow for each storm during the growing season and then averaging these values. However, the mean increase would only be 188% if the average of the observed flows were compared to the average of the predicted flows for this same set of storms.

I am not recommending that percent increases be left unreported, however, because it is useful to understand the relative importance of the changes observed. This is especially true for higher flows. For example, without the percent increases, it may not be readily apparent that an increase of 0.3 L s^{-1} ha^{-1} represents a relatively small change in the 99th percentile flows. If absolute changes are reported, one can calculate the percent change, but the reverse is not true. Thus, authors should always report the absolute changes in flow observed after treatment.

5. CONCLUSIONS

Almost a century has gone by since the first paired-basin studies of the effects of timber harvest on streamflow. A great deal of data has been collected and analyzed over the decades. From these data, much has been learned about the hydrologic influences of forests. This study has focused on the role that forests play in regulating high and low flows.

The review of published studies showed that peak flows typically increase by 35% or less after forest harvest, although the range of results is quite wide. The smaller peak flows, such as those that occur during the growing season and periods of soil recharge, showed the greatest relative increases. While larger peak flows did increase significantly, the changes were relatively small. The smaller increases in the larger peak flows may be attributed to their occurrence when soil moisture levels are high regardless of the forest cover.

The published results for the effects of timber harvest on low flows were consistent for those studies that provided actual changes in flow. Even though the definitions of flows were quite varied, 16 studies reported an increase and 2 studies reported a decrease in low flows after timber harvest. An additional 10 results were reported simply as "not significant".

Published results for afforestation studies showed that peak flows decreased in 11 of 15 cases, while low flows decreased 12 of 14 times after treatment. Reported decreases in peak flows ranged from 11 to 73%. Seven of the eight decreases in low flows were 50% or more.

The analysis of flow duration curves from 26 paired-basin studies showed that much of the increase in flow after forest harvest occurred at the higher flows. The median increase for the 99th percentile was 0.21 L s^{-1} ha^{-1}, but this percentile also had the smallest median relative change (12%). The lowest flows had the most variability and the largest relative increases, but the smallest absolute increases ($\leq$ 0.01 L s^{-1} ha^{-1}). These results are consistent with the analysis of the published data and support the premise that low flows are sensitive to land use changes that reduce interception and evapotranspiration.

Low flows generally recovered within three to four years of logging, while increases for higher percentile flows persisted for at least 10 years after harvest. The quick recovery of low flows suggests a high sensitivity of these flows to transpiration, as regrowth was rapid for most sites. The persistence of increases at the high end of the flow duration curve suggests that these flows are controlled by factors that take longer to recover, such as soil disturbance.

The analysis of flow duration curve data from afforestation studies showed a large reduction in high and low flows as the forest stands matured. As with the timber harvest studies, the lower flows were more variable and exhibited the largest relative changes in flow. The establishment of forest cover had less effect on the largest flows.

The statistical analysis of the relationships between basin characteristics or management activities and the observed changes in flow after forest harvest was hindered by missing data and high variability. The significant relationships that were not driven by influential observations typically had weak correlations and thus limited predictive power.

With these limitations in mind, nine basin characteristics and seven management activities were significantly associated with the observed changes in flow after logging. Though the basin characteristics associated with higher flows cannot be changed (e.g., high annual precipitation), these relationships should be taken into account when making land-use decisions. The management activities associated with higher increases in flow were generally those that caused higher site disturbance (e.g., clearcutting or tractor yarding). If the objective is to minimize the increases in flow due to forest management, these high-impact practices should be avoided.

While the general trends regarding the hydrological influences of forests on streamflow are clear, there will always be exceptions and variations. The best way to estimate the likely changes in flow after forest management is to understand the physical processes controlling streamflow within the basin being managed. The data in this study should provide improved guidance for managing our natural resources, as it is another step towards understanding "how much, at what seasons, and under what conditions of climate, soil, and topography" forests influence streamflow (Bates and Henry, 1928).

6. REFERENCES

Abdul Rahim, N. 1990. The effects of selective logging methods on hydrological parameters in Peninsular Malaysia. Ph.D. thesis, University College of North Wales, Bangor, Wales, UK.

Acreman, M. C. 1985. The effects of afforestation on the flood hydrology of the upper Ettrick valley. Scottish Forestry 39(2):89-99.

Adams, P. W., A. L. Flint, and R. L. Fredriksen. 1991. Long-term patterns in soil moisture and revegetation after a clearcut of a Douglas-fir forest in Oregon. Forest Ecology and Management 41:249-263.

Anderson, H. W. and R. L. Hobba. 1959. Forests and floods in the northwestern United States. IASH Publication 48:30-39.

Anderson, H. W., M. D. Hoover, and K. G. Reinhart. 1976. Forests and water: effects of forest management on floods, sedimentation, and water supply. USDA Forest Service General Technical Report PSW-18. Pacific Southwest Forest and Range Experiment Station, Berkeley, CA. 115 p.

Ayer, G. R. 1968. Reforestation with conifers--its effect on streamflow in central New York. Water Resources Bulletin 4(2):13-24.

Bailey, R. G. 1989. Explanatory supplement to ecoregions map of the continents. Environmental Conservation 16(4):307-309.

Banks, C. H. and C. Kromhout. 1963. The effect of afforestation with *Pinus radiata* on summer baseflow and total annual discharge from Jonkershoek catchments. Forestry in S. Africa 3:43-65.

Barten, P. K. 1988. Modeling streamflow from headwater catchments in the Northern Lake States. Unpublished Doctoral Thesis, University of Minnesota.

Bates, C. G. and A. J. Henry. 1922. Streamflow experiment at Wagon Wheel Gap, Colorado. Preliminary report on termination of first stage of experiment. USDA Monthly Weather Review Supplement No. 17. 55 p.

Bates, C. G. and A. J. Henry. 1928. Forest and stream-flow experiment at Wagon Wheel Gap, Colo. Final report, on completion of the second phase of the experiment. USDA Monthly Weather Review Supplement No. 30. 79 p.

Beasley, R. S. and A. B. Granillo. 1988. Sediment and water yields from managed forests on flat coastal plain sites. Water Resources Bulletin 24(2):361-366.

Bent, G. C. 1994. Effects of timber cutting on runoff to Quabbin Reservoir, central Massachusetts. p. 187-196. *In* R. A. Marston and V. R. Hasfurther (ed.) Effects of human-induced changes on hydrologic systems, Jackson Hole, WY. AWRA, Bethesda, MD.

Bevers, M., J. Hof, and C. Troendle. 1996. Spatially optimizing forest management schedules to meet stormflow constraints. Water Resources Bulletin 32(5):1007-1015.

Blackburn, W. H., R. W. Knight, J. C. Wood, and H. A. Pearson. 1990. Stormflow and sediment loss from intensively managed forest watersheds in East Texas. Water Resources Bulletin 26(3):465-477.

Blackburn, W. H., J. C. Wood, and M. G. DeHaven. 1986. Storm flow and sediment losses from site-prepared forestland in East Texas. Water Resources Research 22(5):776-784.

Bosch, J. M. 1979. Treatment effects on annual and dry period streamflow at Cathedral Peak. South African Forestry Journal 108:29-38.

Bosch, J. M. and J. D. Hewlett. 1982. A review of catchment experiments to determine the effect of vegetation changes on water yield and evapotranspiration. Journal of Hydrology 55:3-23.

Brandt, M., S. Bergström, and M. Gardelin. 1988. Modeling the effects of clearcutting on runoff--examples from central Sweden. AMBIO 17(5):307-313.

Bren, L. J., D. W. Flinn, P. Hopmans, and C. J. Leitch. 1979. The hydrology of small forested catchments in north-eastern Victoria: 1. Establishment of the Cropper Creek Project. Bulletin No. 27. Forests Commission, Melbourne, Victoria, Australia. 48 p.

Bren, L. J. and M. Papworth. 1991. Early water yield effects of conversion of slopes of a eucalypt forest catchment to radiata pine plantation. Water Resources Research 27(9):2421-2428.

Bruijnzeel, L. A. 1986. Environmental impacts of (de)forestation in the humid tropics: a watershed perspective. Wallaceana 46:3-13.

Bruijnzeel, L. A. 1990. Hydrology of moist tropical forests and effects of conversion: A state of knowledge review. UNESCO/Free University, Paris/Amsterdam. 224 p.

Bruijnzeel, L. A. 1991. Hydrological impacts of tropical forest conversion. Nature and Resources 27(2):36-46.

Cheng, J. D. 1989. Streamflow changes after clear-cut logging of a pine beetle-infested watershed in southern British Columbia, Canada. Water Resources Research 25(3):449-456.

Cheng, J. D., T. A. Black, J. de Vries, R. P. Willington, and B. C. Goodell. 1975. The evaluation of initial changes in peak streamflow following logging of a watershed on the west coast of Canada. p. 475-486 *In* Proceedings Tokyo Symposium. IASH Publication 117.

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

Claridge, G. G. C. 1980. Studies of water quality and quantity at Taita and their possible significance to the Nelson situation. pp. 14-39 *In* Seminar Land use in relation to water quantity and quality, Nelson, New Zealand. Nelson Catchment and Regional Water Boards, Nelson, New Zealand.

David, J. S., M. O. Henriques, and Z. C. Rego. 1988. Short term responses of streamflow following clearcutting in *Eucalyptus globulus* stands in central Portugal. p. 225-237. *In* Beitrage sur wildbacherosions -- und lawinenforshung. Mitteilungsband NR. 159.

David, J. S., M. O. Henriques, T. S. David, J. Tomé, and D. C. Ledger. 1994. Clearcutting effects on streamflow in coppiced *Eucalyptus globulus* stands in Portugal. Journal of Hydrology 162:143-154.

Department of Drainage and Irrigation (DID). 1989. Sungai Tekam Experimental Basin Final Report July 1977 to June 1986. Water Resources Publication No. 20. Department of Drainage and Irrigation, Ministry of Agriculture, Kuala Lumpur, Malaysia. 93 p.

Dickerson, B. P. 1976. Soil compaction after tree-length skidding in northern Mississippi. Soil Science Society of America Journal 40(6):965-966.

Dietterick, B. C. and J. A. Lynch. 1989. The cumulative hydrologic effects on stormflows of successive clearcuts on a small headwater basin. p. 473-485. *In* W. W. Woessner and D. F. Potts (ed.) Symposium on Headwaters hydrology, Missoula, MT. AWRA, Bethesda, MD.

Dils, R. E. 1953. Influence of forest cutting and mountain forming on some vegetation, surface soil and surface runoff characteristics. USDA Forest Service Station Paper SE-24. Southeastern Forest Experiment Station, Asheville, NC. 55 p.

Douglass, J. E. and W. T. Swank. 1976. Multiple use in southern Appalachian hardwoods-a ten-year case history. p. 425-436. *In* Proceedings of the XVI International Union of Forestry Research Organizations World Congress, Oslo, Norway. IUFRO Secretariat, Schonbrunn-Triolergarten, A-1131 Vienna, Austria.

Douglass, J. E., D. H. Van Lear, and C. Valverde. 1983. Stormflow changes after prescribed burning and clearcutting pine stands in the South Carolina piedmont. pp. 454-460 *In* E. P. Jones, Jr. (ed.) Proceedings of the second biennial southern silvicultural research conference. USDA Forest Service General Technical Report SE-24. Southeastern Forest Experiment Station, Asheville, NC.

Dragoun, F. J. and L. L. Harrold. 1971. Flood hydrology of a small watershed. Transactions of the ASAE 14:1129-1131.

Duncan, M. J. 1980. The impact of afforestation on small catchment hydrology in Moutere Hills Nelson. p. 61-90. *In* Seminar Land use in relation to water quantity and quality, Nelson, New Zealand. Nelson Catchment and Regional Water Boards, Nelson, New Zealand.

Duncan, M. J. 1990. Moutere Experimental Basin: a catalogue of hydrological measurements. Hydrology Centre Publication Number 23. Christchurch, New Zealand. 125 p.

Duncan, M. J. 1995. Hydrological impacts of converting pasture and gorse to pine plantation, and forest harvesting, Nelson, New Zealand. Journal of Hydrology (NZ) 34(1):15-41.

Duncan, S. H. 1986. Peak stream discharge during thirty years of sustained yield timber management in two fifth order watersheds in Washington state. Northwest Science 60(4):259-264.

Fahey, B. D. and R. Jackson. 1995. Hydrological impacts of converting native forests and grasslands to pine plantations, South Island, New Zealand. Presented at the XX World Congress of the International Union of Forest Research Organisation, Tampere, Finland, August, 1995.

Fahey, B. D. and A. J. Watson. 1991. Hydrological impacts of converting tussock grassland to pine plantation, Otago, New Zealand. Journal of Hydrology (New Zealand) 30(1):1-15.

Federer, C. A., L. D. Flynn, C. W. Martin, J. W. Hornbeck, and R. S. Pierce. 1990. Thirty years of hydrometeorologic data at the Hubbard Brook Experimental Forest, New Hampshire. USDA Forest Service, General Technical Report NE-141. Northeastern Forest Experiment Station, Radnor, PA. 44 p.

Fowler, W. B., J. D. Helvey, and E. N. Felix. 1987. Hydrologic and climatic changes in three small watersheds after timber harvest. USDA Forest Service, Research Paper PNW-RP-379. Pacific Northwest Research Station, Portland, OR. 13 p.

Gilmour, D. A. 1977. Effect of rainforest logging and clearing on water yield and quality in a high rainfall zone of north-east Queensland. p. 156-160 *In* Symposium on the hydrology of northern Australia, Brisbane, Australia, 28-30 June, 1977. Institution of Engineers, Australia.

Golding, D. L. 1987. Changes in streamflow peaks following timber harvest of a coastal British Columbia watershed. p. 509-517. *In* R. H. Swanson (ed.) Proceedings of the Symposium on Forest Hydrology and Watershed Management. Vancouver, B. C., Canada. IAHS-AISH Publication No. 167.

Gottfried, G. J. 1991. Moderate timber harvesting increases water yields from an Arizona mixed conifer watershed. Water Resources Bulletin 27(3):537-547.

Harper, W. C. 1969. Changes in the storm hydrographs due to clearcut logging of coastal watersheds. M. S. thesis, Oregon State University, Corvallis.

Harr, R. D. 1976. Forest practices and streamflow in western Oregon. USDA Forest Service, General Technical Report PNW-49. Pacific Northwest Forest and Range Experiment Station, Portland, OR. 18 p.

Harr, R. D. 1976. Hydrology of small forest streams in western Oregon. USDA Forest Service, General Technical Report PNW-55. Pacific Northwest Forest and Range Experiment Station, Portland, OR. 15 p.

Harr, R. D. 1980. Streamflow after patch logging in small drainages within the Bull Run Municipal Watershed, Oregon. USDA Forest Service, Research Paper PNW-268. Pacific Northwest Forest and Range Experiment Station, Portland, OR. 16 p.

Harr. R. D. 1986. Effects of clearcutting on rain-on-snow runoff in western Oregon: a new look at old studies. Water Resources Research 22(7):1095-1100.

Harr, R. D., R. L. Fredriksen, and J. Rothacher. 1979. Changes in streamflow following timber harvest in southwestern Oregon. USDA Forest Service, Research Paper PNW-249. Pacific Northwest Forest and Range Experiment Station, Portland, OR. 22 p.

Harr, R. D., W. C. Harper, J. T. Krygier, and F. S. Hsieh. 1975. Changes in storm hydrographs after road building and clear-cutting in the Oregon Coast Range. Water Resources Research 11(3):436-444.

Harr, R. D. and J. T. Krygier. 1972. Clearcut logging and low flows in Oregon coastal watersheds. Forest Research Laboratory Research Note 54, Paper 839. Oregon State University, Corvallis. 3 p.

Harr, R. D., A. Levno, and R. Mersereau. 1982. Streamflow changes after logging 130-year-old Douglas Fir (sic) in two small watersheds. Water Resources Research 18(3):637-644.

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

Harris, D. D. 1973. Hydrologic changes after clear-cut logging in a small Oregon coastal watershed. Journal of Research, USGS. 1(4):487-491.

Harris, D. D. 1977. Hydrologic changes after logging in two small Oregon coastal watersheds. USDI Geological Survey, Water-Supply Paper 2037. Washington, D. C. 31 p.

Harrold, L. L., D. L. Brakensiek, J. L. McGuinness, C. R. Amerman, and F. R. Dreibelbis. 1962. Influence of land use and treatment on the hydrology of small watersheds at Coshocton, Ohio, 1938-1957. USDA Technical Bulletin 1256. 194 p.

Hartman, G. F. and J. C. Scrivener. 1990. Impacts of forestry practices on a coastal stream ecosystem, Carnation Creek, British Columbia. Canadian Bulletin of Fisheries and Aquatic Sciences 223. 148p.

Heede, B. 1991. Response of a stream in disequilibrium to timber harvest. Environmental Management 15(2):251-255.

Heede, B. H. and R. M. King. 1990. State-of-the-art timber harvest in an Arizona mixed conifer forest has minimal effect on overland flow and erosion. Hydrological Sciences Journal 35(6):623-635.

Hetherington, E. D. 1982. Effects of forest harvesting on the hydrologic regime of Carnation Creek Experimental Watershed: a preliminary assessment. P. 247-267. *In* Proc. Canadian Hydrology Symposium '82. National Research Council of Canada. Ottawa, Ontario.

Hetherington, E. D. 1987. Carnation Creek, Canada--review of a west coast fish/forestry watershed impact project. IAHS Publication 167:531-538.

Hewlett, J. D. 1978. Forest water quality: an experiment in harvesting and regenerating Piedmont forest. University of Georgia, School of Forest Resources, Athens, GA. 22 p.

Hewlett, J. D. 1982. Forests and floods in the light of recent investigation. p. 543-559. *In* Proceedings of the Canadian hydrology symposium, Fredericton, New Brunswick, Canada.

Hewlett, J. D. and J. M. Bosch. 1984/1985. Dependence of storm flows on rainfall intensity and vegetal cover in South Africa. J. of Hydrology 75(1/4):365-381.

Hewlett, J. D. and R. Doss. 1984. Forests, floods, and erosion: a watershed experiment in the southeastern Piedmont. Forest Science 30(2):424-434.

Hewlett, J. D. and J. D. Helvey. 1970. Effects of forest clear-felling on the storm hydrograph. Water Resources Research 6(3):768-782.

Hewlett, J. D. and A. R. Hibbert. 1961. Increases in water yield after several types of forest cutting. IASH Bulletin 6(3):5-17.

Hewlett, J. D. and A. R. Hibbert. 1966. Factors affecting response of small watersheds to precipitation in humid areas. p. 275-290. *In* W. E. Sopper and H. W. Lull (eds.) International symposium on forest hydrology. Pergamon, Elmsford, NY.

Hibbert, A. R. 1966. Forest treatment effects on water yield. p. 527-543. *In* W. E. Sopper and H. W. Lull (eds.), International symposium on forest hydrology. Pergamon Press, New York, NY.

Hibbert, A. R. 1969. Water yield changes after converting a forested catchment to grass. Water Resources Research 5(3):634-640.

Hibbert, A. R. and G. J. Gottfried. 1987. Stormflow responses to forest treatments on two Arizona mixed conifer watersheds. p. 189-194 *In* Management of subalpine forests: building on 50 years of research. USDA Forest Service General Technical Report RM-149.

Hicks, B. J., R. L. Beschta, and R. D. Harr. 1991. Long-term changes in streamflow following logging in western Oregon and associated fisheries implications. Water Resources Bulletin 27(2):217-226.

Hoover, M. D. 1944. Effect of removal of forest vegetation upon water-yields. Transactions, American Geophysical Union 6:969-975.

Hornbeck, J. W. 1973. Storm flow from hardwood-forested and cleared watersheds in New Hampshire. Water Resources Research 9(2):346-354.

Hornbeck, J. W., M. B. Adams, E. S. Corbett, E. S. Verry, and J. A. Lynch. 1993. Long-term impacts of forest treatments on water yield: a summary for northeastern USA. J. of Hydrology 150:323-344.

Hornbeck, J. W., C. W. Martin, R. S. Pierce, F. H. Bormann, G. E. Likens, and J. S. Eaton. 1987. The northern hardwood forest: ten years of recovery from clearcutting. USDA Forest Service, Northeastern Forest Experiment Station, NE-RP-596. 30 p.

Hornbeck, J. W. and R. S. Pierce. 1970. Changes in snowmelt runoff after forest clearing on a New England watershed. Eastern Snow Conference 26:104-113.

Hornbeck, J. W., R. S. Pierce, and C. A. Federer. 1970. Streamflow changes after forest clearing in New England. Water Resources Research 6(4):1124-1132.

Hsia, Y. 1987. Changes in storm hydrographs after clearcutting a small hardwood forested watershed in central Taiwan. Forest Ecology and Management 20:117-133.

Hsieh, F. S. 1970. Storm runoff from roadbuilding and logging on small watersheds in the Oregon Coast Range. M. S. thesis, Oregon State University, Corvallis.

Huang, J., S. T. Lacey, and P. J. Ryan. 1996. Impact of forest harvesting on the hydraulic properties of surface soil. Soil Science 161(2):79-86.

Johnson, E. A. 1967. Effects of multiple use on peak and low flows. p. 545-550. *In* W. E. Sopper and H. W. Lull (eds.), International symposium on forest hydrology. Pergamon Press, Oxford, UK.

Johnson, E. A. and H. G. Meginnis. 1960. Effect of altering forest vegetation on low flows of small streams. IASH Publication 51:257-266.

Johnston, R. S. 1984. Effect of small aspen clearcuts on water yield and water quality. USDA Forest Service, Research Paper INT-333. Intermountain Forest and Range Experiment Station, Ogden , UT. 9 p.

Kaushal, R. C., D. K. N. Dayal, and P. R. Mishra. 1975. Study on the effect of closure with afforestation and gully control measures on runoff and peak discharge. p. 57-59. *In* Annual Report 1975. Central Soil and Water Conservation Research and Training Institute, Dehra Dun, India.

Keppeler, E. T. and R. R. Ziemer. 1990. Logging effects on streamflow: water yield and summer low flows at Caspar Creek in northwestern California. Water Resources Research 26(7):1669-1679.

King, J. G. 1989. Streamflow responses to road building and harvesting: a comparison with the equivalent clearcut area procedure. USDA Forest Service, Research Paper INT-401. Intermountain Research Station, Ogden, UT. 13 p.

King, J. G. and L. C. Tennyson. 1984. Alteration of streamflow characteristics following road construction in north central Idaho. Water Resources Research, 20(8):1159-1163.

Kovner, J. L. 1956. Evapotranspiration and water yields following forest cutting and natural regrowth. Proceedings, Society of American Foresters. p. 106-110.

Krygier, J. T. and R. D. Harr. 1972. Changes in storm hydrographs due to roadbuilding and clearcut logging on coastal watersheds in Oregon. Oregon State University, Corvallis. Water Resources Research Institute. 59 p.

Langford, K. J., R. J. Moran, and P. J. O'Shaughnessy. 1982. The Coranderrk experiment-the effects of roading and timber harvesting in a mature mountain ash forest on streamflow yield and quality. p. 92-102. *In* O'Loughlin, E. M. and L. J. Bren (eds.), First national symposium on forest hydrology. Institution of Engineers Australia National Conference Publication 82/6.

Leitch, C. J. and D. W. Flinn. 1986. Hydrological effects of clearing native forest in north-east Victoria: the first 3 years. Australian Forest Research 16(1):103-116.

Lieberman, J. A. and M. D. Hoover. 1951. Stream-flow frequency changes on Coweeta Experimental Watersheds. Transactions, American Geophysical Union. 32(1):73-76.

Lull, H. W. and K. G. Reinhart. 1972. Forests and floods in the eastern United States. USDA Forest Service, Research Paper NE-226. Northeast Forest Experiment Station, Upper Darby, PA. 94 p.

Lynch, J. A. 1969. Changes in streamflow following partial clearcutting on a forested watershed. Unpublished Master of Science Thesis, Pennsylvania State University. 84 p.

Lynch, J. A., E. S. Corbett, and W. E. Sopper. 1980. Evaluation of management practices on the biological and chemical characteristics of streamflow from forested watersheds. Institute for Research on Land and Water Resources, Pennsylvania State University, Research Project Technical Completion Report. 107 p.

Lynch, J. A., W. E. Sopper, and D. B. Partridge. 1972. Changes in streamflow following partial clearcutting on a forested watershed. p. 313-320. *In* Csallany, S. C., T. B. McLaughlin and W. D. Striffler (eds.), National symposium watersheds in transition proceedings, Ft. Collins, CO. AWRA, Urbana, IL.

Lyons, J. K. and R. L. Beschta. 1983. Land use, floods and channel changes: upper Middle Fork Willamette River, Oregon (1936-1980). Water Resources Research 19(2):463-471.

Mader, D. L., W. P. MacConnell, and J. W. Bauder. 1972. The effect of riparian vegetation control and stand density reduction on soil moisture in the riparian zone. Massachusetts Agricultural Experiment Station Research Bulletin No. 597. University of Massachusetts, Amherst. 32 p.

Maruyama, I. and T. Inose. 1952. Experiment of forest influences upon streamflow at Kambuti. Bulletin 53. Gov. For. Exp. Stn., Meguro, Japan. 44 p.

Mathur, H. N., Ram Babu, P. Joshie, and B. Singh. 1976. Effect of clearfelling and reforestation on runoff and peak rates in small watersheds. Indian Forester 102(4):219-226.

Mathur, H. N. and S. S. Sajwan. 1978. Vegetation characteristics and their effect on runoff and peak rates from small watersheds. Indian Forester 104(6):398-406.

McGuinness, J. L. and L. L. Harrold. 1971. Reforestation influences on small watershed streamflow. Water Resources Research 7(4):845-852.

Megahan, W. F. 1987. Increased sedimentation following helicopter logging and prescribed burning on granitic soil. IAHS Publication 165:259-260.

Megahan, W. F., J. G. King, and K. A. Seyedbagheri. 1995. Hydrologic and erosional responses of a granitic watershed to helicopter logging. Forest Science 41(4):

Miller, E. L. 1984. Sediment yield and storm flow response to clear-cut harvest and site preparation in the Ouachita Mountains. Water Resources Research 20(4):471-475.

Miller, E. L., R. S. Beasley, and E. R. Lawson. 1988. Forest harvest and site preparation effects on stormflow and peakflow of ephemeral streams in the Ouachita Mountains. Journal of Environmental Quality 17(2):212-218.

Mosley, M. P. 1979. Streamflow generation in a forested watershed, New Zealand. Water Resources Research 15(4):795-806.

Mrazik, B. R., D. L. Mader, and W. P. MacConnell. 1980. Integrated watershed management: an alternative for the Northeast. Massachusetts Agricultural Experiment Station Research Bulletin No. 664. University of Massachusetts, Amherst. 50 p.

Mumeka, A. 1986. Effect of deforestation and subsistence agriculture on runoff of the Kafue river headwaters, Zambia. Hydrological Sciences Journal 31:543-554.

Nakano, H. 1967. Effects of changes of forest conditions on water yield, peak flow and direct runoff of small watersheds in Japan. p. 551-564. *In* W. E. Sopper and H. W. Lull (eds.) International symposium on forest hydrology. Pergamon Press, NY.

Nakano, H. 1971. Effect on streamflow of forest cutting and change in regrowth on cut-over area. Bulletin of the government forest experiment station 240. Tokyo, Japan. 251 p.

Nänni, U. W. 1956. Forest hydrological research at the Cathedral Peak Research Station. South African Forestry Journal 27:2-35.

Nänni, U. W. 1970. The effect of afforestation on streamflow at Cathedral Peak: Report No. 1. South African Forestry Journal 74:6-12.

Nänni, U. W. 1971. The Mokobulaan research catchments. South African Forestry Journal 78:5-13.

Ott, R. L. 1993. An introduction to statistical methods and data analysis. 4th ed. Duxbury Press, Belmont, CA.

Partridge, D. B., III. 1971. Effects of partial forest cover removal on storm hydrographs. Unpublished Master of Science Thesis, Pennsylvania State University. 68 p.

Patric, J. H. 1973. Deforestation effects on soil moisture, streamflow, and water balance in the central Appalachians. USDA Forest Service, Research Paper NE-259. Northeastern Forest Experiment Station, Upper Darby, PA. 12 p.

Patric, J. H. and K. G. Reinhart. 1971. Hydrologic effects of deforesting two mountain watersheds in West Virginia. Water Resources Research 7(5):1182-1188.

Pearce, A. J. , L. K. Rowe, and C. L. O'Loughlin. 1980. Effects of clearfelling and slash-burning on water yield and storm hydrographs in evergreen mixed forests, western New Zealand. p. 119-127. *In* The hydrological regime with special reference to representative and experimental basins, Helsinki, Finland. IAHS Publication No. 130.

Pierce, R. S., J. W. Hornbeck, G. E. Likens, and F. H. Bormann. 1970. Effect of elimination of vegetation on stream water quantity and quality. p. 311-328. *In* Proceedings of the Symposium on the results of research on representative and experimental basins, Wellington, N. Z. IAHS Publication No. 96.

Plamondon, A. P. 1988. The Ruisseau des Eaux-Volées forest experimental watershed, Quebec. Canadian Hydrology Symposium. Associate Committee on Hydrology, National Research Council of Canada. Banff, Alberta.

Plamondon, A. P. and D. C. Ouellet. 1980. Partial clearcutting and streamflow regime of Ruisseau des Eaux-Volées experimental basin. p. 129-136. *In* The hydrological regime with special reference to representative and experimental basins, Helsinki, Finland. IAHS Publication No. 130.

Reinhart, K. G. 1964. Effect of a commercial clearcutting in West Virginia on overland flow and storm runoff. Journal of Forestry 62:167-171.

Reinhart, K. G., A. R. Eschner, and G. R. Trimble. 1963. Effect on streamflow of four forest practices in the mountains of West Virginia. USDA Forest Service, Research Paper NE-1. Northeastern Forest Experiment Station, Upper Darby, PA. 79 p.

Ricca, V. T. , P. W. Simmons, J. L. McGuinness, and E. P. Taiganides. 1970. Influence of land use on runoff from agricultural watersheds. American Society of Agricultural Engineers Transactions 13(2):187-190.

Rice, R. M., J. S. Rothacher, and W. F. Megahan. 1972. Erosional consequences of timber harvesting: an appraisal. p. 321-329. *In* National symposium on watersheds in transition proceedings. AWRA, Urbana, IL.

Riekerk, H. 1989. Influence of silvicultural practices on the hydrology of pine flatwoods in Florida. Water Resources Research 25(4):713-719.

Riekerk, H., B. F. Swindel, and J. A. Replogle. 1980. Initial hydrologic effects of forestry practices in Florida flatwoods watersheds. IMPAC Report 5(4). 24 p.

Robinson, M., B. Gannon, and M. Schuch. 1991. Comparison of the hydrology of moorland under natural conditions, agricultural use and forestry. Hydrological Sciences Journal 36(6):565-577.

Rothacher, J. 1965. Streamflow from small watersheds on the western slope of the Cascade Range of Oregon. Water Resources Research 1(1)125-134.

Rothacher, J. 1970. Increases in water yield following clear-cut logging in the Pacific Northwest. Water Resources Research 6(2):653-658.

Rothacher, J. 1973. Does harvest in West Slope Douglas-fir increase peak flow in small forest streams? USDA Forest Service, Research Paper PNW-163. Pacific Northwest Forest and Range Experiment Station. Portland, OR. 13 p.

Rothacher, J., C. T. Dyrness, and R. L. Fredriksen. 1967. Hydrologic and related characteristics of three small watersheds in the Oregon Cascades. USDA Forest Service. Pacific Northwest Forest and Range Experiment Station. Portland, OR. 54 p.

Rowe, L. K. and A. J. Pearce. 1994. Hydrology and related changes after harvesting native forest catchments and establishing *Pinus radiata* plantations. Part 2. The native forest water balance and changes in streamflow after harvesting. Hydrological Processes 8:281-297.

Rowe, L. K., A. J. Pearce, and C. L. O'Loughlin. 1994. Hydrology and related changes after harvesting native forest catchments and establishing *Pinus radiata* plantations. Part 1. Introduction to study. Hydrological Processes 8:263-279.

Ruprecht, J. K., N. J. Schofield, D. S. Crombie, R. A. Vertessy, and G. L. Stoneman. 1991. Early hydrological response to intense forest thinning in southwestern Australia. Journal of Hydrology 127:261-277.

Satturland, D. R. 1972. Wildland watershed management. The Ronald Press Company, New York, NY.

Schneider, W. J. 1969. Reforestation effects on winter and spring flood peaks in central New York state. Floods and their computation 2. IASH Publication 85:780-787.

Schneider, W. J. and G. R. Ayer. 1961. Effect of reforestation on streamflow in central New York. USDI Geological Survey, Water Supply Paper 1602. 61 p.

Shanley, J. B., J. L. Strause, and J. C. Risley. 1995. Effects of selective forest clearing , fertilization, and liming on the hydrology and water quality of a small tributary to the Quabbin Reservoir, Central Massachusetts. U.S. Geological Survey Water-Resources Investigations Report 95-4124. Marlborough, MA. 57 p.

Shimizu, T. 1983. Forest-watershed experiments in Japan. Japanese Agricultural Research Quarterly 16(4):281-286.

Shimizu, T. 1994. Effects of contour-line strip-cutting on stream flow (II): short-term runoff characteristics during the warm season. Journal of the Japanese Forestry Society 76(6):492-499.

Shimizu, T., Y. Tsuboyama, and I. Hosoda. 1994. Effects of contour-line strip-cutting on stream flow (I): long-term runoff characteristics during the warm season. Journal of the Japanese Forestry Society 76(5):393-401.

Smith, C. M. 1992. Riparian afforestation effects on water yields and water quality in pasture catchments. Journal of Environmental Quality 21:237-245.

Smith, R. E. 1991. Effect of clearfelling pines on water yield in a small eastern Transvaal catchment, South Africa. Water SA 17(3):217-224.

Smith, R. E. and J. M. Bosch. 1989. A description of the Westfalia catchment experiment to determine the effect on water yield of clearing the riparian zone and converting an indigenous forest to a eucalypt plantation. South African Forestry Journal 151:26-31.

Smith, R. E. and D. F. Scott. 1992. The effects of afforestation on low flows in various regions of South Africa. Water SA 18(3):185-194.

Sodemann, P. C. and J. E. Tysinger. 1967. Effects of forest cover upon hydrologic characteristics of a small watershed in the limestone region of east Tennessee. IASH Publication 73(1):139-157.

Springer, E. P. and G. B. Coltharp. 1978. Some hydrologic characteristics of a small forested watershed in eastern Kentucky. Transactions of the Kentucky Academy of Science 39(1-2):31-38.

Springer, E. P. and G. B. Coltharp. 1980. Effects of logging roads on storm hydrographs. pp. 228-239 *In* Symposium on watershed management 1980 v I. American Society of Civil Engineers, New York, NY.

Stednick, J. D. 1996. Monitoring the effects of timber harvest on annual water yield. Journal of Hydrology 176:79-95.

Subba Rao, B. K., B. C. Ramola, and V. N. Sharda. 1985. Hydrologic response of a forested mountain watershed to thinning: a case study. Indian Forester 111:418-431.

Swank, W. T., J. E. Douglass, and G. B. Cunningham. 1982. Changes in water yield and storm hydrographs following commercial clearcutting on a southern Appalachian catchment. p. 583-594 *In* Proceedings of symposium on hydrological research basins, Bern.

Swank, W. T., L. W. Swift, and J. E. Douglass. 1988. Streamflow changes associated with forest cutting, species conversions, and natural disturbances. Forest hydrology and ecology at Coweeta. Ecological Studies 66:297-312.

Swanson, R. H. and G. R. Hillman. 1977. Predicted increased water yield after clear-cutting verified in west-central Alberta. Information Report NOR-X-198. Northern Forest Research Centre, Edmonton, Alberta. 40 p.

Swindel, B. F., C. J. Lassiter, and H. Riekerk. 1982. Effects of clearcutting and site preparation on water yields from slash pine forests. Forest Ecology and Management 4:101-113.

Swindel, B. F., C. J. Lassiter, and H. Riekerk. 1983. Effects of different harvesting and site preparation operations on the peak flows of streams in *Pinus elliottii* flatwoods forests. Forest Ecology and Management 5:77-86.

Tennessee Valley Authority. 1961. Forest cover improvement influences upon hydrologic characteristics of White Hollow Watershed 1935-1958. TVA Division of Water Control Planning, Hydraulics Data Branch. 104 p.

Tennessee Valley Authority. 1962. Reforestation and erosion control influences upon the hydrology of the Pine Tree Branch Watershed, 1941-1960. TVA Division of Water Control Planning, Hydraulics Data Branch. 98 p.

Thomas, R. B. 1990. Problems in determining the return of a watershed to pretreatment conditions: techniques applied to a study at Caspar Creek, California. Water Resources Research 26(9):2079-2087.

Troendle, C. A. 1987. Effect of clearcutting on streamflow generating processes from a subalpine forest slope. p. 545-552. *In* R. H. Swanson (ed.) Proceedings of the Symposium on Forest Hydrology and Watershed Management. Vancouver, B. C., Canada. IAHS-AISH Publication No. 167.

Troendle, C. A. and M. R. Kaufmann. 1987. Influence of forests on the hydrology of the subalpine forest. p. 68-78. *In* Management of subalpine forests: building on 50 years of research. USDA Forest Service General Technical Report RM-149. Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO.

Troendle, C. A. and R. M. King. 1985. The effect of timber harvest on the Fool Creak watershed, 30 years later. Water Resources Research 21(12):1915-1922.

Troendle, C. A. and R. M. King. 1987. The effect of partial and clearcutting on streamflow at Deadhorse Creek, Colorado. Journal of Hydrology 90:145-157.

Troendle, C. A. and W. K. Olsen. 1994. Potential effects of timber harvest and water management on streamflow dynamics and sediment transport. p. 34-41 *In* Sustainable ecological systems: implementing an ecological approach to land management. USDA Forest Service, General Technical Report RM-247. Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO.

Tsukamoto, Y. 1975. Effect of forest litters on runoff cycle in a small experimental watershed. IAHS Publication no. 117. p. 487-495.

Ursic, S. J. 1970. Hydrologic effects of prescribed burning and deadening upland hardwoods in northern Mississippi. USDA Forest Service, Research Paper SO-54. Southern Forest Experiment Station, New Orleans, LA. 15 p.

Ursic, S. J. 1982. Hydrologic changes after replacing hardwoods with southern pine. p 735-746 *In* Proceedings of symposium on hydrological research basins, Bern.

Ursic, S. J. 1991. Hydrological effects of two methods of harvesting mature southern pine. Water Resources Bulletin 27(2):303-315.

USDA Forest Service. 1991. The Hubbard Brook Ecosystem Study: site description and research activities. USDA Forest Service, Northeastern Forest Experiment Station, NE-INF-96-91. 61 p.

Van Haveren, B. P. 1988. A reevaluation of the Wagon Wheel Gap forest watershed experiment. Forest Science 34(1):208-214.

Van Lill, W. S., F. J. Kruger, and D. B. van Wyk. 1980. The effect of afforestation with *Eucalyptus grandis* (Hill ex Maiden) and *Pinus patula* (Schlect. et Cham.) on streamflow from experimental catchments at Mokobulaan, Transvaal. Journal of Hydrology 48:107-118.

van Wyk, D. B. 1987. Some effects of afforestation on streamflow in the western Cape Province, South Africa. Water S. A. 13(1):31-36.

Verry, E. S. 1972. Effect of an aspen clearcutting on water yield and quality in northern Minnesota. p. 276-284. *In* National symposium on watersheds in transition proceedings. AWRA, Urbana, IL.

Verry, E. S. 1986. Forest harvesting and water: the Lake States experience. Water Resources Bulletin 22(6):1039-1047.

Verry, E. S., J. R. Lewis, and K. N. Brooks. 1983. Aspen clearcutting increases snowmelt and storm flow peaks in north central Minnesota. Water resources Bulletin 19(1):59-67.

Vertessy, R. A., T. J. Hatton, R. G. Benyon, and W. R. Dawes. 1996. Long-term growth and water balance predictions for a mountain ash (*Eucalyptus regnans*) forest catchment subject to clear-felling and regeneration. Tree Physiology 16:221-232.

Vogel, R. M. and N. M. Fennessey. 1994. Flow duration curves I: new interpretation and confidence intervals. Journal of Water Resources Planning and Management 120(4):485-504.

Vogel, R. M. and N. M. Fennessey. 1995. Flow duration curves II: a review of applications in water resources planning. Water Resources Bulletin 31(6):1029-1039.

Wolff, N. 1984. "Water yield" as affected by forestland management in the Pacific Northwest...a literature review. Washington State Department of Natural Resources, Northwest Area.

Wright, K. A. 1985. Changes in storm hydrographs after roadbuilding and selective logging on a coastal watershed in northwestern California. M. S. thesis, Humboldt State University, Arcata, CA. 55 p.

Wright, K. A., K. H. Sendek, R. M. Rice, and R. B. Thomas. 1990. Logging effects on streamflow: storm runoff at Caspar Creek in northwestern California. Water Resources Research 26(7):1657-1667.

Young, R. A. and R. L. Giese. 1990. Introduction to forest science. 2nd ed. John Wiley and Sons, New York, NY.

Ziemer, R. R. 1981. Storm flow response to road building and partial cutting in small streams of northern California. Water Resources Research 17(4):907-917.

Zon, R. 1927. Forests and water in the light of scientific investigation. USDA Forest service. United States Government Printing Office, Washington, D.C. 106 p.

APPENDIX I:

SUMMARY TABLES FOR FOREST HARVEST STUDIES

Table I.1. Summary information for forest harvest study number 1 (Anderson and Hobba, 1959).

Study design	Location	Treated basin(s)	Area (ha)	Latitude and longitude	Elevation mean/range (m)	Ecoregion domain	Vegetation type	Pre-harvest stand age	Soil type and depth (m)	Geology
First, a regression equation was developed using 54 basins to explain peak flows for storms given non-forest related variables. They then took 14 basins within the same area that had at least a 10% change in "age-stocking-effectiveness" and determined a regression coefficient to explain the differences in peak flow based solely on the change in forest cover.	Willamette River basin, OR	Mohawk Mollala Long Tom Willamette	Mohawk: 46,600 Mollala: 83,700 Long Tom: 101,300 Willamette 1,886,000	44° 30' N - 45° 30' N; 123° 30' W - 121° 30' W	200-1200 for the 54 basins	humid temperate	Douglas-fir with some lodgepole pine at higher elevations	various		consolidated and unconsolidated alluvium (marine sediments) with young and old volcanics

Mean slope of the basin (%)	Drainage density (km km^{-2})	Annual precipitation (mm)	Annual ET (mm)	Dominant hydrologic regime	Type of silvicultural method	Percent of vegetation cover removed	Use of buffer strips around waterways	Duration of harvest period (months)	Type of yarding	Type of site preparation
		1120-2640 for the 54 basins		winter rainfall with some rain-on-snow	clearcut large blocks	Mohawk: 4.5% Mollala: 10.7% Long Tom: 4.0% Willamette: 2.3% (all ages of trees adjusted to the equivalent of mature crown closure)				slash was broadcast burned

Road density (km km^{-2})	Percent of area compacted	Type of disturbance	Percent of area disturbed	Season of management activities	Mean slope of treated area (%)	Dominant aspect	Rate of regrowth	Type and frequency of precipitation data	Location of precipitation measurements relative to discharge station
		logging and associated activities; broadcast burned				various			

Discharge record before/after treatment (years)	Author's peak flow criteria	Reported percent change in peak flows	Reported absolute change in peak flows (l. s^{-1} ha^{-1})	Author's low flow criteria	Reported percent change in low flows	Reported absolute change in low flows (l. s^{-1} ha^{-1})	Statistical significance of changes
various	instantaneous peaks		changes for double mass plot/covariance: Mohawk: 790/810 Mollala: 3800/3460 Long Tom: 1700/1560 Willamette: 16,700/16,800 (all values are in units of cfs/flood)				"highly significant"

Table I.2. Summary information for forest harvest study number 2 (Bates and Henry, 1928; Van Haveren, 1987). When information for a category differed between studies, the source of the information is provided in parentheses in the form of the authors' initials.

Study design	Location	Treated basin(s)	Area (ha)	Latitude and longitude	Elevation mean/range (m)	Ecoregion domain	Vegetation type	Pre-harvest stand age	Soil type and depth (m)	Geology
Paired basin study: one control, one clearcut; effects of treatment on peak flows were reanalyzed by Van Haveren using pre- and post-treatment regression analysis.	Wagon Wheel Gap, headwaters of the Rio Grande, CO	B	81	37°46'N; 106°53'W	2818-3338	dry	predominantly aspen with Douglas-fir and Engelmann spruce also present		coarse, sandy soil with many small rock fragments throughout the profile	augite-quartz latite

Mean slope of the basin (%)	Drainage density (km km^{-2})	Annual precipitation (mm)	Annual ET (mm)	Dominant hydrologic regime	Type of silvicultural method	Percent of vegetation cover removed	Use of buffer strips around waterways	Duration of harvest period (months)	Type of yarding	Type of site preparation
26%	0.87	533 (for treated watershed over study period)	380 (the annual amount of water that does not appear as runoff declared to be an evaporative loss by (BH))	precipitation is half snow, half rain; 55% of total annual runoff appears during spring snowmelt	clearcut	100%	up to 25 foot buffer on either side of stream for first year only	all but strip along stream in first summer; strip cut during the following summer	dragged to a road within the basin and removed from there	slash and aspen piled in windrows and burned a year late

Road density (km km^{-2})	Percent of area compacted	Type of disturbance	Percent of area disturbed	Season of management activities	Mean slope of treated area (%)	Dominant aspect	Rate of regrowth	Type and frequency of precipitation data	Location of precipitation measurements relative to discharge station
		logging and related activities; burned	100%	summer	26%	NE	aspen sprouts ranged from 1-2 m in height after seven years	six standard gages, with two tipping bucket recording gages during the warm months only; checked daily at 9:30 except the remote one which was checked every six days	two stations in each basin, located near the discharge stations; one at the top of the control basin, near the top of the treated treated; one at the main headquarters, outside of both basins; recording gages were at the extreme sites

Discharge record before/after treatment (years)	Author's peak flow criteria	Reported percent change in peak flows	Reported absolute change in peak flows (L s^{-1} ha^{-1})	Author's low flow criteria	Reported percent change in low flows	Reported absolute change in low flows (L s^{-1} ha^{-1})	Statistical significance of changes
8/7	average annual maximum daily flow	50% (VH)					0.01

Table I.3. Summary information for forest harvest study number 3 (Bent, 1994; Shanley, Strause, and Risley, 1995). When information for a category differed between studies, the source of the information is provided in parentheses in the form of the authors' initials.

Study design	Location	Treated basin(s)	Area (ha)	Latitude and longitude	Elevation mean/range (m)	Ecoregion domain	Vegetation type	Pre-harvest stand age	Soil type and depth (m)	Geology
Paired basin study: one control, one treated; treatment consisted of two different phases of clearing and thinning small patches within the basin; differences in slopes of pre- and post-treatment regression equations developed from log transformed data were compared using analysis of covariance.	Quabbin Reservoir drainage basin, MA	Dickey Brook	308	42°25' - 42°28' N; 72°20' - 72°22' E	274-351	humid temperate	transition hardwoods: between southern oak-hickory and northern hardwoods forest types; mainly oak (red, black, and white), eastern white pine, maple (red and sugar), eastern hemlock, birch (black, white, and yellow), red pine, ash, hickory, and other minor species.	50 years	fine sandy loam to sandy loam; 0-7 m	glacial till overlying granitic gneiss bedrock; glacial outwash deposits present in some stream channel areas; till in upland areas is a dense basal till which can have perched water tables during the winter through the early spring

Mean slope of the basin (%)	Drainage density (km km^{-2})	Annual precipitation (mm)	Annual ET (mm)	Dominant hydrologic regime	Type of silvicultural method	Percent of vegetation cover removed	Use of buffer strips around waterways	Duration of harvest period (months)	Type of yarding	Type of site preparation
2%	1.07	1248 at weather station 6 km to north	PET: 630	precipitation distributed fairly evenly throughout the year as both rain and snow; rain primary, but peak flows can occur from both snowmelt and rain-on-snow	values are for the whole basin: first cut: 7% whole tree clearcut and 3% thinned (50% of basal area in thinned area whole tree cut) second cut: 2% and 2% in same respective fashion as first cut; only pines were removed.	32% of basal area	mixed: most of the cut area is at least 50 m from the main stream; there is about 100 m of one cut near the gaging station that appears to be very close to the stream; a small stream not shown on the maps feeds from Lily Pond and flows through the large cut area	first cut: 4 months second cut: 1.5 months	feller buncher	parts of largest clearcut area had the stumps removed and were raked, harrowed, and seeded with rye grass; natural regrowth was allowed in all other areas

Road density (km km^{-2})	Percent of area compacted	Type of disturbance	Percent of area disturbed	Season of management activities	Mean slope of treated area (%)	Dominant aspect	Rate of regrowth	Type and frequency of precipitation data	Location of precipitation measurements relative to discharge station
1.19 (existing dirt roads; no new ones were constructed)		logging; parts of largest clearcut had stumps removed and were harrowed, raked, and seeded with rye grass	14%	logging: first cut: late fall, winter, and early spring; second cut: late fall and early winter other activities: late summer and early fall	5%	NW		two continuous recording rain gages and four storage gages	one recording gage in the control basin and one downstream from the treated basin; the two storage gages in or near each basin were monitored weekly

Discharge record before/after treatment (years)	Author's peak flow criteria	Reported percent change in peak flows	Reported absolute change in peak flows (l. s^{-1} ha^{-1})	Author's low flow criteria	Reported percent change in low flows	Reported absolute change in low flows (l. s^{-1} ha^{-1})	Statistical significance of changes
1.5/3	instantaneous peak runoff	no significant difference	no significant difference				

Table I.4. Summary information for forest harvest study number 4 (Blackburn, Knight, Wood, and Pearson, 1990).

Study design	Location	Treated basin(s)	Area (ha)	Latitude and longitude	Elevation mean/range (m)	Ecoregion domain	Vegetation	Pre-harvest stand age	Soil type and depth (m)	Geology
Paired basin study: four treated, one control; various site preparation and grazing practices performed on the treated basins.	56 km east of Lufkin, on the Angelina National Forest, TX	1 2 3 4	1: 3.9 2: 3.9 3: 3.9 4: 3.9	31°30' N; 94°15' W		humid temperate	loblolly, longleaf, and shortleaf pines; southern red oak and sweetgum		fine-textured sandy loam A horizon up to 254 mm thick and clay textured B horizon	in the Yegua geologic formation: stratified sandstone and shale with some siltstone

Mean slope of the basin (%)	Drainage density ($km\ km^{-2}$)	Annual precipitation (mm)	Annual ET (mm)	Dominant hydrologic regime	Type of silvicultural method	Percent of vegetation cover removed	Use of buffer strips around waterways	Duration of harvest period (months)	Type of yarding	Type of site preparation
1-8% for all basins		1219		rainfall fairly well distributed throughout the year with slightly more precipitation occurring during the spring and winter	all were clearcut	1: 100% 2: 100% 3: 100% 4: 100%		1: two months 2: 15% cut then 85% cut, one month each 3: 15% cut then 85% cut, one month each 4: 15% cut then 85% cut, one month each		1: sheared and windrowed 2: roller chopped 3: sheared and windrowed 4: sheared and windrowed

Road density ($km\ km^{-2}$)	Percent of area compacted	Type of disturbance	Percent of area disturbed	Season of management activities	Mean slope of treated area (%)	Dominant aspect	Rate of regrowth	Type and frequency of precipitation data	Location of precipitation measurements relative to discharge station
		1: logged, sheared, windrowed, and continuously grazed 2: logged and roller chopped 3: logged, sheared, and windrowed 4: logged, sheared, windrowed and, rotationally grazed	1: 100% (only 50% was windrowed) 2: 100% 3: 100% 4: 100%	1: cut in late fall and early winter; site preparation in early winter and late spring; grazed in mid-summer to late fall for one year and mid-spring to early fall for two different years 2: 15% cut in late fall, 85% cut in late spring; site preparation in mid-fall 3: 15% cut in late fall, 85% cut in late spring; site preparation in late spring 4: 15% cut in late fall, 85% cut in late spring; site preparation in late spring; grazed in spring, summer, and early fall	1-8%			forester type rain gages located in a network of one gage per two ha; intensity and duration were obtained from recording rain gages	

Discharge record before/after treatment (years)	Author's peak flow criteria	Reported percent change in peak flows	Reported absolute change in peak flows ($L\ s^{-1}\ ha^{-1}$)	Author's low flow criteria	Reported percent change in low flows	Reported absolute change in low flows ($L\ s^{-1}\ ha^{-1}$)	Statistical significance of changes
3/5							

Table I.5. Summary information for forest harvest study number 5 (Blackburn, Wood, and DeHaven, 1986).

