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Streamflow Responses to Road Building and Harvesting: a Comparison With the Equivalent Clearcut Area Procedure

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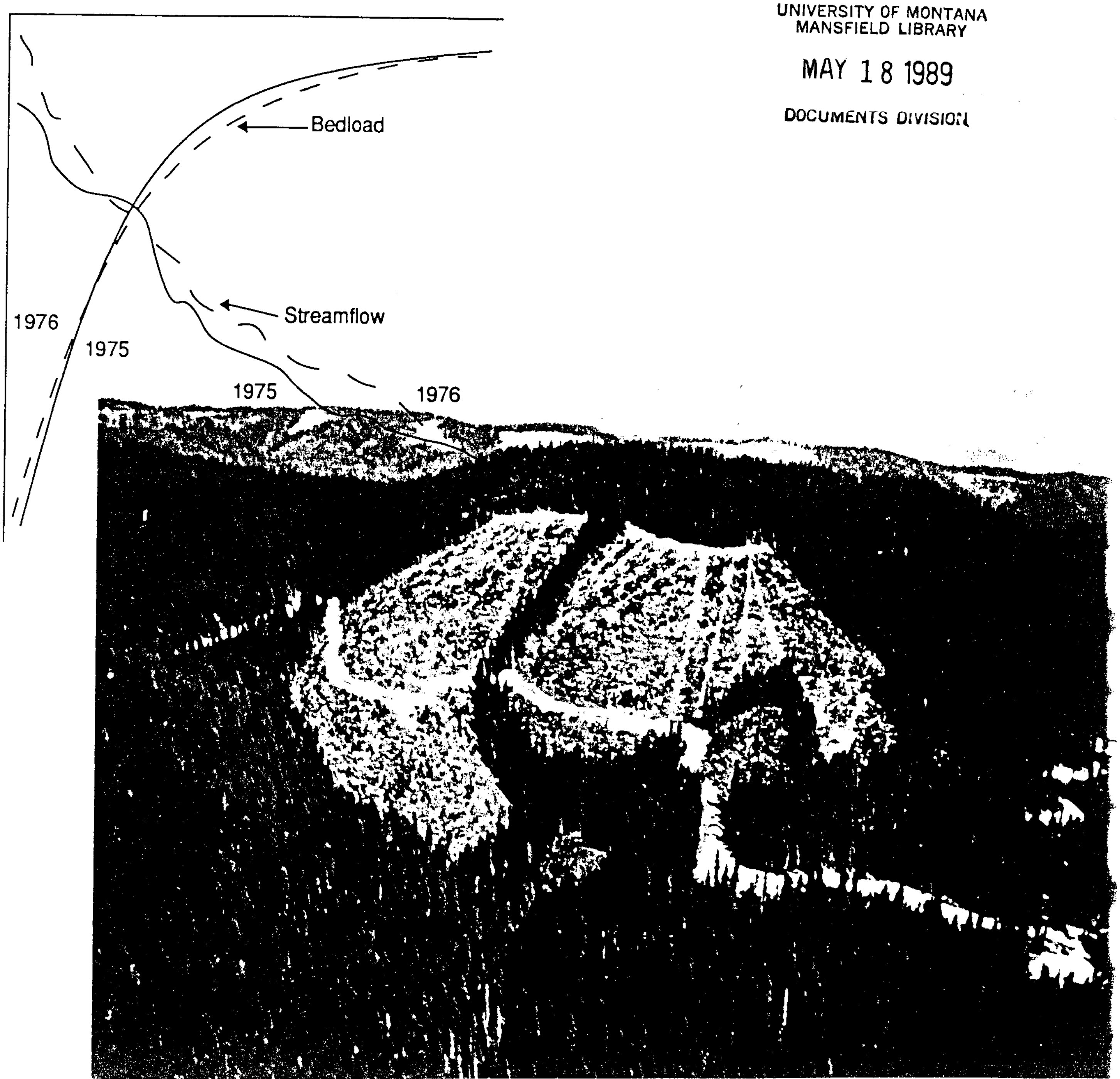

THE AUTHOR

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RESEARCH SUMMARY

Streamflow responses to timber removal by road building and patch clearcutting in four small, south-aspect watersheds in northern Idaho are compared to predicted responses using the equivalent clearcut area (ECA) procedure. The ECA procedure overestimated average annual water yield prior to timber removal by about 4.5 inches (10 percent). Increases in average annual water yield on the areas in equivalent clearcut condition were substantially higher than predicted. The relationship between elevation and annual water yield increase used in the ECA procedure estimated about a 37 percent increase in onsite annual water yield compared to observed increases ranging from 51.2 to 80.1 percent for an average water year. The results emphasize the need to have reliable local precipitation and streamflow records to calibrate relationships in the ECA procedure. The relationships developed at the Horse Creek site may be applicable to many northern Idaho sites if local relationships have not been developed.