Study design	Location	Treated basin(s)	Area (ha)	Latitude and longitude	Elevation mean/range (m)	Ecoregion domain	Vegetation	Pre-harvest stand age	Soil type and depth (m)	Geology
Three replications of three treatments in a randomized block design (three basins per treatment and three controls). Basins grouped by soil types and geomorphic characteristics. Random selection used to determine treatment for each block.	SW Cherokee County, 16 km west of Alto in eastern TX	1 2 3 5 7 9	2.57-2.72 for all nine basins	31°45' N; 95° W		Humid temperate	shortleaf pine and mixed hardwoods	various: selection cutting ended eight years before for two basins and nine years before clearcut for the rest.	78% sandy loam: A horizon up to 25 cm thick with a clay textured B horizon; 22% deep loamy: fine sandy A horizons	marine-deposited sediments of the Queen City Sand geologic formation

Mean slope of the basin (%)	Drainage density (km km^{-2})	Annual precipitation (mm)	Annual ET (mm)	Dominant hydrologic regime	Type of silvicultural method	Percent of vegetation cover removed	Use of buffer strips around waterways	Duration of harvest period (months)	Type of yarding	Type of site preparation
4-25%		1070		rainfall fairly well distributed throughout the year	clearcut	all but buffer strips	6-20 m wide buffer strips on each side of channel	3 months	rubber-tired skidder used to skid logs to landings outside of basin boundaries	1-3: sheared with a V blade, raked into windrows along contours, and burned. 5,7,9: roller chopped with single drum chopper and broadcast burned. Both sets were then hand planted with 1-0 improved loblolly seedlings.

Road density (km km^{-2})	Percent of area compacted	Type of disturbance	Percent of area disturbed	Season of management activities	Mean slope of treated area (%)	Dominant aspect	Rate of regrowth	Type and frequency of precipitation data	Location of precipitation measurements relative to discharge station
0	no landings or roads	1-3: logged, sheared, windrowed and burned. 5, 7 and 9: logged, roller chopped and broadcast burned.	all but buffer strips	summer	4-25%			network of 14 standard and 2 recording rain gages	

Discharge record before/after treatment (years)	Author's peak flow criteria	Reported percent change in peak flows	Reported absolute change in peak flows (L s^{-1} ha^{-1})	Author's low flow criteria	Reported percent change in low flows	Reported absolute change in low flows (L s^{-1} ha^{-1})	Statistical significance of changes
0.5/4.5	instantaneous peaks		post-treatment mean by year: 1981: sheared: 0.049a chopped: 0.025b undisturbed: 0.011c 1982: sheared: 0.014a chopped: 0.004b undisturbed: 0.003b 1983: sheared: 0.014a chopped: 0.006ab undisturbed: 0.004b 1984: sheared: 0.017a chopped: 0.006b undisturbed: 0.005b (annual means followed by the same letter are not significantly different)				0.05

Table I.6. Summary information for forest harvest study number 6 (Brandt, Bergström, and Gardelin, 1988).

Study design	Location	Treated basin(s)	Area (ha)	Latitude and longitude	Elevation mean/range (m)	Ecoregion domain	Vegetation	Pre-harvest stand age	Soil type and depth (m)	Geology
Used hydrological model (PULSE) to compare different pre- and post-treatment scenarios for three different basins; this information was then used to predict results of clearcutting 10% of area at different locations in a larger basin.	Central Sweden	Kullarna Sniptjärn Aspåsen	Kullarna: 150 Sniptjärn: 40 Aspåsen: 16	62° N; 17° E		Polar	moderate continental dark evergreen needleleaf taiga			glacial till

Mean slope of the basin (%)	Drainage density (km km^{-2})	Annual precipitation (mm)	Annual ET (mm)	Dominant hydrologic regime	Type of silvicultural method	Percent of vegetation cover removed	Use of buffer strips around waterways	Duration of harvest period (months)	Type of yarding	Type of site preparation
					clearcut	Kullarna: 70% Sniptjärn: 100% Aspåsen: 85%				Kullarna: drained Sniptjärn: drained

Road density (km km^{-2})	Percent of area compacted	Type of disturbance	Percent of area disturbed	Season of management activities	Mean slope of treated area (%)	Dominant aspect	Rate of regrowth	Type and frequency of precipitation data	Location of precipitation measurements relative to discharge station
		logging	Kullarna: 70% Sniptjärn: 100% Aspåsen: 85%	Kullarna: winter Sniptjärn: fall Aspåsen: winter					precipitation collected from meteorological stations situated 30 km south and 15 km north of the study basins

Discharge record before/after treatment (years)	Author's peak flow criteria	Reported percent change in peak flows	Reported absolute change in peak flows (L s^{-1} ha^{-1})	Author's low flow criteria	Reported percent change in low flows	Reported absolute change in low flows (L s^{-1} ha^{-1})	Statistical significance of changes
Kullarna: 3/3.5 Sniptjärn: 3/3.5 Aspåsen: 3/1.5							

Table I.7. Summary information for forest harvest study number 7 (Cheng, 1989).

Study design	Location	Treated basin(s)	Area (ha)	Latitude and longitude	Elevation mean/range (m)	Ecoregion domain	Vegetation	Pre-harvest stand age	Soil type and depth (m)	Geology
Paired basin study; one control, the other salvage logged to control pine beetle epidemic; regression equation developed during calibration, post logging flows compared with predicted.	25 km northwest of Penticton in the Okanagan Highlands of British Columbia, Canada	Camp Creek	3390	49°30' N; 119°45' W	1070-1920 1450	dry	predominantly lodgepole pine with some ponderosa pine, Douglas-fir, Engelmann spruce, and balsam fir	mature	generally medium to coarse textured	granite, granodiorite, and other intrusive igneous rocks

Mean slope of the basin (%)	Drainage density ($km\ km^{-2}$)	Annual precipitation (mm)	Annual ET (mm)	Dominant hydrologic regime	Type of silvicultural method	Percent of vegetation cover removed	Use of buffer strips around waterways	Duration of harvest period (months)	Type of yarding	Type of site preparation
gentle to moderate		600		more than half of precipitation occurs as snow during Nov-Apr; 80% of annual yield occurs Apr-Aug	clearcut	30%				

Road density ($km\ km^{-2}$)	Percent of area compacted	Type of disturbance	Percent of area disturbed	Season of management activities	Mean slope of treated area (%)	Dominant aspect	Rate of regrowth	Type and frequency of precipitation data	Location of precipitation measurements relative to discharge station
		beetle infestation, salvage logging	30%			S			

Discharge record before/after treatment (years)	Author's peak flow criteria	Reported percent change in peak flows	Reported absolute change in peak flows ($l\ s^{-1}\ ha^{-1}$)	Author's low flow criteria	Reported percent change in low flows	Reported absolute change in low flows ($l\ s^{-1}\ ha^{-1}$)	Statistical significance of changes
6/6	annual maximum daily	six-year average: 21%	0.074				0.05

Table I.8. Summary information for forest harvest study number 8 (Cheng, Black, de Vries, Willington, and Goodell, 1975).

Study design	Location	Treated basin(s)	Area (ha)	Latitude and longitude	Elevation mean/range (m)	Ecoregion domain	Vegetation	Pre-harvest stand age	Soil type and depth (m)	Geology
Paired basin study; one control, one treated; differences based on comparison of actual and predicted values determined from a regression of pre-treatment data (21 peak flow events).	Research Forest of the University of British Columbia, near Haney, British Columbia, Canada	1	23.1	49°15' N; 122°30' W	145-455	humid temperate	western hemlock, western red cedar, and Douglas-fir	mature	gravelly sandy loams	bedrock consists of mostly quartz, granodiorite, or diorite; outcrops of quartz show smooth, superficially weathered surfaces free of open joints, suggesting that the bedrock is generally impermeable

Mean slope of the basin (%)	Drainage density (km km^{-2})	Annual precipitation (mm)	Annual ET (mm)	Dominant hydrologic regime	Type of silvicultural method	Percent of vegetation cover removed	Use of buffer strips around waterways	Duration of harvest period (months)	Type of yarding	Type of site preparation
20%		2285		90% of annual precipitation falls during the winter as rainfall; snow does occur, but no snowpack develops; peaks are caused by long duration, steady storms or rain with snowmelt	clearcut	71%	right through most channels	1 month	most by a high lead spar system	

Road density (km km^{-2})	Percent of area compacted	Type of disturbance	Percent of area disturbed	Season of management activities	Mean slope of treated area (%)	Dominant aspect	Rate of regrowth	Type and frequency of precipitation data	Location of precipitation measurements relative to discharge station
	35.5%	Logging, roads, landings, and yarding activities	logging: 71% *the rest: 35.5% *the rest took place within the logged area	early fall		southerly		two recording rain gages and one weather station in each basin	1: all on basin boundaries, throughout the basin 2: (control) weather station on boundary, halfway up basin; rain gages nearby (within 500 m), but downstream from discharge station

Discharge record before/after treatment (years)	Author's peak flow criteria	Reported percent change in peak flows	Reported absolute change in peak flows (l. s^{-1} ha^{-1})	Author's low flow criteria	Reported percent change in low flows	Reported absolute change in low flows (l. s^{-1} ha^{-1})	Statistical significance of changes
1.33/1.33	instantaneous peak flow less the initial baseflow	average: -22%	1.08				0.01

Table I.9. Summary information for forest harvest study number 9 (David, Henriques, and Rego, 1988; David, Henriques, David, Tomé, and Ledger, 1994). When information for a category differed between studies, the source of the information is provided in parentheses in the form of the authors' initials.

Study design	Location	Treated basin(s)	Area (ha)	Latitude and longitude	Elevation mean/range (m)	Ecoregion domain	Vegetation	Pre-harvest stand age	Soil type and depth (m)	Geology
Paired basin study: one clearcut, "control" cut two years before treated; compared hydrographs before and after; no statistics due to small sample size.	60 km north of Lisbon, Portugal	1	15.2	39°15' N; 09°01' W	114-169	humid temperate	even-aged, second rotation *Eucalyptus globulus* plantation	11-12 years	significant amount of clay (12-20%); 0.25-0.45 m	Jurassic and Cretaceous sandstones; bulk density 50 cm below surface of 1.7-1.8 g cm^{-3}.

Mean slope of the basin (%)	Drainage density ($km\ km^{-2}$)	Annual precipitation (mm)	Annual ET (mm)	Dominant hydrologic regime	Type of silvicultural method	Percent of vegetation cover removed	Use of buffer strips around waterways	Duration of harvest period (months)	Type of yarding	Type of site preparation
		800	850 (open water evaporation)	winter rainfall (Oct-Mar); summers are usually very dry	clearcut	100%		3 months		none-coppice regeneration

Road density ($km\ km^{-2}$)	Percent of area compacted	Type of disturbance	Percent of area disturbed	Season of management activities	Mean slope of treated area (%)	Dominant aspect	Rate of regrowth	Type and frequency of precipitation data	Location of precipitation measurements relative to discharge station
		logging; second clearcut in 12 years	100%	late winter to early spring			1-1.5 m tall after six months; up to 20 $m^3\ ha^{-1}\ yr^{-1}$	standard meteorological station; daily information of rainfall and intensity obtained	midway between catchments (approx. 500 m from each one); long-term precipitation and ET values from 9 km away.

Discharge record before/after treatment (years)	Author's peak flow criteria	Reported percent change in peak flows	Reported absolute change in peak flows ($l.\ s^{-1}\ ha^{-1}$)	Author's low flow criteria	Reported percent change in low flows	Reported absolute change in low flows ($l.\ s^{-1}\ ha^{-1}$)	Statistical significance of changes
2/1.5 (DHR) 2/10 (DHDTL)	instantaneous peak (results given here are a comparison of one event from each time period)	600%					

Table I.10. Summary information for forest harvest study number 10 (Dietterick and Lynch, 1989; Lynch, Sopper, and Partridge, 1972; Partridge, 1971; Lynch, Corbett, and Sopper, 1980; Lynch, 1969). When information for a category differed between studies, the source of the information is provided in parentheses in the form of the authors' initials.

Study design	Location	Treated basin(s)	Area (ha)	Latitude and longitude	Elevation mean/range (m)	Ecoregion domain	Vegetation	Pre-harvest stand age	Soil type and depth (m)	Geology
Paired basin study: one control, one treated in three phases with herbicide treatment applied to cut areas in between each phase; designed to determine effects of the size and location of cuts on peak flows and storm flows; regression equation used to predict flows during first growing season after each cut (DL) and between first and second cuts (LSP).	Leading Ridge Experimental Watershed Research Unit, 14 miles SW of State College, PA	LR2	429	40°40'N; 77°54' W	274-442 360	humid temperate	coppice forest of oak, hickory, and maple	uneven aged	lower slopes: silty and stony loams upper and middle slopes: cobbly and stony loams mean depth: 1.68 m I don't know if it was adjusted for coarse fragments; total water storage capacity was 0.74	Lower: Rosehill shale (213 m thick) Upper lower, middle, and part of upper: Castanea sandstone (152 m thick) Ridge: Tuscarora quartzite

Mean slope of the basin (%)	Drainage density (km km^{-2})	Annual precipitation (mm)	Annual ET (mm)	Dominant hydrologic regime	Type of silvicultural method	Percent of vegetation cover removed	Use of buffer strips around waterways	Duration of harvest period (months)	Type of yarding	Type of site preparation
12.1%		930	635	precipitation distributed fairly evenly throughout the year; 10% occurs as snow; heaviest monthly precipitation occurs in Aug	clearcut in three phases	given year (total) 1967: 20%(20%) 1971/72: 25%(45%) 1975/76: 40%(85%)	1967: essentially a complete riparian cut 1971/72: middle slopes of basin 1975/76: upper slopes and ridge top of basin	1967: four months 1971/72: six months 1975/76: six months		first treatment: all slash removed from stream channel and lopped and scattered except on a small area behind the stream gaging station where it was piled and burned; roads and log loading areas seeded and fertilized after logging(LSP); herbicide spray to control stump sprouting (DL and LSP)

Road density (km km^{-2})	Percent of area compacted	Type of disturbance	Percent of area disturbed	Season of management activities	Mean slope of treated area (%)	Dominant aspect	Rate of regrowth	Type and frequency of precipitation data	Location of precipitation measurements relative to discharge station
		1967: logging 1967-1971: herbicide treatment in cut areas 1971/72: logging 1972-1975: herbicide treatment in cut areas 1975/76: logging 1977: herbicide treatment in cut areas	given year (total) 1967: 20%(20%) 1971/72: 25%(45%) 1975/76: 40%(85%)	logging: 1967: mid-winter to mid-spring 1971/72: early winter to mid-spring 1975/76: early winter to mid-spring	12.1%	southeastern	none	three standard and two recording rain gages	located on the study and control basins

Discharge record before/after treatment (years)	Author's peak flow criteria	Reported percent change in peak flows	Reported absolute change in peak flows (l. s^{-1} ha^{-1})	Author's low flow criteria	Reported percent change in low flows	Reported absolute change in low flows (l. s^{-1} ha^{-1})	Statistical significance of changes
7.6/11.5/1.5* * 11.5 is between first and third cuts and 1.5 is after the end of the third cut	(DL): instantaneous peaks for first growing season after each cut (LSP): instantaneous peaks during growing seasons after first cut and the entire period after the first cut.	(DL): 1967: 419.4% 1974: 370.0% 1977: 563.3% (LSP): growing season: 351% entire period: 118%	(DL): 1967: 2.02 1974: 0.70 1977: 1.79 (LSP): growing season: 2.80 entire period: 1.15	number of days that flow in treated basin was below 0.1 csm (LSP)	first year: -71% second year: ns third year: -42% fourth year: -64%	first year: -40 days second year: ns third year: -61 days fourth year: -46 days	0.01 for peak and 0.05 for low flows (LSP)

Table I.11. Summary information for forest harvest study number 11 (Dils, 1953).

Study design	Location	Treated basin(s)	Area (ha)	Latitude and longitude	Elevation mean/range (m)	Ecoregion domain	Vegetation	Pre-harvest stand age	Soil type and depth (m)	Geology
Paired basin study: one control, the other cleared, farmed and grazed. The purpose of the study was to look at the hydrological effects of clearing a forested basin and carrying out current hillslope farming practices. Comparisons were made by regression for the 15-minute unit hydrograph derived from single or uniform summer storms, all storms which had 30-minute intensities greater than 0.90 in hr^{-1} (peaks produced by these storms were compared with peaks from control for same event before and after treatment) and for flood frequencies.	Coweeta Hydrologic Laboratory, NC	WS 3	9.2	35°03' N; 83°25' W	739-952 825	humid temperate	second growth; predominantly oak-chestnut type with cove-hardwood and yellow pine-hardwood types in smaller areas	mixture of second and third growth, youngest were about 35 years old	loam over clay loam over clay loam mixed with disintegrated rock; 0.5-0.7+ m	Archean Carolina gneiss and schist; folded, but no open faults or fractures exist

Mean slope of the basin (%)	Drainage density ($km\ km^{-2}$)	Annual precipitation (mm)	Annual ET (mm)	Dominant hydrologic regime	Type of silvicultural method	Percent of vegetation cover removed	Use of buffer strips around waterways	Duration of harvest period (months)	Type of yarding	Type of site preparation
mean: 51% range: 10-nearly 80%		1814	852 (evaporation from standard evaporation pan)	precipitation distributed throughout the year with less than 5% occurring as snow	clearcut	100%	no buffer strips	nine months		lower portion: stumps over 16" pulled, brush piled around larger stumps and burned Upper portion: slash scattered over ground to form mulch; about same time, fire burned this area (whether before or after cutting is unclear)

Road density ($km\ km^{-2}$)	Percent of area compacted	Type of disturbance	Percent of area disturbed	Season of management activities	Mean slope of treated area (%)	Dominant aspect	Rate of regrowth	Type and frequency of precipitation data	Location of precipitation measurements relative to discharge station
	60%	logged and burned; farmed 7 of 9 years then grazed for 2; grazed for 10 years	logged/burned: 100% farmed and grazed: 25% grazed: 31%	logging: early winter-mid summer farming: mid spring to late fall grazing: year round	mean: 51% range: 10-nearly 80%	SE	In areas allowed to regrow, DBH for dominant trees was 3-3.5 inches and height was 12-15 feet after 12 years.	three standard rain gages and one recording rain gage; standard gages were checked following each storm or as nearly so as possible; charts were changed at least once a week on recording rain gages	One standard gage is located near the discharge station and one near the ridge; the other one, along with the recording rain gage is located towards the middle of the basin

Discharge record before/after treatment (years)	Author's peak flow criteria	Reported percent change in peak flows	Reported absolute change in peak flows ($L\ s^{-1}\ ha^{-1}$)	Author's low flow criteria	Reported percent change in low flows	Reported absolute change in low flows ($L\ s^{-1}\ ha^{-1}$)	Statistical significance of changes
6/12	instantaneous peaks associated with single/uniform, 15-minute, unit summer storms	first six-years: 2"/hr: 282% 3"/hr: 159% 4"/hr: 126% 5"/hr: 114% second six-years: 2"/hr: 145% 3"/hr: 211% 4"/hr: 228% 5"/hr: 234%	first six-years: 2"/hr: 3.4 3"/hr: 4.7 4"/hr: 5.9 5"/hr: 7.3 second six-years: 2"/hr: 1.7 3"/hr: 6.2 4"/hr: 10.7 5"/hr: 15.1				

Table I.12. Summary information for forest harvest study number 12 (Douglass and Swank, 1976; Swank, Swift, and Douglass, 1988). When information for a category differed between studies, the source of the information is provided in parentheses in the form of the authors' initials.

Study design	Location	Treated basin(s)	Area (ha)	Latitude and longitude	Elevation mean/range (m)	Ecoregion domain	Vegetation	Pre-harvest stand age	Soil type and depth (m)	Geology
Paired basin study: one treated, one control; looked at effects of multiple-use management on flows.	Coweeta Hydrologic Laboratory, NC	WS 28	144.1	35°03' N; 83°25' W	964-1551 1200	humid temperate	predominantly mixed hardwood	mixed ages: some old growth and many 40-45 years old	sandy loams with high rock contents	gneiss

Mean slope of the basin (%)	Drainage density (km km^{-2})	Annual precipitation (mm)	Annual ET (mm)	Dominant hydrologic regime	Type of silvicultural method	Percent of vegetation cover removed	Use of buffer strips around waterways	Duration of harvest period (months)	Type of yarding	Type of site preparation
27%	7.5	2270	500	precipitation distributed throughout the year with less than 5% occurring as snow	55% clearcut; 22% thinned	55% cleared; 22% had 50% reduction in BA		12	cabling or ground skidding uphill with crawler tractors; tractors only allowed to operate on ridges between streams if their blades remained out of the ground; fording or skidding across streams prohibited	

Road density (km km^{-2})	Percent of area compacted	Type of disturbance	Percent of area disturbed	Season of management activities	Mean slope of treated area (%)	Dominant aspect	Rate of regrowth	Type and frequency of precipitation data	Location of precipitation measurements relative to discharge station
		clearcut, thinned	clearcut: 55% thinned: 22%	year round	27%	NE	BA = 7.14 and 11.37 m^2 ha^{-1} in the clearcut and 8.22 and 15.04 m^2 ha^{-1} in the thinned area in 1969 and 1975, respectively		

Discharge record before/after treatment (years)	Author's peak flow criteria	Reported percent change in peak flows	Reported absolute change in peak flows (L s^{-1} ha^{-1})	Author's low flow criteria	Reported percent change in low flows	Reported absolute change in low flows (L s^{-1} ha^{-1})	Statistical significance of changes
25/9	(DS): not defined (SSD): peak associated with mean storm	(DS): 33% during logging, down to 10% after four years (SSD): 30% first two years after cutting					

Table I.13. Summary information for forest harvest study number 13 (Duncan, 1986).

Study design	Location	Treated basin(s)	Area (ha)	Latitude and longitude	Elevation mean/range (m)	Ecoregion domain	Vegetation	Pre-harvest stand age	Soil type and depth (m)	Geology
Used regression relationship with storm rainfall (amount of precipitation on day peak flow occurred and previous three days) and time series for both harvested and nearby "control" to determine effects of harvesting over a 30 year period.	Cascades of southwestern WA	Deschutes River (headwaters region)	23,200	46°45' N; 122°30' W	100-1120	humid temperate	Douglas-fir is principal species with western hemlock and Pacific silver fir at the upper elevations		loams and clay loams; < 0.4-1.0 m	volcanic ash mixed with basalt, andesite, basaltic breccia, and welded tuff with local inclusions of sedimentary rock

Mean slope of the basin (%)	Drainage density (km km^{-2})	Annual precipitation (mm)	Annual ET (mm)	Dominant hydrologic regime	Type of silvicultural method	Percent of vegetation cover removed	Use of buffer strips around waterways	Duration of harvest period (months)	Type of yarding	Type of site preparation
upper basin: commonly 70%+ lower basin: 30% and less		1300-2100 from gage to headwaters		winter rain, with accumulations of 25-40 cm of snow occurring at elevations above 850 m (10% of area); rain-on-snow causes largest peaks	clearcutting	49%		over the course of 30 years	major form was high lead cable, with tractor skidding occurring on gentle slopes in lower part of basin during early years of harvesting	broadcast burned in areas of particularly heavy slash concentrations

Road density (km km^{-2})	Percent of area compacted	Type of disturbance	Percent of area disturbed	Season of management activities	Mean slope of treated area (%)	Dominant aspect	Rate of regrowth	Type and frequency of precipitation data	Location of precipitation measurements relative to discharge station
3.08 by end of study period		logged, burned, and roaded over 30 years	49%					continuous recording instruments	in headwaters region since 1975 and at NOAA station 40 km south before 1975

Discharge record before/after treatment (years)	Author's peak flow criteria	Reported percent change in peak flows	Reported absolute change in peak flows (l. s^{-1} ha^{-1})	Author's low flow criteria	Reported percent change in low flows	Reported absolute change in low flows (l. s^{-1} ha^{-1})	Statistical significance of changes
2/30 (harvesting occurred throughout the 30 year period)	maximum instantaneous discharge above the established baseflow	not significant					

Table I.14. Summary information for forest harvest study number 14 (Fowler, Helvey, and Felix, 1987).

Study design	Location	Treated basin(s)	Area (ha)	latitude and longitude	Elevation mean/range (m)	Ecoregion domain	Vegetation	Pre-harvest stand age	Soil type and depth (m)	Geology
Paired basin study: three treated, one control; different harvest methods tested (large and small clearcuts and shelterwood cut).	22 km northwest of Elgin, OR	1 2 4	1: 29.6 2: 24.4 4: 118.1	45°45' N; 118° W	1439-1617 for entire area	dry	predominantly grand fir and subalpine fir; also Engelmann spruce, western larch, Douglas-fir, and lodgepole pine	160 years maximum	volcanic ash silt loam over basaltic silt loam; up to 1.5 m	fractured basalt

Mean slope of the basin (%)	Drainage density (km km^{-2})	Annual precipitation (mm)	Annual ET (mm)	Dominant hydrologic regime	Type of silvicultural method	Percent of vegetation cover removed	Use of buffer strips around waterways	Duration of harvest period (months)	Type of yarding	Type of site preparation
2-25%		1429	1: 1050 2: 947 4: 961 differences between annual precipitation and runoff	80-90% of annual precipitation falls during Oct-May, much as snow; 80% of total annual flow occurs in May-Jun from snowmelt; infrequent winter rain-on-snow events may cause peak flows equal to snowmelt peak flow	1: two large clearcuts 2: shelterwood 4: 10 small clearcuts	1: 43% 2: 50% 4: 22%	1: wide buffer strips 2: riparian zone cut 4: wide buffer strips (buffer strips adjoined the permanent streams)	four months	tractor logged	1: logs machine-piled and burned with unburned remains machine-scattered after burning; 2: burned half of each clearcut and 4 of 10 patch cuts grass seeded

Road density (km km^{-2})	Percent of area compacted	Type of disturbance	Percent of area disturbed	Season of management activities	Mean slope of treated area (%)	Dominant aspect	Rate of regrowth	Type and frequency of precipitation data	Location of precipitation measurements relative to discharge station
1: 2: 0 4:		logging for all; burning and machine scattering in 1; burning in 2	1: 41% 2: 100% 4: 17%	mid-summer to mid-fall		generally northeast		five recording and 12 storage rain gages	throughout the four basins, ranging in elevation from 731-1706 m

Discharge record before/after treatment (years)	Author's peak flow criteria	Reported percent change in peak flows	Reported absolute change in peak flows (l. s^{-1} ha^{-1})	Author's low flow criteria	Reported percent change in low flows	Reported absolute change in low flows (l. s^{-1} ha^{-1})	Statistical significance of changes
10/6	not given	not significant	not significant	not given	not significant	not significant	

Table I.15. Summary information for forest harvest study number 15 (Golding, 1987).

Study design	Location	Treated basin(s)	Area (ha)	Latitude and longitude	Elevation mean/range (m)	Ecoregion domain	Vegetation	Pre-harvest stand age	Soil type and depth (m)	Geology
Paired basin study: one control, one treated. Purpose was to determine effects of harvesting on peak flows in an area where rain-on-snow is common. Compared peak flows by season (summer and late fall-winter). Looked at cumulative peak flows and pre- and post-treatment regressions for all storms lumped together and by three different size classes.	Seymour River drainage basin in the Vancouver Municipal water-supply area, British Columbia, Canada	Jamieson Creek	299	49°40' N; 123° W	305-1310	humid temperate	Douglas-fir, western hemlock, western red cedar, sitka spruce, subalpine mountain hemlock, yellow cedar, and amabilis fir	mature and over-mature		substantial leakage beneath the weir of the control through gravel deposits

Mean slope of the basin (%)	Drainage density ($km\ km^{2}$)	Annual precipitation (mm)	Annual ET (mm)	Dominant hydrologic regime	Type of silvicultural method	Percent of vegetation cover removed	Use of buffer strips around waterways	Duration of harvest period (months)	Type of yarding	Type of site preparation
More than half the area has a slope of 50% or greater		3525		75% of annual precipitation occurs during Oct-Mar; rain-on-snow and snowmelt dominate the hydrograph during this time; 12% of annual precipitation occurs May-Aug when rain dominates	clearcut	19.2%		over the course of seven years		

Road density ($km\ km^{-2}$)	Percent of area compacted	Type of disturbance	Percent of area disturbed	Season of management activities	Mean slope of treated area (%)	Dominant aspect	Rate of regrowth	Type and frequency of precipitation data	Location of precipitation measurements relative to discharge station
pre: negligible post: 1.3		logging, roads	19.2%	summer and ?					

Discharge record before/after treatment (years)	Author's peak flow criteria	Reported percent change in peak flows	Reported absolute change in peak flows ($l\ s^{-1}\ ha^{-1}$)	Author's low flow criteria	Reported percent change in low flows	Reported absolute change in low flows ($l\ s^{-1}\ ha^{-1}$)	Statistical significance of changes
6.5/8.5	instantaneous during both winter and summer	winter: up to a maximum of 13.5% summer: not significant					slope of regressions different at $p = 0.044$

Table I.16. Summary information for forest harvest study number 16 (Gottfried, 1991; Heede and King, 1990; Heede, 1991). When information for a category differed between studies, the source of the information is provided in parentheses in the form of the authors' initials.

Study design	Location	Treated basin(s)	Area (ha)	Latitude and longitude	Elevation mean/range (m)	Ecoregion domain	Vegetation	Pre-harvest stand age	Soil type and depth (m)	Geology
Paired basin study to compare effects of low impact harvesting on water yield and peak flows. Analysis of covariance was used to determine differences between treated and control basins before and after cutting (G). Plot studies were performed throughout the harvested area to determine effects of different degrees of disturbance on sediment and overland flow production (HK). Effects of harvesting on channel morphology were also studied (H).	Thomas Creek basins, 24 km south of Alpine, White Mountains, east-central AZ	South Fork	227.4	33°45' N; 109° 15' W	2545-2789	dry	southwestern mixed conifer: Engelmann spruce, blue spruce, Doug-fir, white fir, corkbark fir, ponderosa pine, southwestern white pine, and quaking aspen	old-growth	"mostly loamy-skeletal mixed; sandy loam textures are common to all nonalluvial surface soils" (G) "high clay content and generally rocky" (HK) 0.51 to over 1.02 m; deepest (over 1.52 m) found in the stream bottom	"The surface geology is attributed to Tertiary and Quaternary basaltic eruptions which produced extensive flows." (G) "The porous bedrock...is represented by volcanic formations of different ages (basalt and cinders), at least 1200 m deep, and possesses very high infiltration capacities. Subsurface flows and deep seepage appear to be considerable" (H)

Mean slope of the basin (%)	Drainage density ($km\ km^{-2}$)	Annual precipitation (mm)	Annual ET (mm)	Dominant hydrologic regime	Type of silvicultural method	Percent of vegetation cover removed	Use of buffer strips around waterways	Duration of harvest period (months)	Type of yarding	Type of site preparation
22%		1964-86 (entire): 768 ± 36 1964-78 (pre): 709 ± 38 1979-86 (post): 878 ± 61	627 (precipitation-runoff)	56% of annual precipitation occurs Oct-May, mostly as snow; Jul and Aug receive the most rainfall due to the monsoon season characteristic of this area; the hydrograph is dominated by snowmelt, with 80% of annual runoff occurring Mar-May	patch cuts; group and single-tree selection cuts	"25.5% of total basal area; timber sale was on 75% of basin" (G) "28% of total basal area; timber sale was on 80% of basin" (HK, H)	"Buffer strips of at least 35 m between roads and channel" (HK) "50 m wide buffer strips" (H)	eight months	crawler tractors-limited to belts of 30-60 m from roads; rubber tired skidders used also	debris was collected for disposal either by hand or by crawler tractors equipped with normal blades

Road density ($km\ km^{-2}$)	Percent of area compacted	Type of disturbance	Percent of area disturbed	Season of management activities	Mean slope of treated area (%)	Dominant aspect	Rate of regrowth	Type and frequency of precipitation data	Location of precipitation measurements relative to discharge station
		single tree selection, group, and patch logging ["groups are much smaller than patches" (H)]; slash removal both by hand and mechanically	75-80%	most was done during late spring and on through the summer; intermittent activity took place in the fall and on through to mid winter.	22%	N, S	generally satisfactory conifer regeneration	recording rain gage, continuous	near the weir

Discharge record before/after treatment (years)	Author's peak flow criteria	Reported percent change in peak flows	Reported absolute change in peak flows ($L\ s^{-1}\ ha^{-1}$)	Author's low flow criteria	Reported percent change in low flows	Reported absolute change in low flows ($L\ s^{-1}\ ha^{-1}$)	Statistical significance of changes
12/8	(G): annual peaks; instantaneous winter and summer peaks (H): annual instantaneous peaks	(G): annual: 64.7% ± 51.5% winter: 59.8% ± 51.9% summer: not significant (H): 62% (p = 0.11)	(G): annual: 0.28 ± 0.23 winter: 0.26 ± 0.23				(G): 0.05 (H): 0.11

Table I.17. Summary information for forest harvest study number 17 (Harr, 1980 and 1976).

Study design	Location	Treated basin(s)	Area (ha)	Latitude and longitude	Elevation mean/range (m)	Ecoregion domain	Vegetation	Pre-harvest stand age	Soil type and depth (m)	Geology
Paired basin study: one control, two treated; only 25% of each basin cut--two units in one and four units in the other; looked at effects of timber harvest on annual yield, low flows, and instantaneous peak flows using correlations with control to develop pre- and post-treatment regressions; peak flows of 5.6 L s^{-1} ha^{-1} on control and associated flows on treated basins were used.	Fox Creek drainage within the Bull Run Municipal Watershed, 40 km east of Portland, OR	FC-1 FC-3	FC-1: 59 FC-3: 71	45°25' N; 122°02' W	Entire site: 840-1070 FC-1: 955 FC-3: 900	humid temperate	primarily old growth Douglas-fir and western hemlock mixed with younger Pacific silver fir	old-growth	loamy; 1-3 m	igneous glacial till over basalt and andesite

Mean slope of the basin (%)	Drainage density (km km^{-2})	Annual precipitation (mm)	Annual ET (mm)	Dominant hydrologic regime	Type of silvicultural method	Percent of vegetation cover removed	Use of buffer strips around waterways	Duration of harvest period (months)	Type of yarding	Type of site preparation
mean: 5-9% (up to 60% near outlets)		2730		winter rainfall (83% of annual precipitation occurs Oct-Apr), resulting in peaks during Nov-Jan; snow is common, resulting in secondary spring snowmelt peak in most years; rain-on-snow accounts for largest rates of runoff	FC-1: clearcut in four units of 3-4 ha each FC-3: clearcut in two units of 8-10 ha each	FC-1: 25% FC-3: 25%	both appear to have been cut away from streams	FC-1: three months FC-3: over the course of three years	FC-1: high-lead FC-3: tractor and high-lead	FC-1: logging residue burned FC-3: not burned

Road density (km km^{-2})	Percent of area compacted	Type of disturbance	Percent of area disturbed	Season of management activities	Mean slope of treated area (%)	Dominant aspect	Rate of regrowth	Type and frequency of precipitation data	Location of precipitation measurements relative to discharge station
	FC-1: 2% FC-3: 0%	FC-1: logged, burned FC-3: logged	FC-1: 25% FC-3: 25%	FC-1: logged late spring to mid-summer; burned in fall FC-3: began and finished in summers		FC-1: N/NW FC-3: N/NW		one recording rain gage, adjusted according to nearby standard rain gage since February, 1972	nearby all three discharge stations, at same elevation

Discharge record before/after treatment (years)	Author's peak flow criteria	Reported percent change in peak flows	Reported absolute change in peak flows (L s^{-1} ha^{-1})	Author's low flow criteria	Reported percent change in low flows	Reported absolute change in low flows (L s^{-1} ha^{-1})	Statistical significance of changes
FC-1: 8/9 FC-3: 9/8	instantaneous peaks	not significant	not significant	summation of monthly water yields for each consecutive month that monthly water yield at the control basin was less than 5 cm; also did number of days streamflow was less than 0.11 L s^{-1} ha^{-1}	Monthly: FC-1: -15 to -20% FC-3: not significant Daily: significant increase in number of days for both basins (i. e., flows decreased)		0.05

Table I.18. Summary information for forest harvest study number 18 (Harr, Fredriksen, and Rothacher, 1979; Harr, 1976). When information for a category differed between studies, the source of the information is provided in parentheses in the form of the authors' initials.

Study design	Location	Treated basin(s)	Area (ha)	Latitude and longitude	Elevation mean/range (m)	Ecoregion domain	Vegetation	Pre-harvest stand age	Soil type and depth (m)	Geology
Paired basin study: one control, three treated; one clearcut, one patch cut, one shelterwood cut (50% BA removed); looked at effect of these treatments on annual and seasonal yield and instantaneous peak flows; used regressions of peak flows greater than 2.2 L s^{-1} ha^{-1}.	Coyote Creek Experimental Watersheds, 55 km southeast of Roseburg, OR	CC-1 CC-2 CC-3	CC-1: 69.2 CC-2: 68.4 CC-3: 49.8	43°N; 123°W	730-1070	humid temperate	Douglas-fir, mixed conifer	100-300+	gravelly loams; Dumont: 1.5 m Straight: 0.5-1 m	underlain by rhyodacitic pyroclastic rocks consisting of welded and nonwelded ash-flow tuffs with andesite and basalt common on ridges

Mean slope of the basin (%)	Drainage density (km km^{-2})	Annual precipitation (mm)	Annual ET (mm)	Dominant hydrologic regime	Type of silvicultural method	Percent of vegetation cover removed	Use of buffer strips around waterways	Duration of harvest period (months)	Type of yarding	Type of site preparation
20-80%		1229 during study	610	89% of annual precipitation occurs Oct-Mar, mostly as rain; snow is common at higher elevations with some accumulation which usually melts within one to two weeks; highest runoff is caused by rain-on-snow events	CC-1: shelterwood CC-2: 20 small clearcuts (0.7-1.4 ha) CC-3: clearcut	CC-1: 50% of BA CC-2: 30% CC-3: 100%		five months	CC-1: tractor CC-2: 14% tractor, 16% high-lead CC-3: 23% tractor, 77% high-lead	CC-1: slash left where it fell; spur roads and landings were scarified and water-barred CC-2 and CC-3: slash piled and burned by tractor or high-lead, depending on area

Road density (km km^{-2})	Percent of area compacted	Type of disturbance	Percent of area disturbed	Season of management activities	Mean slope of treated area (%)	Dominant aspect	Rate of regrowth	Type and frequency of precipitation data	Location of precipitation measurements relative to discharge station
	CC-1: 13 (HHR), 15(H) CC-2: 5 (HHR), 7(H) CC-3: 12 (HHR), 13(H)	logging, roads, slash disposal (slightly = litter layer removed or mixed in with soil; deeply = surface soil removed and subsoil exposed)	slightly: CC-1: 17.0% CC-2: 9.6% CC-3: 28.0% deeply: CC-1: 9.0% CC-2: 5.7% CC-3: 12.0%	roads in summer, logging in late spring to early fall, burn in fall	CC-1: 20-80% CC-2: CC-3: 20-80%	CC-1: E/NE CC-2: NE CC-3: N		climatic station	adjacent to CC-2

Discharge record before/after treatment (years)	Author's peak flow criteria	Reported percent change in peak flows	Reported absolute change in peak flows (L s^{-1} ha^{-1})	Author's low flow criteria	Reported percent change in low flows	Reported absolute change in low flows (L s^{-1} ha^{-1})	Statistical significance of changes
7/5	instantaneous peaks corresponding to peaks ≥ 2.2 L s^{-1} ha^{-1} on control	@ 10.9 L s^{-1} ha^{-1} for control (nine-year return period): CC-1: 47% CC-2: 10% CC-3: 36%					CC-1: 0.05 CC-2: ns CC-3: 0.05

Table I.19. Summary information for forest harvest study number 19 (Harr, Levno, and Mersereau, 1982).

Study design	Location	Treated basin(s)	Area (ha)	Latitude and longitude	Elevation mean/range (m)	Ecoregion domain	Vegetation	Pre-harvest stand age	Soil type and depth (m)	Geology
Paired basin study: one control, two treated; one clearcut, one shelterwood cut-reducing BA by 60% over basin; looked at effect of these treatments on peak flow, annual yield, and low flow using pre- and post-treatment correlations with control.	H. J. Andrews Experimental Forest, 45 miles east of Eugene, OR	HJA-6 HJA-7	HJA-6: 13.0 HJA-7: 15.4	44°12' N; 122°15' W	863-1013 908-1097	humid temperate	primarily Doug-fir	mostly 130 years old with scattered old growth (450 year old)	surface: sandy or silty loams with granular structure; subsoil: loams or clay loams with subangular blocky structure 2-3 m deep along lower portions of main stream channels; 1+ m elsewhere	basalt and andesite lava flows along upper boundaries and near outlets; welded and nonwelded ash flows underlie the middle portions

Mean slope of the basin (%)	Drainage density (km km^{-2})	Annual precipitation (mm)	Annual ET (mm)	Dominant hydrologic regime	Type of silvicultural method	Percent of vegetation cover removed	Use of buffer strips around waterways	Duration of harvest period (months)	Type of yarding	Type of site preparation
20-40%	no stream on map	2190 during study	HJA-6: 740 HJA-7: 1200 (annual precipitation minus annual streamflow) PET: 610	80% of annual precipitation occurs Oct-Mar mostly as rain, but snow is common; rain-on-snow has caused the maximum rates of runoff	HJA-6: clearcut HJA-7: shelterwood cut	HJA-6: 100% HJA-7: 60% of BA (other 40% cut in 1984)	HJA-6: no buffer strips HJA-7: no buffer strips	four months for both	HJA-6: 10% tractor, 90% high lead HJA-7: 60% tractor, 40% high lead	both were broadcast burned

Road density (km km^{-2})	Percent of area compacted	Type of disturbance	Percent of area disturbed	Season of management activities	Mean slope of treated area (%)	Dominant aspect	Rate of regrowth	Type and frequency of precipitation data	Location of precipitation measurements relative to discharge station
	HJA-6: 1.2%	HJA-6: clearcut logged and burned HJA-7: shelterwood logged and burned	HJA-6: 100% HJA-7: 100% logged, 40% burned	cut in late spring and summer; burned in spring for both basins	20-40% for both	HJA-6: S HJA-7: SSE		daily precipitation	near the HJA-7 stream gage

Discharge record before/after treatment (years)	Author's peak flow criteria	Reported percent change in peak flows	Reported absolute change in peak flows (L s^{-1} ha^{-1})	Author's low flow criteria	Reported percent change in low flows	Reported absolute change in low flows (L s^{-1} ha^{-1})	Statistical significance of changes
11/5	maximum instantaneous rate of streamflow attributable to a storm or snowmelt period	for peaks > 4.5 L s^{-1} ha^{-1} (one year return period): not significant	not significant	number of days mean daily flow was less than 0.022 L s^{-1} ha^{-1}	low flow days decreased significantly for both basins, HJA-6 more than HJA-7 (i. e., low flows increased)		0.05

Table I.20. Summary information for forest harvest study number 20 (Harr and McCorison, 1979; Harr, 1986). When information for a category differed between studies, the source of the information is provided in parentheses in the form of the authors' initials.

Study design	Location	Treated basin(s)	Area (ha)	Latitude and longitude	Elevation mean/range (m)	Ecoregion domain	Vegetation	Pre-harvest stand age	Soil type and depth (m)	Geology
Paired basin study: one control, one clearcut; looked at effects of clearcutting on timing and size of instantaneous peak flows; used all flows > 2.2 $L\ s^{-1}\ ha^{-1}$ on control and associated flows on treated to predict peak flow on treated associated with "annual peak flow"; compared snow and rain caused annual peaks both separately and together (HM). (H) later reanalyzed using only those peaks in the logged basin associated with flows > 5.5 $L\ s^{-1}\ ha^{-1}$ in the control that were caused by rain and snowmelt; his reanalysis was essentially a look at each individual storm instead of a development of general pre- and post-treatment relationships.	H. J. Andrews Experimental Forest, 45 miles east of Eugene, OR	HJA-10	10.2	44°12' N; 122°15' W	433-664	humid temperate	primarily 450-year-old Doug-fir mixed with western hemlock and younger Doug-fir	primarily 450-years-old	clay loam; 1.3 m	highly weathered volcanic tuffs and breccias to a depth of 3.7 m; pyroclastic rocks

Mean slope of the basin (%)	Drainage density ($km\ km^{-2}$)	Annual precipitation (mm)	Annual ET (mm)	Dominant hydrologic regime	Type of silvicultural method	Percent of vegetation cover removed	Use of buffer strips around waterways	Duration of harvest period (months)	Type of yarding	Type of site preparation
60% to over 100%	no stream on map	2300	PET: 610	80% of annual precipitation occurs Oct-Apr mostly as rain, but snow is common; rain-on-snow has caused the maximum rates of runoff	clearcut	100%	no buffer strips		running skyline system yarded all logs and unmerchantable material > 20 cm in diameter or > 2.4 m in length uphill to a single landing	slash piled and burned

Road density ($km\ km^{-2}$)	Percent of area compacted	Type of disturbance	Percent of area disturbed	Season of management activities	Mean slope of treated area (%)	Dominant aspect	Rate of regrowth	Type and frequency of precipitation data	Location of precipitation measurements relative to discharge station
0	one to two passes of equip: 10.2% >2 passes of equip: 19.8%	logging activity; piling and burning of slash	litter and soil mixed to depth of 5 cm: 15.8% > 5 cm: 34.4%	spring and summer	60% to over 100%	W/SW		daily precipitation	1.5 km from each basin

Discharge record before/after treatment (years)	Author's peak flow criteria	Reported percent change in peak flows	Reported absolute change in peak flows ($L\ s^{-1}\ ha^{-1}$)	Author's low flow criteria	Reported percent change in low flows	Reported absolute change in low flows ($L\ s^{-1}\ ha^{-1}$)	Statistical significance of changes
9/1 (HM) 9/7 (H)	(HM): all annual instantaneous peaks, those annual instantaneous peaks associated with some snowmelt, and those associated with rain only	(HM): all peaks: -32% snow peaks: -36% rain peaks: 1%	all peaks: -3.82 snow peaks: -4.45 rain peaks: 0.10				all peaks: 0.01 snow peaks: 0.01 rain peaks: not significant at 0.05

Table I.21. Summary information for forest harvest study number 21 (Harris, 1977 and 1973; Harr, Harper, Krygier, and Hsieh, 1975; Harr and Krygier, 1972; Harper, 1969; Hsieh, 1970). When information for a category differed between studies, the source of the information is provided in parentheses in the form of the authors' initials.

Study design	Location	Treated basin(s)	Area (ha)	Latitude and longitude	Elevation mean/range (m)	Ecoregion domain	Vegetation	Pre-harvest stand age	Soil type and depth (m)	Geology
Paired basin study: one control, two treated; DC also divided up into subbasins by (HHKH) and analyzed separately; all looked at effects of various levels of harvesting on peak and other flows using typical regression analysis; (H and HHKH) looked at change in peaks associated with mean peak in control--H used flows greater than 50 csm and HHKH used all peak flows as far as I can tell; (HHKH) separated flows into recharging (fall) and recharged (winter) time periods for analysis.	Alsea River basin, eight miles south of Toledo, OR	Needle Branch (NB) Deer Creek (DC) DC-2 DC-3 DC-4	NB: 71 DC: 304 DC-2: 56 DC-3: 40 DC-4: 16	44°30'N-44°34'N; 123°50'W-123°54'W	134-488 combined values for all basins	humid temperate	NB: 85% Doug-fir, 15% alder and vine maple (H 1973); mixed Doug-fir and alder (HHKH); nearly purely Doug-fir (HK 1972) DC: 60% Doug-fir and 40% alder (H 1977; HK 1972); mixed Doug-fir and alder (HHKH)	DC: mixed NB: mixed	Bohannon: medium textured, stony and gravelly; derived from sandstone residuum Slickrock: moderately fine textured, moderately gravelly and cobbly; derived from sandstone residuum NB: 65-75% Bohannon DC: 90% Bohannon Bohannon: <0.61 m Slickrock: up to 1.4 m	thick sequence of micaceous sandstones interbedded with mudstones and siltstones

Mean slope of the basin (%)	Drainage density ($km\ km^{-2}$)	Annual precipitation (mm)	Annual ET (mm)	Dominant hydrologic regime	Type of silvicultural method	Percent of vegetation cover removed	Use of buffer strips around waterways	Duration of harvest period (months)	Type of yarding	Type of site preparation
NB: mean 37% DC: mean 30%	NB: 3.3 DC-4: 1.9	NB: 2483 DC: 2474		90% of annual precipitation occurs in Oct-May, mostly as rain	NB: one large clearcut DC: patch cut in three units (30.8, 26.3, and 18.6 ha)	Due to roads and landings/harvest NB: 5%/82% DC: 4%/25% DC-2: 3%/30% DC-3: 12%/65% DC-4: 0%/90%	NB: no buffer strips DC: 15-30 m buffer strips along all stream channels	nine months; 32 ac in headwaters of NB also logged in early 50s	high-lead predominated, but tractor skidding was done on part of NB	slash on NB and on the lower clear-cut unit in DC was burned

Road density ($km\ km^{-2}$)	Percent of area compacted	Type of disturbance	Percent of area disturbed	Season of management activities	Mean slope of treated area (%)	Dominant aspect	Rate of regrowth	Type and frequency of precipitation data	Location of precipitation measurements relative to discharge station
NB: 14.6 DC: 2.6 DC-2: 6.9 DC-3: 2.6 DC-4: 0.0	NB: 5% DC: 4% DC-2: 3% DC-3: 12% DC-4: 0% (total area in roads and landings)	logged, roaded, and burned	NB: roads: 5% logged/burned: 82% DC: roads: 4% logged: 25% burned: 8% DC-2: roads: 3% logged: 30% DC-3: roads: 12% logged: 65% DC-4: logged: 90%	roads: spring-summer logging: spring-fall burn: fall		NB: S DC: S DC-2: SW DC-3: NE DC-4: SW		weighing rain gage	one near each gaging station at control, NB and DC (discontinued in Feb 1968) and National Weather Service gage 10 km away at Tidewater (used throughout the study)

Discharge record before/after treatment (years)	Author's peak flow criteria	Reported percent change in peak flows	Reported absolute change in peak flows ($L\ s^{-1}\ ha^{-1}$)	Author's low flow criteria	Reported percent change in low flows	Reported absolute change in low flows ($L\ s^{-1}\ ha^{-1}$)	Statistical significance of changes
NB and DC: 7/7 (treatment year excluded) (H) NB and DC: 7/3 for after cutting and 7/1 for after roads; DC-2,3, and 4: 3/3 for after cutting and 3/3 for after roads (HHKH)	(H 1977): mean of instantaneous peaks associated with peak ≥ 50 csm on control (HHKH): mean instantaneous peaks for both fall and winter	(H 1977): NB: 20% DC: 2% (HHKH) only the following were significant: NB: after cutting Fall: 53% Winter: 19% DC-3: after roads Fall: 38% Winter: 15% DC-3: after cutting Fall: 50% Winter: 31%	(H 1977): NB: 10 DC: 8.6 (HHKH) only the following were significant: NB: after cutting Fall: 1.75 Winter: 1.10 DC-3: after roads Fall: 0.55 Winter: 0.55 DC-3: after cutting Fall: 0.33 Winter: 1.32	(H): minimum daily Aug-Sept flows (HK): number of mean daily flows below 1 csm and annual minimum streamflow	(H): not significant (HK): 60% for annual minimum and decreased significantly for low flow days on NB; mixed for low flow days on DC	not significant	Peak flows: (H 1977): not significant at 95% confidence level; (HHKH): all flows for DC-3 and all after cutting flows for NB were significant at the 99% confidence level; all other flows were not significant at the 95% confidence level Low flows: 0.05 (H and HK)

Table I.22. Summary information for forest harvest study number 22 (Hetherington, 1982 and 1987; Hartman and Scrivener, 1990). When information for a category differed between studies, the source of the information is provided in parentheses in the form of the authors' initials.

Study design	Location	Treated basin(s)	Area (ha)	Latitude and longitude	Elevation mean/range (m)	Ecoregion domain	Vegetation	Pre-harvest stand age	Soil type and depth (m)	Geology
Paired basin study: two controls, two treated; both controls and one treated basin were sub-basins within the larger treated basin; each treated basin was calibrated with both control basins--a treatment effect was only considered to have occurred if differences were significant for both controls; looked at effects of logging with various streamside treatments on many things including peak flows using regression analysis of pre- and post-treatment relationships; primary focus on fish habitat.	Carnation Creek, Vancouver Island, British Columbia	entire (B weir) tributary (H weir)	B: 950 H: 12	49°N; 125°W	B: 8-884 H: 152-305	humid temperate	primary forest trees were western hemlock, western red cedar, amabilis fir, Douglas-fir, Sitka spruce, and red alder	old-growth	slope soils: gravelly loam and loamy sand with organic surface layer; valley floor: gravel, alluvial sands, lenses of sandy-clay and organics; most common textures: gsl, gls, ls, and vgls slope soils: mean depth of 0.7 m	Jurassic volcanics of the Bonanza Group

Mean slope of the basin (%)	Drainage density (km km^{-2})	Annual precipitation (mm)	Annual ET (mm)	Dominant hydrologic regime	Type of silvicultural method	Percent of vegetation cover removed	Use of buffer strips around waterways	Duration of harvest period (months)	Type of yarding	Type of site preparation
0->60%; 30-60% dominant		2100-5000		75% of annual precipitation occurs in Oct-Mar; only 5% of annual precipitation occurs as snow	clearcut in 7-95 ha patches	B: 41% H: 90%	many leave (buffer) strips of various widths throughout the basin, but not all channels had these; H did not	B: six winters H: one winter	high-lead and grapple cable	B: prescribed burning of slash and some scarification H: light intensity broadcast burn

Road density (km km^{-2})	Percent of area compacted	Type of disturbance	Percent of area disturbed	Season of management activities	Mean slope of treated area (%)	Dominant aspect	Rate of regrowth	Type and frequency of precipitation data	Location of precipitation measurements relative to discharge station
	H: 6.5% (road area)	H: roads, logging, and burning activities	H: 23% exposed or disturbed mineral soil	B: winter (cut); early fall (burn) H: winter (cut); spring (burn)		B: SW H: E		Weighing precipitation gages, checked either daily (B) or weekly (H); ethylene glycol and mineral oil used to prevent freezing or evaporation	10 locations within or on the perimeter of the basin; one near each weir (B and H)

Discharge record before/after treatment (years)	Author's peak flow criteria	Reported percent change in peak flows	Reported absolute change in peak flows (L s^{-1} ha^{-1})	Author's low flow criteria	Reported percent change in low flows	Reported absolute change in low flows (L s^{-1} ha^{-1})	Statistical significance of changes
B: 5/6/5 H: 5/1/8 (middle number represents years of record during treatment)	maximum instantaneous peak less discharge at initial rise	B: not significant H: 20% (mean)		minimum Jul-Sep daily flows and the number of Jul and Aug days with discharge below a given level	B: not significant H: 78% increase in minimum daily flows for first two years, but only significant with one control; change in number of low flow days was not significant		0.05

Table I.23. Summary information for forest harvest study number 23 (Hewlett and Helvey, 1970; Hibbert, 1969). When information for a category differed between studies, the source of the information is provided in parentheses in the form of the authors' initials.

Study design	Location	Treated basin(s)	Area (ha)	Latitude and longitude	Elevation mean/range (m)	Ecoregion domain	Vegetation	Pre-harvest stand age	Soil type and depth (m)	Geology
Paired basin study: one control, one treated by clearcutting and leaving all material where it fell (i.e., no removal of material); thus the hydrologic changes would be attributed to changes in ET only, not changes in soil characteristics; developed multiple regression equation from all storms which includes an intensity predictor and a dummy variable that interacts with intensity; the dummy variable was either -1 or +1 depending on whether it was pre- or post-treatment; results were not reported for WS 6--information provided for use with FDC analysis.	Coweeta Hydrologic Laboratory, NC	WS 37 WS 6	WS 37: 43.7 WS 6: 8.9	35°03' N; 83°25' W	WS 37: 1036-1609; 1280 WS 6: 696-905	humid temperate	northern red oak, other oaks, maple, and birch; rhododendron and laurel in the understory made up about 25% of the total BA	WS 37: mature hardwood forest WS 6: mixed (12% cut in 1942)	sandy loams with high rock contents	schist and gneiss

Mean slope of the basin (%)	Drainage density ($km\ km^{-2}$)	Annual precipitation (mm)	Annual ET (mm)	Dominant hydrologic regime	Type of silvicultural method	Percent of vegetation cover removed	Use of buffer strips around waterways	Duration of harvest period (months)	Type of yarding	Type of site preparation
WS 37: 70%		WS 37: 2244 WS 6: 1000	WS 37: 660 (based on annual precipitation minus annual runoff)	precipitation distributed throughout the year with less than 5% occurring as snow	WS 37: clearcut WS 6: clearcut	WS 37: 100% WS 6: 100%	WS 37: no buffer strips WS 6: no buffer strips		WS 37: none	WS 37: none WS 6: slash piled and burned; site scarified and planted to grass

Road density ($km\ km^{-2}$)	Percent of area compacted	Type of disturbance	Percent of area disturbed	Season of management activities	Mean slope of treated area (%)	Dominant aspect	Rate of regrowth	Type and frequency of precipitation data	Location of precipitation measurements relative to discharge station
WS 37: 0	WS 37: 0%	WS 37: logged WS 6: logged, burned, scarified	WS 37: 100% WS 6: 100%	WS 6: year round	WS 37: 70%	WS 37: SE WS 6: NW		recording rain gages	11 throughout Coweeta

Discharge record before/after treatment (years)	Author's peak flow criteria	Reported percent change in peak flows	Reported absolute change in peak flows ($l\ s^{-1}\ ha^{-1}$)	Author's low flow criteria	Reported percent change in low flows	Reported absolute change in low flows ($l\ s^{-1}\ ha^{-1}$)	Statistical significance of changes
20/4	mean maximum, one-hour storm, instantaneous peak minus the discharge at beginning of hydrograph rise	7%	0.66				

Table I.24. Summary information for forest harvest study number 24 (Hibbert and Gottfried, 1987).

Study design	Location	Treated basin(s)	Area (ha)	Latitude and longitude	Elevation mean/range (m)	Ecoregion domain	Vegetation	Pre-harvest stand age	Soil type and depth (m)	Geology
Paired basins: one control, two treated; 40 years of hydrologic data analyzed to estimate effects of various treatments on stormflow volumes and peaks; only summer peaks analyzed by looking at pre- and post-treatment relationship between peak and storm rainfall.	Workman Creek in the Sierra Ancha Experimental forest, central AZ	North Fork South Fork	NF: 100 SF: 129	33°45' N; 111°45' W	2025-2374 for entire site	dry	mixed-conifer stands of Douglas-fir, white fir, and ponderosa pine on moist sites and just ponderosa on dry sites; New Mexico locust and Gambel oak are common in understory	old-growth	surface: loam-clay loam; granular or crumb structure; subsurface: clay loam-clay few cm to 5 m	Dripping Springs quartzite intruded by diabase and basalt; Troy sandstone on upper parts of basins

Mean slope of the basin (%)	Drainage density (km km^{-2})	Annual precipitation (mm)	Annual ET (mm)	Dominant hydrologic regime	Type of silvicultural method	Percent of vegetation cover removed	Use of buffer strips around waterways	Duration of harvest period (months)	Type of yarding	Type of site preparation
NF: 20-25% SF: 5-10%		1939-81: 833±38	pre-treatment: 716±20	67% of annual precipitation falls during Oct-May, mostly as snow; rainy season occurs Jul-Sep	NF: 1) cut broadleaves in riparian zone; 2) moist sites adjacent to channel cleared (80 ac); 3) dry site merchantable ponderosa cleared (100 ac) SF: 1) single tree selection (BA reduced by 36%); 2) 60 ac wildfire; 3) commercial harvest to remove most merchantable trees and thin remainder to convert mixed conifer stand to ponderosa with density of 40 ft² ac^{-1}	NF: 75% cover SF: 79% in BA	NF: 1) and 2) none; 3) buffer of grass and brush only SF: none	NF: 1) ?; 2) two months; 3) three months SF: 1) 2.5 years; 2) three months; 3) ?	crawler and rubber-tired skidder	slash piled, some burned

Road density (km km^{-2})	Percent of area compacted	Type of disturbance	Percent of area disturbed	Season of management activities	Mean slope of treated area (%)	Dominant aspect	Rate of regrowth	Type and frequency of precipitation data	Location of precipitation measurements relative to discharge station
		NF: riparian cut, moist and dry sites converted to grassland SF: single tree cut, wildfire, commercial cut/thinning	NF: riparian cut: ? moist site cut: 32% dry site cut: 40% SF: single tree cut: ? wildfire: 19% commercial cut/thinning: 83%	NF: 1) ?; 2) fall; 3) mostly fall SF: 1) all open periods; 2) mostly fall; 3) ?	NF: 20-25% SF: 5-10%	NF: SW SF: NW	rapid growth of *Robinia* spp. and *Quercus* spp.; slow recovery of conifers	recording rain gage	in meadow about 1/4 mile from confluence

Discharge record before/after treatment (years)	Author's peak flow criteria	Reported percent change in peak flows	Reported absolute change in peak flows (l. s^{-1} ha^{-1})	Author's low flow criteria	Reported percent change in low flows	Reported absolute change in low flows (l. s^{-1} ha^{-1})	Statistical significance of changes
14/26 (after treatments began)	maximum hydrograph peak minus initial flow rate at rise of storm hydrograph; only summer storms were used	1" 2" NF Riparian cut: 51% 149% Moist conversion: 304% 411% Dry conversion: 299% 307% SF Single tree: 49% 102% 60-ac burn: 264% 848% Post-burn: -22% 10% Commercial: 54% 91%	1" 2" NF Riparian cut: .03 .25 Moist conversion: .17 .70 Dry conversion: .16 .52 SF Single tree: .08 .44 60-ac burn: .42 3.70 Post-burn: -.03 .04 Commercial: .09 .39				all significant except post-burn category on SF

Table I.25. Summary information for forest harvest study number 25 (Hoover, 1944; Lieberman and Hoover, 1951; Hewlett and Hibbert, 1961; Kovner, 1956). When information for a category differed between studies, the source of the information is provided in parentheses in the form of the authors' initials.

Study design	Location	Treated basin(s)	Area (ha)	Latitude and longitude	Elevation mean/range (m)	Ecoregion domain	Vegetation	Pre-harvest stand age	Soil type and depth (m)	Geology
Paired basin studies: each treated has a control; looked at effects of various cuts on flows.	Coweeta Hydrologic Laboratory, NC	WS 1 WS 13 WS 17 WS 22	WS 1: 16.2 WS 13: 16.2 WS 17: 13.4 WS 22: 24.3	35°03' N; 83°25' W	WS 1: 838 705-988 WS 13: 808 725-912 WS 17: 884 760-1021 WS 22: 1036 847-1244	humid temperate	primarily oaks and hickories	WS 13: mostly second growth with some old growth	gravelly and fine sandy loams with rocks abundant throughout soil profile WS 17: mean >1.2 m	gneiss and metasandstone

Mean slope of the basin (%)	Drainage density (km km^{-2})	Annual precipitation (mm)	Annual ET (mm)	Dominant hydrologic regime	Type of silvicultural method	Percent of vegetation cover removed	Use of buffer strips around waterways	Duration of harvest period (months)	Type of yarding	Type of site preparation
		WS 1: 1725 WS 13: 1829 WS 17: 1895 WS 22: 2068	WS 1: 900 WS 13: 900 WS 17: 900 WS 22: 700 (based on estimates from controls within the study area)	precipitation distributed throughout the year with less than 5% occurring as snow	WS 1: clearcut WS 13: clearcut WS 17: clearcut WS 22: strip cut (alternate strips of 1/2 chain, perpendicular to stream channel)	WS 1: 25% deadened (1954) 100% cut (1956-57) WS 13: 100% WS 17: 100% WS 22: 50%	no buffers	WS 1: WS 13: four months WS 17: three months WS 22:	WS 1: none WS 13: none WS 17: none WS 22: none	WS 1: everything felled, scattered, and partially burned; cut annually and sprayed to prevent regrowth of hardwoods WS 13: everything felled and scattered WS 17: everything felled and scattered; regrowth cut annually for 15 years WS 22: recutting and spraying of regrowth as necessary for five years

Road density (km km^{-2})	Percent of area compacted	Type of disturbance	Percent of area disturbed	Season of management activities	Mean slope of treated area (%)	Dominant aspect	Rate of regrowth	Type and frequency of precipitation data	Location of precipitation measurements relative to discharge station
		WS 1: cut (no timber removed), partially burned WS 13, 17, and 22: cut (no timber removed)	WS 1: 100% WS 13: 100% WS 17: 100% WS 22: 50%	WS 1: winter (cut) WS 13: winter (cut) WS 17: winter-spring (cut) WS 22:		WS 1: S WS 13: NE WS 17: NW WS 22: N	WS 1: cut and sprayed annually WS 13: 10 years later, 800 stems ac^{-1} >2" diameter and over 20' mean height WS 17: cut and sprayed annually most of first 15 years WS 22: cut and sprayed annually first five years		

Discharge record before/after treatment (years)	Author's peak flow criteria	Reported percent change in peak flows	Reported absolute change in peak flows (L s^{-1} ha^{-1})	Author's low flow criteria	Reported percent change in low flows	Reported absolute change in low flows (L s^{-1} ha^{-1})	Statistical significance of changes
WS 1: 20/4 (HH). WS 13: 5/8 (LH); 5/12+ (HH). WS 17: 5/2 (H); 5/8 (LH); 5/12+ (HH). WS 22: 19/5 (HH).	(H), (HH): not defined (LH): percentiles were derived from mean daily flows and represent percent of time flow is equaled or exceeded	WS 1: not seriously affected (HH) WS 13: not affected (HH) WS 17: maximum peaks-not significant (H); storm peaks-not affected (HH) WS 22: not affected (HH) (LH) percentiles: WS 13: 17% (16th), 41% (50th), 62% (84th) WS 17: 45% (16th), 83% (50th), 124% (84th)		Useful ones: flows during Oct-Nov; 1-to-30-consecutive-day minimum flows; instantaneous low flows	Oct-Nov: WS 13: initially high, but decreased with regrowth (curve provided in text) WS 17: 92% Percentages were not given for other criteria tested	Oct-Nov: WS 13: initially high, but decreased with regrowth (curve provided in text) WS 17: 49 mm Consecutive days: WS 13: negligible by 12th year after cutting WS 17: 3.8 mm for day of lowest flow and 13 mm for 30 days Instantaneous low flow: WS 13: 0.10 L s^{-1} ha^{-1} first year, declining with regrowth WS 17: 0.05 L s^{-1} ha^{-1} for last eight years analyzed	none given

Table I.26. Summary information for forest harvest study number 26 (Hsia, 1987).

Study design	Location	Treated basin(s)	Area (ha)	Latitude and longitude	Elevation mean/range (m)	Ecoregion domain	Vegetation	Pre-harvest stand age	Soil type and depth (m)	Geology
Paired basin study: one control, one clearcut with minimal soil disturbance; looked at effects on flows using pre- and post-harvest regression comparison.	Lien-Hua-Chi experimental basins, central Taiwan	LHC-4	5.86	23°56'N; 120°54'E	730-785	Humid tropical	Mixed evergreen hardwood trees: mainly *Cryptocarya chinesis, Tucheria shinkoensis, Engelhardtia roxburghiana* , and *Helicia formosana.*	natural stand 150 years	fine silt loam; 1 m	sandstone and shale

Mean slope of the basin (%)	Drainage density (km km^{-2})	Annual precipitation (mm)	Annual ET (mm)	Dominant hydrologic regime	Type of silvicultural method	Percent of vegetation cover removed	Use of buffer strips around waterways	Duration of harvest period (months)	Type of yarding	Type of site preparation
range: 14-58% mean: 40%		1100-3400 2100 mean		as much as 80% of annual precipitation and 90% of annual discharge occur May-Sep; precipitation is rain	clearcut	100%		three months	skyline	scattered logging debris

Road density (km km^{-2})	Percent of area compacted	Type of disturbance	Percent of area disturbed	Season of management activities	Mean slope of treated area (%)	Dominant aspect	Rate of regrowth	Type and frequency of precipitation data	Location of precipitation measurements relative to discharge station
0		logging	100%	winter and early spring (dry season)	14-58%, 40%	SE	natural regrowth vigorous, therefore re-cut one year later and planted with commercial species		rain measured in each basin and checked with nearby climate station which also provides a long-term record

Discharge record before/after treatment (years)	Author's peak flow criteria	Reported percent change in peak flows	Reported absolute change in peak flows (L s^{-1} ha^{-1})	Author's low flow criteria	Reported percent change in low flows	Reported absolute change in low flows (L s^{-1} ha^{-1})	Statistical significance of changes
eight years total, 62 storms before and 36 after cutting	maximum streamflow since rising of hydrograph (i.e., peak minus baseflow); percentiles represent the percent of time that streamflow is less than or equal to a given flow	25th: 62.0% 50th: 48.0% 75th: 19.8%	25th: 0.53 50th: 0.88 75th: 1.54				

Table I.27. Summary information for forest harvest study number 27 (King, 1989; King and Tennyson, 1984). When information for a category differed between studies, the source of the information is provided in parentheses in the form of the authors' initials.

Study design	Location	Treated basin(s)	Area (ha)	Latitude and longitude	Elevation mean/range (m)	Ecoregion domain	Vegetation	Pre-harvest stand age	Soil type and depth (m)	Geology
Paired basin study: one control, six treated (two only had roads put in); designed to look at effects of vegetation removal by roading and harvesting on annual yield and various peak flows; (KT): looked at effect of roads only (Q_{peak}, Q_5, Q_{25}, and Q_{75}); (K) looked at roads and harvesting (Q_{peak}, Q_5, maximum mean daily, and maximum mean monthly).	Horse Creek research basins in Nez Perce National Forest, north-central ID	8 10 12 14 16 18	8: 147.7 10: 65.2 12: 83.8 14: 62.3 16: 21.9 or 28.3 18: 86.2	46° N; 115°30' W	8: 1521 10: 1521 12: 1574 14: 1596 16: 1659 18: 1664 entire area: 1250-1803	dry	grand fir and western red cedar		surface: loam-silt loam; subsoil: loam-sandy loam; substratum: sandy loam-very gravelly sandy loam surface: 0.17-0.53 m; subsoil: 0.56-0.71 m; substratum: 1.02-1.55 m	metamorphosed sedimentary material correlated with the Belt Super Group; rocks primarily of micaceous gneissic material with large proportions of quartz, plagioclase, muscovite, and biotite

Mean slope of the basin (%)	Drainage density (km km^{-2})	Annual precipitation (mm)	Annual ET (mm)	Dominant hydrologic regime	Type of silvicultural method	Percent of vegetation cover removed	Use of buffer strips around waterways	Duration of harvest period (months)	Type of yarding	Type of site preparation
median is 31% for all basins, but slopes frequently exceed 65%		1168		70% of annual precipitation occurs as snow during Nov-Apr; 65% of annual streamflow occurs Apr-Jun; maximum instantaneous and maximum daily flows are usually the result of rain on already melting snow	clearcut in patches ranging from 9-35 ac	Due to roads/harvest 8: 3.7% 10: 2.6% 12: 3.9%/36.6% 14: 1.8%/29.2% 16: 3.0%/25.0% 18: 4.3%/33.4%			8: none 10: none 12: skyline 14: tractor 16: tractor 18: tractor	8 and 10: none 12, 14, 16, and 18: broadcast burned

Road density (km km^{-2})	Percent of area compacted	Type of disturbance	Percent of area disturbed	Season of management activities	Mean slope of treated area (%)	Dominant aspect	Rate of regrowth	Type and frequency of precipitation data	Location of precipitation measurements relative to discharge station
8: 2.8 10: 2.1 12: 1.9 14: 1.5 16: 1.6 or 2.0 18: 2.1	8: 3.7% 10: 2.6% 12: 3.9% 14: 1.8% 16: 3.0% 18: 4.3% by roads	logged, broadcast burned, and roads	8: 3.7% (roads) 10: 2.6% (roads) 12: 36.6% (all) 14: 29.2% (all) 16: 25.0% (all) 18: 33.4% (all)	summer for road construction; fall for burn; logging?		8: SE 10: SE 12: S 14: S 16: S 18: S		eight precipitation gages	throughout the Horse Creek drainage; one was located near basin 16 discharge station

Discharge record before/after treatment (years)	Author's peak flow criteria	Reported percent change in peak flows	Reported absolute change in peak flows (L s^{-1} ha^{-1})	Author's low flow criteria	Reported percent change in low flows	Reported absolute change in low flows (L s^{-1} ha^{-1})	Statistical significance of changes
4/1 or 2 (KT) 4/5 (K)	(K): instantaneous, maximum daily, and 5% equaled or exceeded (KT): Q_{peak} = maximum instantaneous annual; Q_5, Q_{25}, and Q_{75} = flows are equaled or exceeded 5%, 25%, and 75% of the time respectively (based on mean daily flows?)	after roads (only Q_5 and Q_{25} were significantly different and only for basins 18 and 12, respectively): 18(Q_5): -29.4% and -19.2% for the two years of record 12(Q_{25}): 30.5% for the one year of record After roads and cut: max inst./daily/5% exceed: 12: 15%/34%/26% 14: 35%/50%/30% 16: 36%/74%/10% 18: 34%/87%/15%	After roads: 18(Q_5): -0.21 and -0.10 12(Q_{25}): 0.03	Q_{min}: minimum annual flow $Q_{7.5}$: flow equaled or exceeded 75% of the time (represents low flows which normally occur in the late summer and fall seasons)	not significant for any basin	not significant for any basin	Peak flow: After roads: 0.05 After roads and cut: max inst/daily/5%: 12: ns/0.01/0.01 14: 0.05/0.01/0.01 16: 0.10/0.05/ns 18: 0.01/0.01/0.05 Low flow: 0.05

Table I.28. Summary information for forest harvest study number 28 (Langford, Moran, and O'Shaughnessy, 1982; Vertessy, Hatton, Benyon, and Dawes, 1996). When information for a category differed between studies, the source of the information is provided in parentheses in the form of the authors' initials.

Study design	Location	Treated basin(s)	Area (ha)	Latitude and longitude	Elevation mean/range (m)	Ecoregion domain	Vegetation	Pre-harvest stand age	Soil type and depth (m)	Geology
Paired basin study: one control, two treated; one clearcut and other selection cut-both with leave strips around watercourses; compared pre- and post-treatment flows using two different methods: one predicted response based on soil moisture levels in control and other based predicted response on mathematical water balance model.	Coranderrk Experimental Area, near Healesville, Victoria, Australia	Picaninny Blue Jacket	Pic: 52.8 BJ: 64.8	37°30'S; 145°30'E	Pic: 230-780 entire area: 230-850	humid temperate	predominantly old growth mountain ash (*Eucalyptus regnans*) with lesser occurrences of 1939 regrowth mountain ash, mixed species eucalypt forest, and scrub	mostly old growth (200 years old); small amount 30 years old	gradational clay loams; (LMO): 10-15 m (VHBD): 5-20 m	dacitic parent rock

Mean slope of the basin (%)	Drainage density (km km^{-2})	Annual precipitation (mm)	Annual ET (mm)	Dominant hydrologic regime	Type of silvicultural method	Percent of vegetation cover removed	Use of buffer strips around waterways	Duration of harvest period (months)	Type of yarding	Type of site preparation
(LMO): Pic: 80% over 36% BJ: 57% over 36% (VHBD): Pic: 37%		(LMO): 1250-1630 increasing west to east across experimental area. (VHBD): Pic: 1180		(LMO): 75% of annual rainfall occurs Apr-Nov (i.e., winter rainfall) (VHBD): evenly distributed throughout the year	Pic: clearcut with 20 m buffer strips on each side of waterways BJ: selection cut with 20 m buffer strips on each side of waterways	Pic: 86%, 89%, and 88%* BJ: 59%, 65%, and 27%* *area, stems, and BA (VHBD): Pic: 78%	20 m exclusion strip on each side of all definite water courses and associated swampy areas	Pic: five months BJ: four months	prepared at stump, skidded to landings by tractors along slopes	Pic: intense burn of residual debris to expose soil for seeding BJ: none

Road density (km km^{-2})	Percent of area compacted	Type of disturbance	Percent of area disturbed	Season of management activities	Mean slope of treated area (%)	Dominant aspect	Rate of regrowth	Type and frequency of precipitation data	Location of precipitation measurements relative to discharge station
Pic: 2.3 BJ: 3.7 permanent roads	Pic: 9% BJ: 6%	logging activities and roads; Pic also was burned and had firebreaks	Pic: 20% BJ: 20% compacted, buried or disturbed surface horizons	Pic: mid-spring to mid- fall BJ: mid-spring to early fall	Pic: 80% over 36% BJ: 57% over 36%	Pic: SSW BJ: S (southern hemisphere)	Pic: five years later, eucalyptus 10 m high with average density of 3400 stems ha^{-1} (range: 500-6000 stems ha^{-1}); also had vigorous understory growth BJ: five years later, various densities of overstory and dense understory	13 standard and 4 recording rain gages; all were read weekly and at the end of each month	throughout the study area

Discharge record before/after treatment (years)	Author's peak flow criteria	Reported percent change in peak flows	Reported absolute change in peak flows (l. s^{-1} ha^{-1})	Author's low flow criteria	Reported percent change in low flows	Reported absolute change in low flows (l. s^{-1} ha^{-1})	Statistical significance of changes
Pic: 2/1/6 BJ: 2/2/5 middle values are years between road construction and harvest	instantaneous peaks	Pic: approximately 100% during stormflows for first two years BJ: not significant					

Table I.29. Summary information for forest harvest study number 29 (Leitch and Flinn, 1986; Bren and Papworth, 1991; Bren, Flinn, Hopmans, and Leitch, 1979). When information for a category differed between studies, the source of the information is provided in parentheses in the form of the authors' initials.

Study design	Location	Treated basin(s)	Area (ha)	Latitude and longitude	Elevation mean/range (m)	Ecoregion domain	Vegetation	Pre-harvest stand age	Soil type and depth (m)	Geology
Paired basin study: one control, one clearcut using crawler tractors connected with a heavy chain; buffer strips left around stream totaling 6% of area; designed to look at effects of cutting native vegetation and planting *Pinus radiata* on different flows using pre- and post-treatment regression comparison.	Buffalo River basin, Cropper Creek Hydrological Project, 28 km SE of Myrtleford in NE Victoria, Australia	Clem	46.4	36°47'S; 146°33'E	484-734	humid temperate	dry sclerophyll open forest that generally carries little merchantable timber; *Eucalyptus* spp.	uneven-aged	(LF): high permeability with high surface cover of fractured rock on ridges and loams in gullies; (BP): lower slope soil was clay-loam, upper slopes were skeletal and undeveloped; (LF): shallow on ridges and deep in gullies; (BP): 2 m to saprolite on lower slopes	(LF): bedrock consists of tightly folded, fractured, and steeply dipping sequence of Ordovician sediments (BP): dominant rock type was quartzitic sandstones and slates

Mean slope of the basin (%)	Drainage density (km km^{-2})	Annual precipitation (mm)	Annual ET (mm)	Dominant hydrologic regime	Type of silvicultural method	Percent of vegetation cover removed	Use of buffer strips around waterways	Duration of harvest period (months)	Type of yarding	Type of site preparation
(LF): 36-58% (BP): range of 17-58%, with most between 36-47%		(LF): 1000-1400 usually; 1419 during study period. (BP): 1400	1000	rainfall occurring mostly during the winter and spring	clearcut (flattened) with 30 m buffer strips on either side of stream and 50 m above springhead	94%	30 m buffer on either side and 50 m above perennial springhead of creek	five months	felled by two crawler tractors joined by heavy duty chain, with a third used as a "pusher" for particularly resistant trees	debris left to dry and then broadcast burnt

Road density (km km^{-2})	Percent of area compacted	Type of disturbance	Percent of area disturbed	Season of management activities	Mean slope of treated area (%)	Dominant aspect	Rate of regrowth	Type and frequency of precipitation data	Location of precipitation measurements relative to discharge station
0	5%	uprooting of all trees using bulldozers and broadcast burning of the debris	94%	cleared in winter burned in mid-spring	(LF): 36-58% (BP): range of 18-58%, with most 36-47%	NE (southern hemisphere)	recolonization by ferns was rapid, planted pines reached height of 1.5 m by 2-2/3 years later; by 1990, crown closure over most of the stand of radiata pine was observed	Rauchfuss tipping bucket gages recorded on stream height chart and storage gages	one next to each weir plus five auxiliary stations distributed throughout the study basins

Discharge record before/after treatment (years)	Author's peak flow criteria	Reported percent change in peak flows	Reported absolute change in peak flows (L s^{-1} ha^{-1})	Author's low flow criteria	Reported percent change in low flows	Reported absolute change in low flows (L s^{-1} ha^{-1})	Statistical significance of changes
(LF): 5/3 (BP): 5/4	peak instantaneous flows for stormflows which could be detected on the annual plots of mean daily flow for the control	(LF): generally 40-60% increase of larger storms; some (those occurring during annual recharge period) were substantially higher					0.001

Table I.30. Summary information for forest harvest study number 30 (Lyons and Beschta, 1983).

Study design	Location	Treated basin(s)	Area (ha)	Latitude and longitude	Elevation mean/range (m)	Ecoregion domain	Vegetation	Pre-harvest stand age	Soil type and depth (m)	Geology
Analyzed discharge data, aerial photos, and maps from the Middle Fork Willamette River over a 45 year period to determine the effects of harvesting and road building over time on peak flows, landslides, and channel changes; looked at peak flows over 100 $m^3 s^{-1}$.	Middle Fork Willamette River, OR	Upper Middle Fork Willamette River	6680	43°20'N-43°40'N; 122°5'W-122°30'W	260-2664	humid temperate	below 1000 m, typical western hemlock zone; above 1000 m, typical Pacific silver fir zone			tuff, breccia, basaltic andesite, and basalt of Oligocene and Miocene age

Mean slope of the basin (%)	Drainage density ($km\ km^{-2}$)	Annual precipitation (mm)	Annual ET (mm)	Dominant hydrologic regime	Type of silvicultural method	Percent of vegetation cover removed	Use of buffer strips around waterways	Duration of harvest period (months)	Type of yarding	Type of site preparation
		1500		winter rain and rain-on-snow	usually clearcut	15% by 1979		30 years		

Road density ($km\ km^{-2}$)	Percent of area compacted	Type of disturbance	Percent of area disturbed	Season of management activities	Mean slope of treated area (%)	Dominant aspect	Rate of regrowth	Type and frequency of precipitation data	Location of precipitation measurements relative to discharge station
		timber harvesting and roading	harvesting: 15% by 1979 roading: 8% by 1979					rain gage	24 km south of the Middle Fork Willamette River Basin

Discharge record before/after treatment (years)	Author's peak flow criteria	Reported percent change in peak flows	Reported absolute change in peak flows ($L\ s^{-1} ha^{-1}$)	Author's low flow criteria	Reported percent change in low flows	Reported absolute change in low flows ($L\ s^{-1} ha^{-1}$)	Statistical significance of changes
							0.01

Table I.31. Summary information for forest harvest study number 31 (Megahan, King, and Seyedbagheri, 1995; Megahan, 1987). When information for a category differed between studies, the source of the information is provided in parentheses in the form of the authors' initials.

Study design	Location	Treated basin(s)	Area (ha)	Latitude and longitude	Elevation mean/range (m)	Ecoregion domain	Vegetation	Pre-harvest stand age	Soil type and depth (m)	Geology
Paired basin study: one control, one had 23% of area cut and logged using helicopters; study was primarily on the effects of helicopter logging and broadcast burning on sedimentation, but it included a study of peak flows.	headwaters of the Payette River basin, south-central ID	WSD6	162	44°25'N; 115°45'W	1420-1780 1725	dry	ponderosa pine and Doug-fir	mature and old-growth	loamy sands to sandy loams; generally <1 m	granitic bedrock of the Idaho Batholith (coarse-grained quartz monzonite)

Mean slope of the basin (%)	Drainage density (km km^{-2})	Annual precipitation (mm)	Annual ET (mm)	Dominant hydrologic regime	Type of silvicultural method	Percent of vegetation cover removed	Use of buffer strips around waterways	Duration of harvest period (months)	Type of yarding	Type of site preparation
47%	4.2	1000	650	65% of annual precipitation occurs as snow; maximum streamflows occurred during spring snowmelt months of Mar-May	cut in three patches ranging from 8-18 ha in size and totaling 38 ha; only trees 25 cm DBH or larger were cut, but basically all trees fell into this category	23%	buffer strips averaged 15 m in width around all perennial streams	three months	helicopter	slash lopped, scattered, and broadcast burned; only about 50% of each cutting unit was burned due to the presence of scattered snow on the ground

Road density (km km^{-2})	Percent of area compacted	Type of disturbance	Percent of area disturbed	Season of management activities	Mean slope of treated area (%)	Dominant aspect	Rate of regrowth	Type and frequency of precipitation data	Location of precipitation measurements relative to discharge station
0	0	logging and site preparation activities	23%	fall-winter	24-97%; 47% mean	S (mean)	"not discernible"	recording raingage network, storage gages, and nuclear snow gage	variable by season and type of equipment used

Discharge record before/after treatment (years)	Author's peak flow criteria	Reported percent change in peak flows	Reported absolute change in peak flows (L s^{-1} ha^{-1})	Author's low flow criteria	Reported percent change in low flows	Reported absolute change in low flows (L s^{-1} ha^{-1})	Statistical significance of changes
11/10	annual instantaneous peak (snowmelt peak) less base flow	not significant	not significant				0.05

Table I.32. Summary information for forest harvest study number 32 (Miller, 1984).

Study design	Location	Treated basin(s)	Area (ha)	Latitude and longitude	Elevation mean/range (m)	Ecoregion domain	Vegetation	Pre-harvest stand age	Soil type and depth (m)	Geology
Paired basin study: three blocked pairs (three controls, three treated); treated were clearcut and mechanically site prepped in order to convert to even-aged management; looked at treatment effects on storm and peak flows and sediment yield; ranks of observations within blocks were compared using regular ANOVA procedures because the original data were not normally distributed.	Weyerhauser Company lands in Ouachita Mountains of McCurtain County, OK	1, 2, 3 (#s represent pairs of control and treated basins)	1.6-4.2	34°30'N; 95°W	mean of entire area 335	humid temperate	predominately shortleaf pine with minor amount of hardwoods	50-60 years	loamy A over silty clay B; Redland Rocky series contains 40%+ large angular sandstone in the A horizon; A: 0.25-0.30 m total: mean 0.9 m	sandstone and shale of the Atoka Formation

Mean slope of the basin (%)	Drainage density ($km\ km^{-2}$)	Annual precipitation (mm)	Annual ET (mm)	Dominant hydrologic regime	Type of silvicultural method	Percent of vegetation cover removed	Use of buffer strips around waterways	Duration of harvest period (months)	Type of yarding	Type of site preparation
15%		1290	1780 (PET from evaporation pan)	rainfall distributed throughout the year; summer and fall droughts are common	clearcut	100%	no buffer strips	cut: two months site preparation: two months	hand-felled trees skidded with rubber-tired skidders; sheared trees yarded by mechanical shearer (I assume); all skidding done uphill	residual timber chopped with self-propelled tree crushers and then burned (hot with good area coverage); contour ripped with Caterpillar D-8 crawler along contour, 2.5 m apart and 45 cm deep on average everywhere except in channel

Road density ($km\ km^{-2}$)	Percent of area compacted	Type of disturbance	Percent of area disturbed	Season of management activities	Mean slope of treated area (%)	Dominant aspect	Rate of regrowth	Type and frequency of precipitation data	Location of precipitation measurements relative to discharge station
none		logging; contour ripping or subsoiling; not extended into channels, but equipment passed through them; hot burn	100%	cut: summer site preparation: fall	15%	SW	rapid: grasses first growing season, pine seedlings 3' tall after second growing season	four tipping-bucket and standard 10-cm collection gages	distributed throughout the study area

Discharge record before/after treatment (years)	Author's peak flow criteria	Reported percent change in peak flows	Reported absolute change in peak flows ($l\ s^{-1}\ ha^{-1}$)	Author's low flow criteria	Reported percent change in low flows	Reported absolute change in low flows ($l\ s^{-1}\ ha^{-1}$)	Statistical significance of changes
0.5-1/4	instantaneous peaks	all single-storm peaks: not significant; eight largest: not significant	all single-storm peaks: not significant; eight largest: not significant				all: $p > 0.06$ eight largest: $p > 0.50$

Table I.33. Summary information for forest harvest study number 33 (Miller, Beasley, and Lawson, 1988).

Study design	Location	Treated basin(s)	Area (ha)	Latitude and longitude	Elevation mean/range (m)	Ecoregion domain	Vegetation	Pre-harvest stand age	Soil type and depth (m)	Geology
Randomized block design: three blocks of three basins each; one control, one clearcut, and one selection cut in each block; compared individual storms using observation ranks and ANOVA model with precipitation and soil moisture deficit as covariates; designed to look at the effects of different treatments on storm and peak flows.	Alum Creek and Cedar Mountain basins, Ouachita Mountains, 35 km north of Hot Springs, AR	Cedar Mtn. (block 1): 10, 11, and 12; Alum Ck. (block 2): 13, 14, and 15; (block 3): 16, 17, and 18 (11, 13, and 16 were controls)	10: 5.74 12: 5.91 14: 4.35 15: 5.11 17: 4.15 18: 4.08	34°45'N; 93°W.	mean of entire area 340	humid temperate	mixed: shortleaf pine, oak, and hickory	50-60 years	Cedar Mtn.: loamy A; clay B; hard sandstone rock common throughout profile, averages <30% by volume; A to 0.25 m, total to 0.5-1.0 m Alum Ck.: normally overlain by sandstone rock pavement; loamy A; clayey B; A to 0.15 m, total to 1.0 m	Cedar Mtn.: soft-hard sand stone Alum Ck.: shale bedded at steep angles and highly fractured

Mean slope of the basin (%)	Drainage density ($km\ km^{-2}$)	Annual precipitation (mm)	Annual ET (mm)	Dominant hydrologic regime	Type of silvicultural method	Percent of vegetation cover removed	Use of buffer strips around waterways	Duration of harvest period (months)	Type of yarding	Type of site preparation
15% (steeper slopes up to 30% are common)		1317	860	rain, precipitation as snow or ice is negligible	10, 14, and 17: selection cut 12, 15, and 18: clearcut	12, 15, and 18: 100%	no buffer strips for any logging activities		rubber-tired cable skidders dragged delimbed, tree-length stems uphill to log decks located on ridgetops within the basin	12, 15, and 18: a tractor-drawn drum chopper crushed the residual vegetation prior to burning 10, 14, and 17: none

Road density ($km\ km^{-2}$)	Percent of area compacted	Type of disturbance	Percent of area disturbed	Season of management activities	Mean slope of treated area (%)	Dominant aspect	Rate of regrowth	Type and frequency of precipitation data	Location of precipitation measurements relative to discharge station
none		12, 15, and 18: logging and site preparation activities 10, 14, and 17: logging activities	12, 15, and 18: 100%	cut: summer site preparation: later summer-fall	15%	10, 12: W-NW 14, 15: E-SE 17, 18: N		weighing bucket recording gages and standard Weather Bureau-type gages	4 weighing gages, 11 standard gages, and 2 weather stations located throughout the study areas

Discharge record before/after treatment (years)	Author's peak flow criteria	Reported percent change in peak flows	Reported absolute change in peak flows ($L\ s^{-1}\ ha^{-1}$)	Author's low flow criteria	Reported percent change in low flows	Reported absolute change in low flows ($L\ s^{-1}\ ha^{-1}$)	Statistical significance of changes
2/3	instantaneous	not significant	not significant				p-values ranged from 0.092 to 0.887

Table I.34. Summary information for forest harvest study number 34 (Mumeka, 1986).

Study design	Location	Treated basin(s)	Area (ha)	Latitude and longitude	Elevation mean/range (m)	Ecoregion domain	Vegetation	Pre-harvest stand age	Soil type and depth (m)	Geology
Paired basin study; one control, two treated by clearing most woodland vegetation and converting to farm and pasture land; designed to look at the effects of these conversions on runoff; peak flows were compared using unit hydrographs developed from storms with approximately one hour of effective rainfall during the rainy season.	Luano Catchments, headwaters of Kafue River, Zambia	A: G:	A: 142.6 G: 94.6	13°S; 28°E	1300 mean for entire area	humid tropical	mixed Miombo woodland dominated by *Brachystegia* spp.	virgin stands		

Mean slope of the basin (%)	Drainage density (km km^{-2})	Annual precipitation (mm)	Annual ET (mm)	Dominant hydrologic regime	Type of silvicultural method	Percent of vegetation cover removed	Use of buffer strips around waterways	Duration of harvest period (months)	Type of yarding	Type of site preparation
		study period: 1400 long term: 1314		rain occurring from Nov-Apr	clearcut except for buffer strips	A: woodland: 83% of area, 98% of trees; basin: 75% of area, 81% of trees G: woodland: 85% of area, 99% of trees; basin: 75% of area, 84% of trees	60 m buffer strip around each dambo (essentially a seasonally inundated grassland); these in turn make up much of the area immediately adjacent to streams			none, turned into farmland and pasture

Road density (km km^{-2})	Percent of area compacted	Type of disturbance	Percent of area disturbed	Season of management activities	Mean slope of treated area (%)	Dominant aspect	Rate of regrowth	Type and frequency of precipitation data	Location of precipitation measurements relative to discharge station
		A: 10% logged and then farmed for three years using practices that control erosion and soil loss; 65% logged and then put into pasture (grazed by 10 steers) G: same disturbances as in A, but 7% and 68%, respectively	A: 75% G: 75%	fall (prior to the onset of the rainy season)		A: E-NE G: S	controlled for five years	Casella siphon and tilting siphon rainfall recorders were used together with standard rain gages; autographic charts changed daily and standard gages measured daily	four recording gages and seven standard gages distributed throughout each basin; one recording gage at each discharge station; many other gages near the study basins

Discharge record before/after treatment (years)	Author's peak flow criteria	Reported percent change in peak flows	Reported absolute change in peak flows (L s^{-1} ha^{-1})	Author's low flow criteria	Reported percent change in low flows	Reported absolute change in low flows (L s^{-1} ha^{-1})	Statistical significance of changes
8/5	one-hour storm unit hydrograph peaks	nearly doubled					

Table I.35. Summary information for forest harvest study number 35 (Nakano, 1967 and 1971; Maruyama and Inose, 1952; Shimizu, 1983 and 1994; Shimizu, Tsuboyama, and Hosoda, 1994). When information for a category differed between studies, the source of the information is provided in parentheses in the form of the authors' initials.

Study design	Location	Treated basin(s)	Area (ha)	Latitude and longitude	Elevation mean/range (m)	Ecoregion domain	Vegetation	Pre-harvest stand age	Soil type and depth (m)	Geology
Basins were studied before and after a treatment which was not necessarily planned without the use of control basins; compared observed flows with predictions based on relationship with total precipitation for each storm.	K-2: Yamagata prefecture headwater of Mogami River T-K: Okayama prefecture, mid-stream basin of Asahi River, Japan	Kamabuchi-No. 2 (K-2) Tatsunokuchiyama -Kitatani (T-K)	K-2: 2.48 T-K: 17.3	K-2: 38°56'N; 140°16'E T-K: 34°37'N; 133°45'E	K-2: 160-240; 200 T-K: 150	humid temperate	K-2: mainly hardwood stand with mizunara (oak) and buna (beech), but included artificial forests of sugi and hinoki (redwood and cypress families, respectively) T-K: akamatsu (Japanese red pine) and a little artificial stand of hinoki	K-2: 23-30 years	K-2: Andisol K-2: 0.48 m T-K: >1 m	K-2: tuff, shaletic tuff T-K: Paleozoic strata and quartz porphyry

Mean slope of the basin (%)	Drainage density (km km^{-2})	Annual precipitation (mm)	Annual ET (mm)	Dominant hydrologic regime	Type of silvicultural method	Percent of vegetation cover removed	Use of buffer strips around waterways	Duration of harvest period (months)	Type of yarding	Type of site preparation
K-2: 73% T-K: 60%	K-2: 21.1 T-K: 3.35	K-2: 2527 T-K: 1202	K-2: 542 T-K: 859 (pre-treatment annual precipitation minus-runoff)	K-2: 40% of annual precipitation occurs as snow T-K: rain in early summer and early autumn; snow rare	K-2: clearcut T-K: all pines removed	K-2: 100% T-K: all pines removed	K-2: no buffer	K-2: initial: five months; subsequent regrowth cutting: four years; T-K: 2.25 years	K-2: cable skidding on snow surface	K-2: contour terracing constructed 13 years later T-K: many pine stumps were grubbed out

Road density (km km^{-2})	Percent of area compacted	Type of disturbance	Percent of area disturbed	Season of management activities	Mean slope of treated area (%)	Dominant aspect	Rate of regrowth	Type and frequency of precipitation data	Location of precipitation measurements relative to discharge station
K-2: 0	K-2: 0	K-2: logging and burning T-K: logging	100% of each	K-2: initial cut: winter to early spring; regrowth cut for four years at beginning and end of summer and burned for six more in spring T-K: year round	K-2: 73% T-K: 60%	K-2: SE T-K: W	K-2: regrowth cut for first four years and burned for six more T-K: coppice stand developed by 16 years later		K-2: at two places close by and about 1 km from station T-2: by the station

Discharge record before/after treatment (years)	Author's peak flow criteria	Reported percent change in peak flows	Reported absolute change in peak flows (L s^{-1} ha^{-1})	Author's low flow criteria	Reported percent change in low flows	Reported absolute change in low flows (L s^{-1} ha^{-1})	Statistical significance of changes
K-2: 8/18* T-K: 8/21* * at least	(N 1967): instantaneous peak less discharge at beginning of hydrograph rise (N 1971): he says instantaneous peak, but I suspect that it is less the beginning discharge as in 1967	(N 1971): mean of all storms (both basins): 5-91% storms over 100 mm: K-2: 35% T-K: 70% dry antecedent conditions: K-2: -35% T-K: -53% (N 1967): see paper-broken into 11 rainfall intensity classes					

Table I.36. Summary information for forest harvest study number 36 (Patric and Reinhart, 1971; Patric, 1973). When information for a category differed between studies, the source of the information is provided in parentheses in the form of the authors' initials.

Study design	Location	Treated basin(s)	Area (ha)	Latitude and longitude	Elevation mean/range (m)	Ecoregion domain	Vegetation	Pre-harvest stand age	Soil type and depth (m)	Geology
Paired basin study: one control, two treated; lower half cleared on 6 and upper half on 7, regrowth controlled for three years and then other half cleared on each basin; all regrowth was controlled for two more years on each basin; testing the effects of clearcut location on flows; used regression to compare peaks.	Fernow Experimental Forest, WV	6 7	6: 22.34 7: 24.23	39°05'N; 79°41'W	6: 732-823; 805 7: 732-838; 801	humid temperate	6: white and chestnut oaks 7: red oak and sugar maple	uneven-aged (most 40-50 years)	ranged from loam to silty clay loam with silt loam most common mean: 0.81 m range: 0.56-1.19 m	underlain with fractured sandstone and shale

Mean slope of the basin (%)	Drainage density (km km^{-2})	Annual precipitation (mm)	Annual ET (mm)	Dominant hydrologic regime	Type of silvicultural method	Percent of vegetation cover removed	Use of buffer strips around waterways	Duration of harvest period (months)	Type of yarding	Type of site preparation
		6: 1427 7: 1418	559	precipitation distributed fairly evenly throughout the year as both snow and rain; definite annual snowmelt peak, 72% of annual flow occurs Nov-Apr	clearcut half of each basin in two treatments, three years apart; each cut done in three stages: removal of saw logs; removal of pulpwood; and cutting all remaining vegetation over 1" in diameter	6: 100% 7: 100%	first treatment: 6: through most of it 7: through small amount of it second treatment: through rest of each basin	first treatment: 6: eight months 7: five months second treatment: 6: five months 7: six months		

Road density (km km^{-2})	Percent of area compacted	Type of disturbance	Percent of area disturbed	Season of management activities	Mean slope of treated area (%)	Dominant aspect	Rate of regrowth	Type and frequency of precipitation data	Location of precipitation measurements relative to discharge station
	6: 18% 7: 18% roads, skid trails, and landings	6 and 7: logging	6 and 7: 50% of each basin was disturbed after each of the two treatments (i.e., 100% of each basin after the second treatment)	first treatment: 6: spring-summer 7: dormant second treatment: 6: mid fall-winter 7: mid fall-winter		6: S 7: E	herbicide treatment twice each summer on cleared portions; last application was two years after last cut; dense vegetation cover on site by four years later	(PR): two recording and eight standard rain gages	

Discharge record before/after treatment (years)	Author's peak flow criteria	Reported percent change in peak flows	Reported absolute change in peak flows (L s^{-1} ha^{-1})	Author's low flow criteria	Reported percent change in low flows	Reported absolute change in low flows (L s^{-1} ha^{-1})	Statistical significance of changes
7/3/3 (three years of discharge between treatments)	instantaneous peaks during both the dormant and growing seasons	dormant season: 6 and 7: not significant growing season: 6: 300% (mean) 7: not significant					

Table I.37. Summary information for forest harvest study number 37 (Pearce, Rowe, and O'Loughlin, 1980; Rowe, Pearce, and O'Loughlin, 1994; Rowe and Pearce, 1994). When information for a category differed between studies, the source of the information is provided in parentheses in the form of the authors' initials.

Study design	Location	Treated basin(s)	Area (ha)	Latitude and longitude	Elevation mean/range (m)	Ecoregion domain	Vegetation	Pre-harvest stand age	Soil type and depth (m)	Geology
Four basins: one control, two cut, and one reference; regression between reference basin and control was used instead of a pre-treatment calibration; assumed that reference basin had same flow responses that treated basins would have had if they hadn't been cut; looked at effects of treatments on flows; M8 results were not reported--information provided for use with FDC analysis.	Maimai experimental area, Tawhai State Forest, 5 km NW of Reefton, western South Island, New Zealand	M7 M8 M9	M7: 4.14 M8: 3.84 M9: 8.26	42°05'S; 171°48'E	M7: 295 M8: 305 M9: 330	humid temperate	mixed evergreen hardwood forest dominated by *Nothofagus* spp. (southern beech)	previously undisturbed	stony sandy loam; very permeable mean: 0.60 m range: 0.25-1.30 m	weathered conglomerates: Old Man Gravels

Mean slope of the basin (%)	Drainage density (km km^{-2})	Annual precipitation (mm)	Annual ET (mm)	Dominant hydrologic regime	Type of silvicultural method	Percent of vegetation cover removed	Use of buffer strips around waterways	Duration of harvest period (months)	Type of yarding	Type of site preparation
M7: 73% M8: 73% M9: 73%		normal: 2518; study period was much drier than normal, however	PET: 837 (average of several different estimations)	rainfall distributed fairly evenly throughout the year	M7: clearcut M8: clearcut except riparian zone M9: clearcut except riparian zone	M7: 100% M8: 90% M9: 80%	M7: no buffer strip M8: buffers along stream channel M9: 20 m wide buffer strip on both sides of channel	M7: four months M8: six months M9: five months	M7: downhill skyline hauler M8: downhill skyline hauler M9: rubber-tired skidder	slash burned

Road density (km km^{-2})	Percent of area compacted	Type of disturbance	Percent of area disturbed	Season of management activities	Mean slope of treated area (%)	Dominant aspect	Rate of regrowth	Type and frequency of precipitation data	Location of precipitation measurements relative to discharge station
M7: 0 M8: M9: 10	M7: 0 M8: M9: 5	logged and burned	M7: 100% M8: 90% M9: 80%	M7: late winter-late spring (logging); late summer (slash burned). M8: spring-early fall (logging); late summer (slash burned) M9: summer-fall (logging); late summer (slash burned)	M7: 73% M8: 73% M9: 73%	M7: SW M8: SW M9: SW (southern hemisphere)	nil after two years; dense bracken scrub after four years	network of recording and manual raingages	within 500 m

Discharge record before/after treatment (years)	Author's peak flow criteria	Reported percent change in peak flows	Reported absolute change in peak flows (L s^{-1} ha^{-1})	Author's low flow criteria	Reported percent change in low flows	Reported absolute change in low flows (L s^{-1} ha^{-1})	Statistical significance of changes
M7 and M9: 0/1.5	instantaneous peaks: means for each of three event classes	2.0-4.99 L s^{-1} ha^{-1} event class: M7: 67% M9: 55% 5.0-9.99: M7: 50% M9: 41% > 10.00 (maximum = 20.1): M7: 30% M9: 32%					lowest and highest event classes had regressions significantly different than "control"; middle class did not

Table I.38. Summary information for forest harvest study number 38 (Pierce, Hornbeck, Likens, and Bormann, 1970; Hornbeck, 1973; Hornbeck, Pierce, and Federer, 1970; Hornbeck and Pierce, 1970; Hornbeck, Adams, Corbett, Verry, and Lynch, 1993; Hornbeck, Martin, Pierce, Bormann, Likens, and Eaton, 1987). When information for a category differed between studies, the source of the information is provided in parentheses in the form of the authors' initials.

Study design	Location	Treated basin(s)	Area (ha)	Latitude and longitude	Elevation mean/range (m)	Ecoregion domain	Vegetation	Pre-harvest stand age	Soil type and depth (m)	Geology
Paired basin study: one treated, one control; treated basin had all trees felled and left on ground, all debris was cut to within 1 m of the ground; herbicide treatment given each of first three summers after cut; designed to look at effects of vegetation removal without the effects on soil that log removal would cause; results were not reported for basins 4 and 5--information provided for use with FDC analysis.	Hubbard Brook Experimental Forest, NH	2 4 5	2: 15.6 4: 36.1 5: 21.9	43°56'N; 71°45'W	2: 595 4: 606 5: 636	humid temperate	predominantly American beech, yellow birch, and sugar maple; red spruce and balsam fir found at scattered locations and on the ridge tops	uneven-aged: most 60-80 years	2: coarse sands and sandy loams; 50-150 cm of forest humus on surface mean: 0.9 m with a water storage capacity of 0.19 m	glacial till up to 5 m deep on surface; bedrock is a sillimanite-zone gneiss consisting largely of medium to coarse grained quartz, plagioclase, and biotite with small quantities of sillimanite; no evidence of faulting and visible fissures appear to diminish in size rapidly with increasing depth

Mean slope of the basin (%)	Drainage density (km km^{-2})	Annual precipitation (mm)	Annual ET (mm)	Dominant hydrologic regime	Type of silvicultural method	Percent of vegetation cover removed	Use of buffer strips around waterways	Duration of harvest period (months)	Type of yarding	Type of site preparation
2: 33% 4: 28% 5: 28%	2: 1.51	2: 1327 4: 1365 5: 1377	502 (average of annual precipitation-annual runoff for control basins)	precipitation distributed evenly throughout the year, 1/4-1/3 of it occurring as snow; 38% of annual flow occurs in Apr, 5% in Jun-Sep	2: clearcut, all vegetation left on site 4: strip cut in three phases along the contour (each cut was two years apart) 5: all trees above 10 cm DBH were whole-tree harvested	2: 100% 4: 33% each cut 5: 95% (BA)	2: no buffer strips 4: 15-25 m strip on both sides of the stream 5:	2: 1.5 months 4: one month each in 1970, 1972, and 1974 5: almost one year (fall-spring)	2: none 4: rubber tired skidder 5: feller buncher on accessible slopes and skidders elsewhere	2: all trees left where they fell and all branches cut to within 1 m from ground surface; herbicides applied each of first three summers after harvest 4: slash left on site

Road density (km km^{-2})	Percent of area compacted	Type of disturbance	Percent of area disturbed	Season of management activities	Mean slope of treated area (%)	Dominant aspect	Rate of regrowth	Type and frequency of precipitation data	Location of precipitation measurements relative to discharge station
2: 0	2: 0%	2: logged during winter with 300 mm of snow on ground; no removal of timber occurred and vehicles were prohibited in the basin	2: 0%	2: late fall, early winter 4: early fall 5: fall-spring	2: 33% 4: 28% 5: 28%	2: SSE 4: SE 5: SSE	2: herbicide treatment each of first three summers 4: rapid 5: rapid	weather stations	several in and around both control and treated basins

Discharge record before/after treatment (years)	Author's peak flow criteria	Reported percent change in peak flows	Reported absolute change in peak flows (L s^{-1} ha^{-1})	Author's low flow criteria	Reported percent change in low flows	Reported absolute change in low flows (L s^{-1} ha^{-1})	Statistical significance of changes
8/(3 or 4)	(PHLB): instantaneous peaks over 20 mm/day for Jun-Sep and Oct-May (H): instantaneous peaks during each season (HPF): mean instantaneous peaks over 20 csm for growing and dormant seasons and the entire water year (HP): snowmelt season peaks over 20 csm	(PHLB): Jun-Sep: -19 to 250% Oct-May: -66 to 83% (H): just gave regressions and stated that they were not worth comparing due to one extreme value during each period controlling each line (HPF): growing season: 118% dormant season: 0% water year: 13% (HP): -190 to 26%	(PHLB): Jun-Sep: -0.8 to 19.7 mean: 5.3 Oct-May: -2.4 to 7.3 mean: 0.2 (HP): -2.5 to 2.4 mean: -0.3				(PHLB, HP): For all of these, the only statistically significant changes were for specific events and that was at 0.05; no significance was given for ranges and averages (HPF): 0.05 for growing season, unsure about others

Table I.39. Summary information for forest harvest study number 39 (Plamondon and Ouellet, 1980; Plamondon, 1988). When information for a category differed between studies, the source of the information is provided in parentheses in the form of the authors' initials.

Study design	Location	Treated basin(s)	Area (ha)	Latitude and longitude	Elevation mean/range (m)	Ecoregion domain	Vegetation	Pre-harvest stand age	Soil type and depth (m)	Geology
Paired basin study: one control, one had three different periods of patch cutting over two water years; looked at effects of treatment on flows; compared peak flow ratios between basins.	Ruisseau des Eaux-Volées experimental basin, 80 km north of the city of Quebec, Quebec, Canada	6	394	47°16'20"N; 71°09'40"W	742-988; 825	humid temperate	80% balsam fir, 10% white birch, and 10% white spruce	69% under 50 years, rest mature	till (10-40% stone content); sandy loam over bedrock (including till): mean 6 m (0-18) over till: 0.8 m	within the Laurentian Uplands of the Canadian Shield, composed of charnochritic rocks; depth of unconsolidated material (till) ranges from 0-18 m

Mean slope of the basin (%)	Drainage density (km km^{-2})	Annual precipitation (mm)	Annual ET (mm)	Dominant hydrologic regime	Type of silvicultural method	Percent of vegetation cover removed	Use of buffer strips around waterways	Duration of harvest period (months)	Type of yarding	Type of site preparation
14.1%	1.79	1453	487 (pre-harvest)	snow, rain-on-snow; 32% of annual precipitation occurs Jun-Aug	clearcut in large patches	31%	various, sometimes adjacent to channel	over the course of two water years	cut and bunched to 4' logs with a F4 D10N (track vehicle); skid trails were spaced 20 m apart	natural regeneration

Road density (km km^{-2})	Percent of area compacted	Type of disturbance	Percent of area disturbed	Season of management activities	Mean slope of treated area (%)	Dominant aspect	Rate of regrowth	Type and frequency of precipitation data	Location of precipitation measurements relative to discharge station
1.26	0.5 (roads)	logging	31%	summer-early fall	17%	SE	after three years: 100% cover of herbs, shrubs, and seedlings; after 12 years: trees were 4 m tall and the crown closure was 70%	two nipher shield gages, two standard rain gages, 15 weekly totalizer gages, and four recording rain gages	two nipher shield gages, 10 km; rest, throughout the experimental basin (including treated, control, and surrounding basins)

Discharge record before/after treatment (years)	Author's peak flow criteria	Reported percent change in peak flows	Reported absolute change in peak flows (L s^{-1} ha^{-1})	Author's low flow criteria	Reported percent change in low flows	Reported absolute change in low flows (L s^{-1} ha^{-1})	Statistical significance of changes
7/4	highest snowmelt peak	not significant	not significant	longest number of days to obtain 1% and 5% of annual flow in either summer or winter	not significant	not significant	

Table I.40. Summary information for forest harvest study number 40 (Reinhart, Eschner, and Trimble, 1963; Reinhart, 1964). When information for a category differed between studies, the source of the information is provided in parentheses in the form of the authors' initials.

Study design	Location	Treated basin(s)	Area (ha)	Latitude and longitude	Elevation mean/range (m)	Ecoregion domain	Vegetation	Pre-harvest stand age	Soil type and depth (m)	Geology
Paired basin study: four treated, one control; various harvest amounts and levels of skidding restrictions were tested to determine effects on water quality and quantity; regressions used to compare pre- and post-treatment.	Fernow Experimental Forest, WV	1 2 3 5	1: 30.11 2: 15.50 3: 34.27 5: 36.41	39°05'N; 79°41'W	1: 755 2: 716-807; 780 3: 732-850; 805 5: 716-823	humid temperate	mixed hardwoods: oaks (red, chestnut, and white), sugar maple, yellow-poplar, black cherry, and beech	mostly 50 years, some residual left from last harvest even older	most are silt loam with considerable rock content 0.9-1.5 m; humus layer averaged 0.06 m	fractured hard sandstone and softer shale

Mean slope of the basin (%)	Drainage density (km km^{-2})	Annual precipitation (mm)	Annual ET (mm)	Dominant hydrologic regime	Type of silvicultural method	Percent of vegetation cover removed	Use of buffer strips around waterways	Duration of harvest period (months)	Type of yarding	Type of site preparation
1: 40%+ 2: 10-20% and 30-40% 3: 10-20% 5: 20-40%		1: 1501 2: 1464 3: 1476 5: 1467	1: 940 2: 840 3: 860 5: 710 (annual precipitation minus annual runoff)	precipitation distributed fairly evenly throughout the year, both snow and rain; definite annual snowmelt peak, 72% of annual flow occurs Nov-Apr	1: commercial clearcut 2: diameter limit 3: intensive selection 5: extensive selection	By volume 1: 86% 2: 59% 3: 20% 5: 31%		1: 14 months 2: five months 3: five months 5: four months	tractor with rubber-tired sulky; generally, tractor remained on skid road and tree lengths were winched to it; the following restrictions were put on skidding in each basin: 1 and 2: no restrictions 3 and 5: no skidding in stream channels	

Road density (km km^{-2})	Percent of area compacted	Type of disturbance	Percent of area disturbed	Season of management activities	Mean slope of treated area (%)	Dominant aspect	Rate of regrowth	Type and frequency of precipitation data	Location of precipitation measurements relative to discharge station
	1: 7.3% 2: 6.2% 3: 1.9% 5: 5.8% (skid roads)	logging	1: 100% 2, 3, and 5: logging occurred throughout these basins, but not all trees were removed	1: year round 2: summer 3: mid fall through winter 5: late summer through fall		1: NE 2: S 3: S 5: NNE	herbaceous plants and tree sprouts covered site quickly	three recording gages and nine standard gages	located over the five basins

Discharge record before/after treatment (years)	Author's peak flow criteria	Reported percent change in peak flows	Reported absolute change in peak flows (l. s^{-1} ha^{-1})	Author's low flow criteria	Reported percent change in low flows	Reported absolute change in low flows (l. s^{-1} ha^{-1})	Statistical significance of changes
1: 6/3.5 2, 3, and 5: 6/2.5	instantaneous peaks for flows associated with those greater than 10 csm on control for growing and dormant seasons (1, 2, 3, and 5) and annually (1)	1: growing season: 21% mean dormant season: -4% mean annual: 4% mean	1: growing season: 0.61 dormant season: -0.14	number of days per year that stream discharge was below 0.05, 0.075, and 0.10 csm	1*: 0.05 csm: -69% 0.075 csm: -63% 0.10 csm: -56% 2*: 0.05 csm: -77% 0.075 csm: -66% 0.10 csm: -58% 3†: 0.05 csm: -47% 0.075 csm: only significant one year 0.10 csm: 0% 5†: only significant one year for each flow *four years of data †two years of data		Peak flows: only a few of the events were significantly different; level of significance was not provided for the average values given Low flows: 0.05

Table I.41. Summary information for forest harvest study number 41 (Rothacher, 1965, 1970, and 1973; Rothacher, Dyrness, and Fredriksen, 1967; Harr, 1986; Hicks, Beschta, and Harr, 1991). When information for a category differed between studies, the source of the information is provided in parentheses in the form of the authors' initials.

Study design	Location	Treated basin(s)	Area (ha)	Latitude and longitude	Elevation mean/range (m)	Ecoregion domain	Vegetation	Pre-harvest stand age	Soil type and depth (m)	Geology
Paired basin study: two treated, one control; one basin was cleared and the other had 8% cleared for roads and 25% patch cut in three places; looked at effects of different harvest methods on peak flows (greater than 1.1 L s⁻¹ ha⁻¹) using correlation with control, pre- and post-treatment; Harr reanalyzed clearcut basin (HJA-1), looking at peaks greater than 9.8 L s⁻¹ ha⁻¹ caused by rain-on-snow only.	H. J. Andrews Experimental Forest, 45 miles east of Eugene, OR	HJA-1 HJA-3	HJA-1: 96 HJA-3: 101	44°12' N; 122°15' W	HJA-1: 442-1013 HJA-3: 480-1082	humid temperate	predominantly Douglas-fir with varying amounts of western hemlock	100-500 years (old growth and mature)	clays, clay loams, and silty clay loams; high stone content (20-30% by volume) shallow, but underlain by deep unconsolidated parent materials in many places (<1.5 m)	underlain by several thousand feet of volcanic rocks; complex mixture of basaltic, andesitic, and pyroclastic rocks

Mean slope of the basin (%)	Drainage density ($km\ km^{-2}$)	Annual precipitation (mm)	Annual ET (mm)	Dominant hydrologic regime	Type of silvicultural method	Percent of vegetation cover removed	Use of buffer strips around waterways	Duration of harvest period (months)	Type of yarding	Type of site preparation
HJA-1: 63.2% HJA-3: 52.6%	HJA-1: 6.3 HJA-3: 8.2	2200	PET: 610	80% of annual precipitation occurs Oct-Apr mostly as rain, but snow is common (short duration-- < 2 weeks); 7% of annual precipitation occurs Jun-Sep; rain-on-snow has caused the maximum rates of runoff	HJA-1: clearcut HJA-3: three patch cuts totaling 25% of basin	HJA-1: 100% HJA-3: 33%	no buffer strips in either case	HJA-1: 48 HJA-3: roads: 6 harvest: 6	HJA-1: skyline HJA-3: high-lead cable	both were broadcast burned

Road density ($km\ km^{-2}$)	Percent of area compacted	Type of disturbance	Percent of area disturbed	Season of management activities	Mean slope of treated area (%)	Dominant aspect	Rate of regrowth	Type and frequency of precipitation data	Location of precipitation measurements relative to discharge station
HJA-1: none HJA-3: 2.6	HJA-1: 0% HJA-3: 2% (logging roads only)	HJA-1: logged and burned HJA-3: roaded, logged, and burned	HJA-1: 100% HJA-3: 25% logged and burned, 8% roaded	HJA-1: logging: year round burn: fall HJA-3: road construction: spring-fall logging: late summer-late winter burn: fall	HJA-1: 63.2% HJA-3: 50%	HJA-1: W/NW HJA-3: NW	HJA-1: 75% crown coverage two to three years after burn* HJA-3: almost 90% crown coverage six to eight years after burning* *burning took place same year as end of harvest	eight rain gages	located in and around the control and treated basins (including near each discharge station)

Discharge record before/after treatment (years)	Author's peak flow criteria	Reported percent change in peak flows	Reported absolute change in peak flows ($L\ s^{-1}\ ha^{-1}$)	Author's low flow criteria	Reported percent change in low flows	Reported absolute change in low flows ($L\ s^{-1}\ ha^{-1}$)	Statistical significance of changes
HJA-1: 13/5 (R) 13/18 (H) HJA-3: 6/9	(R 1965, 1970): not defined (R 1973): average peak on control (30 csm)	HJA-1: no change in highest peaks (R 1970); 24% increase in mean peak and 40-200% increase in first fall peak (R 1973). HJA-3: no change after roads (R 1965); 10% increase in mean peak after harvesting (gone after 6-8 years) (R 1973)	HJA-1: mean: 0.98 HJA-3: mean: 0.31	used monthly flows for three lowest months, Jul-Sep, and combinations of these months	first period: HJA-1/HJA-3 Jul: 121%/ ns Aug: 159%/59% Sep: 183%/40% Jul-Aug: 138%/25% Jul-Sep: 164%/28% second period: Aug: -25%/ns Jul-Aug: -14%/ns rest: ns/ns	first period: HJA-1/HJA-3 Jul: 8.1/ns Aug: 6.2/4.6 Sep: 7.7/4.0 Jul-Aug: 14.4/5.7 Jul-Sep: 22.8/9.4 second period: Aug: -1.0/ns Jul-Aug: -1.7/ns (all values in mm)	peak flows: HJA-1: slopes significantly different (0.05) HJA-3: 0.05 for roads; adjusted means "highly significantly different." low flows: HJA-1: second period: Aug: 0.032 Jul-Aug: 0.039 rest: "significant"

Table I.42. Summary information for forest harvest study number 42 (Ruprecht, Schofield, Crombie, Vertessy, and Stoneman, 1991).

Study design	Location	Treated basin(s)	Area (ha)	Latitude and longitude	Elevation mean/range (m)	Ecoregion domain	Vegetation	Pre-harvest stand age	Soil type and depth (m)	Geology
Paired basin study: one control, one treated; looked at effect of intensive, uniform thinning on flows; compared pre- and post-treatment hydrographs.	100 km south of Perth and 8 km NNW of Dwellingup, southwest Western Australia	Hansen	80	32°30'S; 116°E	260-325	humid temperate	open forest dominated by jarrah and marri (both are types of eucalyptus) with a patchy understory of sclerophyllous shrubs	uneven aged, most 35-45 years	continuum of textures from coarse gravels in a loamy sand matrix at ridge to finer gravels along side slope and valley to sandy loam in low lying swamp ridge: 0.0-0.1 m side slope: 0.2-0.7 m valley: up to 2.0 m swamp: 0.5 m	duricrust underlies soil from ridge to valley, changing from continuous (ridge) to highly fractured (valley) to nonexistent (swamp); under this is a saprolite layer of light to medium clays with some sand and fine gravel overlying silt loams to light clays; saprolite varies from 15 m at ridge to 6 m under swamp; this is underlain by bedrock

Mean slope of the basin (%)	Drainage density (km km^{-2})	Annual precipitation (mm)	Annual ET (mm)	Dominant hydrologic regime	Type of silvicultural method	Percent of vegetation cover removed	Use of buffer strips around waterways	Duration of harvest period (months)	Type of yarding	Type of site preparation
5%		Long term: 1600 Study: 1179	1600 (pan evaporation)	high winter rainfall and hot, dry summers	intensive, uniform thinning throughout basin except for buffers around swamp and stream	BA: 74% Stems: 84% CC: reduced from 60% to 14%	50 m buffer surrounding the swamp and stream	two months	tractor	piling

Road density (km km^{-2})	Percent of area compacted	Type of disturbance	Percent of area disturbed	Season of management activities	Mean slope of treated area (%)	Dominant aspect	Rate of regrowth	Type and frequency of precipitation data	Location of precipitation measurements relative to discharge station
0.5	negligible	thinned uniformly and burned	all but swamp and 50 m buffer strip around swamp and stream	summer	5%	S (southern hemisphere)	stump coppice after four years was abundant and vigorous, but it did not contribute much to the basin BA	two freestanding pluviometers	located in forest clearings, one at discharge station and one in middle of basin

Discharge record before/after treatment (years)	Author's peak flow criteria	Reported percent change in peak flows	Reported absolute change in peak flows (L s^{-1} ha^{-1})	Author's low flow criteria	Reported percent change in low flows	Reported absolute change in low flows (L s^{-1} ha^{-1})	Statistical significance of changes
8/3	instantaneous peaks	approximately 50%					

Table I.43. Summary information for forest harvest study number 43 (Smith, 1991).

Study design	Location	Treated basin(s)	Area (ha)	Latitude and longitude	Elevation mean/range (m)	Ecoregion domain	Vegetation	Pre-harvest stand age	Soil type and depth (m)	Geology
Paired basin study: one treated, one control; most of afforested area cut, but nearly half of basin was not a forest; looked at effects of this cut on flows using regression analysis (pre- and post-treatment) based on monthly values.	Witklip experimental basin area near White River in Eastern Transvaal, South Africa	Catchment V	108	25°14'S; 30°53'E		humid tropical	exotic planted species: pines: 43.3% eucalyptus: 8.8% total: 52.1% native grassland and scrub: 47.9%	30-40 years		

Mean slope of the basin (%)	Drainage density (km km^{-2})	Annual precipitation (mm)	Annual ET (mm)	Dominant hydrologic regime	Type of silvicultural method	Percent of vegetation cover removed	Use of buffer strips around waterways	Duration of harvest period (months)	Type of yarding	Type of site preparation
		1475 1054-1921		summer rainfall	clearcut in several patches over several years	"most of exotic plantations were clearfelled"		1st: six months 2nd: one month 3rd: 11 months 4th: three months 5th: one month 6th: one month		

Road density (km km^{-2})	Percent of area compacted	Type of disturbance	Percent of area disturbed	Season of management activities	Mean slope of treated area (%)	Dominant aspect	Rate of regrowth	Type and frequency of precipitation data	Location of precipitation measurements relative to discharge station
		logging	52.13% of the basin, 100% of the trees	1st: winter-spring 2nd: winter 3rd: year round 4th: late summer-mid fall 5th: winter 6th: winter			vigorous regrowth of understory	network of Casella recording gages (recording on a weekly basis) and standard non-recording Snowden rain gages with nipher shields	one near far ridge within treated and one about 500 m east of discharge station, just outside of treated basin; also many other gages throughout experimental basin

Discharge record before/after treatment (years)	Author's peak flow criteria	Reported percent change in peak flows	Reported absolute change in peak flows (l. s^{-1} ha^{-1})	Author's low flow criteria	Reported percent change in low flows	Reported absolute change in low flows (l. s^{-1} ha^{-1})	Statistical significance of changes
6/5.5* (treatments for several extended periods during first three years of "after")	peak definition is unclear as the author reported the change in uniform depth; the model used says monthly peak flows		-0.04 mm				regressions significantly different at 0.01

Table I.44. Summary information for forest harvest study number 44 (Subba Rao, Ramola, and Sharda, 1985).

Study design	Location	Treated basin(s)	Area (ha)	Latitude and longitude	Elevation mean/range (m)	Ecoregion domain	Vegetation	Pre-harvest stand age	Soil type and depth (m)	Geology
Paired basin study: one control, one uniformly thinned to determine effects on flows; compared pre- and post-treatment regressions along with hydrographs with similar antecedent moisture and almost equal total rainfall.	Rajpur Forest Experimental Station, 10 km NE of Dehra Dun, India	WS 2	5.22	30°23'N; 78°05'E	895	humid tropical	predominantly uniform coppice sal forest		sandy-sandy clay loam shallow	mainly gray colored, soft, coarse-grained micaceous sandstones having some thin bands of shales; deposits over older rock formation are just debris without any stratification or sorting arrangement

Mean slope of the basin (%)	Drainage density ($km\ km^{-2}$)	Annual precipitation (mm)	Annual ET (mm)	Dominant hydrologic regime	Type of silvicultural method	Percent of vegetation cover removed	Use of buffer strips around waterways	Duration of harvest period (months)	Type of yarding	Type of site preparation
26%	0.0363	2950		the major portion of the annual rainfall occurs during the rainy season (Jul-Oct); winter rainfall amounts to only about 4% of the annual total; streams only flow Jul-Sep; snow is rare	uniform thinning: one out of every five trees was removed, leaving four trees standing around a stump	20% of stems removed; 22% reduction in crown density				

Road density ($km\ km^{-2}$)	Percent of area compacted	Type of disturbance	Percent of area disturbed	Season of management activities	Mean slope of treated area (%)	Dominant aspect	Rate of regrowth	Type and frequency of precipitation data	Location of precipitation measurements relative to discharge station
		uniform thinning (one out of every five trees was removed throughout the basin)	100%		26%	W		standard 127 cm diameter non-recording rain gage and a recording rain gage; measurements recorded daily during rainy season (Jun-Oct)	

Discharge record before/after treatment (years)	Author's peak flow criteria	Reported percent change in peak flows	Reported absolute change in peak flows ($L\ s^{-1}\ ha^{-1}$)	Author's low flow criteria	Reported percent change in low flows	Reported absolute change in low flows ($L\ s^{-1}\ ha^{-1}$)	Statistical significance of changes
10/5 (only first two years were analyzed in this study)	instantaneous peaks	first year: 8.6% (mean) second year: not significant					0.05

Table I.45. Summary information for forest harvest study number 45 (Swank, Douglass, and Cunningham, 1982).

Study design	Location	Treated basin(s)	Area (ha)	Latitude and longitude	Elevation mean/range (m)	Ecoregion domain	Vegetation	Pre-harvest stand age	Soil type and depth (m)	Geology
Paired basin study: one control, one treated; compared the effects of road construction and logging on flows using comparison of pre- and post-treatment regression comparison.	Coweeta Hydrologic Laboratory, NC	WS 7	58.7	35°03' N; 83°25' W	724-1060	humid temperate	mostly oaks and hickories		gravelly and fine sandy loams with high rock contents	a series of metasedimentary and metaigneous rocks which overlie older rocks of Precambrian origin; the bedrock is predominantly biotite paragneiss and biotite schist occurring in thick to medium layers; regolith is deeply weathered and averages about 7 m in depth

Mean slope of the basin (%)	Drainage density ($km\ km^{-2}$)	Annual precipitation (mm)	Annual ET (mm)	Dominant hydrologic regime	Type of silvicultural method	Percent of vegetation cover removed	Use of buffer strips around waterways	Duration of harvest period (months)	Type of yarding	Type of site preparation
57%		1893	900 (based on annual precipitation minus annual runoff on control)	precipitation distributed throughout the year with less than 5% occurring as snow	clearcut	100%	no buffer strips	six months	mobile cable system: 58% tractor: 15% none: 27%	cut any stems remaining after harvest

Road density ($km\ km^{-2}$)	Percent of area compacted	Type of disturbance	Percent of area disturbed	Season of management activities	Mean slope of treated area (%)	Dominant aspect	Rate of regrowth	Type and frequency of precipitation data	Location of precipitation measurements relative to discharge station
4.96	4.9% (roads)	roads and logging activities	9.7% (area of mineral soil exposed)	Spring-early summer (roads) Winter-early summer (cut) Fall (regeneration treatment)	57%	S	rapid due to stump and root sprouting		

Discharge record before/after treatment (years)	Author's peak flow criteria	Reported percent change in peak flows	Reported absolute change in peak flows ($L\ s^{-1}\ ha^{-1}$)	Author's low flow criteria	Reported percent change in low flows	Reported absolute change in low flows ($L\ s^{-1}\ ha^{-1}$)	Statistical significance of changes
11/4	instantaneous peak for mean storm	14.6%	0.19				0.01 level of significance for regression coefficients

Table I.46. Summary information for forest harvest study number 46 (Swanson and Hillman, 1977).

Study design	Location	Treated basin(s)	Area (ha)	Latitude and longitude	Elevation mean/range (m)	Ecoregion domain	Vegetation	Pre-harvest stand age	Soil type and depth (m)	Geology
Composite paired study; they went in after the fact and paired logged (1-20 years after harvest) and unlogged sites, assuming that flow would be equal from the basins if neither had been logged. Composite hydrographs made from averaging each day's data for the two basin types.	Within the Athabasca River Basin, central Alberta, Canada	composite of nine basins	700- 2210 mean: 1500	53-54°N; 116-118°W	1140-1740 mean: 1410	humid temperate	Spruce-lodgepole pine forest: 53% lodgepole 19% white spruce 8% black spruce 5% alpine fir 9% *Populus* spp. 6% standing dead	even-aged, mature		

Mean slope of the basin (%)	Drainage density (km km^{-2})	Annual precipitation (mm)	Annual ET (mm)	Dominant hydrologic regime	Type of silvicultural method	Percent of vegetation cover removed	Use of buffer strips around waterways	Duration of harvest period (months)	Type of yarding	Type of site preparation
		500-550		30% of annual precipitation occurs as snow between Oct-Apr; snowmelt, rain-on-spring-snowmelt, and frontal storms during summer are major sources of high flows	clearcut in 16-25 ha alternate cut and leave strips	range: 35-84% mean: 54%	throughout basins; buffer strips left along channels and "steep" slopes left unlogged	end of first 20 year cycle; approximately 50% cut		

Road density (km km^{-2})	Percent of area compacted	Type of disturbance	Percent of area disturbed	Season of management activities	Mean slope of treated area (%)	Dominant aspect	Rate of regrowth	Type and frequency of precipitation data	Location of precipitation measurements relative to discharge station
		logging			various	various	30 years before effects begin to diminish; crown closure 40-60 years after cut	precipitation: one Atmos. Env. Serv. of Canada MSC type "A" gage per basin, serviced at least weekly; six Belfort and three Fischer-Porter weighing gages snowmelt: two snow courses per working circle to determine snow level before melt; also had access to an intensive climatic study conducted in the area at same time	the type "A" gages were near the discharge stations; other gages and snow courses were throughout the drainage basin

Discharge record before/after treatment (years)	Author's peak flow criteria	Reported percent change in peak flows	Reported absolute change in peak flows (L s^{-1} ha^{-1})	Author's low flow criteria	Reported percent change in low flows	Reported absolute change in low flows (L s^{-1} ha^{-1})	Statistical significance of changes
0/2	unclear	mean: 50-100%					

Table I.47. Summary information for forest harvest study number 47 (Swindel, Lassiter, and Riekerk, 1983 and 1982; Riekerk, 1989, Riekerk, Swindel, and Replogle, 1980). When information for a category differed between studies, the source of the information is provided in parentheses in the form of the authors' initials.

Study design	Location	Treated basin(s)	Area (ha)	Latitude and longitude	Elevation mean/range (m)	Ecoregion domain	Vegetation	Pre-harvest stand age	Soil type and depth (m)	Geology
Paired basin study: one control, two treated; one had "minimum" harvest and site preparation practices and other had "maximum"; compared pre- and post-treatment regressions; best equation for maximum site included dummy variable for before and after windrowing.	8 km west of Starke, Bradford County, FL	WS 1 WS 2	WS 1: 67 WS 2: 49	30°N; 82°10'W	43-45.5	humid temperate	open stands of slash pine with cypress and hardwoods; pinelands make up 49% and 74% of basins 1 and 2, respectively	40 years	sandy underlain by a clay layer clay layer ranges from 0-2.5 m thick	area underlain by Hawthorn formation of sand, clay, and limestone layers

Mean slope of the basin (%)	Drainage density (km km^{-2})	Annual precipitation (mm)	Annual ET (mm)	Dominant hydrologic regime	Type of silvicultural method	Percent of vegetation cover removed	Use of buffer strips around waterways	Duration of harvest period (months)	Type of yarding	Type of site preparation
	WS 1: 1.59 WS 2: 1.8	1400-1450	1680 (pan evaporation)	rainfall distributed evenly throughout the year with dry periods during spring and fall	clearcut pinelands only; one manually, other mechanically	WS 1: 49% WS 2: 74%	WS 1: mostly buffered WS 2: mostly not buffered	both: two months	WS 1: merchantable trees were felled, delimbed, and bucked into 1.5 m bolts which were stacked by hand and transported from the woods by a small prehauler WS 2: felled and stacked with tops intact by a feller-buncher and dragged by skidders to centrally located delimbing gates	WS 1: debris and residual understory plants were double chopped with a roller drum chopper and the site was bedded before machine planting WS 2: lightwood stumps removed, logging debris burned and pushed into windrows, inter-windrow spaces were disced and bedded before machine planting

Road density (km km^{-2})	Percent of area compacted	Type of disturbance	Percent of area disturbed	Season of management activities	Mean slope of treated area (%)	Dominant aspect	Rate of regrowth	Type and frequency of precipitation data	Location of precipitation measurements relative to discharge station
WS 1: 0 WS 2: 0	WS 1: 0% WS 2: 70%	WS 1: logged, site prepped, bedded, and machine planted WS 2: logged, stumps removed, burned, windrowed, disced, bedded, and machine planted	WS 1: 59% WS 2: 74%	WS 1: late fall-early winter (harvest); spring and summer (site preparation); fall (bed and plant). WS 2: late fall-early winter (harvest); stump removal (winter); spring (burn); summer (windrow and discing); fall (bed and plant)	WS 1: < 1% WS 2: < 1%	WS 1: SE WS 2 : SW	WS 1: "fast" WS 2 : "fast"	seven standard rain gages	six along perimeter roads and one near center of three contiguous basins

Discharge record before/after treatment (years)	Author's peak flow criteria	Reported percent change in peak flows	Reported absolute change in peak flows (L s^{-1} ha^{-1})	Author's low flow criteria	Reported percent change in low flows	Reported absolute change in low flows (L s^{-1} ha^{-1})	Statistical significance of changes
1/1*/1.6 *during treatment period	maximum instantaneous peak rate minus the initial discharge rate	WS 1: did not increase WS 2: 500% after windrowing					0.05

Table I.48. Summary information for forest harvest study number 48 (Troendle and King, 1985; Troendle and Kaufmann, 1987).

Study design	Location	Treated basin(s)	Area (ha)	Latitude and longitude	Elevation mean/range (m)	Ecoregion domain	Vegetation	Pre-harvest stand age	Soil type and depth (m)	Geology
Paired basin study: one control, one harvested using alternating cut and leave strips ranging in widths from 1-6 tree heights; looked at effect of cut on flows using regression analysis of pre- and post-treatments flows.	Fraser Experimental Forest, CO	Fool Creek	289	39°50'N; 105°50'W	2800-3500	dry	spruce-fir and lodgepole pine			

Mean slope of the basin (%)	Drainage density (km km^{-2})	Annual precipitation (mm)	Annual ET (mm)	Dominant hydrologic regime	Type of silvicultural method	Percent of vegetation cover removed	Use of buffer strips around waterways	Duration of harvest period (months)	Type of yarding	Type of site preparation
		635 @ 2740 m	285-350 (based on annual precipitation minus annual yield)	annual precipitation distributed evenly throughout the year, 2/3 occurring as snow; 70% of annual streamflow occurs Apr-Jun	harvested in alternating cut and leave strips varying in width from one to six tree heights; located throughout the basin with various orientations	40% of basin and 50% of forested area		three summers		

Road density (km km^{-2})	Percent of area compacted	Type of disturbance	Percent of area disturbed	Season of management activities	Mean slope of treated area (%)	Dominant aspect	Rate of regrowth	Type and frequency of precipitation data	Location of precipitation measurements relative to discharge station
	4.8% (roads and log decks)	roads, log decks, and logging	roads/decks: 4.8% logged: 40%	summer (cut)		N			at main headquarters

Discharge record before/after treatment (years)	Author's peak flow criteria	Reported percent change in peak flows	Reported absolute change in peak flows (L s^{-1} ha^{-1})	Author's low flow criteria	Reported percent change in low flows	Reported absolute change in low flows (L s^{-1} ha^{-1})	Statistical significance of changes
12/28	peak mean daily discharge	23%	0.19				

Table I.49. Summary information for forest harvest study number 49 (Troendle and King, 1987; Troendle and Kaufmann, 1987).

Study design	Location	Treated basin(s)	Area (ha)	Latitude and longitude	Elevation mean/range (m)	Ecoregion domain	Vegetation	Pre-harvest stand age	Soil type and depth (m)	Geology
Paired basin study: one control, two treated; sub-basin harvested in 12 small, circular units; main basin included this one plus another area which was thinned; looked at effects of these treatments on flows and snow water equivalent using regression analysis of pre- and post-treatment flows.	Fraser Experimental Forest, CO	Deadhorse Creek (main gage) North Fork	Main: 270 NF: 41	39°50'N; 105°50'W	2880-3536	dry	Main: spruce-fir along streams, north slopes, and upper-slope positions; lodgepole pine at low- and mid-elevation southerly or high-energy exposures NF: mostly lodgepole pine			

Mean slope of the basin (%)	Drainage density (km km^{-2})	Annual precipitation (mm)	Annual ET (mm)	Dominant hydrologic regime	Type of silvicultural method	Percent of vegetation cover removed	Use of buffer strips around waterways	Duration of harvest period (months)	Type of yarding	Type of site preparation
		635 @ 2740 m	285-350 (based on annual precipitation minus annual yield)	annual precipitation distributed evenly throughout the year, 2/3 occurring as snow; 70% of annual streamflow occurs Apr-Jun	Main: 40% reduction in BA on 41 acres by removal of individual trees 17.8 cm DBH and larger; 36% of NF clearcut in 12 circular units, 122m in diameter	Main: 10% NF: 36%				

Road density (km km^{-2})	Percent of area compacted	Type of disturbance	Percent of area disturbed	Season of management activities	Mean slope of treated area (%)	Dominant aspect	Rate of regrowth	Type and frequency of precipitation data	Location of precipitation measurements relative to discharge station
Main: 4.3	Main: 3.4% NF: 3.1% (roads, including cut and fill slopes)	Main: roads, logging NF: roads, logging, site preparation	Main: 13.4% NF: 39.1%			Main: E NF: SE		two recording, three standard.	within the drainage

Discharge record before/after treatment (years)	Author's peak flow criteria	Reported percent change in peak flows	Reported absolute change in peak flows (L s^{-1} ha^{-1})	Author's low flow criteria	Reported percent change in low flows	Reported absolute change in low flows (L s^{-1} ha^{-1})	Statistical significance of changes
Main: 21/6 NF: 6/6	adjustment mean peak	Main: "no change" NF: 49%	Main: none NF: 0.32				NF: $p = 0.07$

Table I.50. Summary information for forest harvest study number 50 (Ursic, 1970 and 1982). When information for a category differed between studies, the source of the information is provided in parentheses in the form of the authors' initials.

Study design	Location	Treated basin(s)	Area (ha)	Latitude and longitude	Elevation mean/range (m)	Ecoregion domain	Vegetation	Pre-harvest stand age	Soil type and depth (m)	Geology
Paired basin study: one control, two treated; treated were burned, had all remaining trees killed with herbicides and planted with pine seedlings; looked at effects of conversion from hardwoods to pines on flows using pre- and post-treatment regression analysis.	Upper coastal plain in northern MS	C-II C-III	C-II: 0.86 C-III: 0.86	34°29'N; 89°31'W	relief: C-II: 18 m C-III: 13 m	humid temperate	post oak, hickories, and blackjack oak before treatment; replanted with loblolly pine seedlings		C-II: silt loam on upper slopes (34% of basin) and sandy loam on the rest, lower slopes C-III: silt loam; fragipan near surface of silt loams	underlain by unconsolidated strata of sands and clays; parts of area on the eastern fringe of a loessial blanket

Mean slope of the basin (%)	Drainage density (km km^{-2})	Annual precipitation (mm)	Annual ET (mm)	Dominant hydrologic regime	Type of silvicultural method	Percent of vegetation cover removed	Use of buffer strips around waterways	Duration of harvest period (months)	Type of yarding	Type of site preparation
10% on ridges and up to 45% on the hillsides		1350		rainfall distributed fairly evenly throughout the year	herbicide injected into the bases of all stems 1" and greater in diameter; all others cut and mopped with mixture of herbicides and diesel fuel	C-II: 100% C-III: 100%	no buffers	one to three days	none on either	area burned with a slow backfire to remove most of litter

Road density (km km^{-2})	Percent of area compacted	Type of disturbance	Percent of area disturbed	Season of management activities	Mean slope of treated area (%)	Dominant aspect	Rate of regrowth	Type and frequency of precipitation data	Location of precipitation measurements relative to discharge station
		burn exposed mineral soil	C-II: 17% C-III: 11%	burn: winter planting: spring herbicide treatment: late spring and early summer	10% on ridges and up to 45% on hillsides		sprouts and stems >1" in diameter increased from 150 per acre before burn to 6644 and 11,020 per acre two and three years after burning, respectively	one recording rain gage and six non-recording gages	recording gage was near center of study area and others were placed throughout the area

Discharge record before/after treatment (years)	Author's peak flow criteria	Reported percent change in peak flows	Reported absolute change in peak flows (L s^{-1} ha^{-1})	Author's low flow criteria	Reported percent change in low flows	Reported absolute change in low flows (L s^{-1} ha^{-1})	Statistical significance of changes
6/3 and 6/14 for 1970 and 1982 studies respectively.	(U 1970 and 1982): average of instantaneous peaks ≥ 3.5 L s^{-1} ha^{-1} on either the control or the treated basins	(U 1970): C-II: 36% C-III: 28%	(U 1970): C-II: 5.7 C-III: 4.9 (U 1982): C-II: 21.2* C-III: 15.6* *mean of the peaks which increased significantly for the first three and four years after treatment, respectively				(U 1970): 0.05 for change in regression

Table I.51. Summary information for forest harvest study number 51 (Ursic, 1991).

Study design	Location	Treated basin(s)	Area (ha)	Latitude and longitude	Elevation mean/range (m)	Ecoregion domain	Vegetation	Pre-harvest stand age	Soil type and depth (m)	Geology
Paired basin study: one control, two treated; treated each had a different yarding technique used; looked at the effects of these practices on flows and sediment yield by comparing pre- and post-treatment regressions.	Holly Springs National Forest, northern MS	Iy III_S	Iy: 1.34 III_S: 1.62	34°30'N; 89°24'W	relief: Iy: 23 m III_S: 29 m	humid temperate	dominated by shortleaf pine; also contained white and red oaks and hickories		sandy loams, silt loams, and fines	freshwater geologic formations of sands and heavily mottled clays

Mean slope of the basin (%)	Drainage density (km km^{-2})	Annual precipitation (mm)	Annual ET (mm)	Dominant hydrologic regime	Type of silvicultural method	Percent of vegetation cover removed	Use of buffer strips around waterways	Duration of harvest period (months)	Type of yarding	Type of site preparation
	Iy: 11.7 III_S: 9.7	1387	Iy: 1107 III_S: 1077 (mean annual precipitation minus mean annual runoff for calibration)	rainfall distributed throughout the year, snowfall is negligible	both were clearcut	Iy: 100% III_S: 100%	no buffers	Iy: four days III_S: two weeks	Iy: cable III_S: skidder	

Road density (km km^{-2})	Percent of area compacted	Type of disturbance	Percent of area disturbed	Season of management activities	Mean slope of treated area (%)	Dominant aspect	Rate of regrowth	Type and frequency of precipitation data	Location of precipitation measurements relative to discharge station
	III_S: 4.5% (skid trail)	Iy: logging bared soils III_S: logging bared soils and skid trail	Iy: 5% III_S: 15.5%	late fall-early winter (cut); spring (planting); summer (herbicide treatment of residual hardwoods)				network of standard and recording rain gages	

Discharge record before/after treatment (years)	Author's peak flow criteria	Reported percent change in peak flows	Reported absolute change in peak flows (L s^{-1} ha^{-1})	Author's low flow criteria	Reported percent change in low flows	Reported absolute change in low flows (L s^{-1} ha^{-1})	Statistical significance of changes
23/5	instantaneous peaks > 0.3 L s^{-1} ha^{-1} from either of the paired basins	Iy: 29% III_S: 46% (regression slope changes)					0.05

Table I.52. Summary information for forest harvest study number 52 (Verry, 1972 and 1986; Verry, Lewis, and Brooks, 1983; Barten, 1988). When information for a category differed between studies, the source of the information is provided in parentheses in the form of the authors' initials.

Study design	Location	Treated basin(s)	Area (ha)	Latitude and longitude	Elevation mean/range (m)	Ecoregion domain	Vegetation	Pre-harvest stand age	Soil type and depth (m)	Geology
Paired basin study: one control, one treated (S4); treated had upland aspen and birch clearcut, black spruce in and around the bogs were left untouched; looked at effects of harvest on flows and water quality using regression analysis; results were not reported for basins S4S and S4N--information provided for use with FDC analysis.	Marcell Experimental Forest, north-central MN	S4 (total) S4S S4N (S4S and S4N are the two sub-basins that make up S4)	S4: 34.2 S4S: 11.0 S4N: 23.2	47°32'N; 93°28'W	S4: 433	humid temperate	aspen and birch in uplands and black spruce in bogs	52 years	S4: 23% peats (bog); 77% sandy loams (uplands) 1.5-2.2 m	glacial till 8-12' thick over sand

Mean slope of the basin (%)	Drainage density (km km^{-2})	Annual precipitation (mm)	Annual ET (mm)	Dominant hydrologic regime	Type of silvicultural method	Percent of vegetation cover removed	Use of buffer strips around waterways	Duration of harvest period (months)	Type of yarding	Type of site preparation
uplands: 8.5% bog: 0.1%		772	579 (annual precipitation minus annual runoff; treated basin considered watertight) (V 1972); most of annual precipitation is lost to ET (VLB)	80% of annual precipitation occurs Apr-Oct; 17% of annual precipitation occurs as snow; flooding is almost always associated with snowmelt or rain-on-snow	commercial clearcut of uplands with noncommercial species cut later	(B): S4: 77% S4S: 89% S4N: 72%	only uplands were cut-bogs were left alone	13 months	cable skidded	none

Road density (km km^{-2})	Percent of area compacted	Type of disturbance	Percent of area disturbed	Season of management activities	Mean slope of treated area (%)	Dominant aspect	Rate of regrowth	Type and frequency of precipitation data	Location of precipitation measurements relative to discharge station
	>2%	logging	S4: 77% S4S: 89% S4N: 72%	year round	8.5%	no predominant aspect	total stems ac^{-1} of shrubs and trees <10' increased threefold within a year after harvest; aspen suckers were 6' by first summer and 20' nine years later		

Discharge record before/after treatment (years)	Author's peak flow criteria	Reported percent change in peak flows	Reported absolute change in peak flows (L s^{-1} ha^{-1})	Author's low flow criteria	Reported percent change in low flows	Reported absolute change in low flows (L s^{-1} ha^{-1})	Statistical significance of changes
peak flow: 9/9 low flow: 9/1	instantaneous snowmelt peaks; instantaneous rainfall peaks for events that produced at least 0.02 area inches of storm flow volume	snowmelt: first year when only part of area was cut: -35%; subsequent years: 11-143%. rainfall: 2 year and 10 year events increased 50% and 150% respectively		mean daily flow equal to or exceeding 0.0001 cfs	11%		Peak flow: snowmelt: 0.05 (except 11% increase) rainfall: 0.05 Low flow: 0.10

Table I.53. Summary information for forest harvest study number 53 (Ziemer, 1981; Wright, Sendek, Rice, and Thomas, 1990; Thomas, 1990; Wright, 1985; Keppeler and Ziemer, 1990). When information for a category differed between studies, the source of the information is provided in parentheses in the form of the authors' initials.

Study design	Location	Treated basin(s)	Area (ha)	Latitude and longitude	Elevation mean/range (m)	Ecoregion domain	Vegetation	Pre-harvest stand age	Soil type and depth (m)	Geology
Paired basin study: one treated, one control; treated had roads built and then, beginning four years later, was selectively harvested in three sections over three years; looked at effects of these treatments on flows using many analysis techniques and flow classes.	Caspar Creek, 10 km south of Ft. Bragg, CA	South Fork	424	39°30'N; 123°40'W	37-320 210 (study area)	humid temperate	second-growth redwood, Douglas-fir, and grand fir	85 years (second growth, originally harvested in late 1800s)	well drained clay loam; 1-2 m	mostly hard, coarse-grained sandstone and shale that is deeply shattered and moderately weathered; also highly weathered sandstone with clay lenses and weakly consolidated marine terrace deposits

Mean slope of the basin (%)	Drainage density (km km^{-2})	Annual precipitation (mm)	Annual ET (mm)	Dominant hydrologic regime	Type of silvicultural method	Percent of vegetation cover removed	Use of buffer strips around waterways	Duration of harvest period (months)	Type of yarding	Type of site preparation
35%	3.73 (including ephemeral)	1109	538 (annual precipitation-yield)	90% of annual precipitation occurs Oct-Apr; snow is very rare	selection cut on entire basin in three sales over three years	given year (total) 1967: 4% (4%) 1971: 14% (18%) 1972: 21% (39%) 1973: 27% (66%) (percent of volume removed in entire basin)	no buffers, first cut was near weir, third cut was in headwaters, second cut was in between; road right of way generally located near the stream	over the course of three years	tractor	untreated

Road density (km km^{-2})	Percent of area compacted	Type of disturbance	Percent of area disturbed	Season of management activities	Mean slope of treated area (%)	Dominant aspect	Rate of regrowth	Type and frequency of precipitation data	Location of precipitation measurements relative to discharge station
1967: 1.6 1973: 1.9* *including temporary roads	1967: 4% 1973: 16% *roads, landings, and skid trails	roads, logging, skid trails, and landings	1967: 4% 1973: 100%	spring and summer	35%	W		four weighing rain gages	three around control basin (1.5-3 km away) and one approximately 0.5 km downstream from treated weir

Discharge record before/after treatment (years)	Author's peak flow criteria	Reported percent change in peak flows	Reported absolute change in peak flows (l. s^{-1} ha^{-1})	Author's low flow criteria	Reported percent change in low flows	Reported absolute change in low flows (l. s^{-1} ha^{-1})	Statistical significance of changes
(Z): 9/4 (separated during middle year of logging) (WSRT): 5/4/5 (untouched/between roads and logging/during and after logging) (T): 5/4/3/2/4/4 (calibration/roads/logging/recovery 1/2/3) (KZ): 8/13, post-road construction years (1967-1970) were included in the prelogging time period	(Z): instantaneous peak flow less discharge at hydrograph rise (WSRT): instantaneous peaks associated with those at least 0.056 l. s^{-1} ha^{-1} on control (T): instantaneous peaks of at least 0.57 m^3 s^{-1} on control	(Z): 10% (adjusted mean); 4% (double mass curve mean); not significant (regression); 255% for small flows (0.08-0.33 m^3 s^{-1}); and not significant for larger flows (>0.33 m^3 s^{-1})(mean ratio of peak differences between treated and control to control) (WSRT): 111% for smallest flows (< 566 l. s^{-1}), not significant for others (T): not significant	(Z): 0.3 (adjusted mean)	(KZ): total volume for summer low flow period (between the times when the control mean daily flow dropped below and rose above 28 l. s^{-1}); proportion of summer low flow volume relative to total annual volume; number of low flow days (days in low flow season with mean daily flow <5.66 l. s^{-1}); rate of flow at start of season and end of season (when the mean daily flow of the control drops below and rises above 28 l. s^{-1}, respectively)	summer total: 1972-1978: 29% (mean) 1981: -27% only 1972, 74, 75, 78, and 81 were significantly different proportion: 1972 and 1981 were significantly greater and lower than predicted; all others were not low flow days: not significant starting discharge: 1973-1983: 25% (mean) only 1973-76, 82, and 83 were significant ending discharge: 1973-1983: 87% (mean) only 1974, 75, 77, and 78 were significant	Summer total: 1972-1978: 5 * 10^5 m^3 per low flow season (mean) Ending discharge: 1973-1983: 63 l. s^{-1} (mean)	(Z): 0.05 (regression); 0.01 for significant difference and 0.10 for not significant (ratio comparison) (WSRT): ? (T): 0.00625 (0.05/8 comparisons) (KZ): 0.05

Table I.54. Summary information for forest harvest study number 54 (Johnston, 1984).

Study design	Location	Treated basin(s)	Area (ha)	Latitude and longitude	Elevation mean/range (m)	Ecoregion domain	Vegetation	Pre-harvest stand age	Soil type and depth (m)	Geology
Paired basin study, one control, one cut; looked at effects of partial cutting of aspen on flows.	Chicken Creek, 22 km NE of Salt Lake City, in the Davis County Experimental Watershed	West Branch	88	40°52' N; 111°50' W	2301-2559	dry	66% aspen and less than 4% conifers; rest consists of grasses, forbes, and brush	aspen: a few were 70-80 years, but the mean age was 32 years old	ranging from loamy alluvial in bottoms to clayey colluvial on the side slopes and gravelly loams on the ridges; deep in the bottoms and side slopes and shallow on the ridges	igneous outcrops on the ridges; metamorphic and sedimentary materials on the side slopes and lower portions

Mean slope of the basin (%)	Drainage density ($km\ km^{-2}$)	Annual precipitation (mm)	Annual ET (mm)	Dominant hydrologic regime	Type of silvicultural method	Percent of vegetation cover removed	Use of buffer strips around waterways	Duration of harvest period (months)	Type of yarding	Type of site preparation
19.5%	1.45	1143	PET: 422 (Thornthwaite)	80% of precipitation occurs Nov-Apr as snow; 88% of annual flow occurs during Apr-Jun	five small clearcuts ranging from 1.2-4.1 ha in size; all aspen greater than 5 cm were cut	20% of the aspen, but only 13% of basin area	cutting occurred at least 137 m from all permanent stream channels		mostly hand loaded or horse skidded; minimal vehicle use occurred on cut areas; no material was removed from the largest harvest unit	slash was cut and scattered on all but the largest harvest unit where the material was left untouched

Road density ($km\ km^{-2}$)	Percent of area compacted	Type of disturbance	Percent of area disturbed	Season of management activities	Mean slope of treated area (%)	Dominant aspect	Rate of regrowth	Type and frequency of precipitation data	Location of precipitation measurements relative to discharge station
		logging	13% of basin	summer and ?	12-45	NW		two shielded storage gages and one shielded intensity gage year round with two more intensity gages operated during the summer; snow course was also used to monitor snowfall in the treated basin	in the treated basin

Discharge record before/after treatment (years)	Author's peak flow criteria	Reported percent change in peak flows	Reported absolute change in peak flows ($L\ s^{-1}\ ha^{-1}$)	Author's low flow criteria	Reported percent change in low flows	Reported absolute change in low flows ($L\ s^{-1}\ ha^{-1}$)	Statistical significance of changes
9/4		not significant	not significant				0.05

Table I.55. Summary information for forest harvest study number 55 (Douglass, Van Lear, and Valverde, 1983).

Study design	Location	Treated basin(s)	Area (ha)	Latitude and longitude	Elevation mean/range (m)	Ecoregion domain	Vegetation	Pre-harvest stand age	Soil type and depth (m)	Geology
Randomized complete block design with four control and four treated basins; only three pairs were used; looked at effects of prescribed burning with natural regeneration on flows as opposed to mechanical site preparation and planting.	Clemson Forest, in the South Carolina Piedmont	64, 66, and 68	64: 1.1 66: 1.3 68: 0.6	34°42'N; 82°49'W	230-270	humid temperate	loblolly pine plantations	40 years	upper slopes: sandy loam plow layer over clay B horizon; 1 m	granite and gneiss

Mean slope of the basin (%)	Drainage density (km km^{-2})	Annual precipitation (mm)	Annual ET (mm)	Dominant hydrologic regime	Type of silvicultural method	Percent of vegetation cover removed	Use of buffer strips around waterways	Duration of harvest period (months)	Type of yarding	Type of site preparation
64: 16% 66: 11% 68: 12%	64: 0.4 66: 16.4 68: 28.7	1295	770	precipitation well distributed throughout the year; 30% of rainfall occurs in winter with runoff usually greatest in that season; all flow occurs only during and for a short time after substantial rain storms	clearcut	64: 100% 66: 100% 68: 100%	no buffers	64: 1.5 months 66: 1.5 months 68: 1.5 months	64, 66, and 68: skidded uphill to landing using rubber-tired skidders	64: three prescribed burns before harvesting and slash bladed off the basin afterwards 66 and 68: three prescribed burns before harvesting; slash left in place

Road density (km km^{-2})	Percent of area compacted	Type of disturbance	Percent of area disturbed	Season of management activities	Mean slope of treated area (%)	Dominant aspect	Rate of regrowth	Type and frequency of precipitation data	Location of precipitation measurements relative to discharge station
	64: 50% 66: 20-25% 68: 20-25%	64: burning, logging, site preparation 66: burning, logging 68: burning, logging	64: 50% 66: 20-25% 68: 20-25% (soil surface exposed)	burning: first-spring; second and third-late summer logging: winter	64: 16% 66: 11% 68: 12%	S-SW	rapid, but no effect on hydrological response until second year	standard rain gage	adjacent to flume

Discharge record before/after treatment (years)	Author's peak flow criteria	Reported percent change in peak flows	Reported absolute change in peak flows (l. s^{-1} ha^{-1})	Author's low flow criteria	Reported percent change in low flows	Reported absolute change in low flows (l. s^{-1} ha^{-1})	Statistical significance of changes
64 and 66: 3.5/1.75 68: 2.3/1.75	maximum instantaneous peak including base flow for the mean storm before and after treatment	64: 150% 66: 55-60% 68: 55-60%					0.01

Table I.56. Summary information for forest harvest study number 56 (Beasley and Granillo, 1988).

Study design	Location	Treated basin(s)	Area (ha)	Latitude and longitude	Elevation mean/range (m)	Ecoregion domain	Vegetation	Pre-harvest stand age	Soil type and depth (m)	Geology
Randomized block design; three blocks, each consisted of one clearcut, one selection cut, and one control; determined the effects of each treatment on flows and sediment production.	near Monticello, Drew County, AR	Ten Mile Creek (six basins) and Ilungerrun Creek (three basins)	2.3-4.0 mean = 3.1	33°40'N; 91°47'W		humid temperate	mixed hardwood and pine		silt loams and loams	

Mean slope of the basin (%)	Drainage density (km km^{-2})	Annual precipitation (mm)	Annual ET (mm)	Dominant hydrologic regime	Type of silvicultural method	Percent of vegetation cover removed	Use of buffer strips around waterways	Duration of harvest period (months)	Type of yarding	Type of site preparation
most average slightly >1%; none are >3%		1338			three were clearcut; three had selective cutting of pines, removal of all commercial hardwoods, and deadening of the rest of the hardwoods	three clearcut: 100%	three clearcut: no buffers; it should be noted that only one of the nine basins had a well defined drainage channel	1.5 months		clearcut: shearing, windrowing, and burning selection cut: deadening of remaining hardwoods

Road density (km km^{-2})	Percent of area compacted	Type of disturbance	Percent of area disturbed	Season of management activities	Mean slope of treated area (%)	Dominant aspect	Rate of regrowth	Type and frequency of precipitation data	Location of precipitation measurements relative to discharge station
		clearcut: logging, site preparation, planting	clearcut: 100%	logging: summer site preparation: early fall planting: winter	<3%			seven standard and two recording rain gages	four standard and one recording gage at the Ten Mile Creek site with the rest located at the Ilungerrun Creek site

Discharge record before/after treatment (years)	Author's peak flow criteria	Reported percent change in peak flows	Reported absolute change in peak flows (L s^{-1} ha^{-1})	Author's low flow criteria	Reported percent change in low flows	Reported absolute change in low flows (L s^{-1} ha^{-1})	Statistical significance of changes
1/4	mean annual peak	clearcut basins were significantly greater than the selection cut and control basins for the first year only					0.05

Table I.57. Summary information for forest harvest study number 57 (Hewlett, 1978).

Study design	Location	Treated basin(s)	Area (ha)	Latitude and longitude	Elevation mean/range (m)	Ecoregion domain	Vegetation	Pre-harvest stand age	Soil type and depth (m)	Geology
Paired basin study; one clearcut, one control; looked at effects of clearcutting with buffer strips, mechanical site preparation, and mechanical planting activities on flows; compared flows prior to and including the harvest period with those which occurred during and after the site preparation activities.	B. F. Grant Memorial Forest, Putnam County, GA	WS 14	32.5	33°25'N; 83°25' W	250	humid temperate	loblolly and hardwoods	35 years	mostly sandy loam plow layer over loamy B soil: 1.5 m regolith: 10 m	igneous/granite, gneiss, and saprolite

Mean slope of the basin (%)	Drainage density ($km\ km^{-2}$)	Annual precipitation (mm)	Annual ET (mm)	Dominant hydrologic regime	Type of silvicultural method	Percent of vegetation cover removed	Use of buffer strips around waterways	Duration of harvest period (months)	Type of yarding	Type of site preparation
2-25%; 6% mean		1300	920	rain dominated	clearcut except for buffer zones which were partially cut	97%	12 m wide buffer zones which were partially cut and which had 1/4 taken down by a tornado leaving about 50% vertical coverage in these areas	five months	used timber jacks and tree length hauling	roller chopped in April 1975 (one drum), allowed to rot down during the summer, and chopped again using tandem rollers (two drums); mechanically planted with a V-blade that was pushed at a mean depth of 10-15 cm, exposing B horizon materials over about 45% of the basin

Road density ($km\ km^{-2}$)	Percent of area compacted	Type of disturbance	Percent of area disturbed	Season of management activities	Mean slope of treated area (%)	Dominant aspect	Rate of regrowth	Type and frequency of precipitation data	Location of precipitation measurements relative to discharge station
	10%	logging, site preparation, and planting activities	about 50% of the mineral soil surface was exposed for the first year	fall and winter	2-25% 6% mean	W	rapid	two Friez-type weighing bucket recording rain gages and four Weather Service standard gages; checked at least weekly	one standard gage was located next to the discharge station and one standard and one recording gage was located in the upper basin of each basin

Discharge record before/after treatment (years)	Author's peak flow criteria	Reported percent change in peak flows	Reported absolute change in peak flows ($L\ s^{-1}\ ha^{-1}$)	Author's low flow criteria	Reported percent change in low flows	Reported absolute change in low flows ($L\ s^{-1}\ ha^{-1}$)	Statistical significance of changes
1.3/3	maximum instantaneous discharge less the flow at the beginning of stormflow; looked at small (<11 $L\ s^{-1}\ ha^{-1}$) and large peaks (>55 $L\ s^{-1}\ ha^{-1}$)	small: 100% large: not significant					

Table I.58. Summary information for forest harvest study number 58 (Gilmour, 1977).

Study design	Location	Treated basin(s)	Area (ha)	Latitude and longitude	Elevation mean/range (m)	Ecoregion domain	Vegetation	Pre-harvest stand age	Soil type and depth (m)	Geology
Paired basin study; one treated, one control; treated basin had majority of the area logged; 67% was cleared and converted to pasture; looked at effect of these changes on flows.	tropical coast of North Queensland near Babinda	North Creek	18.3	27°30'S; 153°10'	9.2-118.3	humid tropical	tropical rainforest	mostly virgin, but 30% was cut three years prior to main harvest	clays	deeply weathered metamorphic rocks

Mean slope of the basin (%)	Drainage density (km km^{-2})	Annual precipitation (mm)	Annual ET (mm)	Dominant hydrologic regime	Type of silvicultural method	Percent of vegetation cover removed	Use of buffer strips around waterways	Duration of harvest period (months)	Type of yarding	Type of site preparation
22%	220	4037	1348 (annual precipitation-annual yield)	rainfall; about 50% of annual precipitation occurs Jan-Mar; about 60% of annual flow occurs Feb-Apr		67% cleared in 1973		30%: ? "majority": one month 67% cleared: one month		67% completely cleared two years after logging, stick raked, and partly ploughed to ready it for the establishment of tropical pastures

Road density (km km^{-2})	Percent of area compacted	Type of disturbance	Percent of area disturbed	Season of management activities	Mean slope of treated area (%)	Dominant aspect	Rate of regrowth	Type and frequency of precipitation data	Location of precipitation measurements relative to discharge station
		30% logged in 1968; "majority" logged in 1971; 67% cleared in 1973 (unsure if this included the original cut area); site preparation activities		first cut: ?; other disturbances: summer				meteorological station	between the two basins

Discharge record before/after treatment (years)	Author's peak flow criteria	Reported percent change in peak flows	Reported absolute change in peak flows (L s^{-1} ha^{-1})	Author's low flow criteria	Reported percent change in low flows	Reported absolute change in low flows (L s^{-1} ha^{-1})	Statistical significance of changes
1.5/2/2 (before logging /between logging and clearing/after clearing)	unclear if peak included base flow; peaks chosen were those on the treated basin which were associated with identifiable peaks on the control	using flows taken from a log transformed regression equation: after logging: 1.6 L s^{-1} ha^{-1}: 5% 7.7 L s^{-1} ha^{-1}: 22% 15.5 L s^{-1} ha^{-1}: 30% 30.9 L s^{-1} ha^{-1}: 39% after clearing: 1.6 L s^{-1} ha^{-1}: 21% 7.7 L s^{-1} ha^{-1}: 19% 15.5 L s^{-1} ha^{-1}: 20% 30.9 L s^{-1} ha^{-1}: 18%	after logging: 1.6 L s^{-1} ha^{-1}: 0.1 7.7 L s^{-1} ha^{-1}: 1.7 15.5 L s^{-1} ha^{-1}: 4.6 30.9 L s^{-1} ha^{-1}: 12.1 after clearing: 1.6 L s^{-1} ha^{-1}: 0.3 7.7 L s^{-1} ha^{-1}: 1.5 15.5 L s^{-1} ha^{-1}: 3.1 30.9 L s^{-1} ha^{-1}: 5.6	minimum weekly instantaneous discharges; all data before clearing was combined and compared to post-clearing data because there was no significant difference between pre- and post-logging flows	for the following minimum weekly flows: 0.1 L s^{-1} ha^{-1}: 60% 0.2 L s^{-1} ha^{-1}: 40% 0.8 L s^{-1} ha^{-1}: 16% 1.5 L s^{-1} ha^{-1}: 14%	for the following minimum weekly flows: 0.1 L s^{-1} ha^{-1}: 0.05 0.2 L s^{-1} ha^{-1}: 0.06 0.8 L s^{-1} ha^{-1}: 0.12 1.5 L s^{-1} ha^{-1}: 0.22	Peak flow: "significantly different" Low flow: p = 0.001 for difference between regression coefficients

Table I.59. Summary information for forest harvest study number 59 (Springer and Coltharp, 1980 and 1978). When information for a category differed between studies, the source of the information is provided in parentheses in the form of the authors' initials.

Study design	Location	Treated basin(s)	Area (ha)	Latitude and longitude	Elevation mean/range (m)	Ecoregion domain	Vegetation	Pre-harvest stand age	Soil type and depth (m)	Geology
Paired basin study; one control, one treated; looked at effects of logging road construction on peak flows during the dormant season using regression equation analysis.	University of Kentucky's Robinson Forest, 40 km south of Jackson, KY	Little Millseat	81.4	37°10'N; 83°25'W		humid temperate	mixed hardwoods: oaks, hickories, maples, and yellow poplar			alternating layers of sandstones, siltstones, shales, and coal

Mean slope of the basin (%)	Drainage density (km km^{-2})	Annual precipitation (mm)	Annual ET (mm)	Dominant hydrologic regime	Type of silvicultural method	Percent of vegetation cover removed	Use of buffer strips around waterways	Duration of harvest period (months)	Type of yarding	Type of site preparation
42%	1.3	1360		snow is insignificant; most of precipitation occurs during winter and spring, but the summers are by no means lacking in precipitation; 64% of annual flow occurs Jan-Apr and 75% occurs by Jun	the only trees cut were those associated with the establishment of a logging road	8.5%	the cutting did not cross the stream, but it was near (approximately 30 m or greater) the channel for much of its length; the road was positioned at mid-slope throughout the entire basin	one year (this includes the entire road construction period)		seeded with grass

Road density (km km^{-2})	Percent of area compacted	Type of disturbance	Percent of area disturbed	Season of management activities	Mean slope of treated area (%)	Dominant aspect	Rate of regrowth	Type and frequency of precipitation data	Location of precipitation measurements relative to discharge station
	8.5%	roads	8.5%	year round (?)		SE	none	two recording gages	one at the mouth of each basin

Discharge record before/after treatment (years)	Author's peak flow criteria	Reported percent change in peak flows	Reported absolute change in peak flows (l. s^{-1} ha^{-1})	Author's low flow criteria	Reported percent change in low flows	Reported absolute change in low flows (l. s^{-1} ha^{-1})	Statistical significance of changes
2/3.25	mean dormant season (Nov-Apr) peak for the control (for events equal to or greater than 0.64 cm of total quickflow volume)	-25%	-1.7				regression equations significantly different at 0.05

Table I.60. Summary information for forest harvest study number 60 (Mrazik, Mader, and MacConnell, 1980; Mader, MacConnell, and Bauder, 1972).

Study design	Location	Treated basin(s)	Area (ha)	Latitude and longitude	Elevation mean/range (m)	Ecoregion domain	Vegetation	Pre-harvest stand age	Soil type and depth (m)	Geology
Paired basin study: one control, one treated; the treated and control basins were in the same basin; the treated area was located in the headwaters and the control consisted of the remaining area in the Cadwell Creek basin; treatment consisted of herbicide deadening of trees and understory vegetation around the riparian zones, chemical thinning of the pine plantations, and harvesting by small patch clearcuts of upslope areas; looked at effects of treatments on flows.	Central Massachusetts, on the western side of Quabbin Reservoir near the towns of Pelham and Belchertown	upper Cadwell Creek	163	42°25'N; 72°23'W	274-350	humid temperate	80% mixed oaks and northern hardwoods; 10% mixed hardwoods and conifers; 10% pine plantation	60 years	sands and sandy loams; many times they are excessively stony; shallow	glacial till

Mean slope of the basin (%)	Drainage density (km km^{-2})	Annual precipitation (mm)	Annual ET (mm)	Dominant hydrologic regime	Type of silvicultural method	Percent of vegetation cover removed	Use of buffer strips around waterways	Duration of harvest period (months)	Type of yarding	Type of site preparation
slopes seldom exceed 15%		1067		precipitation fairly evenly distributed throughout the year; approximately 25% of annual precipitation occurs as snowfall between mid-Dec and mid-Mar	various: chemical deadening of all trees along the riparian zone of the two major streams (19.8 ha) and all understory vegetation within 61 m of the stream; thinning of 8.5 ha of pine plantation by 50% of BA using herbicides; 40% reduction in BA of another 56.7 ha by cutting in small patch clearcuts; chemical deadening of a riparian zone of a secondary brook (6.5 ha)	34.4% of original BA either deadened or harvested	deadening and some harvesting occurred in the riparian zone; most harvesting was conducted in upslope areas (no skidder trail was within 100' of riparian zone)	6	skidded with very careful supervision	

Road density (km km^{-2})	Percent of area compacted	Type of disturbance	Percent of area disturbed	Season of management activities	Mean slope of treated area (%)	Dominant aspect	Rate of regrowth	Type and frequency of precipitation data	Location of precipitation measurements relative to discharge station
	1% (ground frozen)	logging and herbicide treatment	64%	late fall-early spring	<15%	S	during first three years after treatment, the riparian and patch clearcut areas were maintained in meadow-like conditions (ferns, grasses, and herbaceous plants)	initially two recording rain gages and three standard gages; reduced to one recording and two standard gages	located throughout the basin

Discharge record before/after treatment (years)	Author's peak flow criteria	Reported percent change in peak flows	Reported absolute change in peak flows (l. s^{-1} ha^{-1})	Author's low flow criteria	Reported percent change in low flows	Reported absolute change in low flows (l. s^{-1} ha^{-1})	Statistical significance of changes
6/4	average peak on control for storms occurring during Apr-Oct; not sure whether baseflow was separated out	46%	0.17				regression slopes: 0.01

Table I.61. Summary information for forest harvest study number 61 (Department of Drainage and Irrigation, Malaysia, 1989).

Study design	Location	Treated basin(s)	Area (ha)	Latitude and longitude	Elevation mean/range (m)	Ecoregion domain	Vegetation	Pre-harvest stand age	Soil type and depth (m)	Geology
Paired basin study: one control, two treated (A and B); A was inside B; A was cleared and converted to cocoa production and sub-B (the rest of basin B) was cleared and converted to an oil palm plantation; clearing of A began at about the time that the oil palm was being planted in sub-B; the evaluation (post-treatment) period for basin B was during the time after sub-B was replanted and before the time that A was finished being converted, so the results are unclear; they did not account for changes in flow to B caused by on-going disturbance in basin A; at the same time, all flow records that are provided for A appear to end in 1986--the beginning of the evaluation period for this basin; yet, they still have results from an evaluation period for this basin.	Sungai Tekam Experimental Basin, Peninsular Malaysia	A, B (A is within B)	A: 37.7 B: 96.9	3°54'N; 102°32'E	relief: A: 72.5 B: 68.5	humid tropical	rainforest			

Mean slope of the basin (%)	Drainage density (km km^{-2})	Annual precipitation (mm)	Annual ET (mm)	Dominant hydrologic regime	Type of silvicultural method	Percent of vegetation cover removed	Use of buffer strips around waterways	Duration of harvest period (months)	Type of yarding	Type of site preparation
A and B: 11-14%		1878	1252 (pan method--considered to be too low); 1500 from water balance	rainfall throughout the year, but there are two monsoon seasons (Oct-Dec and Apr-May) which cause distinct peaks in annual precipitation; the Oct-Dec season is typically higher	A and B: clearcut	A and B: 100%		A: 6 B: 5 (sub-basin B) and 6 (basin A, two years after sub-B)		A: burned twice; latter burn due to poor initial burn--partially burnt logs were stacked with a D6 bulldozer and reburnt; site was planted with shade trees and cocoa; B: sub-B: same as A only planted with legume cover and then oil palms; A: see above

Road density (km km^{-2})	Percent of area compacted	Type of disturbance	Percent of area disturbed	Season of management activities	Mean slope of treated area (%)	Dominant aspect	Rate of regrowth	Type and frequency of precipitation data	Location of precipitation measurements relative to discharge station
		A and B: logging, clearing, burning, planting	A and B: 100%	A: logging: late fall-early winter; clearing: winter; burning: early spring and early summer; planting: fall B: logging and clearing: mid-summer to late fall; burning: late winter; planting: legume cover was in spring and oil palm in fall	A and B: 11-14%	A: W B: SW	oil palms in sub-B were "fully established" by end of transition period	four weekly automatic rainfall recorders and one storage gage	one recording gage each at the top and bottom of control; one recording gage each at the bottom and middle of B; and the storage gage near the outlet of A

Discharge record before/after treatment (years)	Author's peak flow criteria	Reported percent change in peak flows	Reported absolute change in peak flows (L s^{-1} ha^{-1})	Author's low flow criteria	Reported percent change in low flows	Reported absolute change in low flows (L s^{-1} ha^{-1})	Statistical significance of changes
calibration/transition/evaluation A: 5/3.5/?* B: 3/?/?* *very unclear	peak for one hour unit hydrograph (no intensity provided)	A: 180% (after deforestation only)* B: 38% (after clearing of sub-B only)* *control changed by 28%	A: 0.90* B: 0.18* *control changed by 0.14				

Table I.62. Summary information for forest harvest study number 62 (Abdul Rahim, 1990).

Study design	Location	Treated basin(s)	Area (ha)	Latitude and longitude	Elevation mean/range (m)	Ecoregion domain	Vegetation	Pre-harvest stand age	Soil type and depth (m)	Geology
Paired basin study; one control, two treated; both were cut using selective logging methods, but C1 was cut using standard procedures while C3 was cut using more restrictive procedures; looked at effects of these different methods on flows.	Berembun Experimental Watershed, in the Berembun Forest Reserve, 70 km SE of Kuala Lumpur, Peninsular Malaysia	C1 C3	C1: 13.3 C3: 30.8	2°50'N; 102°10'E	C1: 171-289 C3: 171-302	humid tropical	mostly *Shorea* spp.; other common overstory species are *Koompassia malaccensis* and *Intsia palembanica*	virgin stand	medium to coarse sandy clay loams; 0.8+ m	underlain by a single granite body; the rock consists of medium to coarse-grained porphyritic biotite granite with both quartz and feldspar as phenocrysts

Mean slope of the basin (%)	Drainage density (km km^{-2})	Annual precipitation (mm)	Annual ET (mm)	Dominant hydrologic regime	Type of silvicultural method	Percent of vegetation cover removed	Use of buffer strips around waterways	Duration of harvest period (months)	Type of yarding	Type of site preparation
C1: 42% C3: 34%	C1: 6.17 C3: 4.68	1442-2611 2126	1362-1481 1438	rainfall distributed throughout the year with distinct peaks in Nov and Apr coinciding with monsoon seasons; Oct-Jan normally has the highest rainfall amounts	C1: selective logging: 40% of stocking removed C3: selective logging: 33% of stocking removed	C1: 40% C3: 33%	C1: C3: 20 m buffers from each side of the stream	C1: 1 C3: 1	C1: C3: tractor	

Road density (km km^{-2})	Percent of area compacted	Type of disturbance	Percent of area disturbed	Season of management activities	Mean slope of treated area (%)	Dominant aspect	Rate of regrowth	Type and frequency of precipitation data	Location of precipitation measurements relative to discharge station
C1: 14 C3: 10 (includes both logging roads and skid trails)		logging activities	C1: 11% C3: 9%	summer		C1: S C3: S		three recording (0.5 mm tipping-bucket) and eight storage; both have 8-inch diameter openings; gages are serviced at least weekly; those at the climate station near the headquarters are serviced daily	throughout the study area

Discharge record before/after treatment (years)	Author's peak flow criteria	Reported percent change in peak flows	Reported absolute change in peak flows (L s^{-1} ha^{-1})	Author's low flow criteria	Reported percent change in low flows	Reported absolute change in low flows (L s^{-1} ha^{-1})	Statistical significance of changes
3.5/4	instantaneous peak? (page describing type used was missing)	not significant	not significant				not significant at $p = 0.10$

Table I.63. Summary information for forest harvest study number 63 (Shimizu, 1994; Shimizu, Tsuboyama, and Hosoda, 1994). When information for a category differed between studies, the source of the information is provided in parentheses in the form of the authors' initials.

Study design	Location	Treated basin(s)	Area (ha)	Latitude and longitude	Elevation mean/range (m)	Ecoregion domain	Vegetation	Pre-harvest stand age	Soil type and depth (m)	Geology
Single basin study; looked at changes in streamflow characteristics based on relationship with storm characteristics; only looked at warm season storms (Jun-Oct) not affected by snowfalls.	Takaragawa Forest Watershed Experiment Station; upstream area of the Tone River, Japan	1-gosawa	6.48	36°51'N; 139°01'E	806-1075 940	humid temperate	natural mixed forest of hardwoods and softwoods; mainly: *Thujopsis dolabrata*, *Fagus* spp., and *Quercus* spp.		"brown forest soils"	mainly tuff of the Tertiary layer

Mean slope of the basin (%)	Drainage density (km km^{-2})	Annual precipitation (mm)	Annual ET (mm)	Dominant hydrologic regime	Type of silvicultural method	Percent of vegetation cover removed	Use of buffer strips around waterways	Duration of harvest period (months)	Type of yarding	Type of site preparation
49%		1918 (over study period)	989 (annual precipitation-annual runoff during pre-treatment)	39% of precipitation falls during snow season (Dec-Mar)	strip cut in 50 m strips along the contour, alternating between cut and leave strips	area: 52% volume: 54%	no buffers	9	skyline	none

Road density (km km^{-2})	Percent of area compacted	Type of disturbance	Percent of area disturbed	Season of management activities	Mean slope of treated area (%)	Dominant aspect	Rate of regrowth	Type and frequency of precipitation data	Location of precipitation measurements relative to discharge station
none				late fall to early summer	49%	S		weather station	100 m from mouth of treated basin

Discharge record before/after treatment (years)	Author's peak flow criteria	Reported percent change in peak flows	Reported absolute change in peak flows (L s^{-1} ha^{-1})	Author's low flow criteria	Reported percent change in low flows	Reported absolute change in low flows (L s^{-1} ha^{-1})	Statistical significance of changes
5/5	instantaneous peak during warm season (Jun-Oct)	16-41% for large storms					

Table I.64. Summary information for forest harvest study number 64 (Fahey and Jackson, 1995).

Study design	Location	Treated basin(s)	Area (ha)	Latitude and longitude	Elevation mean/range (m)	Ecoregion domain	Vegetation	Pre-harvest stand age	Soil type and depth (m)	Geology
Paired basin study; one control, two treated; direct comparison of mean flows for various size classes between treated and control basins; pre-treatment comparison showed that the means were close enough to justify this direct comparison.	Big Bush; Tadmor Valley in north-western South Island, New Zealand	DC1 DC4	DC1: 8.6 DC4: 20.2	41°36'S; 172°30'E	5550 m over entire area	humid temperate	dominant species are hard beech (*Nothofagus truncata*) and red beech (*N. fusca*)		stony Dystrochrepts; shallow	underlain by the moderately weathered, tightly compacted, early Pleistocene Moutere Gravel Formation

Mean slope of the basin (%)	Drainage density ($km\ km^{-2}$)	Annual precipitation (mm)	Annual ET (mm)	Dominant hydrologic regime	Type of silvicultural method	Percent of vegetation cover removed	Use of buffer strips around waterways	Duration of harvest period (months)	Type of yarding	Type of site preparation
		1530 (over study period)		rainfall, evenly distributed throughout the year	clearcut	DC1: 83% DC4: 94%	DC1: 10 m wide buffer strip on either side of the stream channel DC4:	DC1: 9 DC4: 13	DC1: rubber-tired skidders on tracks approximately 40 m apart DC4: hauler (skyline cable)	DC1: partially burnt, root-raked, and planted with *Pinus radiata* DC4: planted with *Pinus radiata*

Road density ($km\ km^{-2}$)	Percent of area compacted	Type of disturbance	Percent of area disturbed	Season of management activities	Mean slope of treated area (%)	Dominant aspect	Rate of regrowth	Type and frequency of precipitation data	Location of precipitation measurements relative to discharge station
				DC1: early fall to late spring DC4: year round		NW		one meteorological station, two recording rain gages, and four standard rain gages	throughout the study area

Discharge record before/after treatment (years)	Author's peak flow criteria	Reported percent change in peak flows	Reported absolute change in peak flows ($L\ s^{-1}\ ha^{-1}$)	Author's low flow criteria	Reported percent change in low flows	Reported absolute change in low flows ($L\ s^{-1}\ ha^{-1}$)	Statistical significance of changes
4/6	instantaneous peaks; mean for each of four different size classes ($L\ s^{-1}\ ha^{-1}$): 2-5, 5-8, 8-15, and >15	2-5 $L\ s^{-1}\ ha^{-1}$: DC1: 77% DC4: 52% 5-8 $L\ s^{-1}\ ha^{-1}$: DC1: >100% DC4: 64% 8-15 $L\ s^{-1}\ ha^{-1}$: DC1: 16% DC4: slight decrease ≥15 $L\ s^{-1}\ ha^{-1}$: DC1: 73% DC4: 26%					

Table I.65. Summary information for forest harvest study number 65 (Turton and Clendenen, pers. comm.).

Study design	Location	Treated basin(s)	Area (ha)	Latitude and longitude	Elevation mean/range (m)	Ecoregion domain	Vegetation	Pre-harvest stand age	Soil type and depth (m)	Geology
Paired basin: one control, one treated; no analysis done--information provided for use with FDC analysis.	Clayton Creek; Weyerhaeuser Company lands, Pushmataha, OK	Cl-1	7.6		320	humid temperate	mixed shortleaf pine and oak-hickory	50-60 years	fine sandy loam A horizon over silty clay to clay B horizon; mean: 1.0 m	interbedded sandstone and shale of the Jackfork unit

Mean slope of the basin (%)	Drainage density (km km^{-2})	Annual precipitation (mm)	Annual ET (mm)	Dominant hydrologic regime	Type of silvicultural method	Percent of vegetation cover removed	Use of buffer strips around waterways	Duration of harvest period (months)	Type of yarding	Type of site preparation
18% with steep breaks near streams up to 40%		1194	813 (from regional water balance)	rainfall distributed throughout the year	clearcut	98%	50' buffers in lower half of basin; no buffers in upper half	2	rubber-tired skidders; skidded upslope to one of two landings	residual vegetation drum chopped; slash broadcast burned; sub-soiling on the contour to a depth of 45 cm, spaced 2.5 m apart

Road density (km km^{-2})	Percent of area compacted	Type of disturbance	Percent of area disturbed	Season of management activities	Mean slope of treated area (%)	Dominant aspect	Rate of regrowth	Type and frequency of precipitation data	Location of precipitation measurements relative to discharge station
0		soil laid bare by skidding, compaction from skidders; soil loosened by subsoiling; hot burn	98%	logged, chopped, and burned in summer; ripped and planted in winter	18%	NNW	rapid; entire basin covered with grasses the first growing season after harvest	weighing bucket and can precipitation gages	30 m from stream gage

Discharge record before/after treatment (years)	Author's peak flow criteria	Reported percent change in peak flows	Reported absolute change in peak flows (l. s^{-1} ha^{-1})	Author's low flow criteria	Reported percent change in low flows	Reported absolute change in low flows (l. s^{-1} ha^{-1})	Statistical significance of changes
4/5							

APPENDIX II:

SUMMARY TABLES FOR AFFORESTATION STUDIES

Table II.1. Summary information for afforestation study number 1 (Acreman, 1984).

Study design	Location	Treated basin(s)	Area (ha)	Latitude and longitude	Elevation mean/range (m)	Ecoregion domain	Pre-planting vegetation	Planted vegetation	Soil type and depth (m)	Geology
Looked at effects of afforestation and associated pre-planting activities on flows; no control basin was used; treated basin was 31% afforested over the course of 11 years; looked at flows for four different time periods: before planting, after lower valley was planted, after upper valley was planted, and after all planting was completed.	Upper Ettrick Valley, 60 km south of Edinburgh, Scotland	River Ettrick at Brockhoperig	3750	55°22'N; 3°12'W		humid temperate	purple moor grass, cotton grass, cross-leaved heather and *Sphagnum rubellum*; a few birch and rowan were the only naturally occurring trees		much of the area is covered by blanket peat up to several meters deep	area is underlain by folded sedimentary rocks, mainly greywackes

Mean slope of the basin (%)	Drainage density (km km⁻²)	Annual precipitation (mm)	Annual ET (mm)	Dominant hydrologic regime	Prevalence of dry season	Revegetation method and other site treatments	Percent of area revegetated	Location of revegetation relative to channel	Road density (km km⁻²)
		upwards of 2000 mm				31% of basin afforested over the course of 11 years; lower part afforested during first three years; second three years saw primary afforestation efforts in the upper valley; last five years saw afforestation in both areas; each site was drained and all but steepest slopes were plowed prior to planting; channels used for drainage disturbed more than 31% of the area	31%		

Percent of area compacted before revegetated	Aspect of revegetated areas	Rate of growth	Type and frequency of precipitation data	Location of measurements relative to discharge station	Discharge record before/after (years)
			one continuous recording rain gage and one storage gage which was checked daily	recording: 5 km SE storage: 5 km NE	

Author's peak flow criteria	Reported percent change in peak flows	Reported absolute change in peak flows (L s⁻¹ ha⁻¹)	Author's low flow criteria	Reported percent change in low flows	Reported absolute change in low flow (L s⁻¹ ha⁻¹)	Statistical significance of changes
10 10 mm one-hour unit hydrographs from each time period were averaged; unsure as to whether peak included base flow or not	1970/71: -14% 1973/74: 38% 1975/76: 6%	1970/71: -0.6 1973/74: 1.6 1975/76: 0.3				1970/71: 0.10 1973/74: 0.01 1975/76: ?

Table II.2. Summary information for afforestation study number 2 (Banks and Kromhout, 1963; van Wyk, 1987; Smith and Scott, 1992). When information for a category differed between studies, the source of the information is provided in parentheses in the form of the authors' initials.

Study design	Location	Treated basin(s)	Area (ha)	Latitude and longitude	Elevation mean/range (m)	Ecoregion domain	Pre-planting vegetation	Planted vegetation	Soil type and depth (m)	Geology
(BK): paired basin study; one control, two afforested (Bosboukloof, 57% in 1940 and Biesievlei, 98% in 1948); looked at changes in flows for the time periods 1945-48 and 1956-59. (SS): paired basin study; one control, one afforested (Lambrechtsbos B, 82% in 1964/65); looked at effects of treatment on flows over time.	Jonkershoek Forest Research Station, Stellenbosch, South Africa	Bosboukloof (Bos), Biesievlei (Bie), and Lambrechtsbos B (Lam B)	Bos: 200.9 Bie: 27.2 Lam B: 66.5	18°15'E; 33°57'S	Bos: 543 Bie: 396 Lam B: 660	humid temperate	tall fynbos (shrubland)	Bos: *Pinus radiata* Bie: *P. radiata* Lam B: *P. radiata*	loams to sandy loams	sandstones underlain by granite; a shale band runs through the sandstone and small lenses of shale occur irregularly

Mean slope of the basin (%)	Drainage density (km km⁻²)	Annual precipitation (mm)	Annual ET (mm)	Dominant hydrologic regime	Prevalence of dry season	Revegetation method and other site treatments	Percent of area revegetated	Location of revegetation relative to channel	Road density (km km⁻²)
Bos: 26% Bie: 23% Lam B: 46%	Bos: 4.7 Bie: Lam B:	Bos: 1296 Bie: 1427 Lam B: 1473		Mediterranean climate; 85% of annual rainfall occurs in winter (Apr-Sep)	yes, only 15% of annual precipitation occurs Oct-Mar	Sites planted eight years apart beginning with Bosboukloof (1940) then Biesievlei (1948) and Lambrechtsbos B (1964) (another basin which was not reported in these papers was planted in 1956); *Pinus radiata* was planted at an initial spacing of 2.7 x 2.7 m (1330 stems/ha); trees were (or will be) thinned three to four times over 30 years to a final density of 150-175 stems ha^{-1} and then harvested at age 40; Lambrechtsbos B was thinned to 770, 510 and 324 stems ha^{-1} 8, 13 and 18 years after planting respectively.	Bos: 57% Bie: 98% Lam B: 82%	Bos and Lam B: 20 m strip along all streambanks was left unplanted (natural vegetation was left intact and allowed to grow) Bie: planted up to streambanks	

Percent of area compacted before revegetated	Aspect of revegetated areas	Rate of growth	Type and frequency of precipitation data	Location of measurements relative to discharge station	Discharge record before/after (years)
	Bos: SW Bie: SW Lam B: SW		20 rain gages	located through out the study area	(BK): used 4/11 (SS): used 6/16

Author's peak flow criteria	Reported percent change in peak flows	Reported absolute change in peak flows ($L\ s^{-1}\ ha^{-1}$)	Author's low flow criteria	Reported percent change in low flows	Reported absolute change in low flow ($L\ s^{-1}\ ha^{-1}$)	Statistical significance of changes
			(BK): mean two-hourly flows from rainless days in the midsummer month of Jan; flows on treated basins were adjusted for changes in flow on control (SS): used a low flow cut-off value of 13 mm per month so that the two to three driest months could be included for analysis each year	Bos: -26% Bie: -53% Lam B: -77.8% and -77.6% for 15th and 16th year after treatment, respectively	Bos: -0.017 Bie: -0.005 Lam B: -40.8 mm per month and 15.0 mm per month for 15th and 16th year after treatment, respectively	(BK): "highly significant" (0.01) (SS): 0.01

Table II.3. Summary information for afforestation study number 3 (Bosch, 1979; Nänni, 1970 and 1956; Smith and Scott, 1992). When information for a category differed between studies, the source of the information is provided in parentheses in the form of the authors' initials.

Study design	Location	Treated basin(s)	Area (ha)	Latitude and longitude	Elevation mean/range (m)	Ecoregion domain	Pre-planting vegetation	Planted vegetation	Soil type and depth (m)	Geology
(B): paired basin study; one control, two afforested (CII and CIII); looked at effects of treatment on flows; results were derived graphically, not statistically. (N): paired basin study; one control, one afforested (CII); looked at effect of treatment on flows. (SS): paired basin study; one control, one afforested (CIII); looked at effects of treatment on flows over time.	Cathedral Peak, near Winterton in the Natal Drakensberg, South Africa	CII and CIII	CII: 190 CIII: 142	29°00'S; 29°15'E	CII: 1844-2454, 2070 CIII: 1844-2316, 2019	dry	CII: grassland CIII: grassland	*Pinus patula*	loams in the top horizon underlain by clay loams and weathered rock material in the lower horizons; 0.8 m	basaltic lavas underlain by sandstone

Mean slope of the basin (%)	Drainage density (km km-2)	Annual precipitation (mm)	Annual ET (mm)	Dominant hydrologic regime	Prevalence of dry season	Revegetation method and other site treatments	Percent of area revegetated	Location of revegetation relative to channel	Road density (km km-2)
CII: 45% CIII: 38%	CII: 2.6	1550		rainfall, 84% of which occurs during late spring to early fall (Oct-Mar); 67% of total annual streamflow occurs Jan-Apr	yes; only 16% of annual precipitation occurs during late fall to early spring	CII: percent of area planted (year): 52% (1950/51); 6.5%* (1954/55); 2.5%* (1962/63); 13%* (1964/65); 40% of plantation thinned by 50% (1965/66); 46% of plantation thinned by 50% (1969/70); 25% of trees defoliated by moth infestation (1971/72); 8% of area litter stacked and burned (1974/75); 10% of area thinned by 30% (1975/76) *percent of additional area planted CIII: 83% (1958/59); 29% destroyed by fire and replanted (1964/65); 25% of plantation thinned by 40% (1969/70); 25% of trees defoliated and 80% of plantation thinned by 40% (1972/73)	CII: 52% 1st year, up to 74% by 15th year CIII: 83%		

Percent of area compacted before revegetated	Aspect of revegetated areas	Rate of growth	Type and frequency of precipitation data	Location of measurements relative to discharge station	Discharge record before/after (years)
	CII: N CIII: N		two rain gages in each basin	one located at the top and one in the middle of each basin; the upper gage measured monthly volumes and the lower gage was a recording rain gage	(B): 8/19 (CII), 15/12 (CIII) (N): 8/10 (CII) (SS): 8/16 (CIII)

Author's peak flow criteria	Reported percent change in peak flows	Reported absolute change in peak flows (L s-1 ha-1)	Author's low flow criteria	Reported percent change in low flows	Reported absolute change in low flow (L s-1 ha-1)	Statistical significance of changes
			(B) & (N): used total volume for a 50-day period during the driest part of the year (Jul 15-Sep 2); (SS): used a low flow cut-off value of 17 mm per month so that the two to three driest months could be included for analysis each year	(SS): -64.7% and -48.1% for 22nd and 23rd years after treatment	(B): CII: -0.024, -0.035 & -0.029 (mean reduction, first 9 years, 10-14 years and 15-19 years after calibration respectively) CIII: -0.023 (mean reduction, first 12 years after calibration) (N): CII: -0.042 (for 10th year after calibration) (SS): -30.2 and -35.4 mm per month for 22nd and 23rd years after treatment	(SS): 0.01

Table II.4. Summary information for afforestation study number 4 (Claridge, 1980).

Study design	Location	Treated basin(s)	Area (ha)	Latitude and longitude	Elevation mean/range (m)	Ecoregion domain	Pre-planting vegetation	Planted vegetation	Soil type and depth (m)	Geology
Paired basin study; one treated, one control; looked at effects of afforestation with exotic conifers; the control was a basin in which partial native forest regeneration was occurring; overall, the vegetation changed little in the control; discharge records for the treated basin began two years after planting; comparison made using ratio of peaks for different size events over time.	Taita Experimental Station, 15 miles from Wellington, New Zealand	Exotic		41°S; 175°E		humid temperate	mostly scrub	western red cedar, Douglas-fir and, Corsican pine; radiata pine has also established itself on the site naturally		deeply weathered argillite and greywacke sandstone and siltstone

Mean slope of the basin (%)	Drainage density ($km\ km^{-2}$)	Annual precipitation (mm)	Annual ET (mm)	Dominant hydrologic regime	Prevalence of dry season	Revegetation method and other site treatments	Percent of area revegetated	Location of revegetation relative to channel	Road density ($km\ km^{-2}$)
		886-1990; 1390		rainfall, highest frequency occurring May-Aug; driest in Oct-Apr		originally cleared in the 1850s; swept by fire several times since then; felled and burnt in 1958-59; planted with various conifers in 1959; self-sown radiata pines have also become established over much of the area	100%		

Percent of area compacted before revegetated	Aspect of revegetated areas	Rate of growth	Type and frequency of precipitation data	Location of measurements relative to discharge station	Discharge record before/after (years)
	N	forest was 7 m high with complete crown closure 30 years after planting			two years after planting/19

Author's peak flow criteria	Reported percent change in peak flows	Reported absolute change in peak flows ($L\ s^{-1}\ ha^{-1}$)	Author's low flow criteria	Reported percent change in low flows	Reported absolute change in low flow ($L\ s^{-1}\ ha^{-1}$)	Statistical significance of changes
broke into four size classes: 1-2 $mm\ hr^{-1}$, 1-3 $mm\ hr^{-1}$, 1-4 $mm\ hr^{-1}$, and >4 $mm\ hr^{-1}$	reduced	reduced				

Table II.5. Summary information for afforestation study number 5 (Duncan, 1980, 1990, and 1995).

Study design	Location	Treated basin(s)	Area (ha)	Latitude and longitude	Elevation mean/range (m)	Ecoregion domain	Pre-planting vegetation	Planted vegetation	Soil type and depth (m)	Geology
Paired basin study; three control, three treated; looked at effects of vegetation conversion from different vegetation types (gorse and pasture) to *Pinus radiata*.	Moutere Experimental Station, 20 km SW of Nelson City, New Zealand	8, 13, and 14	8: 4.41 13: 7.65 14: 4.33	41°22'S; 173°04'E	mean is 100 m for entire area	humid temperate	8: tall dense gorse 13: tall dense gorse 14: pasture (converted from gorse six years before afforestation)	*Pinus radiata*	all soils usually include a horizon of clay or clay loam; 0.4-0.9 m	underlain by the Moutere Gravel Formation: deeply weathered early Pleistocene gravels, sand, silt, and clay

Mean slope of the basin (%)	Drainage density (km km^{-2})	Annual precipitation (mm)	Annual ET (mm)	Dominant hydrologic regime	Prevalence of dry season	Revegetation method and other site treatments	Percent of area revegetated	Location of revegetation relative to channel
32% for entire area		1105		rainfall distributed fairly evenly among the seasons on average	no	8: gorse burned in Mar 1970; linedozed and planted at 1500 stems ha^{-1} in the following Aug; thinned to 600 stems ha^{-1} and pruned to 2.5 m in Nov 1978; area of broom sprayed in 1972 13: gorse burned in Mar 1970; disced in Nov, 1970, and remaining gorse raked into rows and burned in the following Mar; two graded banks were constructed May-Jun 1971, and planted at 1500 stems ha^{-1} in the following Aug; thinned to 600 stems ha^{-1} and pruned to 2.5 m in Nov 1978; gorse sprayed in 1972 14: converted from gorse to pasture in 1964 with vigorous pasture becoming established over entire basin by 1968; disced and planted at 1500 stems ha^{-1} in Aug 1970; pasture regrowth sprayed in Dec 1970; thinned to 500 stems ha^{-1} and pruned to 2.5 m during May-Jul 1975	8: 100% 13: 100% 14: 100%	

Road density (km km^{-2})	Percent of area compacted before revegetated	Aspect of revegetated areas	Rate of growth	Type and frequency of precipitation data	Location of measurements relative to discharge station	Discharge record before/after (years)
		8: S 13: N 14: N		four standard rain gages	one located 250 m outside of basin 14 and three within it	8/8

Author's peak flow criteria	Reported percent change in peak flows	Actual change in peak (L s^{-1} ha^{-1})	Author's low flow criteria	Reported percent change in low flows	Reported absolute change in low flows (L s^{-1} ha^{-1})	Statistical significance of changes
maximum discharge less base flow that would have occurred had there been no storm; only used storms from 1975-78 where there was a response in all basins; changes provided were the average of all three treated basins	1975-76: -45% 1977: -62% 1978: -73%		80th percentile of a flow duration curve		basins 14 & 8 were reduced	

Table II.6. Summary information for afforestation study number 6 (Harrold, Brakensiek, McGuinness, Amerman, and Dreibelbis, 1962; McGuinness and Harrold, 1971; Ricca, Simmons, McGuinness, and Taiganides, 1970; Dragoun and Harrold, 1971). When information for a category differed between studies, the source of the information is provided in parentheses in the form of the authors' initials.

Study design	Location	Treated basin(s)	Area (ha)	Latitude and longitude	Elevation mean/range (m)	Ecoregion domain	Pre-planting vegetation	Planted vegetation	Soil type and depth (m)	Geology
Paired basin study; one control, three treated (only one was reforested); looked at effects of planting 70.6% of a basin along with the natural regeneration of the rest of the area (which was in woodland) on flows; different authors used different techniques to analyze the flow changes.	North Appalachian Experimental Watershed, near Coshocton, OH	No. 172	17.7	40°23'N; 81°45'W	306-393	humid temperate	29.4% woodland (uneven age hardwoods); 50.5% pasture (grasses?); 20.1% idle (vegetation type not mentioned)	49.9% pitch, red, scotch, Virginia, and white pines; 7.3% black locust; 42.8% naturally regenerating hardwoods	silt loams; 1.5-2.4 m	underlain by layers of sandstones, shales, clays, coals, and limestones

Mean slope of the basin (%)	Drainage density (km km⁻²)	Annual precipitation (mm)	Annual ET (mm)	Dominant hydrologic regime	Prevalence of dry season	Revegetation method and other site treatments	Percent of area revegetated	Location of revegetation relative to channel	Road density (km km⁻²)
22.8%		960		precipitation distributed fairly evenly throughout the year with spring and early summer receiving slightly more than the rest of the year; only about 5% of annual precipitation occurs as snow; Feb-Apr has several times more flow than Aug-Oct		Farmed prior to reforestation; 29.4% was already in natural hardwood vegetation; 70.6% was planted to pines and black locust during the springs of 1938-1939; approximately 15 in² were "scalped" and holes grubbed in the center for planting each tree; spacing was 6 x 6 ft; the only cutting in the pine areas was that done for access roads and light Christmas tree cutting; during 1949-1953, 1/4 ac plots were cut in one of the two black locust areas to establish rotation cutting for fence posts.	70.6% planted and regenerated naturally		

Percent of area compacted before revegetated	Aspect of revegetated areas	Rate of growth	Type and frequency of precipitation data	Location of measurements relative to discharge station	Discharge record before/after (years)
70.6% had been farmed, eroded and abandoned prior to 1935	S	by 1945, the trees had formed a complete ground cover			(HBMAD): 2/18 (RSMT): 2/28 (MH): 2/29 (DH): 11/18* *used the 1st 11 years of study as the "calibration" period

Author's peak flow criteria	Reported percent change in peak flows	Reported absolute change in peak flows (L s⁻¹ ha⁻¹)	Author's low flow criteria	Reported percent change in low flows	Reported absolute change in low flow (L s⁻¹ ha⁻¹)	Statistical significance of changes
(HBMAD): extreme (0.457 in hr⁻¹); average seasonal high flow (0.100-0.457 in hr⁻¹) (RSMT): extreme ? (0.457 in hr⁻¹) (DH): ?	(HBMAD): extreme: no change; average high: growing: 3% dormant: 4% (RSMT): no change (DH): no change	(HBMAD): extreme: no change; average moderate: growing: 0.1 dormant: 0.3 (RSMT): no change (DH): no change				

Table II.7. Summary information for afforestation study number 7 (Hewlett and Bosch, 1984/1985; Bosch, 1979; Nänni, 1956). When information for a category differed between studies, the source of the information is provided in parentheses in the form of the authors' initials.

Study design	Location	Treated basin(s)	Area (ha)	Latitude and longitude	Elevation mean/range (m)	Ecoregion domain	Pre-planting vegetation	Planted vegetation	Soil type and depth (m)	Geology
Paired basin study; one control, one 74% afforested by planting over the course of 15 years according to (B) or in one year according to (HB); (HB) looked at effects of land use change on peak flows.	Cathedral Peak Forestry Research Station in Natal, South Africa	CP 2	190	29°00'S; 29°15'E	1844-2454; 2070	dry	99% fire-type grass (1% was cliffs)	*Pinus patula*	loams over clay loams and weathered rock material; at least 1.5 m	basaltic layers (nearly 1525 m thick) over sandstone (180 m thick); no evidence of faults

Mean slope of the basin (%)	Drainage density (km km⁻²)	Annual precipitation (mm)	Annual ET (mm)	Dominant hydrologic regime	Prevalence of dry season	Revegetation method and other site treatments	Percent of area revegetated	Location of revegetation relative to channel	Road density (km km⁻²)
49%	2.6	1400	770 (annual precipitation minus annual yield)	summer rainfall: 84% occurs Oct-Mar; 67% of annual flow occurs Jan-Apr		percent of area planted (year): 52% (1950/51) 6.5%* (1954/55) 2.5%* (1962/63) 13%* (1964/65) 40% of area thinned by 50% (1965/66) 46% of area thinned by 50% (1969/70) 25% of trees defoliated by moth infestation (1971/72) 8% of area litter stacked and burned (1974/75) 10% of area thinned by 30% (1975/76) *percent of additional area planted	74%	not within one chain of the larger water courses	

Percent of area compacted before revegetated	Aspect of revegetated areas	Rate of growth	Type and frequency of precipitation data	Location of measurements relative to discharge station	Discharge record before/after (years)
	NNE		25 rain gages, 12 of which have Nipher shields	throughout the study area	9/21 with the calibration period set arbitrarily by (HB)

Author's peak flow criteria	Reported percent change in peak flows	Reported absolute change in peak flows ($L\ s^{-1}\ ha^{-1}$)	Author's low flow criteria	Reported percent change in low flows	Reported absolute change in low flow ($L\ s^{-1}\ ha^{-1}$)	Statistical significance of changes
peak discharge less discharge at initiation of storm flow	reduced	reduced				0.05

Table II.8. Summary information for afforestation study number 8 (Mathur, Ram Babu, Joshie, and Singh, 1976; Mathur and Sajwan, 1978). When information for a category differed between studies, the source of the information is provided in parentheses in the form of the authors' initials.

Study design	Location	Treated basin(s)	Area (ha)	Latitude and longitude	Elevation mean/range (m)	Ecoregion domain	Pre-planting vegetation	Planted vegetation	Soil type and depth (m)	Geology
Paired basin study; one cut, one left as a control after eight year calibration period; looked at treatment effects on flows.	Selakui, Doon Valley, northern India	W_1F	1.45	30°21'N; 77°52'E	520-529	humid tropical	originally a sal (*Shorea robusta*) forest; remnant coppice sprout saplings and shrubby vegetation dominated immediately before planting	*Eucalyptus grandis* and *E. camaldulensis* ; dense shrubby understory grew as well	silt loam with silty clay loam in deeper layers; very deep	

Mean slope of the basin (%)	Drainage density ($km\ km^{-2}$)	Annual precipitation (mm)	Annual ET (mm)	Dominant hydrologic regime	Prevalence of dry season	Revegetation method and other site treatments	Percent of area revegetated	Location of revegetation relative to channel	Road density ($km\ km^{-2}$)
5.1 (range: 2-15)	22.5	calibration mean: 727 post-treatment mean: 438	661 (mean annual precipitation minus mean annual runoff before treatment)	runoff producing rainfall is normally confined to a period from the third week of Jun to the end of Sep		area cleared in 1969; saleable material disposed of without use of mechanical dragging; remaining material dried and burned; 2500 pits per ha, 30 cm^3 in size, dug at a spacing of 2x2 m for planting; planted evenly with *Eucalyptus grandis* and *E. camaldulensis*	100%		

Percent of area compacted before revegetated	Aspect of revegetated areas	Rate of growth	Type and frequency of precipitation data	Location of measurements relative to discharge station	Discharge record before/after (years)
	general slope towards ESE	after five years: stocking = 75%; crown density of eucalyptus = 0.8; mean height = 10 m; mean DBH = 10 cm			8/5

Author's peak flow criteria	Reported percent change in peak flows	Reported absolute change in peak flows ($L\ s^{-1}\ ha^{-1}$)	Author's low flow criteria	Reported percent change in low flows	Reported absolute change in low flow ($L\ s^{-1}\ ha^{-1}$)	Statistical significance of changes
two to three highest peak flows from each year used to develop regression equations	-73%					

Table II.9. Summary information for afforestation study number 9 (Robinson, Gannon, and Schuch, 1991).

Study design	Location	Treated basin(s)	Area (ha)	Latitude and longitude	Elevation mean/range (m)	Ecoregion domain	Pre-planting vegetation	Planted vegetation	Soil type and depth (m)	Geology
Looked at effects of afforestation on peats; two treated, one control; treated were planted seven years apart; study began two years after second basin was planted, so "calibration" was determined using a basin which was under similar conditions to the treated basins prior to planting; looked at a range of peaks from two time periods which equated to forest ages of 2, 9, 15 and 22 for the two basins combined; also looked at large storm events from each period in greater detail.	The southern Chiemseemoors, 70 km SE of Munich, Germany	FM/S and FM/N	FM/S: 3 FM/N: 3	47°48'N; 12°26'E	study area: 520-530	humid temperate	originally in peat with a few trees; before the study, it was drained and used as a meadow and thus was comprised of grasses	coniferous trees, mainly Norway spruce	peat over impermeable clay; peat several meters deep	

Mean slope of the basin (%)	Drainage density ($km\ km^{-2}$)	Annual precipitation (mm)	Annual ET (mm)	Dominant hydrologic regime	Prevalence of dry season	Revegetation method and other site treatments	Percent of area revegetated	Location of revegetation relative to channel	Road density ($km\ km^{-2}$)
		1410	FM/S: 980 FM/N: 935 (annual precipitation minus discharge)	64% of precipitation occurs May-Oct, wettest in Jun and Jul; snows in winter	no	both were drained and used as meadows where grass was grown for hay or silage beginning in the early part of this century; pipe drains are 8-10 m apart; trees planted about 800 mm apart; FM/S and FM/N were planted in 1962 and 1969, respectively; both were thinned starting in 1985 and continuing over several years as labor was available	FM/S and FM/N: 100%		

Percent of area compacted before revegetated	Aspect of revegetated areas	Rate of growth	Type and frequency of precipitation data	Location of measurements relative to discharge station	Discharge record before/after (years)
	FM/S and FM/N: N	FM/S: 1.5-2 m in height after 9 years and 12 m after 25 years FM/N: 0.3-0.5 m in height after 9 years and 10 m after 25 years		precipitation measured on each site plus a meteorological station nearby	discharge began two and seven years after afforestation on FM/N and FM/S, respectively; post treatment record was 13 years

Author's peak flow criteria	Reported percent change in peak flows	Reported absolute change in peak flows ($L\ s^{-1}\ ha^{-1}$)	Author's low flow criteria	Reported percent change in low flows	Reported absolute change in low flow ($L\ s^{-1}\ ha^{-1}$)	Statistical significance of changes
looked at a range of peaks with a mean of 1 $L\ s^{-1}\ ha^{-1}$ and a maximum of 2.8 $L\ s^{-1}\ ha^{-1}$ and at the average of large peaks; unsure about the definition used for a peak flow	average of large flows: FM/N (change from ages 2 to 15): -11% FM/S (change from ages 9 to 22): -12%	average of large flows: FM/N (change from ages 2 to 15): -0.28 FM/S (change from ages 9 to 22): -0.21	daily mean discharge exceeded for 70% of the time (225 days $year^{-1}$)	over 60% reduction		

Table II.10. Summary information for afforestation study number 10 (Schneider and Ayer, 1961; Ayer, 1968; Schneider, 1969). When information for a category differed between studies, the source of the information is provided in parentheses in the form of the authors' initials.

Study design	Location	Treated basin(s)	Area (ha)	Latitude and longitude	Elevation mean/range (m)	Ecoregion domain	Pre-planting vegetation	Planted vegetation	Soil type and depth (m)	Geology
Compared changes in reforested basins over time; one control, three treated; used covariance and multiple-regression time analyses to determine changes in flows for two six-month periods (roughly associated with the dormant and growing seasons) and annually over the length of the data record; later study by Schneider (1969) compared more recent data (post 1958) to data from the latter part of the earlier study (Schneider and Ayer, 1961) to see if decreases had stabilized.	Central New York, USA	Shackham Brook	808	42°45' N; 76° W	393-610	humid temperate	25% deciduous; 1% coniferous; 74% pasture and crops	mostly coniferous: predominantly pine and spruce with a few larch and firs	silt loams	shallow Pleistocene deposits of glacial till (0.6-6.1 m deep) over bedrock of unaltered shales and limestones of Devonian age

Mean slope of the basin (%)	Drainage density (km km^{-2})	Annual precipitation (mm)	Annual ET (mm)	Dominant hydrologic regime	Prevalence of dry season	Revegetation method and other site treatments	Percent of area revegetated	Location of revegetation relative to channel	Road density (km km^{-2})
	0.9	1020		precipitation distributed fairly evenly throughout the year with snow in the winter and rain in the summer; the runoff is not evenly distributed: higher flows occur in the spring (5-6" month^{-1}) and lower flows occur in late summer and early fall (≤1" month^{-1})	lower flows occur in summer and early fall even though precipitation is distributed fairly evenly throughout the year	farmed in early to mid 1800s; farming ended and many areas were abandoned during late 1800s and early 1900s; 1931: hand planted three-to-four-year-old transplants over much of the area; trees placed in slit made with a grubhoe and then back-filled; different densities were used for the different planting blocks; location of planting was based on ownership of the property, not physiographic area (i.e., only blocks owned by the government were planted within a basin, not the entire basin); 1934, 1936, and 1939: almost 1/3 replanted due to death	by 1958 2% deciduous; 56% coniferous; total cover raised from 26% to 84%	various	

Percent of area compacted before revegetated	Aspect of revegetated areas	Rate of growth	Type and frequency of precipitation data	Location of measurements relative to discharge station	Discharge record before/after (years)
	S	DBH = 10-18 cm; height = 4-9 m (mean = 7 m); almost complete crown closure by 1958 on the sites where natural reforestation and plantings occurred	both recording (8-inch weighing type) and nonrecording (4-inch tube type) rain gages; neither were shielded; two recording gages in treated basin: one had weekly chart and other daily chart; one recording gage (weekly chart) and one nonrecording gage in control (checked daily since 1940)	treated: both near mid-basin--one at similar elevation and one 300' higher than discharge station; control: both near mid-basin at different elevations	began one year after planting/30 years after that

Author's peak flow criteria	Reported percent change in peak flows	Reported absolute change in peak flows (L s^{-1} ha^{-1})	Author's low flow criteria	Reported percent change in low flows	Reported absolute change in low flow (L s^{-1} ha^{-1})	Statistical significance of changes
seasonal peak flows used were those on the treated basin associated with those that were greater than 10 cfs mile^{-2} during Nov-Apr and 2 cfs mile^{-2} during May-Oct on the control	1938-1958: Nov-Apr: -41% May-Oct: ns 1953-1957 & 1962-1967: ns 1938-1967 Nov-Apr mean: -59%		annual minimum daily flow	none	none	time trend factor in equation: above the 99% level of significance in both peak flow cases; time trend factor in equation: 0.05

Table II.11. Summary information for afforestation study number 11 (Smith, 1992).

Study design	Location	Treated basin(s)	Area (ha)	Latitude and longitude	Elevation mean/range (m)	Ecoregion domain	Pre-planting vegetation	Planted vegetation	Soil type and depth (m)	Geology
Paired basin study: one control, one treated; looked at effects of afforestation of area surrounding stream channels on flows; compared regression equations relating control and treated basins from three randomly selected years prior to treatment with data from the seven to nine years after treatment.	Moutere hills, 20 km SW of Nelson City, New Zealand	C4	2.71	41°22'S; 173°04'E		humid temperate	pasture: mixed ryegrass, browntop, white clover and cocksfoot	radiata pine	silt-sandy loam on hills and clay loam subsoils in low-lying areas; 0.45-0.60 m	deeply weathered early Pleistocene gravels in a silty clay matrix

Mean slope of the basin (%)	Drainage density (km km^{-2})	Annual precipitation (mm)	Annual ET (mm)	Dominant hydrologic regime	Prevalence of dry season	Revegetation method and other site treatments	Percent of area revegetated	Location of revegetation relative to channel	Road density (km km^{-2})
29%	4.8	1051	9-35 mm week^{-1} (annual ET not provided)	winter rainfall (most occurring Jun-Oct), driest in Feb		entire area grazed year round and fertilized in late summer or autumn at a rate of 40 kg P ha^{-1} 1970-1978 (and probably earlier also); contour furrowed at 1.8 m intervals in Mar 1970; 25-35 m wide strip encompassing stream channel/riparian area and lower slopes was fenced off and planted with one-year-old radiata pine at a rate of 1400 stems ha^{-1} in Aug 1978; trees were thinned to 500 stems ha^{-1} in late 1983; stock were allowed to lightly graze under the pine from ? until mid-1986	20%	25-35 m strips encompassing stream channels	0

Percent of area compacted before revegetated	Aspect of revegetated areas	Rate of growth	Type and frequency of precipitation data	Location of measurements relative to discharge station	Discharge record before/after (years)
	N	by 1986, trees were 10 m high; canopy closure occurred by mid-late 1986	one meteorological station	in study area	9/9

Author's peak flow criteria	Reported percent change in peak flows	Reported absolute change in peak flows (L s^{-1} ha^{-1})	Author's low flow criteria	Reported percent change in low flows	Reported absolute change in low flow (L s^{-1} ha^{-1})	Statistical significance of changes
observed peak flow minus the baseflow immediately prior to the onset of quickflow for single peaked events or the minimum flow rate on the receding limb of the preceding peak for double peaked events	reduced peaks for small events, did not affect medium events and may have increased in large events					0.05

Table II.12. Summary information for afforestation study number 12 (Smith and Scott, 1992; Smith and Bosch, 1989; Nänni, 1971; Van Lill, Kruger, and van Wyk, 1980). When information for a category differed between studies, the source of the information is provided in parentheses in the form of the authors' initials.

Study design	Location	Treated basin(s)	Area (ha)	Latitude and longitude	Elevation mean/range (m)	Ecoregion domain	Pre-planting vegetation	Planted vegetation	Soil type and depth (m)	Geology
Paired basin study; one control, one afforested at Westfalia; one control, two afforested at Mokobulaan; looked at effects of treatment on flows over time.	Westfalia estate, near Tzaneen, and Mokobulaan, SE of Lydenburg in the Eastern Transvaal, South Africa	Westfalia D (West D) Mokobulaan A (Mok A) Mokobulaan B (Mok B)	West D: 39.6 Mok A: 26.2 Mok B: 34.6	Westfalia: 23°43'S; 30°04'E Mokobulaan: 25°17'S; 30°34'E	West D: 1164.5 Mok A: 1354; 1292-1433 Mok B: 1396; 1318-1486	humid tropical	West D: indigenous scrub forest Mok A & B: seasonally dry grasslands with evergreen broadleaf forests in narrow strips (about 20 m) along much of the length of each stream channel	West D: *Eucalyptus grandis* Mok A: *Eucalyptus grandis* Mok B: *Pinus patula*	Mok A & B: clayey sand interspersed with shale and sandstone fragments; pockets of loam occur along streamsides Mok A & B: "a few cm"; loams are "deep"	West D: granite gneiss Mok A & B: basal shales

Mean slope of the basin (%)	Drainage density (km km^{-2})	Annual precipitation (mm)	Annual ET (mm)	Dominant hydrologic regime	Prevalence of dry season	Revegetation method and other site treatments	Percent of area revegetated	Location of revegetation relative to channel	Road density (km km^{-2})
West D: 33% Mok A: 23% Mok B: 22%	Mok A: 1.7 Mok B: 1.5	West D: 1611 Mok A & B: 1150	West D: 1063* Mok A & B: 1270† * annual precipitation minus annual yield †evaporation based on map of iso-evaporation rates	Westfalia: rainfall, 84% occurring during the summer months of Oct-Mar Mok A & B: rainfall, 82% occurring during the summer months of Oct-Mar	yes, less than 20% of annual flow occurs during six months of winter at each site	West D: riparian vegetation 20 m on both sides of stream (10% of basin area) cut and left on the ground (Feb 1981); regrowth slashed again (Nov 1981); cleared 83% of area including riparian zone by bulldozing (material was piled in stacks and burned) (Dec 1982); planted 83% of area at a rate of 1370 stems ha^{-1} (Mar-Apr 1983); thinned to 700, 450, and 300 stems ha^{-1} in 1986, 1988, and 1991, respectively. Mok A: entire grassland planted at a rate of 1370 stems ha^{-1} in a rectangular pattern with a spacing of 2.7 m between seedlings (Feb 1969); thinned to 750, 418, and 250 stems ha^{-1} in 1974, 1979, and 1983, respectively. Mok B: planted at a rate of 1370 stems ha^{-1} in a rectangular pattern with a spacing of 2.7 m between seedlings (Jan 1971)	West D: 83% Mok A: 100% Mok B: 100 %		

Percent of area compacted before revegetated	Aspect of revegetated areas	Rate of growth	Type and frequency of precipitation data	Location of measurements relative to discharge station	Discharge record before/after (years)
	West D: SE Mok A & B: E	West D: 18 m high and 13.1 cm DBH after 3.5 years; undergrowth was 1.5 m high	Westfalia: nine rain gages Mokobulaan: six rain gages	Westfalia: five different sites throughout the study area Mokobulaan: two gages in each basin, one near the top and one near the weir	West D: 7/8 Mok A: 7.5/12 Mok B: 9.3/11

Author's peak flow criteria	Reported percent change in peak flows	Reported absolute change in peak flows (L s^{-1} ha^{-1})	Author's low flow criteria	Reported percent change in low flows	Reported absolute change in low flow (L s^{-1} ha^{-1})	Statistical significance of changes
			(SS) used a low flow cut-off value of 36 mm month^{-1} for Westfalia D and 7.5 mm month^{-1} for Mokobulaan A & B so that the two to three driest months could be included for analysis each year	West D: -79.2% and -90.0% for seventh and eighth years after treatment, respectively Mok A: -100.0% and -100.0% for 11th and 12th years after treatment, respectively Mok B: -85.3% and -86.3% for 10th and 11th years after treatment, respectively	West D: -202.6 and 135.2 mm month^{-1} for seventh and eighth years after treatment, respectively Mok A: -118.8 and -122.9 mm month^{-1} for 11th and 12th years after treatment, respectively Mok B: -64.6 and -66.1 mm month^{-1} for 10th and 11th years after treatment, respectively	0.01

Table II.13. Summary information for afforestation study number 13 (TVA, 1961; Sodemann and Tysinger, 1967). When information for a category differed between studies, the source of the information is provided in parentheses in the form of the authors' initials.

Study design	Location	Treated basin(s)	Area (ha)	Latitude and longitude	Elevation mean/range (m)	Ecoregion domain	Pre-planting vegetation	Planted vegetation	Soil type and depth (m)	Geology
Single basin study-no control basin; looked at effects of reforestation (34% of the basin) along with natural regeneration (66% of the area that was already in forests of various degrees of stocking) on flows over time; compared by season using correlations with rainfall intensity for summers and surface runoff for winters taking into account antecedent soil moisture conditions based and pre-event stage height; also looked at change in peak flow frequencies over time.	headwaters of White Creek, northern Union County, TN	White Hollow	694	36°22'N; 83°54'W	329-512	humid temperate	66% mixed forests in various degrees of stocking; 4% cultivated; 26% abandoned (mostly broom sedge); 4% grass	principally shortleaf pine, white pine, and yellow poplar; also loblolly pine, black walnut, and several other species	"cherty" silt loams and silt loams	underlain by dolomite formations with sinkholes present along the upper periphery of the basin

Mean slope of the basin (%)	Drainage density (km km^{-2})	Annual precipitation (mm)	Annual ET (mm)	Dominant hydrologic regime	Prevalence of dry season	Revegetation method and other site treatments	Percent of area revegetated	Location of revegetation relative to channel	Road density (km km^{-2})
30%		903-1615 1193		precipitation year round with slightly greater amount in winter than late summer/early fall; snows only occasionally and not usually to very great depths; snow usually lasts for only a few days at a time		all of the area was cleared and much of it was cultivated during the 150 years of settlement prior to the acquisition of the land by the TVA; erosion control occurred during 1934-1935 (log dams, drainage control, bank protection, brush matting, brush paving, etc.); part of this control included the planting of trees (black locust and shortleaf pine), clover, and grasses; during 1936-1937, cultivated and natural forests allowed to recover with herbaceous and woody plants becoming established; 34% of the basin planted with various species of trees during 1938-1942	34%		

Percent of area compacted before revegetated	Aspect of revegetated areas	Rate of growth	Type and frequency of precipitation data	Location of measurements relative to discharge station	Discharge record before/after (years)
most of the area was cultivated at one time or another during the 150 years of settlement prior to the study; roads and trails: 0.5%	southerly	from 1936-1956: stems ac^{-1} >1" increased 125% from 406 to 912; BA ac^{-1} increased 116% from 43.0 ft^2 to 92.8 ft^2; crown closure increased 86% from 50% to 93%	one to six recording rain gages over the course of the study; the six were placed in 1937 to gain an idea of storm distributions over the basin; it was eventually determined that one gage (properly placed) was sufficient	in and around the basin with the final placement near the center of the basin	(TVA): 0/24 (ST): 0/30

Author's peak flow criteria	Reported percent change in peak flows	Reported absolute change in peak flows (L s^{-1} ha^{-1})	Author's low flow criteria	Reported percent change in low flows	Reported absolute change in low flow (L s^{-1} ha^{-1})	Statistical significance of changes
TVA: separated out by season (summer and winter) and wetness of soil; for summers, also used one-hour intensities; for winters, also used surface runoff in area inches; looked at frequency curves for each season, also; did not specify type of peak used	for the summer (1935-1936 vs. 1950-1958): dry soils/wet soils: 0.4" hr^{-1}: -73%/-92% 0.6" hr^{-1}: -84%/-95% 0.8" hr^{-1}: -90%/-95% 1.0" hr^{-1}: -92%/ -- for the winter (1935-1941 vs. 1950-1958): 0.25": -11% 0.50": 0% 0.75": -24% 1.00": -28% 1.20": -26%	for the summer (1935-1936 vs. 1950-1958): dry soils/wet soils: 0.4" hr^{-1}: -0.2/-1.6 0.6" hr^{-1}: -0.5/-3.8 0.8" hr^{-1}: -1.1/-6.0 1.0" hr^{-1}: -1.7/ -- for the winter (1935-1941 vs. 1950-1958): 0.25": -0.1 0.50": 0.0 0.75": -0.7 1.00": -1.4 1.20": -1.7				

Table II.14. Summary information for afforestation study number 14 (TVA, 1962).

Study design	Location	Treated basin(s)	Area (ha)	Latitude and longitude	Elevation mean/range (m)	Ecoregion domain	Pre-planting vegetation	Planted vegetation	Soil type and depth (m)	Geology
Single basin study-no control basin; looked at effects of reforestation (65.2% of the basin) along with natural regeneration (33.2% of the area that was already in forests of various degrees of stocking) on flows over time; compared by season using correlations with rainfall intensity and taking into account antecedent soil moisture conditions; also looked at change in peak flow frequencies over time using three post treatment five-year periods for summer and three four-year periods for winter.	7.25 km NE of Lexington in Henderson County, TN	Pine Tree Branch	35.7	35°39'N; 88°20'W	137-181	humid temperate	immediately prior to treatment: 23% forest (hardwoods, principally oak); 9% cultivated; 19% pasture (grasses and weeds); 1% meadow; 47% abandoned and idle (broom sedge, perennials and scattering of hardwoods)	loblolly (78%), pitch (8%), slash (4%), and longleaf (5%) pines; black locust (4%), yellow poplar (1%), and mulberry (0.05%)	51% silt loam (ridge crests); 37% fine sandy loam (ridge slopes); 7% fine sandy loam (colluvial-alluvial deposits along small streams); 5% silt loam and fine sandy loam (bottomlands)	formation of sandy, unconsolidated material up to 150' deep and underlain by a clay stratum which restricts further downward movement of water

Mean slope of the basin (%)	Drainage density (km km^{-2})	Annual precipitation (mm)	Annual ET (mm)	Dominant hydrologic regime	Prevalence of dry season	Revegetation method and other site treatments	Percent of area revegetated	Location of revegetation relative to channel	Road density (km km^{-2})
		719-1722 1280		precipitation year round with higher amounts in the winter than the summer; only 2% of annual precipitation occurs as snow		settled and farmed for more than 100 years prior to study; various erosion control activities occurred in Nov 1945-Mar 1946; tree planting took place in 1946-1948 with 90% occurring in the first year; trees were planted in a pattern of 16 rows of loblolly pine, a row of pitch pine, a row of slash pine, another row of pitch pine and a row of longleaf pine; black locust was planted around check dams and in gullies that were more than 5' deep; yellow poplar was confined to a 1/2 acre tract near the outlet	65.2%		

Percent of area compacted before revegetated	Aspect of revegetated areas	Rate of growth	Type and frequency of precipitation data	Location of measurements relative to discharge station	Discharge record before/after (years)
practically every acre has been under cultivation at some time; the area had been settled and farmed for more than 100 years prior to the study	principally N and S with more to E than W	by 16 years after planting began, 98% of the basin was forested; 85% of this was occupied by pines with a mean BA of 77.6 ft^2 ac^{-1}; the rest was in hardwoods with a mean BA of 46.6 ft^2 ac^{-1}	one recording rain gage and one non-recording rain gage; the non-recording gage was checked daily	both in the basin; standard was near the discharge station and the recording was near the far end of the basin	5/15

Author's peak flow criteria	Reported percent change in peak flows	Reported absolute change in peak flows (L s^{-1} ha^{-1})	Author's low flow criteria	Reported percent change in low flows	Reported absolute change in low flow (L s^{-1} ha^{-1})	Statistical significance of changes
looked at seasonal peaks associated with various antecedent soil moisture conditions and various maximum 20-minute rainfall intensities; also looked at peak frequencies; did not specify if peak included baseflow	peak exceeded five times: summer/winter: first: -43%/-69% second: -86%/-80% third: -96%/-89% peak flow rates: summer (15 years post-treatment): wet soil 0.5"/hr: -95% 1.0"/hr: -95% 2.0"/hr: -93% dry soil 1.0"/hr: -97% 2.0"/hr: -96% 3.0"/hr: -92% winter (12 years post treatment) wet soil/dry soil 1.0"/hr: -79%/-92% 2.0"/hr: -71%/-90%	peak exceeded five times: summer/winter: first: -26/-44 second: -52/-51 third: -59/-56 peak flow rates: summer (15 years post treatment): wet soil 0.5"/hr: -6 1.0"/hr: -16 2.0"/hr: -58 dry soil 1.0"/hr: -9 2.0"/hr: -27 3.0"/hr: -51 winter (12 years post treatment): wet soil/dry soil 1.0"/hr: -18/-11 2.0"/hr: -47/-39				

APPENDIX III:

GENERAL INFORMATION AND REPORTED RESULTS FOR EACH STUDY BY PEAK FLOW TYPE

Table III.1. General information and results for the instantaneous peak flow type.

Study number	Location	Basin	Peak flow type	Peak flow changes (%)	Comments
3	Massachusetts	Dickey Brook	instantaneous		not significant
8	British Columbia	1	instantaneous minus base flow	-22	
10	Pennsylvania	LR2	instantaneous	118	
13	Washington	Deschutes River	instantaneous minus base flow		not significant
17	Oregon	FC-1	instantaneous		not significant
17	Oregon	FC-3	instantaneous		not significant
22	British Columbia	weir B	instantaneous minus base flow		not significant
22	British Columbia	weir H	instantaneous minus base flow	20	
28	Victoria, Australia	Blue Jacket	instantaneous		not significant
28	Victoria, Australia	Picaninny	instantaneous	100	
32	Oklahoma	1	instantaneous		not significant
32	Oklahoma	2	instantaneous		not significant
32	Oklahoma	3	instantaneous		not significant
33	Arkansas	10	instantaneous		not significant
33	Arkansas	12	instantaneous		not significant
33	Arkansas	14	instantaneous		not significant
33	Arkansas	15	instantaneous		not significant
33	Arkansas	17	instantaneous		not significant
33	Arkansas	18	instantaneous		not significant
42	Western Australia	Hansen	instantaneous	50	
44	India	WS 2	instantaneous	8.6	
47	Florida	WS 1	instantaneous minus base flow	0	did not increase
47	Florida	WS 2	instantaneous minus base flow	500	
62	Malaysia	C1	instantaneous		not significant
62	Malaysia	C2	instantaneous		not significant

Table III.2. General information and results for the daily peak flow type.

Study number	Location	Basin	Peak flow type	Peak flow changes (%)	Comments
2	Colorado	B	daily	50	
7	British Columbia	Camp Creek	daily	21	
27	Idaho	12	daily	34	
27	Idaho	14	daily	50	
27	Idaho	16	daily	74	
27	Idaho	18	daily	87	
48	Colorado	Fool Creek	daily	23	

Table III.3. General information and results for the growing season peak flow type.

Study number	Location	Basin	Peak flow type	Peak flow changes (%)	Comments
10	Pennsylvania	LR2	growing season	419	
10	Pennsylvania	LR2	growing season	370	
10	Pennsylvania	LR2	growing season	563	
15	British Columbia	Jamieson Creek	summer flows		not significant
16	Arizona	South Fork	summer flows		not significant
36	West Virginia	6	growing season	300	
36	West Virginia	7	growing season		not significant

Table III.4. General information and results for the dormant season peak flow type.

Study number	Location	Basin	Peak flow type	Peak flow changes (%)	Comments
15	British Columbia	Jamieson Creek	winter flows	13.5	
16	Arizona	South Fork	winter flows	59.8	
21	Oregon	DC-2	fall flows	11	
21	Oregon	DC-2	winter flows	14	
21	Oregon	DC-3	fall flows	50	
21	Oregon	DC-3	winter flows	31	
21	Oregon	DC-4	fall flows	51	
21	Oregon	DC-4	winter flows	20	
21	Oregon	Deer Creek	fall flows	-11	
21	Oregon	Deer Creek	winter flows	4	
21	Oregon	Needle Branch	fall flows	53	
21	Oregon	Needle Branch	winter flows	19	
36	West Virginia	6	dormant season		not significant
36	West Virginia	7	dormant season		not significant

Table III.5. General information and results for the annual peak flow type.

Study number	Location	Basin	Peak flow type	Peak flow changes (%)	Comments
16	Arizona	South Fork	annual	64.7	
20	Oregon	HJA-10	annual	-32	
27	Idaho	12	annual	15	
27	Idaho	14	annual	35	
27	Idaho	16	annual	36	
27	Idaho	18	annual	34	
31	Idaho	WSD6	annual minus base flow		not significant

Table III.6. General information and results for the mean peak flow type.

Study number	Location	Basin	Peak flow type	Peak flow changes (%)	Comments
12	North Carolina	WS 28	mean	30	
41	Oregon	HJA-1	mean	24	
41	Oregon	HJA-3	mean	10	
45	North Carolina	WS 7	mean	14.6	
49	Colorado	Deadhorse Creek	mean	0	no change
49	Colorado	North Fork	mean	49	
53	California	South Fork	mean	10	
55	South Carolina	64	mean	150	
55	South Carolina	66	mean	55	
55	South Carolina	68	mean	55	
60	Massachusetts	Cadwell Creek 1	mean growing season	46	

Table III.7. General information and results for the large peak flow type.

Study number	Location	Basin	Peak flow type	Peak flow changes (%)	Comments
18	Oregon	CC-1	nine year RI	47	
18	Oregon	CC-2	nine year RI	10	
18	Oregon	CC-3	nine year RI	36	
21	Oregon	Needle Branch	big mean	20	
21	Oregon	Deer Creek	big mean	2	
26	Taiwan	LHC-4	75th percentile (≤)	19.8	
27	Idaho	12	fifth percentile (≥)	26	
27	Idaho	14	fifth percentile (≥)	30	
27	Idaho	16	fifth percentile (≥)	10	
27	Idaho	18	fifth percentile (≥)	15	
29	Victoria, Australia	Clem	big instantaneous	50	
37	New Zealand	M7	large	30	
37	New Zealand	M9	large	32	
38	New Hampshire	2	big instantaneous	13	
40	West Virginia	1	big instantaneous	4	
50	Mississippi	C-II	big instantaneous	36	
50	Mississippi	C-III	big instantaneous	28	
57	Georgia	WS 14	instantaneous minus base flow (large)		not significant

Table III.8. General information and results for the all peak flow type.

Study number	Location	Basin	Peak flow type	Peak flow changes (%)	Comments
2	Colorado	B	daily	50	
3	Massachusetts	Dickey Brook	instantaneous		not significant
7	British Columbia	Camp Creek	daily	21	
8	British Columbia	1	instantaneous minus base flow	-22	
10	Pennsylvania	LR2	growing season	419	
10	Pennsylvania	LR2	growing season	370	
10	Pennsylvania	LR2	growing season	563	
10	Pennsylvania	LR2	instantaneous	118	
12	North Carolina	WS 28	mean	30	
13	Washington	Deschutes River	instantaneous minus base flow		not significant
14	Oregon	1	?		not significant
14	Oregon	2	?		not significant
14	Oregon	4	?		not significant
15	British Columbia	Jamieson Creek	summer flows		not significant
15	British Columbia	Jamieson Creek	winter flows	13.5	
16	Arizona	South Fork	annual	64.7	
16	Arizona	South Fork	summer flows		not significant
16	Arizona	South Fork	winter flows	59.8	
17	Oregon	FC-1	instantaneous		not significant
17	Oregon	FC-3	instantaneous		not significant
18	Oregon	CC-1	nine year RI	47	
18	Oregon	CC-2	nine year RI	10	
18	Oregon	CC-3	nine year RI	36	
19	Oregon	HJA-6	one year RI		not significant
19	Oregon	HJA-7	one year RI		not significant
20	Oregon	HJA-10	annual	-32	
20	Oregon	HJA-10	associated with rain	1	
20	Oregon	HJA-10	associated with snow	-36	
21	Oregon	Needle Branch	big mean	20	
21	Oregon	Deer Creek	big mean	2	
21	Oregon	DC-2	fall flows	11	
21	Oregon	DC-3	fall flows	50	
21	Oregon	DC-4	fall flows	51	
21	Oregon	Deer Creek	fall flows	-11	
21	Oregon	Needle Branch	fall flows	53	
21	Oregon	DC-2	winter flows	14	
21	Oregon	DC-3	winter flows	31	
21	Oregon	DC-4	winter flows	20	
21	Oregon	Deer Creek	winter flows	4	
21	Oregon	Needle Branch	winter flows	19	
22	British Columbia	weir B	instantaneous minus base flow		not significant
22	British Columbia	weir H	instantaneous minus base flow	20	
23	North Carolina	WS 37	too specific	7	
25	North Carolina	WS 1	?		not significant
25	North Carolina	WS 13	?		not significant
25	North Carolina	WS 17	?		not significant
25	North Carolina	WS 22	?		not significant
26	North Carolina	WS 13	16th percentile (≥)	17	
25	North Carolina	WS 17	16th percentile (≥)	45	
26	Taiwan	LHC-4	25th percentile (≤)	62	
26	Taiwan	LHC-4	50th percentile (≤)	48	
26	Taiwan	LHC-4	75th percentile (≤)	19.8	
27	Idaho	12	annual	15	
27	Idaho	14	annual	35	
27	Idaho	16	annual	36	
27	Idaho	18	annual	34	
27	Idaho	12	daily	34	
27	Idaho	14	daily	50	
27	Idaho	16	daily	74	
27	Idaho	18	daily	87	

Table III.8. (cont.)

Study number	Location	Basin	Peak flow type	Peak flow changes (%)	Comments
27	Idaho	12	fifth percentile (≥)	26	
27	Idaho	14	fifth percentile (≥)	30	
27	Idaho	16	fifth percentile (≥)	10	
27	Idaho	18	fifth percentile (≥)	15	
28	Victoria, Australia	Blue Jacket	instantaneous		not significant
28	Victoria, Australia	Picaninny	instantaneous	100	
29	Victoria, Australia	Clem	big instantaneous	50	
31	Idaho	WSD6	annual minus base flow		not significant
32	Oklahoma	1	instantaneous		not significant
32	Oklahoma	2	instantaneous		not significant
32	Oklahoma	3	instantaneous		not significant
33	Arkansas	10	instantaneous		not significant
33	Arkansas	12	instantaneous		not significant
33	Arkansas	14	instantaneous		not significant
33	Arkansas	15	instantaneous		not significant
33	Arkansas	17	instantaneous		not significant
33	Arkansas	18	instantaneous		not significant
36	West Virginia	6	growing season	300	
36	West Virginia	6	dormant season		not significant
36	West Virginia	7	dormant season		not significant
36	West Virginia	7	growing season		not significant
37	New Zealand	M7	large	30	
37	New Zealand	M7	medium	50	
37	New Zealand	M7	small	67	
37	New Zealand	M9	large	32	
37	New Zealand	M9	medium	41	
37	New Zealand	M9	small	55	
38	New Hampshire	2	big instantaneous dormant season	0	
38	New Hampshire	2	big instantaneous	13	
38	New Hampshire	2	big instantaneous growing season	118	
39	Quebec	6	maximum snow		not significant
40	West Virginia	1	big instantaneous dormant season	-4	
40	West Virginia	1	big instantaneous	4	
40	West Virginia	1	big instantaneous growing season	21	
41	Oregon	HJA-1	mean	24	
41	Oregon	HJA-3	mean	10	
42	Western Australia	Hansen	instantaneous	50	
44	India	WS 2	instantaneous	8.6	
45	North Carolina	WS 7	mean	14.6	
47	Florida	WS 1	instantaneous minus base flow	0	did not increase
47	Florida	WS 2	instantaneous minus base flow	500	
48	Colorado	Fool Creek	daily	23	
49	Colorado	Deadhorse Creek	mean	0	no change
49	Colorado	North Fork	mean	49	
50	Mississippi	C-II	big instantaneous	36	
50	Mississippi	C-III	big instantaneous	28	
53	California	South Fork	mean	10	
54	Utah	West Branch	?		not significant
55	South Carolina	64	mean	150	
55	South Carolina	66	mean	55	
55	South Carolina	68	mean	55	
57	Georgia	WS 14	instantaneous minus base flow (small)	100	
57	Georgia	WS 14	instantaneous minus base flow (large)		not significant
60	Massachusetts	Cadwell Creek 1	mean growing season	46	
61	Malaysia	A	unit hydrograph	119	calculated from absolute changes
62	Malaysia	C1	instantaneous		not significant
62	Malaysia	C2	instantaneous		not significant

APPENDIX IV:

DATA AND RESULTS FOR THE STATISTICAL ANALYSES OF REPORTED CHANGES IN PEAK FLOW AFTER FOREST HARVEST

Table IV.1. Basin characteristics, management activities, and reported percent change in peak flows for each study used in the detailed statistical analysis of published data.

Study number	Location	Basin	Area (ha)	Latitude	Basin relief (m)	Mean elevation (m)	Ecoregion domain	Vegetation type	Pre-harvest stand age	Soil type	Mean basin slope (%)	Drainage density (km km^{-2})	Annual precipitation (mm)	Annual ET (mm)	Domonant hydrologic regime	Type of silvicultural method
2	Colorado	B	81.0	37.77	520	3078	1	4		2	26.0	0.9	533	380	2	1
7	British Columbia	Camp Creek	3390.0	49.50	850	1450	1	1	2	2			600		2	1
8	British Columbia	1	23.1	49.25	310	300	2	1	2	2	20.0		2285		3	1
10	Pennsylvania	LR2	42.9	40.67	168	360	2	5	3	3	12.1		930	635	3	1
12	North Carolina	WS 28	144.1	35.05	587	1200	2	5	3	2	27.0	7.5	2270	500	1	4
16	Arizona	South Fork	227.4	33.75	244	2667	1	2	2	3	22.0		768	627	2	3
18	Oregon	CC-1	69.2	43.00			2	1	2	2			1229	610	3	3
18	Oregon	CC-2	68.4	43.00			2	1	2	2			1229	610	3	2
18	Oregon	CC-3	49.8	43.00			2	1	2	2			1229	610	3	1
20	Oregon	HJA-10	10.2	44.20	231	549	2	1	2	1			2300		3	1
21	Oregon	DC-2	56.0	44.53			2	3	3	3			2474		1	1
21	Oregon	DC-3	40.0	44.53			2	3	3	3			2474		1	1
21	Oregon	DC-4	16.0	44.53			2	3	3	3		1.9	2474		1	1
21	Oregon	Deer Creek	304.0	44.53			2	3	3	3	30.0		2474		1	2
21	Oregon	Needle Branch	71.0	44.53			2	2	3	3	37.0	3.3	2483		1	1
22	British Columbia	weir H	12.0	49.00	153	229	2	2	2	2					1	1
23	North Carolina	WS 37	44.0	35.05	573	1280	2	5	2	2	70.0		2244	660	1	1
26	Taiwan	LHC-4	5.9	23.93	55	758	3	5	2	1	40.0		2100		1	1
27	Idaho	12	83.8	46.00		1574	1	1		3			1168		3	2
27	Idaho	14	62.3	46.00		1596	1	1		3			1168		3	2
27	Idaho	16		46.00		1659	1	1		3			1168		3	1
27	Idaho	18	86.2	46.00		1664	1	1		3			1168		3	2
28	Victoria, Australia	Picaninny	52.8	37.50	550	505	2	5	3	1	37.0		1180		1	1
29	Victoria, Australia	Clem	46.4	36.78	250	609	2	5	3	3			1419	1000	1	1
37	New Zealand	M7	4.1	42.08		295	2	5	2	2	73.0		2518		1	1
37	New Zealand	M9	8.3	42.08		330	2	5	2	2	73.0		2518		1	1
38	New Hampshire	2	15.6	43.93		595	2	4	3	2	33.0	1.5	1327	502	3	1
40	West Virginia	1	30.1	39.08		755	2	5	2	3			1501	940	3	1
41	Oregon	HJA-1	96.0	44.20	565	728	2	1	2	3	63.2	6.3	2200		3	1
41	Oregon	HJA-3	101.0	44.20	590	781	2	1	2	3	52.6	8.2	2200		3	2
42	Western Australia	Hansen	80.0	32.50	65	293	2	5	3	2	5.0		1179		1	3
44	India	WS 2	5.2	30.38		895	3	5		3	26.0	0.0	2950		1	3
45	North Carolina	WS 7	58.7	35.05	336	892	2	5		2	57.0		1893	900	1	1
47	Florida	WS 1	67.0	30.00	2.5	44	2	3	1	3		1.6	1450		1	1
48	Colorado	Fool Creek	289.0	39.83	700	3150	1	1					635	320	2	2
49	Colorado	Deadhorse Creek	270.0	39.83	656	3208	1	1					635	320	2	3
49	Colorado	North Fork	41.0	39.83			1	1					635	320	2	2
50	Mississippi	C-II	0.9	34.48	18		2	5		3			1350		1	
50	Mississippi	C-III	0.9	34.48	13		2	5		3			1350		1	
53	California	South Fork	424.0	39.50			2	1	2	1	35.0	3.7	1109	538	1	3
55	South Carolina	64	1.1	34.70			2	1	1	3	16.0	0.4	1295	770	1	1
55	South Carolina	66	1.3	34.70			2	1	1	3	11.0	16.4	1295	770	1	1
55	South Carolina	68	0.6	34.70			2	1	1	3	12.0	28.7	1295	770	1	1
60	Massachusetts	Cadwell Creek 1	163.0	42.40	76	312	2	4	2	2			1067		3	4
61	Malaysia	A	37.7	3.90		73	3						1878	1500	1	1

Table IV.1. (cont.)

Study number	Location	Basin	Percent of vegetation removed	Use of buffer strips	Duration of harvest period (months)	Type of yarding	Type of site preparation	Road density (km km^{-2})	Percent of area compacted	Season	Aspect	Peak flow changes (%)	Comments
2	Colorado	B	100	3		1	3			2	2	50	
7	British Columbia	Camp Creek	30								5	21	
8	British Columbia	1	71	2	1.0	4			35.5	1	5	-22	
10	Pennsylvania	LR2	20	2	4.0		1			3	4	118	
12	North Carolina	WS 28	66		12.0	5				3	2	30	
16	Arizona	South Fork	26	1	8.0	1	1			3		65	
18	Oregon	CC-1	50		5.0	1	4		14.0	3	2	47	
18	Oregon	CC-2	30		5.0	5	3		6.0	3	2	10	
18	Oregon	CC-3	100		5.0	5	3		12.5	3	1	36	
20	Oregon	HJA-10	100	2		3	3	0.0	19.8	2	6	-32	
21	Oregon	DC-2	30	1		4		6.9	3.0	3	6	13	weighted average of fall and winter flows
21	Oregon	DC-3	65	1		4		2.6	12.0	3	2	37	weighted average of fall and winter flows
21	Oregon	DC-4	90	1		4		0.0	0.0	3	6	25	weighted average of fall and winter flows
21	Oregon	Deer Creek	25	1	9.0	4	2	2.6	4.0	3	5	2	
21	Oregon	Needle Branch	82	2	9.0	5	2	14.6	5.0	3	5	20	
22	British Columbia	weir H	90	2		4	2		6.5	3	3	20	
23	North Carolina	WS 37	100	2		6	4	0.0	0.0		4	7	
26	Taiwan	LHC-4	100		3.0	3	4	0.0		3	4	48	
27	Idaho	12	37			3	2	1.9	3.9	3	5	15	
27	Idaho	14	29			1	2	1.5	1.8	3	5	35	
27	Idaho	16	25			1	2		3.0	3	5	36	
27	Idaho	18	33			1	2	2.1	4.3	3	5	34	
28	Victoria, Australia	Picaninny	78	1	5.0	1	2	2.3	9.0	3	8	100	
29	Victoria, Australia	Clem	94	1	5.0	1	2	0.0	5.0	3	4	50	
37	New Zealand	M7	100	2	4.0	4	2	0.0	0.0	3	8	53	weighted average of three different size classes
37	New Zealand	M9	80	1	5.0	2	2	10.0	5.0	3	8	46	weighted average of three different size classes
38	New Hampshire	2	100	2	1.5	6	4	0.0	0.0	1	4	13	
40	West Virginia	1	86		14.0	1			7.3	3	2	4	
41	Oregon	HJA-1	100	2	48.0	3	2	0.0	0.0	3	8	24	
41	Oregon	HJA-3	33	2	6.0	4	2	2.6	2.0	3	8	10	
42	Western Australia	Hansen	74	1	2.0	1	1	0.5	0.0	2	1	50	
44	India	WS 2	20								7	9	
45	North Carolina	WS 7	100	2	6.0	5	4	5.0	4.9	3	5	15	
47	Florida	WS 1	49	3	2.0	1	1	0.0	0.0	3	4	0	did not increase
48	Colorado	Fool Creek	40						4.8	2	1	23	
49	Colorado	Deadhorse Creek	10					4.3	3.4		3	0	no change
49	Colorado	North Fork	36						3.1		4	49	
50	Mississippi	C-II	100	2	0.1	6	2			3		36	
50	Mississippi	C-III	100	2	0.1	6	2			3		28	
53	California	South Fork	66	2		1	4	1.9	16.0	2	7	10	
55	South Carolina	64	100	2	1.5	2	1		50.0	3		150	
55	South Carolina	66	100	2	1.5	2	4		22.5	3		55	
55	South Carolina	68	100	2	1.5	2	4		22.5	3		55	
60	Massachusetts	Cadwell Creek 1	34	3	6.0	1			1.0	3	5	46	
61	Malaysia	A	100		6.0		3			3	7	119	calculated from absolute changes

Table IV.2. Results for statistical analysis of continuous basin characteristics and management activities.

Variable	N	Coefficients y-int	Coefficients slope	Standard error	R^2	p-value	Comments
Basin characteristics							
Area (ha)	43	41	-0.076	35	0.04	0.197	one outlier included
Latitude (degrees)	44	98	-1.6	32	0.08	0.060	one influential observation removed; two outliers included
Basin relief (m)	22	37	-0.018	35	0.02	0.546	
Mean elevation(m)	30	38	-0.0045	35	0.01	0.534	
Mean basin slope (%)	22	63	-0.61	39	0.10	0.155	
Drainage density (km km^{-2})	12	15	1.5	15	0.44	0.019	one outlier removed; driven by one observation
Annual precipitation (mm)	44	58	-0.015	34	0.08	0.065	two outliers included
Annual ET (mm)	20	5.2	0.060	39	0.17	0.075	one outlier included; driven by one observation
Management activities							
Area cut (%)	45	24	0.17	35	0.02	0.325	two outliers included
Duration of cut (months)	27	53	-1.9	40	0.03	0.417	
Road density (km km^{-2})	23	25	-0.00021	27	0.00	1.000	one outlier included
Area compacted (%)	35	21	1.1	31	0.13	0.035	one outlier included; driven by one observation

Table IV.3. Results for statistical analysis of categorical basin characteristics and management activities.

Variable	Mean 1st	Mean 2nd	N 1st	N 2nd	p-value
Basin characteristics					
Ecoregion domain					0.697
Vegetation type					0.165
Pre-harvest stand age					0.207
Soil type					0.960
Hydrologic regime					0.346
Dominant aspect					--
NW-NE vs. SE-SW	37	24	14	20	0.200
NE-SE vs. SW-NW	32	34	15	11	0.896
Management activities					
Type of silvicultural method					0.459
Buffer strips					0.583
Type of yarding					0.028
Tractor and rubber-tired skidders vs. cable systems	17	12	49	16	0.007
Tractor and rubber-tired skidders vs. mixed tractor and cable	17	5	49	22	0.012
Tractor and rubber-tired skidders vs. none	17	4	49	21	0.021
Cable systems vs. mixed tractor and cable	12	5	16	22	0.499
Cable systems vs. none	12	4	16	21	0.629
Mixed tractor and cable vs. none	5	4	22	21	0.896
Type of site preparation					0.403
Season of harvest activities					--
growing vs. mixed					0.243

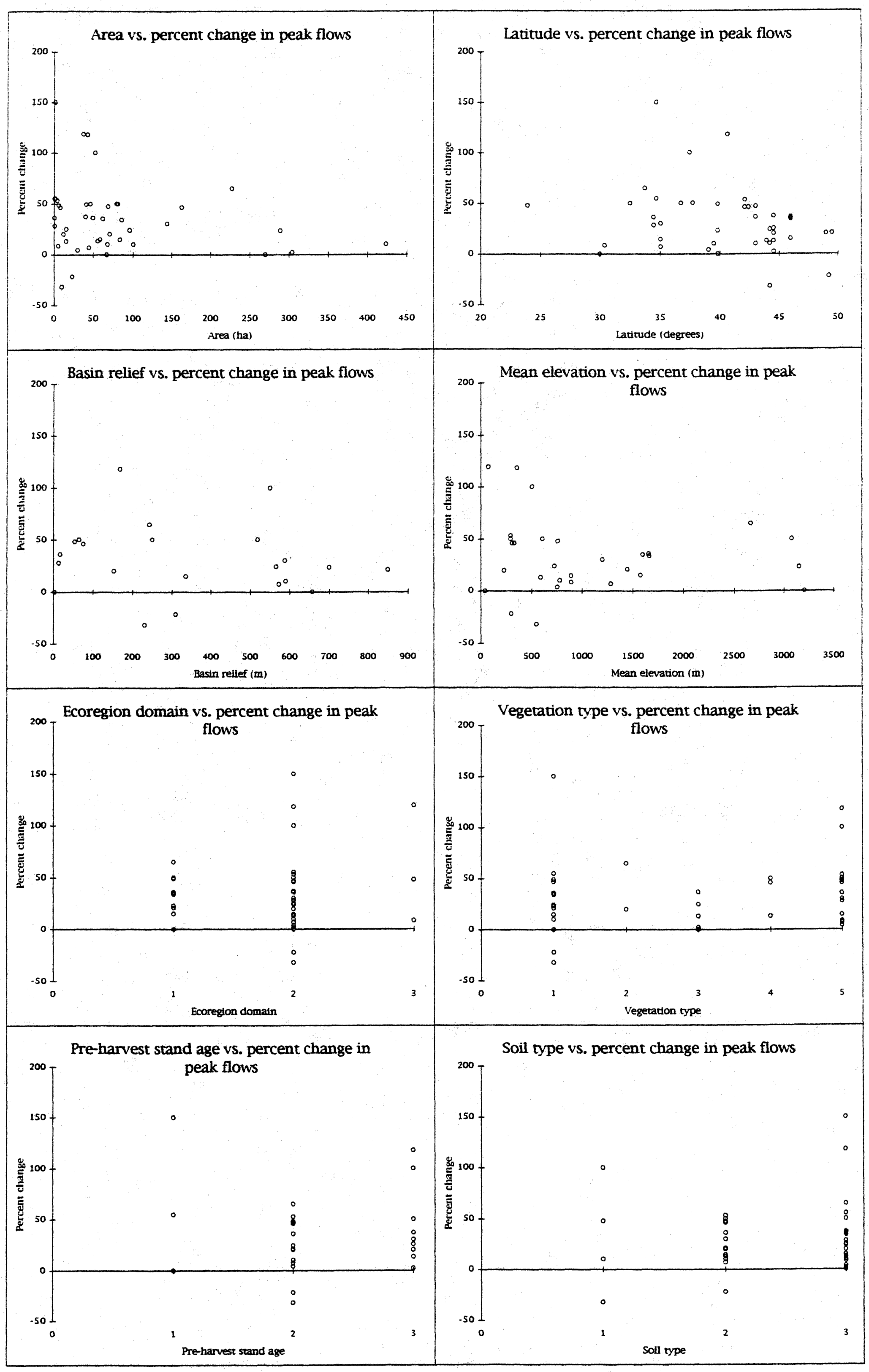
APPENDIX V:

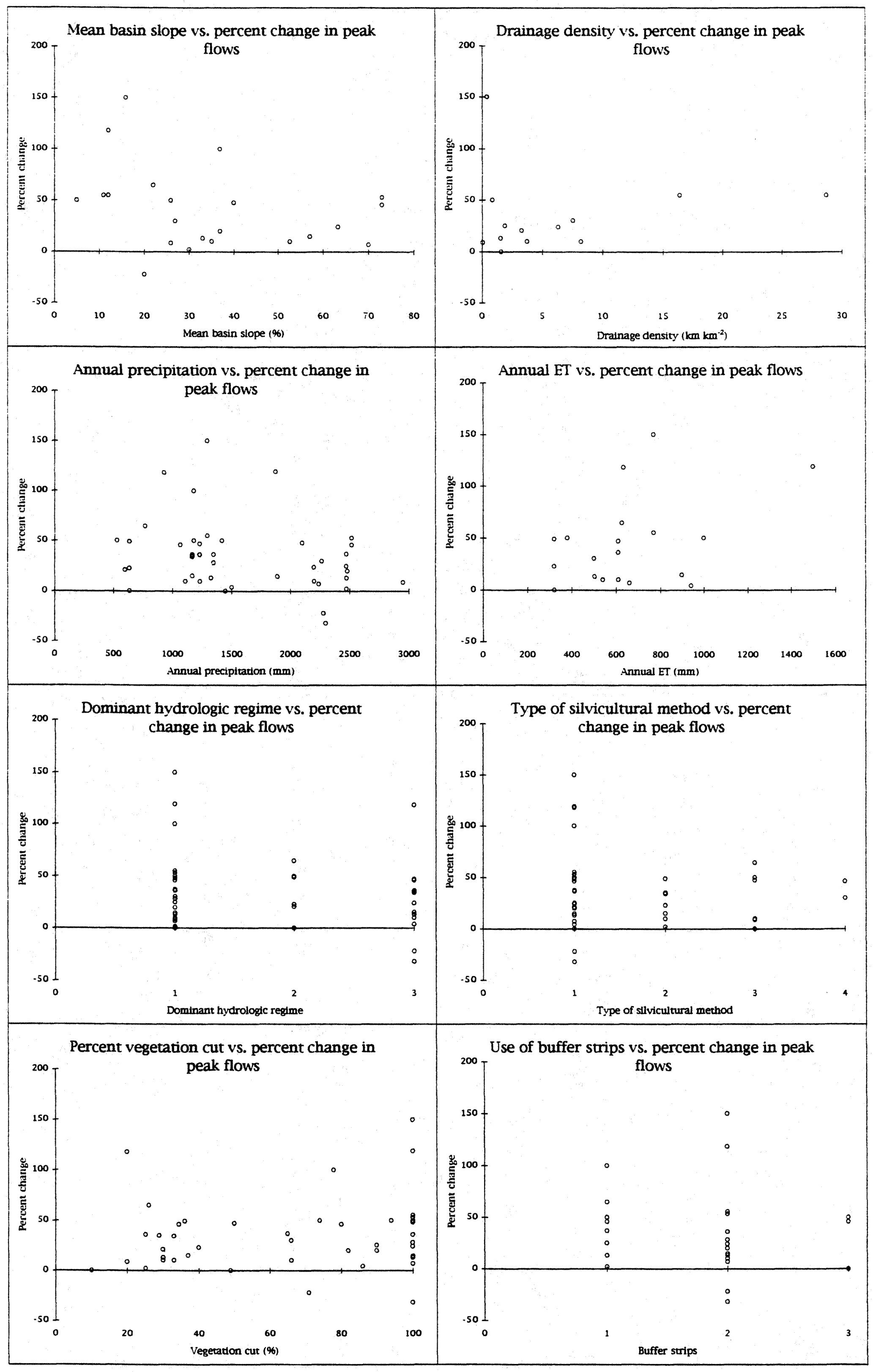
CORRELATION TABLE AND SCATTER PLOTS FOR THE PUBLISHED DATA USED IN THE DETAILED ANALYSIS

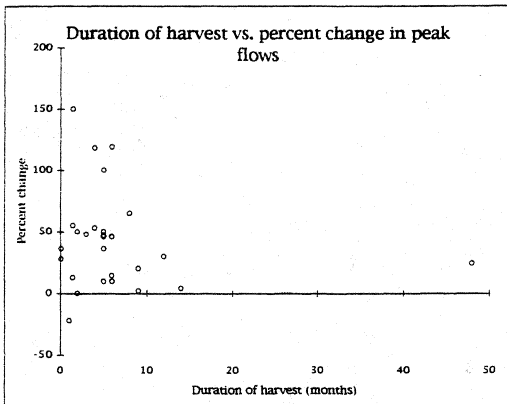
(See Table 2.2 for the coding of the categorical variables.)

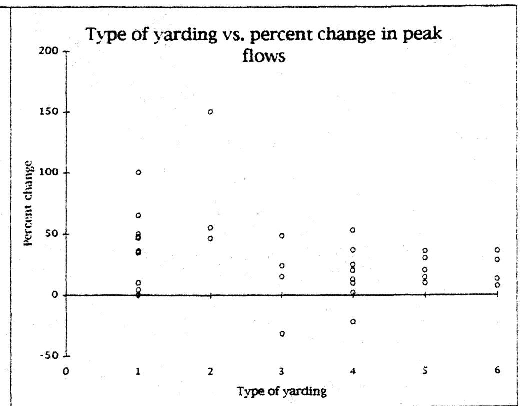
Table V.1. Correlations for the continuous basin characteristics and management activities used in the detailed analysis of published data.

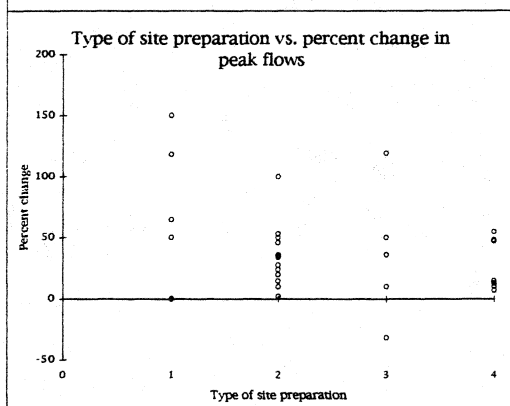
	Area	Latitude	Basin relief	Mean elevation	Mean basin slope	Drainage density	Annual precipitation	Annual ET	Percent of vegetation removed	Duration of harvest period	Road density	Percent of area compacted	Percent change in peak flows
Area	1.000												
Latitude	0.218	1.000											
Basin relief	0.487	0.415	1.000										
Mean elevation	0.174	0.147	0.570	1.000									
Mean basin slope	-0.059	0.240	0.574	-0.173	1.000								
Drainage density	-0.156	-0.136	0.628	-0.176	-0.345	1.000							
Annual precipitation	-0.279	-0.024	-0.108	-0.576	0.543	-0.172	1.000						
Annual ET	-0.423	-0.752	-0.721	-0.723	0.066	0.599	0.560	1.000					
Percent of vegetation removed	-0.269	-0.301	-0.274	-0.404	0.266	0.263	0.243	0.503	1.000				
Duration of harvest period	0.290	0.173	0.536	0.180	0.390	-0.124	0.290	0.089	0.035	1.000			
Road density	0.047	0.255	0.465	0.182	0.076	0.051	0.268	-0.147	-0.177	-0.063	1.000		
Percent of area compacted	-0.167	-0.106	-0.063	-0.153	-0.568	0.212	-0.041	0.275	0.312	-0.285	0.084	1.000	
Percent change in peak flows	-0.095	-0.447	-0.136	-0.118	-0.314	0.111	-0.280	0.407	0.150	-0.150	0.000	0.357	1.000

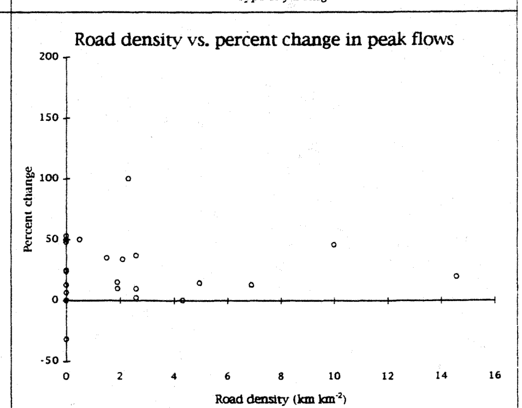

Area vs. percent change in peak flows
Percent change
Area (ha)
Latitude vs. percent change in peak flows
Percent change
Latitude (degrees)
Basin relief vs. percent change in peak flows
Percent change
Basin relief (m)
Mean elevation vs. percent change in peak flows
Percent change
Mean elevation (m)
Ecoregion domain vs. percent change in peak flows
Percent change
Ecoregion domain
Vegetation type vs. percent change in peak flows
Percent change
Vegetation type
Pre-harvest stand age vs. percent change in peak flows
Percent change
Pre-harvest stand age
Soil type vs. percent change in peak flows
Percent change
Soil type

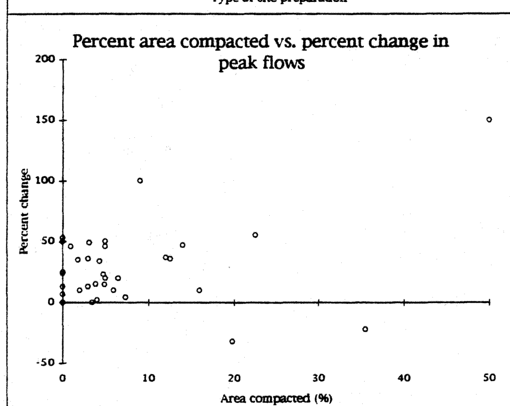

Mean basin slope vs. percent change in peak flows
Percent change
Mean basin slope (%)
Drainage density vs. percent change in peak flows
Percent change
Drainage density (km km^{-2})
Annual precipitation vs. percent change in peak flows
Percent change
Annual precipitation (mm)
Annual ET vs. percent change in peak flows
Percent change
Annual ET (mm)
Dominant hydrologic regime vs. percent change in peak flows
Percent change
Dominant hydrologic regime
Type of silvicultural method vs. percent change in peak flows
Percent change
Type of silvicultural method
Percent vegetation cut vs. percent change in peak flows
Percent change
Vegetation cut (%)
Use of buffer strips vs. percent change in peak flows
Percent change
Buffer strips

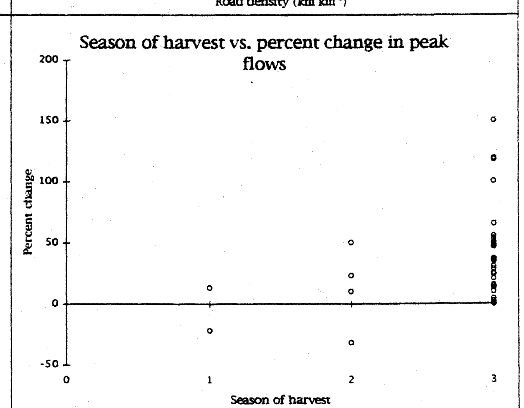

Duration of harvest vs. percent change in peak flows
Percent change
200
150
100
50
0
-50
0
10
20
30
40
50
Duration of harvest (months)

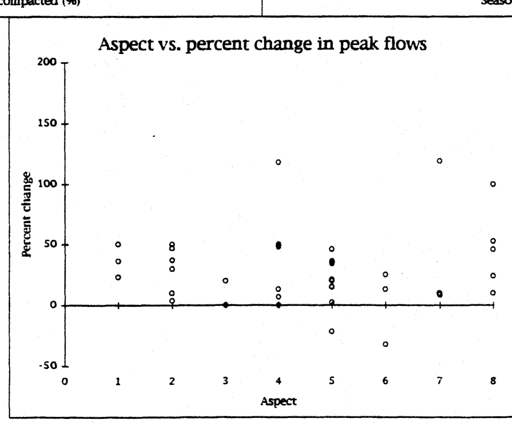

Type of yarding vs. percent change in peak flows
Percent change
200
150
100
50
0
-50
0
1
2
3
4
5
6
Type of yarding


Type of site preparation vs. percent change in peak flows
Percent change
200
150
100
50
0
-50
0
1
2
3
4
Type of site preparation


Road density vs. percent change in peak flows
Percent change
200
150
100
50
0
-50
0
2
4
6
8
10
12
14
16
Road density (km km⁻²)


Percent area compacted vs. percent change in peak flows
Percent change
200
150
100
50
0
-50
0
10
20
30
40
50
Area compacted (%)


Season of harvest vs. percent change in peak flows
Percent change
200
150
100
50
0
-50
0
1
2
3
Season of harvest


Aspect vs. percent change in peak flows
Percent change
200
150
100
50
0
-50
0
1
2
3
4
5
6
7
8
Aspect

APPENDIX VI:

FLOW DURATION CURVE DATA AND RESULTS FOR THE STATISTICAL ANALYSES OF BASIN CHARACTERISTICS AND MANAGEMENT ACTIVITIES

Table VI.1. Flow duration curve data used for the statistical analyses of basin characteristics and management activities.

Study number	Location	Basin	Area (ha)	Latitude	Basin relief (m)	Mean elevation (m)	Ecoregion domain	Vegetation type	Pre-harvest stand age	Soil type	Mean basin slope (%)	Drainage density (km km^{-2})	Annual precipitation (mm)	Annual ET (mm)
2	Colorado	B	81.0	37.77	520	3078	1	4		2	26	0.9	533	380
16	Arizona	Thomas Ck South	227.4	33.75	244	2667	1	2	2	3	22		768	627
17	Oregon	FC-1	59.0	45.42		955	2	1	2	3	7		2730	
17	Oregon	FC-3	71.0	45.42		950	2	1	2	3	7		2730	
18	Oregon	CC-1	69.2	43.00			2	1	2	2			1229	610
18	Oregon	CC-2	68.4	43.00			2	1	2	2			1229	610
18	Oregon	CC-3	49.8	43.00			2	1	2	2			1229	610
19	Oregon	HJA-6	13.0	44.20	150	938	2	1	2	3			2190	740
19	Oregon	HJA-7	15.4	44.20	99	1003	2	1	2	3			2190	1200
20	Oregon	HJA-10	10.2	44.20	231	549	2	1	2	1			2300	
21	Oregon	Deer Ck	304.0	44.53			2	3	3	3	30		2474	
21	Oregon	Needle Branch	71.0	44.53			2	2	3	3	37	3.3	2483	
23	North Carolina	WS 37	44.0	35.05	573	1280	2	5	2	2	70		2244	660
23	North Carolina	WS 6	8.9	35.05	209	801	2	5	3	2			1000	
37	New Zealand	M8	3.8	42.08		305	2	5	2	2	73		2518	
38	New Hampshire	HB-2	15.6	43.93		595	2	4	3	2	33	1.5	1327	502
38	New Hampshire	HB-4	36.1	43.93		606	2	4	3		28		1365	502
38	New Hampshire	HB-5	21.9	43.93		636	2	4	3		28		1377	502
41	Oregon	HJA-1	96.0	44.20	565	728	2	1	2	3	63.2	6.3	2200	
41	Oregon	HJA-3	101.0	44.20	590	781	2	1	2	3	52.6	8.2	2200	
48	Colorado	Fool Ck	289.0	39.83	700	3150	1	1					635	320
52	Minnesota	S4N	23.2	47.53			2	3	2	3			772	579
52	Minnesota	S4S	11.0	47.53			2	4	2	3			772	579
53	California	Caspar Ck South	424.0	39.50			2	1	2	1	35	3.7	1109	538
60	Massachusetts	Cadwell Ck 1	163.0	42.40	76	312	2	4	2	2			1067	
65	Oklahoma	CL1	7.6			320	2	3	2	3	18		1194	813

Table VI.1. (cont.)

Study number	Location	Basin	Domonant hydrologic regime	Type of silvicultural method	Percent of vegetation removed	Use of buffer strips	Duration of harvest period (months)	Type of yarding	Type of site preparation	Road density (km km^{-2})	Percent of area compacted	Season	Aspect
2	Colorado	B	2	1	100	3		1	3			2	2
16	Arizona	Thomas Ck South	2	3	26	1	8	1	1			3	
17	Oregon	FC-1	3	2	25	1	3	4	2		2.0	2	8
17	Oregon	FC-3	3	2	25	1		5	4		0.0	2	8
18	Oregon	CC-1	3	3	50		5	1	4		14.0	3	2
18	Oregon	CC-2	3	2	30		5	5	3		6.0	3	2
18	Oregon	CC-3	3	1	100		5	5	3		12.5	3	1
19	Oregon	HJA-6	3	1	100	2	4	5	2		1.2	2	5
19	Oregon	HJA-7	3	3	60	2	4	5	2			2	4
20	Oregon	HJA-10	3	1	100	2		3	3	0.0	19.8	2	6
21	Oregon	Deer Ck	1	2	25	1	9	4	2	2.6	4.0	3	5
21	Oregon	Needle Branch	1	1	82	2	9	5	2	14.6	5.0	3	5
23	North Carolina	WS 37	1	1	100	2		6	4	0.0	0.0		4
23	North Carolina	WS 6	1	1	100	2			3			3	8
37	New Zealand	M8	1	1	90	1	6	4	2			3	8
38	New Hampshire	HB-2	3	1	100	2	1.5	6	4	0.0	0.0	1	4
38	New Hampshire	HB-4	3	1		1	3	2	4			1	4
38	New Hampshire	HB-5	3	1	95			1				3	4
41	Oregon	HJA-1	3	1	100	2	48	3	2	0.0	0.0	3	8
41	Oregon	HJA-3	3	2	33	2	6	4	2	2.6	2.0	3	8
48	Colorado	Fool Ck	2	2	40						4.8	2	1
52	Minnesota	S4N	3	1	72	3	13	1	4			3	
52	Minnesota	S4S	3	1	89	3		1	4			3	
53	California	Caspar Ck South	1	3		2		1	4	1.9	16.0	2	7
60	Massachusetts	Cadwell Ck 1	3	4	34.4	3	6	1			1	3	5
65	Oklahoma	CL1	1	1	98	3	2	2	3	0.0		3	8

Table VI.1. (cont.)

Study number	Location	Basin	1.0%		2.5%		5.0%		10.0%		25.0%		50.0%	
			%	$L\,s^{-1}\,ha^{-1}$	%	$L\,s^{-1}\,ha^{-1}$	%	$L\,s^{-1}\,ha^{-1}$	%	$L\,s^{-1}\,ha^{-1}$	%	$L\,s^{-1}\,ha^{-1}$	%	$L\,s^{-1}\,ha^{-1}$
2	Colorado	B	19.5	0.0048	8.7	0.0024	1.1	0.0003	1.9	0.0006	4.0	0.0013	11.1	0.0036
16	Arizona	Thomas Ck South									885.5	0.0006	416.3	0.0035
17	Oregon	FC-1	-36.3	-0.0147	-40.5	-0.0208	-34.6	-0.0208	-19.8	-0.0175	-38.3	-0.1157	-20.4	-0.1446
17	Oregon	FC-3	-20.7	-0.0044	-36.4	-0.0109	-19.4	-0.0061	-13.2	-0.0060	-31.9	-0.0611	-5.1	-0.0276
18	Oregon	CC-1	13.8	0.0003	20.7	0.0005	16.7	0.0005	37.7	0.0016	37.3	0.0040	7.0	0.0051
18	Oregon	CC-2	81.1	0.0001	35.3	0.0001	37.3	0.0002	89.3	0.0006	147.2	0.0036	88.3	0.0326
18	Oregon	CC-3	58.7	0.0028	68.2	0.0037	80.9	0.0053	99.5	0.0076	110.0	0.0150	96.6	0.0674
19	Oregon	HJA-6	183.3	0.0146	152.1	0.0152	132.3	0.0172	159.0	0.0239	128.0	0.0391	44.6	0.0517
19	Oregon	HJA-7	-7.0	-0.0014	2.1	0.0004	7.0	0.0016	34.2	0.0077	77.9	0.0190	51.2	0.0410
20	Oregon	HJA-10	1325.2	0.0204	943.5	0.0229	489.6	0.0263	318.6	0.0312	72.4	0.0274	59.2	0.0604
21	Oregon	Deer Ck	0.0	0.0000	20.4	0.0041	20.9	0.0048	5.9	0.0023	25.9	0.0211	15.5	0.0407
21	Oregon	Needle Branch	118.2	0.0065	66.7	0.0048	57.1	0.0058	48.2	0.0091	93.1	0.0482	22.2	0.0560
23	North Carolina	WS 37	50.9	0.0280	45.6	0.0284	36.4	0.0263	40.8	0.0332	20.7	0.0278	6.2	0.0168
23	North Carolina	WS 6	10.9	0.0108	13.4	0.0136	13.7	0.0148	14.4	0.0173	2.5	0.0041	15.4	0.0310
37	New Zealand	M8									44.2	0.0163	18.5	0.0257
38	New Hampshire	HB-2					30165.7	0.0609	6267.3	0.0711	224.5	0.0730	73.8	0.0758
38	New Hampshire	HB-4	260.2	0.0082	278.7	0.0158	170.4	0.0194	57.7	0.0179	-9.8	-0.0105	1.7	0.0031
38	New Hampshire	HB-5			1818.1	0.0033	490.0	0.0091	814.5	0.0267	30.0	0.0140	5.9	0.0063
41	Oregon	HJA-1	347.4	0.0124	109.1	0.0100	103.3	0.0105	131.1	0.0169	144.9	0.0412	63.0	0.0798
41	Oregon	HJA-3	643.9	0.0188	472.9	0.0197	152.7	0.0163	106.7	0.0154	70.4	0.0182	33.2	0.0389
48	Colorado	Fool Ck												
52	Minnesota	S4N											133.2	0.0104
52	Minnesota	S4S												
53	California	Caspar Ck South	107.5	0.0057	56.4	0.0041	39.4	0.0036	25.1	0.0029	21.8	0.0041	35.9	0.0168
60	Massachusetts	Cadwell Ck 1							313.5	0.0118	131.9	0.0276	22.1	0.0207
65	Oklahoma	CL1												

Table VI.1. (cont.)

Study			75.0%		90.0%		95.0%		97.5%		99.0%	
number	Location	Basin	%	$L s^{-1} ha^{-1}$	%	$L s^{-1} ha^{-1}$	%	$L s^{-1} ha^{-1}$	%	$L s^{-1} ha^{-1}$	%	$L s^{-1} ha^{-1}$
2	Colorado	B	29.1	0.0122	16.5	0.0182	26.4	0.0525	38.1	0.0856	48.4	0.1409
16	Arizona	Thomas Ck South	41.3	0.0116	8.1	0.0115	37.2	0.1089	27.8	0.1339	2.7	0.0254
17	Oregon	FC-1	-4.7	-0.0562	-3.8	-0.0734	7.7	0.1950	9.9	0.3363	0.6	0.0277
17	Oregon	FC-3	-0.8	-0.0092	-5.1	-0.1063	-4.9	-0.1472	3.7	0.1303	-3.6	-0.1754
18	Oregon	CC-1	1.5	0.0044	8.1	0.0510	3.1	0.0303	4.4	0.0695	-1.2	-0.0292
18	Oregon	CC-2	20.5	0.0486	15.1	0.0779	3.0	0.0265	12.6	0.1835	3.4	0.0785
18	Oregon	CC-3	43.7	0.1133	32.9	0.1839	41.0	0.3664	31.7	0.4735	29.1	0.6748
19	Oregon	HJA-6	46.7	0.2138	37.9	0.3319	31.8	0.4397	13.3	0.2823	11.9	0.3651
19	Oregon	HJA-7	34.8	0.1100	25.9	0.1590	30.9	0.2870	11.6	0.1696	12.2	0.2700
20	Oregon	HJA-10	18.0	0.0711	30.4	0.2848	16.5	0.2732	-2.8	-0.0841	-14.1	-0.6590
21	Oregon	Deer Ck	0.0	-0.0003	6.7	0.0933	11.6	0.2425	1.8	0.0605	-2.3	-0.1004
21	Oregon	Needle Branch	31.6	0.2113	35.5	0.5236	23.4	0.5282	29.5	1.0009	36.1	1.5914
23	North Carolina	WS 37	-1.9	-0.0104	0.2	0.0016	4.0	0.0597	6.9	0.1598	5.9	0.1863
23	North Carolina	WS 6	10.8	0.0370	2.4	0.0122	1.3	0.0081	-0.8	-0.0063	-1.0	-0.0101
37	New Zealand	M8	22.3	0.0910	13.9	0.1667	13.6	0.2642	0.3	0.0092	20.3	0.8955
38	New Hampshire	HB-2	23.8	0.0633	4.1	0.0285	0.0	0.0004	15.6	0.2910	30.3	0.8706
38	New Hampshire	HB-4	5.5	0.0210	-2.1	-0.0178	8.6	0.0995	10.1	0.1733	13.7	0.3343
38	New Hampshire	HB-5	-4.3	-0.0105	-1.5	-0.0081	-9.2	-0.0886	14.5	0.1948	11.2	0.2176
41	Oregon	HJA-1	50.0	0.1775	43.3	0.3627	17.8	0.2596	30.5	0.6006	22.4	0.6834
41	Oregon	HJA-3	16.6	0.0730	7.4	0.0643	6.2	0.0856	4.5	0.0900	21.1	0.7458
48	Colorado	Fool Ck			37.5	0.0983	59.5	0.3109	39.8	0.3068	22.2	0.2341
52	Minnesota	S4N	78.3	0.0359	39.3	0.0629	41.3	0.1108	21.4	0.1104	10.9	0.0833
52	Minnesota	S4S	40.2	0.0135	30.9	0.0413	39.4	0.0968	21.3	0.1077	21.5	0.1977
53	California	Caspar Ck South	13.9	0.0332	23.4	0.1430	5.7	0.0761	-0.1	-0.0028	-7.7	-0.3535
60	Massachusetts	Cadwell Ck 1	11.2	0.0227	14.5	0.0592	7.1	0.0438	14.4	0.1147	51.8	0.6547
65	Oklahoma	CL1	139.5	0.0500	1.3	0.0033	12.1	0.0654	20.3	0.1911	26.1	0.5316

Table VI.2. Results for the statistical analyses of the relationships between absolute changes in flow (L s^{-1} ha^{-1}) and continuous basin characteristics and management activities. Results are provided by percentile.

1st percentile (L s^{-1} ha^{-1})							
		Coefficients			Std.		
Variable	N	y-int	x	R^2	error	p-value	Comments
Basin characteristics							
Latitude (degrees)	17	0.062	-0.0013	0.18	0.0096	0.086	p = 0.058 for intercept
Area (ha)	17	0.0079	-0.000015	0.02	0.010	0.555	
Mean elevation (m)	11	0.011	-0.0000021	0.01	0.013	0.729	
Elevation range (m)	8	0.0068	0.000018	0.18	0.0090	0.291	
Mean slope (%)	10	-0.012	0.00051	0.83	0.0051	0.000	p = 0.008 for intercept
Drainage density (km km^{-2})	5	0.00086	0.0020	0.88	0.0023	0.017	p = 0.711 for intercept
Annual precipitation (mm)	17	0.0073	-0.00000035	0.00	0.011	0.928	
Annual ET (mm)	9	0.011	-0.0000058	0.02	0.0098	0.711	
Management activities							
Area cut (%)	15	-0.0071	0.00020	0.38	0.0090	0.015	p = 0.212 for intercept
Duration of cut (months)	10	-0.00075	0.00081	0.04	0.0097	0.604	
Road density (km km^{-2})	7	0.016	-0.00080	0.18	0.0097	0.345	
Area compacted (%)	13	0.0068	0.000032	0.00	0.012	0.952	

Table VI.2. (cont.)

Variable	N	Coefficients: y-int	Coefficients: x	R^2	Std. error	p-value	Comments
		2.5 percentile (L s^{-1} ha^{-1})					
Basin characteristics							
Latitude (degrees)	18	0.067	-0.0014	0.16	0.011	0.099	p = 0.071 for intercept
Mean slope (%)	11	-0.014	0.00057	0.74	0.0073	0.001	p = 0.011 for intercept
Drainage density (km km^{-2})	5	-0.0021	0.0023	0.86	0.0030	0.022	p = 0.491 for intercept
Management activities							
Area cut (%)	16	-0.0087	0.00021	0.32	0.010	0.021	p = 0.187 for intercept

Table VI.2. (cont.)

Variable	N	Coefficients: y-int	Coefficients: x	R^2	Std. error	p-value	Comments
		5th percentile (L s^{-1} ha^{-1})					
Basin characteristics							
Latitude (degrees)	18	0.055	-0.0011	0.10	0.011	0.193	one outlier removed; p = 0.560 with outlier
Mean slope (%)	11	-0.011	0.00050	0.63	0.0082	0.004	one outlier removed; p = 0.131 with outlier; p = 0.057 for intercept
Drainage density (km km^{-2})	6	0.023	-0.0016	0.04	0.025	0.703	no outliers, but one observation did stand out
Management activities							
Area cut (%)	16	-0.0084	0.00022	0.38	0.0097	0.012	one outlier removed; p = 0.020 with outlier; p = 0.173 for intercept

Table VI.2. (cont.)

		10th percentile (L s^{-1} ha^{-1})					
		Coefficients			Std.		
Variable	N	y-int	x	R^2	error	p-value	Comments
Basin characteristics							
Mean slope (%)	11	-0.010	0.00055	0.58	0.010	0.007	one outlier removed; p = 0.145 with outlier; p = 0.142 for intercept
Management activities							
Area cut (%)	17	-0.0079	0.00027	0.45	0.010	0.003	one outlier removed; p = 0.007 with outlier; p = 0.197 for intercept

Table VI.2. (cont.)

		25th percentile (L s^{-1} ha^{-1})					
		Coefficients			Std.		
Variable	N	y-int	x	R^2	error	p-value	Comments
Basin characteristics							
Mean slope (%)	14	-0.044	0.0014	0.37	0.038	0.021	p = 0.061 for intercept
Management activities							
Area cut (%)	18	0.0065	0.00021	0.13	0.018	0.145	two outliers removed; p = 0.016 with outliers

Table VI.2. (cont.)

Variable	N	Coefficients: y-int	Coefficients: x	R^2	Std. error	p-value	Comments
		50th percentile ($L\ s^{-1}\ ha^{-1}$)					
Basin characteristics							
Latitude (degrees)	22	-0.046	0.0018	0.06	0.027	0.283	one outlier removed; p = 0.976 with outlier
Area (ha)	22	0.033	-0.000039	0.02	0.028	0.499	one outlier removed; p = 0.840 with outlier
Mean elevation (m)	15	0.042	-0.000013	0.13	0.029	0.186	one outlier removed; p = 0.496 with outlier
Elevation range (m)	10	0.034	0.000026	0.00	0.026	0.951	
Mean slope (%)	13	-0.0033	0.00076	0.23	0.028	0.095	one outlier removed; p = 0.029 with outlier; p = 0.859 for intercept
Drainage density ($km\ km^{-2}$)	6	0.034	0.0027	0.06	0.034	0.639	
Annual precipitation (mm)	22	0.013	0.000010	0.07	0.027	0.250	one outlier removed; p = 0.618 with outlier
Annual ET (mm)	13	0.0030	0.000037	0.08	0.026	0.354	

Table VI.2. (cont.)

		50th percentile ($L\ s^{-1}\ ha^{-1}$)					
		Coefficients			Std.		
Variable	N	y-int	x	R^2	error	p-value	Comments
Management activities							
Area cut (%)	20	0.0040	0.00039	0.20	0.026	0.049	one outlier removed; p = 0.022 with outlier; p = 0.786 for intercept
Duration of cut (months)	14	0.049	-0.0026	0.10	0.023	0.265	one outlier removed; p = 0.715 with outlier
Road density ($km\ km^{-2}$)	8	0.048	0.000065	0.00	0.026	0.975	
Area compacted (%)	14	0.038	0.00010	0.00	0.031	0.937	one outlier removed; p = 0.623 with outlier

Table VI.2. (cont.)

		75th percentile ($L\ s^{-1}\ ha^{-1}$)					
		Coefficients			Std.		
Variable	N	y-int	x	R^2	error	p-value	Comments
Basin characteristics							
Mean slope (%)	14	-0.026	0.0016	0.38	0.047	0.020	one outlier removed; p = 0.068 with outlier; p = 0.322 for intercept
Management activities							
Area cut (%)	23	-0.011	0.00093	0.17	0.066	0.049	p = 0.763 for intercept
Road density ($km\ km^{-2}$)	9	0.051	0.0097	0.37	0.063	0.080	p = 0.071 for intercept; plots suggest not trusting significance

Table VI.2. (cont.)

		90th percentile (L s^{-1} ha^{-1})					
		Coefficients			Std.		
Variable	N	y-int	x	R^2	error	p-value	Comments
Basin characteristics							
Mean slope (%)	14	-0.079	0.0037	0.45	0.090	0.008	one outlier removed; p = 0.076 with outlier; p = 0.120 for intercept
Management activities							
Area cut (%)	23	-0.014	0.0014	0.15	0.11	0.068	one outlier removed; p = 0.089 with outlier; p = 0.802 for intercept
Road density (km km^{-2})	9	0.10	0.026	0.46	0.14	0.044	p = 0.100 for intercept; plots suggest not trusting significance

Table VI.2. (cont.)

		95th percentile (L s^{-1} ha^{-1})					
		Coefficients			Std.		
Variable	N	y-int	x	R^2	error	p-value	Comments
Basin characteristics							
Area (ha)	26	0.14	0.000053	0.00	0.16	0.864	non-constant variance
Mean elevation (m)	18	0.11	0.000018	0.01	0.16	0.667	
Mean slope (%)	14	0.0027	0.0025	0.20	0.11	0.113	one outlier removed; p = 0.223 with outlier

Table VI.2. (cont.)

		95th percentile (L s^{-1} ha^{-1})					
		Coefficients			Std.		
Variable	N	y-int	x	R^2	error	p-value	Comments
Management activities							
Area cut (%)	24	0.086	0.00093	0.03	0.17	0.407	
Road density (km km^{-2})	9	0.11	0.027	0.61	0.11	0.013	p = 0.034 for intercept; plots suggest not trusting significance
Area compacted (%)	16	0.15	0.0042	0.02	0.19	0.581	

Table VI.2. (cont.)

		97.5 percentile (L s^{-1} ha^{-1})					
		Coefficients			Std.		
Variable	N	y-int	x	R^2	error	p-value	Comments
Basin characteristics							
Area (ha)	23	0.14	-0.000100	0.01	0.11	0.620	three outliers removed; never close to being significant
Mean elevation (m)	17	0.13	0.000023	0.04	0.12	0.466	one outlier removed; p = 0.791 with outlier
Mean slope (%)	13	0.21	-0.0022	0.20	0.092	0.121	two outliers removed; p = 0.885 with outliers
Management activities							
Area cut (%)	22	0.17	-0.00057	0.03	0.11	0.445	two outliers removed; p = 0.511 with outliers
Road density (km km^{-2})	9	0.13	0.053	0.53	0.25	0.025	p = 0.217 for intercept; plots suggest not trusting significance
Area compacted (%)	15	0.27	-0.012	0.19	0.17	0.104	one outlier removed; p = 0.252 with outlier

Table VI.2. (cont.)

		99th percentile (L s^{-1} ha^{-1})					
		Coefficients			Std.		
Variable	N	y-int	x	R^2	error	p-value	Comments
Basin characteristics							
Latitude (degrees)	24	-0.29	0.012	0.01	0.39	0.583	one outlier removed; p = 0.436 with outlier
Area (ha)	24	0.39	-0.0013	0.18	0.32	0.041	two outliers removed; p = 0.210 with outliers; p = 0.0001 for intercept
Mean elevation (m)	17	0.54	-0.00016	0.21	0.30	0.062	one outlier removed; p = 0.272 with outlier; p = 0.0003 for intercept
Elevation range (m)	11	0.10	0.00039	0.05	0.41	0.506	
Mean slope (%)	15	0.0061	0.010	0.18	0.48	0.117	
Drainage density (km km^{-2})	6	0.50	0.029	0.01	0.74	0.819	
Annual precipitation (mm)	25	0.24	-0.0000037	0.00	0.39	0.974	one outlier removed; p = 0.503 with outlier
Annual ET (mm)	16	0.15	0.00014	0.01	0.30	0.715	

Table VI.2. (cont.)

		99th percentile ($L\ s^{-1}\ ha^{-1}$)					
		Coefficients			Std.		
Variable	N	y-int	x	R^2	error	p-value	Comments
Management activities							
Area cut (%)	22	0.020	0.0041	0.17	0.31	0.060	two outliers removed; p = 0.277 with outliers; p = 0.901 for intercept
Duration of cut (months)	15	0.60	-0.044	0.14	0.33	0.166	one outlier removed; p = 0.833 with outlier
Road density ($km\ km^{-2}$)	9	0.17	0.089	0.37	0.59	0.085	p = 0.462 for intercept; plots suggest not trusting significance
Area compacted (%)	15	0.43	-0.040	0.35	0.38	0.021	one outlier removed; p = 0.064 with outlier; p = 0.005 for intercept

Table VI.3. Results for the statistical analyses of the relationships between absolute changes in flow (L s^{-1} ha^{-1}) and categorical basin characteristics and management activities. Results are provided by percentile.

1st percentile (L s^{-1} ha^{-1})					
	Mean		N		
Variable	1st	2nd	1st	2nd	p-value
Basin characteristics					
Ecoregion domain					--
Vegetation type					--
mostly and all conifer vs. mostly and all hardwood	0.0051	0.013	12	4	0.242
Pre-harvest stand age					--
>50 years vs. mixed	0.0069	0.0064	12	4	0.906
Hydrologic regime					--
rain vs. mixed	0.0102	0.0052	5	11	0.410
Soil type					--
coarse vs. mixed	0.0078	0.0040	6	8	0.526
Dominant aspect					--
NW-NE vs. SE-SW	0.0034	0.0109	9	7	0.179
NE-SE vs. SW-NW	0.0067	0.0070	6	7	0.963

Table VI.3. (cont.).

	1st percentile (L s^{-1} ha^{-1})				
	Mean		N		
Variable	1st	2nd	1st	2nd	p-value
Management activities					
Type of silvicultural method					0.034
clearcut vs. patch cut	0.012	-0.000024	9	5	0.092
clearcut vs. selection cut	0.012	0.0015	9	3	0.015
patch cut vs. selection cut	-0.000024	0.0015	5	3	0.801
clearcut vs. both	0.012	0.00056	9	8	0.017
Buffer strips					--
with vs. without	-0.0027	0.013	4	9	0.039
Type of yarding					0.624
Type of site preparation					0.941
Season of harvest activities					--
growing vs. mixed	0.0036	0.0065	7	8	0.585

Table VI.3. (cont.)

	2.5 percentile (L s^{-1} ha^{-1})				
	Mean		N		
Variable	1st	2nd	1st	2nd	p-value
Management activities					
Type of silvicultural method					--
clearcut vs. selection cut	0.012	0.0017	10	3	0.006
clearcut vs. both	0.012	-0.00036	10	8	0.029
Buffer strips					--
with vs. without	-0.0030	0.013	4	9	0.135

Table VI.3. (cont.)

	5th percentile (L s^{-1} ha^{-1})				
	Mean		N		
Variable	1st	2nd	1st	2nd	p-value
Management activities					
Type of silvicultural method					--
clearcut vs. selection cut	0.018	0.0019	11	3	0.010
clearcut vs. both	0.018	0.000017	11	8	0.011
Buffer strips					--
with vs. without	-0.00067	0.018	4	10	0.108

Table VI.3. (cont.)

	10th percentile (L s^{-1} ha^{-1})				
	Mean		N		
Variable	1st	2nd	1st	2nd	p-value
Management activities					
Type of silvicultural method					--
clearcut vs. selection cut	0.023	0.0041	11	3	0.007
clearcut vs. both	0.023	0.00086	11	8	0.004
Buffer strips					--
with vs. without	-0.00084	0.023	4	10	0.044

Table VI.3. (cont.)

	25th percentile (L s^{-1} ha^{-1})				
	Mean		N		
Variable	1st	2nd	1st	2nd	p-value
Management activities					
Type of silvicultural method					--
clearcut vs. selection cut	0.025	0.0069	12	4	0.039
clearcut vs. both	0.025	-0.012	12	9	0.052
Buffer strips					--
with vs. without	-0.025	0.030	6	10	0.052

Table VI.3. (cont.)

	50th percentile ($L\ s^{-1}\ ha^{-1}$)				
	Mean		N		
Variable	1st	2nd	1st	2nd	p-value
Basin characteristics					
Ecoregion domain					--
Vegetation type					--
mostly and all conifer vs. mostly and all hardwood	0.022	0.023	13	8	0.945
Pre-harvest stand age					--
>50 years vs. mixed	0.019	0.035	16	6	0.343
Hydrologic regime					--
rain vs. mixed	0.031	0.021	6	15	0.538
Soil type					--
coarse vs. mixed	0.031	0.015	9	10	0.478
Dominant aspect					--
NW-NE vs. SE-SW	0.011	0.037	10	10	0.246
NE-SE vs. SW-NW	0.023	0.010	8	8	0.634

Table VI.3. (cont.)

Variable	50th percentile ($L\ s^{-1}\ ha^{-1}$) Mean 1st	Mean 2nd	N 1st	N 2nd	p-value
Management activities					
Type of silvicultural method					0.308
clearcut vs. both	0.038	0.00069	13	9	0.111
Buffer strips					0.010
with vs. without	-0.017	0.047	6	10	0.066
with vs. mixed	-0.017	0.012	6	3	0.358
without vs. mixed	0.047	0.012	10	3	0.003
Type of yarding					0.047
tractor/skidder vs. cable	0.0086	0.017	9	6	0.815
tractor/skidder vs. mixed	0.0086	0.037	9	6	0.099
cable vs. mixed	0.017	0.037	6	6	0.595
Type of site preparation					0.175
Season of harvest activities					--
growing vs. mixed	0.00017	0.032	7	13	0.284

Table VI.3. (cont.)

Variable	75th percentile ($L\ s^{-1}\ ha^{-1}$) Mean 1st	Mean 2nd	N 1st	N 2nd	p-value
Management activities					
Buffer strips					--
without vs. mixed	0.098	0.027	10	5	0.020

Table VI.3. (cont.)

Variable	90th percentile ($L\ s^{-1}\ ha^{-1}$) Mean 1st	Mean 2nd	N 1st	N 2nd	p-value
Management activities					
Buffer strips					--
without vs. mixed	0.19	0.037	10	5	0.022

Table VI.3. (cont.)

Variable	95th percentile (L s^{-1} ha^{-1}) Mean 1st	Mean 2nd	N 1st	N 2nd	p-value
Management activities					
Type of silvicultural method					--
clearcut vs. both	0.17	0.12	15	10	0.464
Buffer strips					--
without vs. mixed	0.20	0.074	10	5	0.058
Season of harvest activities					--
growing vs. mixed	0.19	0.14	8	15	0.590

Table VI.3. (cont.)

Variable	97.5 percentile (L s^{-1} ha^{-1}) Mean 1st	Mean 2nd	N 1st	N 2nd	p-value
Management activities					
Type of silvicultural method					--
clearcut vs. both	0.24	0.15	15	10	0.259
Buffer strips					--
without vs. mixed	0.25	0.12	10	5	0.252
Season of harvest activities					--
growing vs. mixed	0.15	0.22	8	15	0.440

Table VI.3. (cont.)

Variable	99th percentile ($L\ s^{-1}\ ha^{-1}$) Mean 1st	2nd	N 1st	2nd	p-value
Basin characteristics					
Ecoregion domain					- -
dry vs. humid temperate	0.13	0.31	3	23	0.157
Vegetation type					- -
mostly and all conifer vs. mostly and all hardwood	0.25	0.39	14	9	0.462
Pre-harvest stand age					- -
>50 years vs. mixed	0.23	0.48	19	6	0.395
Hydrologic regime					0.823
Soil type					- -
coarse vs. mixed	0.38	0.35	9	12	0.873
Dominant aspect					- -
NW-NE vs. SE-SW	0.32	0.37	12	10	0.797
NE-SE vs. SW-NW	0.26	0.19	8	9	0.735
Management activities					
Type of silvicultural method					0.083
clearcut vs. patch cut	0.41	0.14	15	6	0.172
clearcut vs. selection cut	0.41	-0.022	15	4	0.042
patch cut vs. selection cut	0.14	-0.022	6	4	0.425
clearcut vs. both	0.41	0.072	15	10	0.051
Buffer strips					0.599
Type of yarding					0.660
Type of site preparation					0.183
Season of harvest activities					- -
growing vs. mixed	-0.019	0.42	8	15	0.022

Table VI.4. Results for the statistical analyses of the relationships between relative changes in flow and continuous basin characteristics and management activities. Results are provided by percentile.

		1st percentile (%)					
		Coefficients			Std.		
Variable	N	y-int	x	R^2	error	p-value	Comments
Basin characteristics							
Latitude (degrees)	15	-137	5.1	0.03	112	0.553	two outliers removed; p = 0.389 with outliers
Area (ha)	15	81	-0.016	0.00	114	0.953	two outliers removed; p = 0.539 with outliers
Mean elevation (m)	11	483	-0.22	0.14	404	0.265	
Elevation range (m)	8	315	0.018	0.00	500	0.985	
Mean slope (%)	10	-43	5.4	0.29	191	0.110	
Drainage density (km km^{-2})	5	-134	85	0.91	86	0.011	p = 0.185 for intercept
Annual precipitation (mm)	15	90	-0.0063	0.00	114	0.884	two outliers removed; p = 0.463 with outliers
Annual ET (mm)	9	160	-0.12	0.09	89	0.425	
Management activities							
Area cut (%)	13	-45	1.6	0.26	94	0.078	two outliers removed; p = 0.398 with outliers; p = 0.479 for intercept
Duration of cut (months)	10	119	2.3	0.00	214	0.946	
Road density (km km^{-2})	7	455	-27	0.09	498	0.516	
Area compacted (%)	13	73	23	0.18	360	0.151	

Table VI.4. (cont.)

Variable	N	Coefficients y-int	Coefficients x	R^2	Std. error	p-value	Comments
			2.5 percentile (%)				
Basin characteristics							
Drainage density (km km^{-2})	5	-109	56	0.72	115	0.070	
Management activities							
Area cut (%)	14	70	-0.049	0.00	133	0.965	two outliers removed; p = 0.294 with outliers

Table VI.4. (cont.)

Variable	N	Coefficients y-int	Coefficients x	R^2	Std. error	p-value	Comments
			5th percentile (%)				
Basin characteristics							
Drainage density (km km^{-2})	6	12500	-1870	0.18	12417	0.398	
Management activities							
Area cut (%)	16	-37	1.9	0.16	153	0.126	one outlier removed; p = 0.382 with outlier

No variables were tested for the 10th and 25th percentiles because no relative changes for adjacent percentiles were significantly related to site or management variables.

Table VI.4. (cont.)

Variable	N	Coefficients: y-int	Coefficients: x	R^2	Std. error	p-value	Comments
		50th percentile (%)					
Basin characteristics							
Latitude (degrees)	22	-118	3.6	0.09	37	0.168	one outlier removed; non-constant variance; p = 0.091 with outlier
Area (ha)	22	39	-0.046	0.02	38	0.584	one outlier removed; non-constant variance; p = 0.313 with outlier
Mean elevation (m)	15	33	-0.0089	0.05	28	0.447	one outlier removed; one influential observation left; p = 0.046 with outlier
Elevation range (m)	10	104	-0.097	0.03	128	0.645	one outlier included; p = 0.606 without outlier
Mean slope (%)	13	-0.32	0.54	0.19	25	0.131	one outlier removed; p = 0.747 with outlier
Drainage density (km km^{-2})	6	35	1.1	0.02	27	0.806	
Annual precipitation (mm)	22	68	-0.019	0.12	36	0.114	one outlier removed; p = 0.057 with outlier
Annual ET (mm)	12	29	0.028	0.02	45	0.680	one outlier removed; p = 0.846 with outlier

Table VI.4. (cont.)

		50th percentile (%)					
		Coefficients			Std.		
Variable	N	y-int	x	R^2	error	p-value	Comments
Management activities							
Area cut (%)	20	16	0.29	0.06	39	0.308	one outlier removed; p = 0.433 with outlier
Duration of cut (months)	14	14	5.0	0.12	41	0.219	one outlier removed; p = 0.241 with outlier
Road density (km km^{-2})	8	44	-1.9	0.14	24	0.355	
Area compacted (%)	15	29	1.3	0.07	34	0.348	

No variables were tested for the 75th and 90th percentiles because no relative changes for adjacent percentiles were significantly related to site or management variables.

Table VI.4. (cont.)

		95th percentile (%)					
		Coefficients			Std.		
Variable	N	y-int	x	R^2	error	p-value	Comments
Management activities							
Area compacted (%)	15	9.3	0.42	0.05	13	0.427	one outlier removed; p = 0.615 with outlier

Table VI.4. (cont.)

		97.5 percentile (%)					
		Coefficients			Std.		
Variable	N	y-int	x	R^2	error	p-value	Comments
Management activities							
Area compacted (%)	16	16	-0.50	0.06	13	0.352	

Table VI.4. (cont.)

		99th percentile (%)					
		Coefficients			Std.		
Variable	N	y-int	x	R^2	error	p-value	Comments
Basin characteristics							
Latitude (degrees)	25	4.2	0.23	0.00	17	0.813	
Area (ha)	26	16	-0.023	0.02	17	0.471	
Mean elevation (m)	18	13	0.0025	0.02	17	0.598	
Elevation range (m)	11	12	0.014	0.03	21	0.635	
Mean slope (%)	15	9.5	0.15	0.04	16	0.478	
Drainage density (km km^{-2})	6	36	-2.7	0.16	19	0.426	
Annual precipitation (mm)	26	25	-0.0066	0.08	16	0.153	
Annual ET (mm)	16	25	-0.017	0.06	14	0.382	
Management activities							
Area cut (%)	24	6.4	0.13	0.06	16	0.252	
Duration of cut (months)	16	20	-0.54	0.01	16	0.697	
Road density (km km^{-2})	9	9.3	1.6	0.17	18	0.276	
Area compacted (%)	16	20	-1.3	0.20	17	0.085	p = 0.004 for intercept; p = 0.305 without influential observation

Table VI.5. Results for the statistical analyses of the relationships between relative changes in flow and categorical basin characteristics and management activities. Results are provided by percentile.

Variable	1st percentile (%) Mean 1st	2nd	N 1st	2nd	p-value
Basin characteristics					
Ecoregion domain					--
Vegetation type					--
mostly and all conifer vs. mostly and all hardwood	235	85	12	4	0.263
Pre-harvest stand age					--
>50 years vs. mixed	229	97	12	4	0.326
Hydrologic regime					--
rain vs. mixed	57	259	5	11	0.136
Soil type					--
coarse vs. mixed	39	154	6	8	0.220
Dominant aspect					--
NW-NE vs. SE-SW	124	276	9	7	0.457
NE-SE vs. SW-NW	70	340	6	7	0.205
Management activities					
Type of silvicultural method					0.188
clearcut vs. both	264	98	9	8	0.317
Buffer strips					--
with vs. without	51	309	4	9	0.136
Type of yarding					0.638
Type of site preparation					0.904
Season of harvest activities					--
growing vs. mixed	224	159	7	8	0.755

No variables were tested for the 2.5 and 5th percentiles because no significant differences within categories were associated with relative changes for adjacent percentiles.

Table VI.5. (cont.)

	10th percentile (%)				
	Mean		N		
Variable	1st	2nd	1st	2nd	p-value
Basin characteristics					
Hydrologic regime					--
rain vs. mixed	27	600	6	14	0.215

Table VI.5. (cont.)

	25th percentile (%)				
	Mean		N		
Variable	1st	2nd	1st	2nd	p-value
Basin characteristics					
Hydrologic regime					--
rain vs. mixed	35	78	6	14	0.087

Table VI.5. (cont.)

	50th percentile (%)				
	Mean		N		
Variable	1st	2nd	1st	2nd	p-value
Basin characteristics					
Ecoregion domain					- -
Vegetation type					- -
mostly and all conifer vs. mostly and all hardwood	69	19	13	8	0.141
Pre-harvest stand age					- -
>50 years vs. mixed	66	22	16	6	0.134
Hydrologic regime					- -
rain vs. mixed	19	44	6	15	0.053
Soil type					- -
coarse vs. mixed	38	75	9	10	0.389
Dominant aspect					- -
NW-NE vs. SE-SW	31	30	10	10	0.973
NE-SE vs. SW-NW	31	25	8	8	0.728
Management activities					
Type of silvicultural method					0.444
clearcut vs. both	42	69	13	9	0.577
Buffer strips					0.205
Type of yarding					0.662
Type of site preparation					0.508
Season of harvest activities					- -
growing vs. mixed	25	72	7	13	0.174

Table VI.5. (cont.)

	75th percentile (%)				
	Mean		N		
Variable	1st	2nd	1st	2nd	p-value
Basin characteristics					
Hydrologic regime					- -
rain vs. mixed	31	24	7	16	0.729

No variables were tested for the 90th percentile because no significant differences within categories were associated with relative changes for adjacent percentiles.

Table VI.5. (cont.)

	95th percentile (%)				
	Mean		N		
Variable	1st	2nd	1st	2nd	p-value
Basin characteristics					
Vegetation type					--
mostly and all conifer vs. mostly and all hardwood	20	10	14	9	0.173
Management activities					
Type of silvicultural method					--
clearcut vs. selection cut	18	19	15	4	0.895
clearcut vs. both	18	16	15	10	0.806
Buffer strips					--
with vs. mixed	12	25	6	5	0.184

Table VI.5. (cont.)

	97.5 percentile (%)				
	Mean		N		
Variable	1st	2nd	1st	2nd	p-value
Basin characteristics					
Vegetation type					--
mostly and all conifer vs. mostly and all hardwood	15	13	14	9	0.702
Management activities					
Type of silvicultural method					--
clearcut vs. selection cut	17	11	15	4	0.445
clearcut vs. both	17	12	15	10	0.340
Buffer strips					--
with vs. mixed	8.9	23.1	6	5	0.036

Table VI.5. (cont.)

Variable	99th percentile (%)				
	Mean		N		
	1st	2nd	1st	2nd	p-value
Basin characteristics					
Ecoregion domain					- -
dry vs. humid temperate	24	13	3	23	0.489
Vegetation type					- -
mostly and all conifer vs. mostly and all hardwood	9.7	22.5	14	9	0.097
Pre-harvest stand age					- -
>50 years vs. mixed	12	15	19	6	0.762
Hydrologic regime					0.584
Soil type					- -
coarse vs. mixed	21	13	9	12	0.352
Dominant aspect					- -
NW-NE vs. SE-SW	16	16	12	10	0.999
NE-SE vs. SW-NW	15.5	7.1	8	9	0.293

Table VI.5. (cont.)

Variable	99th percentile (%)				
	Mean		N		
	1st	2nd	1st	2nd	p-value
Management activities					
Type of silvicultural method					0.058
clearcut vs. patch cut	18.1	6.9	15	6	0.095
clearcut vs. selection cut	18.1	1.5	15	4	0.018
patch cut vs. selection cut	6.9	1.5	6	4	0.420
clearcut vs. both	18.2	4.8	15	10	0.016
Buffer strips					0.056
with vs. without	5.2	11.7	6	10	0.334
with vs. mixed	5.2	31.7	6	5	0.024
without vs. mixed	11.7	31.7	10	5	0.072
Type of yarding					0.676
Type of site preparation					0.631
Season of harvest activities					--
growing vs. mixed	8.7	16.8	8	15	0.340

APPENDIX VII:

DATA AND SUMMARY STATISTICS FOR THE CALCULATED CHANGES OVER TIME AFTER FOREST HARVEST

Table VII.1. Absolute change in L s^{-1} ha^{-1} by percentile for first two-year period after treatment.

Study	Basin	Percentile										
		1.0	2.5	5.0	10.0	25.0	50.0	75.0	90.0	95.0	97.5	99.0
Alsea, OR	Needle Branch	0.0040	0.0054	0.0033	0.0084	0.0360	0.0560	0.1435	0.4578	0.3997	0.5620	1.0924
	Deer Creek	0.0004	0.0039	0.0044	0.0009	0.0241	0.0392	-0.0067	0.1272	0.2331	-0.0988	-0.1150
Cadwell Creek, MA	Cadwell Creek 1				0.0192	0.0308	0.0264	0.0315	0.0400	-0.0299	-0.0443	0.5403
Caspar Creek, CA	South Fork	0.0057	0.0057	0.0049	0.0034	0.0028	0.0184	0.0311	0.1325	0.0843	0.1536	0.1567
Clayton, OK	CL1							0.0638	0.0213	0.0699	0.3419	0.4679
Coweeta	WS 6	0.0033	0.0033	-0.0156	-0.0394	-0.0134	0.0131	0.0058	0.0073	0.0040	-0.0014	-0.0015
	WS 37	0.0406	0.0347	0.0354	0.0386	0.0549	0.0262	-0.0050	0.0124	0.0344	0.2155	0.1588
Coyote Creek, OR	CC-1	0.0000	0.0004	0.0007	0.0016	0.0036	-0.0002	0.0157	0.0583	0.0558	0.2302	-0.1048
	CC-2	0.0002	0.0002	0.0004	0.0010	0.0046	0.0305	0.0435	0.1020	0.1121	0.1328	0.0470
	CC-3	0.0069	0.0070	0.0077	0.0119	0.0202	0.0719	0.1033	0.1832	0.3831	0.2788	0.4642
Dickey Brook, MA	Dickey Brook	-0.0148	-0.0130	-0.0118	-0.0156	-0.0116	0.0028	0.0164	0.0237	0.0150	-0.0912	-0.0974
Fernow, WV	WS 6B						0.0499	0.0448	0.0835	0.1019	0.0606	0.1347
	WS 7B						0.0758	0.0624	0.0735	0.0855	-0.0390	0.1984
	WS 7				0.0531	0.0639	0.0682	0.0861	0.1156	0.2275	0.2695	0.1174
Fool Creek, CO	Fool Creek								0.0851	0.4041	0.3926	0.2171
Fox Creek, OR	FC-1	-0.0152	-0.0265	-0.0323	-0.0414	-0.2174	-0.1846	-0.0812	-0.0997	0.1315	0.3393	0.0652
	FC-3	-0.0057	-0.0092	-0.0039	-0.0020	-0.0280	-0.0226	-0.0005	0.0099	0.0834	0.2172	-0.2831
H. J. Andrews, OR	HJA-1	0.0138	0.0108	0.0106	0.0188	0.0419	0.0885	0.1464	0.3531	0.5551	0.7616	0.8111
	HJA-3	0.0120	0.0146	0.0148	0.0151	0.0172	0.0397	0.0325	0.0555	0.0772	-0.0810	0.7324
	HJA-6	0.0146	0.0153	0.0149	0.0227	0.0404	0.0493	0.1779	0.3292	0.3630	0.4067	0.4020
	HJA-7	0.0002	0.0009	0.0027	0.0080	0.0221	0.0339	0.1033	0.1493	0.2590	0.3139	0.3345
	HJA-10	0.0200	0.0209	0.0269	0.0339	0.0280	0.0666	0.0951	0.2792	0.4951	-0.2427	-0.8037
Hubbard Brook, NH	HB-2			0.0584	0.0662	0.0724	0.0618	0.0298	0.0306	0.1103	0.2054	0.6033
	HB-4	0.0076	0.0137	0.0167	0.0156	-0.0101	-0.0021	0.0083	-0.0303	0.0209	0.1986	0.1277
	HB-5		0.0038	0.0121	0.0330	0.0238	0.0140	0.0013	0.0051	-0.0615	0.2080	0.1946
Mai Mai, NZ	M8					0.0144	0.0270	0.0679	0.0987	0.2354	-0.1085	0.8548
Marcell, MN	S4S							0.0219	0.0567	0.1289	0.1969	0.0757
	S4N						0.0118	0.0375	0.0568	0.0971	0.1692	0.1332
Thomas Creek, AZ	Thomas Creek South					0.0013	0.0124	-0.0072	0.0602	0.1669	0.1024	0.0648
Wagon Wheel Gap, CO	B	0.0062	0.0031	0.0016	0.0019	0.0020	0.0039	0.0129	0.0265	0.0590	0.1055	0.1175
	minimum	-0.0152	-0.0265	-0.0323	-0.0414	-0.2174	-0.1846	-0.0812	-0.0997	-0.0615	-0.2427	-0.8037
	maximum	0.0406	0.0347	0.0584	0.0662	0.0724	0.0885	0.1779	0.4578	0.5551	0.7616	1.0924
	median	0.0049	0.0039	0.0046	0.0102	0.0187	0.0270	0.0315	0.0593	0.1061	0.1977	0.1457
	mean	0.0055	0.0050	0.0076	0.0116	0.0093	0.0251	0.0442	0.0968	0.1634	0.1718	0.2235
	n	18	19	20	22	24	27	29	30	30	30	30

Table VII.2. Absolute change in L s^{-1} ha^{-1} by percentile for second two-year period after treatment.

Study	Basin	Percentile										
		1.0	2.5	5.0	10.0	25.0	50.0	75.0	90.0	95.0	97.5	99.0
Alsea, OR	Needle Branch	-0.0030	-0.0050	-0.0011	0.0037	0.0482	0.0619	0.2755	0.4335	0.6368	1.1041	1.0431
	Deer Creek	-0.0025	0.0002	0.0009	0.0031	0.0275	0.0393	0.0639	0.0593	0.1119	-0.0699	-0.0047
Cadwell Creek, MA	Cadwell Creek 1				0.0039	0.0160	0.0056	0.0033	0.0485	0.1084	0.2600	0.3493
Caspar Creek, CA	South Fork	0.0031	0.0022	0.0011	0.0011	0.0048	0.0156	0.0302	0.1549	0.1695	0.1822	-0.0458
Coweeta	WS 6	0.0162	0.0207	0.0239	0.0281	0.0453	0.0537	0.0619	0.0578	0.0451	0.0953	0.0386
	WS 37	0.0132	0.0022	0.0003	0.0075	0.0153	-0.0016	-0.0031	-0.0144	0.2133	-0.0007	0.1953
Coyote Creek, OR	CC-1	0.0003	0.0004	0.0003	0.0020	0.0029	0.0112	0.0445	0.0230	0.0630	0.0970	0.1887
	CC-2	0.0001	0.0000	0.0000	0.0002	0.0008	0.0258	0.0721	0.0721	0.1126	0.1401	0.2345
	CC-3	0.0024	0.0027	0.0030	0.0030	0.0069	0.0412	0.0795	0.1680	0.3994	0.6008	0.8755
Fool Creek, CO	Fool Creek								0.1484	0.1794	0.3381	0.3572
Fox Creek, OR	FC-1	-0.0149	-0.0186	-0.0094	-0.0164	-0.0699	-0.1232	-0.0871	0.0451	-0.0165	-0.0215	0.2178
	FC-3	-0.0016	-0.0078	-0.0091	-0.0114	-0.0729	-0.0507	0.0116	-0.1032	-0.1146	0.0268	-0.0739
H. J. Andrews, OR	HJA-1	-0.0036	-0.0010	-0.0004	0.0024	0.0281	0.0574	0.1937	0.2637	0.0653	0.2739	0.3933
	HJA-3	0.0174	0.0197	0.0189	0.0145	0.0141	0.0432	0.0809	0.1483	0.3018	0.0960	0.1446
	HJA-6	0.0099	0.0093	0.0128	0.0184	0.0209	0.0737	0.1487	0.2785	0.3524	0.2935	0.0106
	HJA-7	-0.0033	-0.0021	-0.0021	-0.0009	0.0089	0.0461	0.0493	0.1109	0.2237	0.2017	0.1581
	HJA-10	0.0025	0.0090	0.0087	0.0128	0.0180	0.0120	0.0912	0.2197	0.2024	0.1734	0.2929
Hubbard Brook, NH	HB-2			0.0541	0.0693	0.0745	0.0509	0.0624	0.0969	-0.0597	0.2498	0.8553
	HB-4	0.0119	0.0165	0.0154	0.0136	-0.0113	0.0050	-0.0133	-0.0154	0.0475	0.1797	0.6185
	HB-5		-0.0001	0.0004	0.0075	-0.0015	-0.0061	-0.0274	-0.0392	0.0199	-0.0202	0.1265
Mai Mai, NZ	M8					0.0099	0.0213	0.0619	0.2106	0.3552	0.2408	0.5132
Marcell, MN	S4S							-0.0010	0.0382	0.0993	0.1612	-0.0055
	S4N						0.0066	0.0238	0.0600	0.1225	-0.0506	-0.0076
Thomas Creek, AZ	Thomas Creek South					0.0001	0.0013	0.0049	0.0312	0.0891	0.1165	0.1346
Wagon Wheel Gap, CO	B	0.0021	0.0014	-0.0006	0.0002	0.0006	0.0018	0.0035	0.0069	0.0376	0.0690	0.1387
	minimum	-0.0149	-0.0186	-0.0094	-0.0164	-0.0729	-0.1232	-0.0871	-0.1032	-0.1146	-0.0699	-0.0739
	maximum	0.0174	0.0207	0.0541	0.0693	0.0745	0.0737	0.2755	0.4335	0.6368	1.1041	1.0431
	median	0.0021	0.0009	0.0004	0.0034	0.0094	0.0156	0.0469	0.0600	0.1119	0.1612	0.1887
	mean	0.0029	0.0028	0.0062	0.0081	0.0085	0.0170	0.0513	0.1001	0.1506	0.1895	0.2700
	n	17	18	19	20	22	23	24	25	25	25	25

Table VII.3. Absolute change in L s^{-1} ha^{-1} by percentile for third two-year period after treatment.

Study	Basin	Percentile										
		1.0	2.5	5.0	10.0	25.0	50.0	75.0	90.0	95.0	97.5	99.0
Alsea, OR	Needle Branch	-0.0025	-0.0050	-0.0040	-0.0010	0.0105	0.0360	0.2198	0.2529	0.5502	1.8725	2.2595
	Deer Creek	-0.0065	-0.0047	0.0007	0.0016	0.0147	0.0918	-0.0187	0.1102	0.2518	0.2931	0.4837
Cadwell Creek, MA	Cadwell Creek 1				0.0039	0.0096	0.0191	0.0323	-0.0362	0.0424	0.1128	0.5628
Coyote Creek, OR	CC-1	0.0007	0.0009	0.0012	0.0031	0.0032	0.0014	0.0167	0.0719	0.0529	0.2029	0.0694
	CC-2	0.0002	0.0002	0.0003	0.0011	0.0028	0.0042	0.0534	0.0869	0.0287	0.1204	0.2161
	CC-3	0.0015	0.0016	0.0018	0.0038	0.0068	0.0185	0.1293	0.1659	0.2339	0.3004	0.3444
Fool Creek, CO	Fool Creek								0.2281	0.1964	0.1170	0.0257
Fox Creek, OR	FC-1	-0.0437	-0.0530	-0.0958	-0.1200	-0.1825	-0.4570	-0.6513	-0.9609	-1.0298	-1.2187	-0.1506
	FC-3	-0.0113	-0.0160	-0.0067	-0.0106	-0.0115	-0.0459	-0.0366	0.0258	0.0635	-0.0258	-0.2356
H. J. Andrews, OR	HJA-1	-0.0002	0.0027	0.0031	0.0027	0.0075	0.0751	0.1764	0.2282	0.4583	0.9517	1.2878
	HJA-3	0.0073	0.0146	0.0165	0.0179	0.0240	0.0240	0.0435	0.0956	-0.0547	0.0165	0.2061
	HJA-6	0.0100	0.0091	0.0103	0.0135	0.0322	0.0786	0.1462	0.1754	0.2348	0.5616	0.9043
	HJA-7	0.0001	-0.0007	0.0000	0.0004	0.0082	0.0301	0.0403	0.0787	0.1127	0.2188	0.1839
	HJA-10	-0.0038	-0.0074	-0.0122	-0.0104	-0.0405	-0.0514	0.0349	0.0578	0.1421	0.2851	-0.0034
Hubbard Brook, NH	HB-2			0.0256	0.0328	0.0247	-0.0095	0.0107	0.0191	-0.0005	0.0899	0.1989
	HB-4	0.0008	0.0003	0.0003	0.0005	0.0063	0.0078	0.0000	0.0864	0.1102	-0.0658	0.0994
	HB-5		0.0024	0.0063	0.0175	0.0116	0.0196	-0.0076	0.0169	-0.0492	0.0567	-0.4033
Mai Mai, NZ	M8					-0.0196	-0.0051	0.0354	0.1350	0.2192	0.2146	0.3588
Marcell, MN	S4S							0.0003	0.0512	0.0695	0.1311	0.3537
	S4N							0.0078	0.0399	0.0451	0.0563	0.1894
Thomas Creek, AZ	Thomas Creek South					0.0022	0.0033	-0.0008	0.0222	0.0683	0.2369	0.2191
Wagon Wheel Gap, CO	B	-0.0005	-0.0007	-0.0019	-0.0016	-0.0010	0.0026	0.0046	0.0025	0.0326	0.0454	0.0655
	minimum	-0.0437	-0.0530	-0.0958	-0.1200	-0.1825	-0.4570	-0.6513	-0.9609	-1.0298	-1.2187	-0.4033
	maximum	0.0100	0.0146	0.0256	0.0328	0.0322	0.0918	0.2198	0.2529	0.5502	1.8725	2.2595
	median	-0.0001	0.0002	0.0005	0.0016	0.0068	0.0078	0.0167	0.0753	0.0689	0.1257	0.2025
	mean	-0.0034	-0.0037	-0.0034	-0.0026	-0.0048	-0.0083	0.0113	0.0433	0.0808	0.2079	0.3289
	n	14	15	16	17	19	19	21	22	22	22	22

Table VII.4. Absolute change in $L\ s^{-1}\ ha^{-1}$ by percentile for fourth two-year period after treatment.

Study	Basin	Percentile										
		1.0	2.5	5.0	10.0	25.0	50.0	75.0	90.0	95.0	97.5	99.0
Cadwell Creek, MA	Cadwell Creek 1				0.0064	0.0212	0.0066	-0.0079	-0.0248	0.0368	0.1447	0.6725
Caspar Creek, CA	South Fork	0.0023	0.0022	0.0016	0.0014	0.0009	0.0033	0.0114	0.0669	0.1694	0.0815	0.2118
Coyote Creek, OR	CC-1	0.0015	0.0025	0.0032	0.0037	0.0036	0.0108	0.0184	0.0548	0.0939	0.1225	-0.1220
	CC-2	0.0003	0.0004	0.0005	0.0009	0.0016	0.0169	0.0217	0.0556	0.0517	0.1355	0.1007
	CC-3	0.0010	0.0008	0.0010	0.0026	0.0030	0.0215	0.0930	0.1513	0.2509	0.3291	0.5136
Fool Creek, CO	Fool Creek								0.0598	0.0877	0.1384	0.1487
Fox Creek, OR	FC-1	-0.0142	-0.0177	-0.0068	-0.0194	-0.0294	-0.0451	-0.0326	-0.0003	0.0794	-0.1610	-0.1459
	FC-3	-0.0008	-0.0149	-0.0089	-0.0075	-0.0125	-0.0021	0.0138	0.1051	-0.0402	-0.1358	0.3752
H. J. Andrews, OR	HJA-1	-0.0025	-0.0003	0.0002	-0.0014	-0.0008	0.0373	0.1644	0.1688	0.4270	0.4205	0.8740
	HJA-3	0.0155	0.0170	0.0194	0.0216	0.0134	0.0248	0.0498	0.1312	0.1690	0.0902	0.5561
	HJA-6	0.0068	0.0069	0.0060	0.0066	0.0064	0.0566	0.1553	0.3229	0.5489	0.3432	1.1369
	HJA-7	-0.0252	-0.0190	-0.0185	-0.0170	-0.0059	0.0188	0.0402	0.1075	0.1864	-0.0129	0.2806
	HJA-10	-0.0229	-0.0148	-0.0166	-0.0230	-0.0436	-0.0324	-0.0581	0.1296	0.1094	-0.2195	0.1258
Hubbard Brook, NH	HB-2			0.0136	0.0376	0.0336	-0.0111	-0.0033	-0.0446	0.0774	0.3201	0.0223
	HB-4	0.0007	0.0012	0.0003	-0.0002	-0.0031	0.0006	-0.0059	0.0035	-0.0418	-0.0746	0.0583
	HB-5		0.0023	0.0033	0.0113	0.0138	0.0164	0.0181	0.0257	0.0146	0.1908	-0.2160
Marcell, MN	S4S							-0.0012	0.0001	0.0961	0.1783	0.0152
	S4N						0.0036	0.0148	0.0079	-0.0019	-0.0595	-0.1400
Thomas Creek, AZ	Thomas Creek South					0.0023	0.0066	0.0152	0.0075	0.0602	0.0348	-0.0125
	minimum	-0.0252	-0.0190	-0.0185	-0.0230	-0.0436	-0.0451	-0.0581	-0.0446	-0.0418	-0.2195	-0.2160
	maximum	0.0155	0.0170	0.0194	0.0376	0.0336	0.0566	0.1644	0.3229	0.5489	0.4205	1.1369
	median	0.0005	0.0008	0.0008	0.0014	0.0019	0.0066	0.0150	0.0556	0.0877	0.1225	0.1258
	mean	-0.0031	-0.0026	-0.0001	0.0016	0.0003	0.0078	0.0282	0.0699	0.1250	0.0982	0.2345
	n	12	13	14	15	16	17	18	19	19	19	19

Table VII.5. Absolute change in $L\ s^{-1}\ ha^{-1}$ by percentile for fifth two-year period after treatment.

Study	Basin	Percentile										
		1.0	2.5	5.0	10.0	25.0	50.0	75.0	90.0	95.0	97.5	99.0
Cadwell Creek, MA	Cadwell Creek 1				0.0038	0.0123	0.0045	-0.0189	-0.0251	-0.0306	0.0722	0.4795
Caspar Creek, CA	South Fork	0.0016	0.0018	0.0023	0.0018	0.0032	0.0084	0.0215	0.1025	0.0484	0.2852	0.0237
Fool Creek, CO	Fool Creek							-0.3210	-0.2730	-0.2968	-0.1963	0.1272
Fox Creek, OR	FC-1	-0.0038	-0.0169	-0.0133	-0.0175	-0.0151	-0.1300	0.0069	-0.0175	-0.0362	0.2313	0.1377
	FC-3	-0.0019	-0.0068	-0.0020	-0.0114	-0.0112	0.0093	0.0345	0.0805	0.1135	0.0721	0.0898
H. J. Andrews, OR	HJA-1	-0.0046	-0.0031	-0.0028	-0.0028	-0.0019	0.0281	0.0838	0.1035	0.4177	0.5851	0.8576
	HJA-3	0.0232	0.0263	0.0259	0.0275	0.0202	0.0229	0.0281	0.0781	0.0685	0.0979	0.1471
	HJA-6	0.0044	0.0050	0.0065	0.0112	0.0128	0.0952	0.1457	0.2637	0.1524	0.3482	0.5182
	HJA-10	-0.0419	-0.0248	-0.0284	-0.0420	-0.0556	-0.0471	-0.0196	0.1459	0.1878	-0.1188	0.2180
Hubbard Brook, NH	HB-2			0.0098	0.0228	0.0233	-0.0143	-0.0316	-0.0313	0.0770	0.1105	0.4892
	HB-4	-0.0002	0.0008	0.0003	-0.0101	-0.0315	-0.0128	-0.0084	-0.0292	-0.0320	-0.1244	0.1631
	HB-5		0.0014	0.0013	0.0064	0.0087	-0.0028	0.0056	-0.0011	0.0291	0.0686	0.3699
Marcell, MN	S4S							-0.0008	0.0042	0.0477	0.0149	-0.0903
	S4N						0.0032	0.0045	-0.0267	-0.0126	-0.0464	-0.1536
	minimum	-0.0419	-0.0248	-0.0284	-0.0420	-0.0556	-0.1300	-0.3210	-0.2730	-0.2968	-0.1963	-0.1536
	maximum	0.0232	0.0263	0.0259	0.0275	0.0233	0.0952	0.1457	0.2637	0.4177	0.5851	0.8576
	median	-0.0010	0.0008	0.0008	0.0018	0.0032	0.0038	0.0050	0.0015	0.0481	0.0721	0.1551
	mean	-0.0029	-0.0018	0.0000	-0.0009	-0.0032	-0.0030	-0.0050	0.0267	0.0524	0.1000	0.2412
	n	8	9	10	11	11	12	14	14	14	14	14

Table VII.6. Percent change by percentile for first two-year period after treatment.

Study	Basin	Percentile										
		1.0	2.5	5.0	10.0	25.0	50.0	75.0	90.0	95.0	97.5	99.0
Alsea, OR	Needle Branch	78.6	81.8	37.5	54.3	82.1	23.3	22.6	34.1	18.9	17.2	26.6
	Deer Creek	1.9	21.2	22.2	2.9	34.9	15.7	-1.0	10.0	11.9	-3.0	-2.9
Cadwell Creek, MA	Cadwell Creek 1				569.7	142.5	27.2	14.9	8.6	-4.0	-4.2	35.0
Caspar Creek, CA	South Fork	108.9	79.9	54.7	27.0	13.6	30.0	10.2	22.1	6.2	6.4	3.4
Clayton, OK	CL1							363.4	8.4	13.0	31.2	23.1
Coweeta	WS 6	3.1	2.9	-10.8	-20.8	-7.1	5.5	1.4	1.3	0.6	-0.2	-0.1
	WS 37	77.7	56.4	50.8	50.6	48.9	8.9	-0.8	1.2	2.2	9.5	5.1
Coyote Creek, OR	CC-1	-1.9	17.3	22.6	37.0	32.6	-0.3	7.3	14.3	8.0	17.5	-4.2
	CC-2	121.1	72.3	99.6	141.5	181.0	93.7	25.4	30.4	17.4	11.1	2.0
	CC-3	132.3	123.3	115.7	149.4	142.8	116.9	55.1	50.4	59.6	22.6	19.8
Dickey Brook, MA	Dickey Brook	-63.4	-49.8	-39.1	-35.4	-15.2	2.6	9.3	7.7	3.2	-11.2	-8.1
Fernow, WV	WS 6B						585.6	46.9	30.3	19.7	6.1	8.2
	WS 7B						387.9	35.8	14.9	11.1	-2.9	11.4
	WS 7				1388.2	334.5	77.6	34.0	22.7	30.1	27.3	6.6
Fool Creek, CO	Fool Creek								27.9	69.9	49.0	17.4
Fox Creek, OR	FC-1	-37.6	-48.9	-47.0	-36.3	-46.4	-19.5	-5.6	-4.5	4.9	9.7	1.4
	FC-3	-27.8	-32.5	-13.6	-4.7	-19.8	-5.0	-0.1	0.6	3.2	6.1	-5.7
H. J. Andrews, OR	HJA-1	808.6	158.1	114.8	171.4	178.5	93.3	52.5	52.2	48.8	42.1	30.2
	HJA-3	84.0	118.7	109.4	91.7	55.8	29.1	6.5	5.5	5.0	-3.7	18.1
	HJA-6	204.6	176.4	130.1	187.0	198.5	67.4	39.9	40.0	28.9	22.2	14.4
	HJA-7	1.4	5.2	14.0	44.4	136.6	67.2	33.4	25.9	30.6	24.9	16.7
	HJA-10	2063.8	1352.2	795.9	437.4	78.3	87.1	28.1	33.7	35.4	-8.2	-18.7
Hubbard Brook, NH	HB-2			33048.2	6502.3	177.6	47.8	9.5	4.4	10.0	11.4	21.6
	HB-4	199.2	206.8	119.7	41.1	-8.5	-0.9	1.9	-3.4	1.7	11.8	5.2
	HB-5		21833.3	2656.4	1192.9	59.1	13.3	0.5	0.9	-6.6	14.9	10.1
Mai Mai, NZ	M8					39.3	19.7	14.9	7.7	11.5	-3.3	18.6
Marcell, MN	S4S							62.9	46.8	60.5	57.9	8.9
	S4N						103.0	78.9	39.1	41.8	48.8	18.8
Thomas Creek, AZ	Thomas Creek South					401.9	403.6	-9.8	27.3	48.5	15.9	6.7
Wagon Wheel Gap, CO	B	26.1	11.4	5.5	6.4	6.3	12.2	28.5	22.0	28.6	44.4	37.4
	minimum	-63.4	-49.8	-47.0	-36.3	-46.4	-19.5	-9.8	-4.5	-6.6	-11.2	-18.7
	maximum	2063.8	21833.3	33048.2	6502.3	401.9	585.6	363.4	52.2	69.9	57.9	37.4
	median	78.2	72.3	52.8	52.4	57.4	29.1	14.9	18.5	12.4	11.6	9.5
	mean	210.0	1273.0	1864.3	499.9	93.7	84.9	33.3	19.4	20.7	15.7	10.9
	n	18	19	20	22	24	27	29	30	30	30	30

Table VII.7. Percent change by percentile for second two-year period after treatment.

Study	Basin	Percentile										
		1.0	2.5	5.0	10.0	25.0	50.0	75.0	90.0	95.0	97.5	99.0
Alsea, OR	Needle Branch	-42.9	-55.6	-8.3	22.7	101.1	27.9	45.6	26.9	26.5	29.9	21.6
	Deer Creek	-9.7	0.8	3.1	9.1	36.5	17.0	10.2	3.9	5.0	-1.9	-0.1
Cadwell Creek, MA	Cadwell Creek 1				80.9	58.2	4.9	1.2	10.7	17.2	32.7	32.0
Caspar Creek, CA	South Fork	45.1	26.0	9.9	8.9	23.2	44.4	33.3	45.6	18.0	10.8	-1.4
Coweeta	WS 6	19.1	24.6	27.7	31.6	47.4	34.7	22.2	11.3	6.5	11.9	3.7
	WS 37	20.1	2.6	0.3	5.5	7.9	-0.5	-0.6	-1.5	14.1	0.0	6.5
Coyote Creek, OR	CC-1	12.8	18.1	10.8	57.4	36.4	17.1	10.5	2.9	6.0	6.8	9.6
	CC-2	66.7	13.9	5.2	42.4	46.3	77.9	21.6	11.1	11.7	10.7	13.1
	CC-3	51.1	55.6	54.7	45.8	67.4	65.8	21.8	24.0	41.7	44.7	48.2
Fool Creek, CO	Fool Creek								71.0	40.3	57.3	52.3
Fox Creek, OR	FC-1	-34.3	-35.3	-17.3	-20.8	-30.5	-19.4	-7.1	2.2	-0.6	-0.7	5.0
	FC-3	-9.6	-31.9	-32.2	-25.6	-39.9	-8.6	0.9	-4.8	-4.0	0.8	-1.6
H. J. Andrews, OR	HJA-1	-34.5	-11.1	-3.6	14.0	81.0	38.6	48.1	24.4	3.8	11.3	10.1
	HJA-3	621.1	846.5	481.9	106.0	56.6	41.4	21.6	23.1	27.4	5.1	5.9
	HJA-6	140.2	109.4	108.9	102.3	51.6	49.7	30.6	28.2	22.7	11.8	0.3
	HJA-7	-18.5	-12.0	-10.7	-3.3	27.5	45.1	14.6	16.0	21.4	11.8	5.9
	HJA-10	17.7	92.0	74.3	93.4	65.7	7.9	20.3	20.3	10.9	6.0	7.1
Hubbard Brook, NH	HB-2			24644.4	5547.2	358.8	53.9	28.6	15.3	-4.6	12.1	29.9
	HB-4	387.0	256.1	102.6	42.8	-11.4	3.1	-3.8	-2.1	3.7	10.5	25.6
	HB-5		-5.3	21.7	216.3	-3.0	-5.9	-12.3	-8.8	2.5	-1.7	7.5
Mai Mai, NZ	M8					17.2	13.8	16.0	16.9	16.5	7.3	11.8
Marcell, MN	S4S							-3.7	28.0	28.4	20.3	-0.4
	S4N						546.5	68.2	36.7	32.1	-6.2	-0.6
Thomas Creek, AZ	Thomas Creek South					668.5	866.5	539.8	142.8	238.2	181.1	145.9
Wagon Wheel Gap, CO	B	7.9	4.9	-1.8	0.7	1.8	5.7	8.5	6.3	19.6	28.5	46.3
	minimum	-42.9	-55.6	-32.2	-25.6	-39.9	-19.4	-12.3	-8.8	-4.6	-6.2	-1.6
	maximum	621.1	846.5	24644.4	5547.2	668.5	866.5	539.8	142.8	238.2	181.1	145.9
	median	17.7	9.4	9.9	37.0	41.4	27.9	18.2	16.0	16.5	10.8	7.5
	mean	72.9	72.2	1340.6	318.9	75.8	83.8	39.0	22.0	24.2	20.0	19.4
	n	17	18	19	20	22	23	24	25	25	25	25

Table VII.8. Percent change by percentile for third two-year period after treatment.

Study	Basin	Percentile										
		1.0	2.5	5.0	10.0	25.0	50.0	75.0	90.0	95.0	97.5	99.0
Alsea, OR	Needle Branch	-38.5	-55.6	-33.3	-6.1	22.1	12.5	24.4	11.8	17.7	50.3	42.4
	Deer Creek	-26.9	-18.5	2.6	4.3	19.7	30.6	-2.0	5.4	8.8	7.9	9.3
Cadwell Creek, MA	Cadwell Creek 1				80.9	41.1	14.4	11.5	-5.9	4.4	9.4	36.5
Coyote Creek, OR	CC-1	36.3	41.4	42.0	86.5	40.0	5.3	15.2	23.4	9.2	22.7	4.8
	CC-2	138.3	76.0	75.5	184.3	151.0	30.4	61.0	34.2	5.4	14.8	16.4
	CC-3	33.2	34.7	30.6	57.0	66.8	70.6	135.3	60.4	44.3	35.9	25.8
Fool Creek, CO	Fool Creek								98.7	47.5	17.2	3.0
Fox Creek, OR	FC-1	-65.4	-68.3	-61.5	-58.2	-52.3	-43.4	-36.5	-34.1	-28.6	-26.8	-3.1
	FC-3	-43.6	-43.4	-17.1	-17.8	-8.5	-10.4	-3.9	1.7	3.3	-1.0	-6.2
H. J. Andrews, OR	HJA-1	-3.1	40.5	40.8	26.0	29.9	46.1	36.8	17.1	21.9	28.1	24.8
	HJA-3	21.4	48.0	47.4	44.7	31.0	12.8	9.8	11.0	-3.9	0.9	7.8
	HJA-6	211.9	135.8	120.4	114.9	64.7	50.3	36.6	25.2	20.0	28.5	25.5
	HJA-7	0.6	-5.4	0.1	2.4	20.7	27.9	14.6	16.1	14.2	16.1	7.2
	HJA-10	-48.2	-57.6	-56.4	-35.8	-47.0	-22.8	8.0	6.6	10.4	14.2	-0.1
Hubbard Brook, NH	HB-2			7329.3	1390.2	52.5	-7.3	4.6	2.8	0.0	4.7	8.6
	HB-4	87.1	18.1	8.9	7.2	17.0	6.9	0.0	13.7	9.9	-3.7	3.0
	HB-5		82.2	201.1	379.5	25.9	15.0	-2.1	2.5	-4.1	2.8	-13.0
Mai Mai, NZ	M8					-35.9	-4.0	10.0	13.7	11.0	7.1	7.2
Marcell, MN	S4S							12.4	73.8	45.4	52.0	96.0
	S4N							277.9	48.0	27.0	21.9	61.6
Thomas Creek, AZ	Thomas Creek South					307.2	61.2	-2.3	23.4	29.7	59.6	40.5
Wagon Wheel Gap, CO	B	-2.3	-3.3	-7.8	-6.1	-3.5	9.4	14.7	4.1	42.5	48.2	57.5
	minimum	-65.4	-68.3	-61.5	-58.2	-52.3	-43.4	-36.5	-34.1	-28.6	-26.8	-13.0
	maximum	211.9	135.8	7329.3	1390.2	307.2	70.6	277.9	98.7	47.5	59.6	96.0
	median	-0.8	18.1	19.7	26.0	25.9	12.8	11.5	13.7	10.7	15.5	8.9
	mean	21.5	15.0	482.7	132.6	39.1	16.1	29.8	20.6	15.3	18.7	20.7
	n	14	15	16	17	19	19	21	22	22	22	22

Table VII.9. Percent change by percentile for fourth two-year period after treatment.

Study	Basin	Percentile										
		1.0	2.5	5.0	10.0	25.0	50.0	75.0	90.0	95.0	97.5	99.0
Cadwell Creek, MA	Cadwell Creek 1				112.5	53.8	4.3	-2.6	-4.4	4.3	11.5	47.7
Caspar Creek, CA	South Fork	73.2	56.5	31.7	21.0	8.8	11.9	11.1	17.8	21.5	6.2	9.5
Coyote Creek, OR	CC-1	59.9	90.3	92.9	93.1	38.8	22.0	11.6	13.3	15.4	14.6	-8.4
	CC-2	142.1	108.7	110.7	142.0	73.4	67.6	17.3	16.4	9.2	17.8	7.6
	CC-3	17.8	12.4	14.5	35.2	25.4	45.6	67.6	41.1	44.8	42.0	38.3
Fool Creek, CO	Fool Creek								41.1	37.6	43.5	37.3
Fox Creek, OR	FC-1	-28.7	-28.7	-10.4	-18.0	-13.0	-10.0	-3.9	0.0	4.3	-6.1	-3.9
	FC-3	-2.6	-32.4	-18.1	-10.9	-8.0	-0.6	1.9	7.7	-1.8	-4.1	8.6
H. J. Andrews, OR	HJA-1	-38.0	-5.5	3.0	-14.6	-3.7	38.0	43.7	12.2	21.7	16.9	29.0
	HJA-3	103.7	119.9	120.0	105.0	22.8	14.4	10.3	13.7	11.0	3.6	17.5
	HJA-6	42.1	38.9	26.9	24.3	10.4	26.1	27.1	24.4	27.1	9.1	21.2
	HJA-7	-62.7	-52.9	-48.5	-42.2	-12.1	12.5	10.2	11.6	13.7	-0.5	7.3
	HJA-10	-70.1	-50.7	-47.0	-46.2	-43.6	-13.5	-8.1	8.4	4.0	-5.5	2.5
Hubbard Brook, NH	HB-2			2684.7	1077.1	54.3	-5.1	-0.7	-4.9	6.0	17.6	0.8
	HB-4	41.0	43.7	6.5	-2.0	-15.2	1.0	-2.4	0.6	-4.6	-4.6	2.2
	HB-5		626.3	177.8	238.5	22.5	10.8	5.7	4.3	1.4	14.7	-8.7
Marcell, MN	S4S							-2.0	0.1	26.6	29.1	1.2
	S4N						23.2	17.4	3.1	-0.5	-9.5	-13.0
Thomas Creek, AZ	Thomas Creek South					392.6	201.1	59.3	5.1	22.3	7.7	-2.0
	minimum	-70.1	-52.9	-48.5	-46.2	-43.6	-13.5	-8.1	-4.9	-4.6	-9.5	-13.0
	maximum	142.1	626.3	2684.7	1077.1	392.6	201.1	67.6	41.1	44.8	43.5	47.7
	median	29.4	38.9	20.7	24.3	16.5	12.5	10.2	8.4	11.0	9.1	7.3
	mean	23.1	71.3	224.6	114.3	38.0	26.4	14.6	11.1	13.9	10.7	10.2
	n	12	13	14	15	16	17	18	19	19	19	19

Table VII.10. Percent change by percentile for fifth two-year period after treatment.

Study	Basin	Percentile										
		1.0	2.5	5.0	10.0	25.0	50.0	75.0	90.0	95.0	97.5	99.0
	S4N						69.3	11.3	-19.2	-6.7	-16.1	-30.7
Marcell, MN	S4S							-2.6	3.6	27.6	5.3	-15.1
Caspar Creek, CA	South Fork	61.5	64.0	61.1	33.5	39.6	34.6	17.2	20.7	4.7	18.8	0.8
	FC-3	-10.5	-26.1	-8.0	-28.4	-10.5	2.2	4.0	5.7	5.5	2.7	2.2
	HJA-3	187.5	248.2	216.8	182.6	43.5	15.2	7.3	8.8	3.8	3.3	3.6
Fox Creek, OR	FC-1	-10.7	-31.0	-24.0	-23.5	-9.5	-22.3	0.7	-1.1	-1.7	8.5	3.9
	HB-4	-9.1	24.5	3.6	-31.6	-32.8	-9.7	-2.7	-4.5	-2.6	-5.9	5.2
	HJA-10	-70.8	-55.1	-54.8	-58.9	-50.7	-15.1	-2.9	11.2	9.4	-4.1	6.1
	HB-5		134.5	46.2	156.2	17.8	-2.3	2.1	-0.2	3.1	4.6	13.9
Fool Creek, CO	Fool Creek							-78.8	-50.8	-42.3	-23.8	14.5
Hubbard Brook, NH	HB-2			1802.6	781.0	45.6	-8.9	-9.1	-4.1	5.8	6.0	18.5
	HJA-6	44.4	41.6	45.6	75.8	27.1	33.4	23.2	23.9	9.3	17.4	21.6
H. J. Andrews, OR	HJA-1	-50.2	-34.7	-29.0	-24.3	-9.1	20.9	17.5	7.7	21.5	23.1	28.3
Cadwell Creek, MA	Cadwell Creek 1				119.4	47.4	4.5	-7.7	-4.6	-3.3	6.3	33.5
	minimum	-70.8	-55.1	-54.8	-58.9	-50.7	-22.3	-78.8	-50.8	-42.3	-23.8	-30.7
	maximum	187.5	248.2	1802.6	781.0	47.4	69.3	23.2	23.9	27.6	23.1	33.5
	median	-9.8	24.5	24.6	33.5	17.8	3.3	1.4	1.7	4.2	4.9	5.6
	mean	17.8	40.7	206.0	107.4	9.8	10.1	-1.5	-0.2	2.4	3.3	7.6
	n	8	9	10	11	11	12	14	14	14	14	14

APPENDIX VIII:

DATA AND SUMMARY STATISTICS FOR THE CALCULATED CHANGES OVER TIME AFTER AFFORESTATION

Table VIII.1. Absolute change in L s^{-1} ha^{-1} by percentile for first three-year period after afforestation.

Study	Basin	Percent change by percentile										
		1.0	2.5	5.0	10.0	25.0	50.0	75.0	90.0	95.0	97.5	99.0
Moutere Hills, NZ	C8							0.0540	0.1851	0.3608	0.6037	1.1606
	C13						0.0038	0.0212	0.0707	0.1601	0.4807	0.9521
	C14						0.0014	0.0083	0.0172	0.0304	0.0308	0.2504
Shackham Brook, NY	Shackham Brook	-0.0044	-0.0050	-0.0037	-0.0053	-0.0092	-0.0122	-0.0063	-0.0242	-0.0462	-0.1529	-0.3197
	minimum	-0.0044	-0.0050	-0.0037	-0.0053	-0.0092	-0.0122	-0.0063	-0.0242	-0.0462	-0.1529	-0.3197
	maximum	-0.0044	-0.0050	-0.0037	-0.0053	-0.0092	0.0038	0.0540	0.1851	0.3608	0.6037	1.1606
	median	-0.0044	-0.0050	-0.0037	-0.0053	-0.0092	0.0014	0.0147	0.0439	0.0953	0.2558	0.6013
	mean	-0.0044	-0.0050	-0.0037	-0.0053	-0.0092	-0.0023	0.0193	0.0622	0.1263	0.2406	0.5108
	n	1	1	1	1	1	3	4	4	4	4	4

Table VIII.2. Absolute change in L s^{-1} ha^{-1} by percentile for second three-year period after afforestation.

Study	Basin	Percent change by percentile										
		1.0	2.5	5.0	10.0	25.0	50.0	75.0	90.0	95.0	97.5	99.0
Moutere Hills, NZ	C8							-0.0060	0.0756	0.0812	0.1491	0.8475
	C13						0.0008	0.0020	0.0014	-0.0094	0.0023	0.0191
	C14					-0.0037	-0.0202	-0.0276	-0.0739	-0.1134	-0.2198	0.2857
Shackham Brook, NY	Shackham Brook	-0.0113	-0.0147	-0.0124	-0.0198	-0.0096	-0.0299	-0.0307	-0.0781	-0.0746	-0.1592	-0.0391
	minimum	-0.0113	-0.0147	-0.0124	-0.0198	-0.0096	-0.0299	-0.0307	-0.0781	-0.1134	-0.2198	-0.0391
	maximum	-0.0113	-0.0147	-0.0124	-0.0198	-0.0037	0.0008	0.0020	0.0756	0.0812	0.1491	0.8475
	median	-0.0113	-0.0147	-0.0124	-0.0198	-0.0067	-0.0202	-0.0168	-0.0362	-0.0420	-0.0785	0.1524
	mean	-0.0113	-0.0147	-0.0124	-0.0198	-0.0067	-0.0164	-0.0156	-0.0188	-0.0290	-0.0569	0.2783
	n	1	1	1	1	2	3	4	4	4	4	4

Table VIII.3. Absolute change in L s^{-1} ha^{-1} by percentile for third three-year period after afforestation.

Study	Basin	Percent change by percentile										
		1.0	2.5	5.0	10.0	25.0	50.0	75.0	90.0	95.0	97.5	99.0
Moutere Hills, NZ	C8							-0.0223	-0.0514	-0.0636	-0.1484	-0.2228
	C13						0.0001	-0.0010	-0.0089	-0.0288	-0.0704	-0.2296
	C14						-0.0047	-0.0193	-0.0626	-0.1117	-0.2514	-0.4142
Shackham Brook, NY	Shackham Brook	-0.0049	-0.0078	-0.0070	-0.0092	-0.0233	-0.0373	-0.0012	-0.0323	-0.0574	-0.1528	-0.1756
	minimum	-0.0049	-0.0078	-0.0070	-0.0092	-0.0233	-0.0373	-0.0223	-0.0626	-0.1117	-0.2514	-0.4142
	maximum	-0.0049	-0.0078	-0.0070	-0.0092	-0.0233	0.0001	-0.0010	-0.0089	-0.0288	-0.0704	-0.1756
	median	-0.0049	-0.0078	-0.0070	-0.0092	-0.0233	-0.0047	-0.0102	-0.0419	-0.0605	-0.1506	-0.2262
	mean	-0.0049	-0.0078	-0.0070	-0.0092	-0.0233	-0.0140	-0.0109	-0.0388	-0.0654	-0.1558	-0.2606
	n	1	1	1	1	1	3	4	4	4	4	4

Table VIII.4. Absolute change in $L\ s^{-1}\ ha^{-1}$ by percentile for fourth three-year period after afforestation.

Study	Basin	Percent change by percentile										
		1.0	2.5	5.0	10.0	25.0	50.0	75.0	90.0	95.0	97.5	99.0
Moutere Hills, NZ	C8							-0.0268	-0.0626	-0.1023	-0.1547	-0.0821
	C13						0.0015	0.0054	0.0064	-0.0046	-0.0159	0.1128
	C14						-0.0127	-0.0236	-0.0795	-0.1612	-0.3100	-0.4710
Shackham Brook, NY	Shackham Brook	0.0003	-0.0022	-0.0016	-0.0024	-0.0038	-0.0157	-0.0238	-0.0350	-0.1105	-0.1824	-0.0597
	minimum	0.0003	-0.0022	-0.0016	-0.0024	-0.0038	-0.0157	-0.0268	-0.0795	-0.1612	-0.3100	-0.4710
	maximum	0.0003	-0.0022	-0.0016	-0.0024	-0.0038	0.0015	0.0054	0.0064	-0.0046	-0.0159	0.1128
	median	0.0003	-0.0022	-0.0016	-0.0024	-0.0038	-0.0127	-0.0237	-0.0488	-0.1064	-0.1686	-0.0709
	mean	0.0003	-0.0022	-0.0016	-0.0024	-0.0038	-0.0090	-0.0172	-0.0427	-0.0946	-0.1657	-0.1250
	n	1	1	1	1	1	3	4	4	4	4	4

Table VIII.5. Absolute change in $L\ s^{-1}\ ha^{-1}$ by percentile for fifth three-year period after afforestation.

Study	Basin	Percent change by percentile										
		1.0	2.5	5.0	10.0	25.0	50.0	75.0	90.0	95.0	97.5	99.0
Moutere Hills, NZ	C8							-0.0476	-0.0901	-0.1073	-0.1381	0.0272
	C13											
	C14			0.0000	-0.0019	-0.0111	-0.0262	-0.0380	-0.1156	-0.2110	-0.3585	-0.4848
Shackham Brook, NY	Shackham Brook	0.0003	-0.0008	-0.0010	-0.0021	-0.0074	-0.0325	-0.0414	-0.0350	-0.1505	-0.4554	-0.8143
	minimum	0.0003	-0.0008	-0.0010	-0.0021	-0.0111	-0.0325	-0.0476	-0.1156	-0.2110	-0.4554	-0.8143
	maximum	0.0003	-0.0008	0.0000	-0.0019	-0.0074	-0.0262	-0.0380	-0.0350	-0.1073	-0.1381	0.0272
	median	0.0003	-0.0008	-0.0005	-0.0020	-0.0092	-0.0294	-0.0414	-0.0901	-0.1505	-0.3585	-0.4848
	mean	0.0003	-0.0008	-0.0005	-0.0020	-0.0092	-0.0294	-0.0423	-0.0802	-0.1563	-0.3173	-0.4240
	n	1	1	2	2	2	2	3	3	3	3	3

Note: Extra percentiles for C14 during 5th interval are due to extra flow on the control basin.

Table VIII.6. Percent change by percentile for first three-year period after afforestation.

Study	Basin	Percent change by percentile										
		1.0	2.5	5.0	10.0	25.0	50.0	75.0	90.0	95.0	97.5	99.0
Moutere Hills, NZ	C8							370.4	303.0	227.4	144.9	179.1
	C13						1470.0	366.9	180.6	122.7	176.0	172.5
	C14						132.7	69.4	31.7	19.9	7.0	35.5
Shackham Brook, NY	Shackham Brook	-55.6	-52.1	-38.2	-39.8	-22.3	-10.7	-2.4	-4.1	-5.4	-11.3	-15.9
	minimum	-55.6	-52.1	-38.2	-39.8	-22.3	-10.7	-2.4	-4.1	-5.4	-11.3	-15.9
	maximum	-55.6	-52.1	-38.2	-39.8	-22.3	1470.0	370.4	303.0	227.4	176.0	179.1
	median	-55.6	-52.1	-38.2	-39.8	-22.3	132.7	218.1	106.2	71.3	75.9	104.0
	mean	-55.6	-52.1	-38.2	-39.8	-22.3	530.7	201.1	127.8	91.2	79.1	92.8
	n	1	1	1	1	1	3	4	4	4	4	4

Table VIII.7. Percent change by percentile for second three-year period after afforestation.

Study	Basin	Percent change by percentile										
		1.0	2.5	5.0	10.0	25.0	50.0	75.0	90.0	95.0	97.5	99.0
Moutere Hills, NZ	C8							-12.0	53.6	27.7	27.4	108.6
	C13						43.8	27.8	4.0	-9.5	1.2	4.8
	C14					-69.9	-74.8	-56.8	-46.8	-36.1	-37.9	33.3
Shackham Brook, NY	Shackham Brook	-68.2	-67.3	-58.7	-60.8	-13.2	-19.1	-9.8	-12.9	-8.2	-11.7	-1.8
	minimum	-68.2	-67.3	-58.7	-60.8	-69.9	-74.8	-56.8	-46.8	-36.1	-37.9	-1.8
	maximum	-68.2	-67.3	-58.7	-60.8	-13.2	43.8	27.8	53.6	27.7	27.4	108.6
	median	-68.2	-67.3	-58.7	-60.8	-41.6	-19.1	-10.9	-4.5	-8.8	-5.2	19.1
	mean	-68.2	-67.3	-58.7	-60.8	-41.6	-16.7	-12.7	-0.5	-6.5	-5.2	36.2
	n	1	1	1	1	2	3	4	4	4	4	4

Table VIII.8. Percent change by percentile for third three-year period after afforestation.

Study	Basin	Percent change by percentile										
		1.0	2.5	5.0	10.0	25.0	50.0	75.0	90.0	95.0	97.5	99.0
Moutere Hills, NZ	C8							-90.6	-67.8	-49.6	-52.6	-44.8
	C13						12.4	-13.9	-29.5	-41.0	-46.8	-52.2
	C14						-97.0	-90.3	-86.4	-82.9	-83.3	-75.8
Shackham Brook, NY	Shackham Brook	-58.2	-65.1	-58.9	-59.4	-54.3	-29.4	-0.5	-7.1	-8.7	-15.4	-10.4
	minimum	-58.2	-65.1	-58.9	-59.4	-54.3	-97.0	-90.6	-86.4	-82.9	-83.3	-75.8
	maximum	-58.2	-65.1	-58.9	-59.4	-54.3	12.4	-0.5	-7.1	-8.7	-15.4	-10.4
	median	-58.2	-65.1	-58.9	-59.4	-54.3	-29.4	-52.1	-48.6	-45.3	-49.7	-48.5
	mean	-58.2	-65.1	-58.9	-59.4	-54.3	-38.0	-48.8	-47.7	-45.5	-49.5	-45.8
	n	1	1	1	1	1	3	4	4	4	4	4

Table VIII.9. Percent change by percentile for fourth three-year period after afforestation.

Study	Basin	Percent change by percentile										
		1.0	2.5	5.0	10.0	25.0	50.0	75.0	90.0	95.0	97.5	99.0
Moutere Hills, NZ	C8							-95.8	-72.1	-60.0	-47.3	-15.2
	C13						115.8	99.1	23.3	-5.7	-9.0	27.2
	C14						-100.0	-100.0	-98.0	-93.8	-90.6	-79.5
Shackham Brook, NY	Shackham Brook	14.3	-44.0	-30.2	-31.6	-19.1	-13.8	-9.1	-7.1	-14.2	-16.4	-4.3
	minimum	14.3	-44.0	-30.2	-31.6	-19.1	-100.0	-100.0	-98.0	-93.8	-90.6	-79.5
	maximum	14.3	-44.0	-30.2	-31.6	-19.1	115.8	99.1	23.3	-5.7	-9.0	27.2
	median	14.3	-44.0	-30.2	-31.6	-19.1	-13.8	-52.5	-39.6	-37.1	-31.8	-9.7
	mean	14.3	-44.0	-30.2	-31.6	-19.1	0.7	-26.5	-38.5	-43.4	-40.8	-18.0
	n	1	1	1	1	1	3	4	4	4	4	4

Table VIII.10. Percent change by percentile for fifth three-year period after afforestation.

Study	Basin	Percent change by percentile										
		1.0	2.5	5.0	10.0	25.0	50.0	75.0	90.0	95.0	97.5	99.0
Moutere Hills, NZ	C8							-89.5	-58.0	-40.5	-29.2	3.6
	C13											
	C14			-100.0	-100.0	-100.0	-98.8	-85.7	-82.3	-77.0	-72.5	-57.4
Shackham Brook, NY	Shackham Brook	15.1	-24.6	-26.4	-35.4	-44.8	-32.8	-18.2	-7.1	-19.3	-33.3	-35.1
	minimum	15.1	-24.6	-100.0	-100.0	-100.0	-98.8	-89.5	-82.3	-77.0	-72.5	-57.4
	maximum	15.1	-24.6	-26.4	-35.4	-44.8	-32.8	-18.2	-7.1	-19.3	-29.2	3.6
	median	15.1	-24.6	-63.2	-67.7	-72.4	-65.8	-85.7	-58.0	-40.5	-33.3	-35.1
	mean	15.1	-24.6	-63.2	-67.7	-72.4	-65.8	-64.5	-49.2	-45.6	-45.0	-29.6
	n	1	1	2	2	2	2	3	3	3	3	3

Note: Extra percentiles for C14 during 5th interval are due to extra flow on the control basin.