Timber cutting guidelines used in the ECA procedure often place limits on expected increases in the maximum monthly streamflow during spring snowmelt. This limit is to prevent increases in high streamflows that potentially could damage or alter the channel. In the small Horse Creek watersheds, high streamflows of relatively short duration, about the 7 or 8 days of highest flow, are responsible for the majority of bedload sediment transport and have the potential to modify the channel. Limits on expected increases in instantaneous peak or maximum daily streamflows would be more appropriate for providing channel protection than limits on maximum monthly streamflow increases, especially for first and second order streams.

The ECA procedure currently estimates streamflow responses in third to fifth order watersheds and does not directly consider hydrologic responses in smaller headwater streams. Relatively large increases in instantaneous peak and maximum daily streamflows following timber removal occurred in the first and second order Horse Creek watersheds. Consideration of hydrologic responses in small watersheds should be incorporated into predictive procedures, especially in stream systems that may be sensitive to increases in high streamflows.

Streamflow Responses to Road Building and Harvesting: a Comparison With the Equivalent Clearcut Area Procedure

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INTRODUCTION

Many National Forest hydrologists in the Northern Region use some adaptation of the equivalent clearcut area (ECA) procedure to forecast average streamflow responses to vegetation removal by timber harvesting, road building, and fire. This procedure is used to estimate the effects of past activities on streamflow and to develop a schedule of entry for future activities that manipulate vegetation in third to fifth order watersheds. Each hydrologist, in conjunction with other resource specialists, develops guidelines that set limits on the expected increases in certain streamflow variables. For example, the Idaho Panhandle National Forests (USDA FS 1977) have timber cutting guidelines that (1) limit the increase in mean annual streamflow to 10 percent, which may be adjusted depending on channel stability or soil characteristics or both,(2) limit the increase in the highest monthly yield to 20 percent, and (3) limit the increase in the channel impact period to 20 percent. The channel impact period is that time during which streamflow exceeds 75 percent of the highest average monthly streamflow for undisturbed conditions. Inherent in these guidelines is the assumption that increases in high flows or the duration of high flows may accelerate channel erosion and that certain channel characteristics can be evaluated to define the ability of the channel to safely handle increases in streamflow. The application of this procedure and guidelines provides a means of comparing different management options for a watershed and of estimating the amount of timber that can be removed from a watershed over a given period. It is one of many tools used by the hydrologists, in addition to their professional judgment, to aid in making land management decisions.

This procedure was based on the best available information at the time it was developed. Different versions of this procedure now exist mainly to reflect local conditions. Many of the relationships used in the various forms of this procedure are based on limited local data or data extrapolated from other geographical areas. Thus, as additional knowledge becomes available on streamflow modification following management activities, the relationships within the procedure should be modified for those geographic areas to which the data are applicable.

Currently there are 5 years of streamflow data following road building and harvesting available from four of the Horse Creek administrative-research watersheds in north-central Idaho. In addition, there are 4 or 5 years of streamflow and precipitation data for 11 watersheds prior to any new road building or harvesting and 10 to 12 years of data from four undisturbed watersheds. These data were used to develop several of the relationships in the ECA procedure for comparison with some of the currently used relationships for the purpose of calibrating the model and improving its reliability and usefulness.

The ECA procedure was first published in "Forest Hydrology Part II: Hydrologic Effects of Vegetation Manipulation" (USDA FS 1974). Although many forms of this procedure exist, the basic procedural steps remain the same. Average annual water yields for undisturbed forest conditions are estimated for the different elevation zones, and average annual water yield for the watershed is determined by summing the area-weighted yield from each elevation zone. Because there is greater availability of precipitation data, a relationship between average annual precipitation and average annual water yield is often used to estimate water yield. Local precipitation data are used to estimate average annual precipitation for the elevation zones within a watershed. The Horse Creek data will be compared with the relationship between average annual precipitation and water yield developed by the Soil Conservation Service (SCS) (Farnes 1972) for mountain watersheds in Montana and commonly used in the ECA procedure.

The next step in the ECA procedure is to estimate the increase in the average annual water yield by elevation zone following vegetation removal. Roads, clearcuts, burned areas, and partial cuts are all expressed as "equivalent clearcut areas," hence the name of the procedure. For example, a 100-acre partial cut where 40 percent of the crown area is removed would be equated to a 25-acre clearcut, a smaller area than the 100 acres on which the activity occurred (USDA FS 1974, p. 39). The increase in average annual water yield on an equivalent clearcut area is estimated as a function of elevation. However, some National Forest hydrologists also incorporate land type or soils information that modifies this elevation versus water yield increase function. The Horse

Creek data will be used to compare with one of the commonly used elevation versus water yield increase relationships (USDA FS 1974, p. 41).

In the ECA procedure the increase in annual water yield is distributed by month over the snowmelt season as a function of general aspect and elevation of the equivalent clearcut areas. This distribution of the annual water yield is done to allow estimation of the increases in the highest monthly yield and the channel impact period. The channel impact period is the time during which streamflow exceeds 75 percent of the maximum average monthly streamflow. The harvesting-induced responses in several variables that describe high streamflows during the spring snowmelt period will be evaluated using data from the Horse Creek watersheds. This analysis will be used to describe the peakflow responses for small south-facing watersheds. These results cannot be used to improve any relationship in the ECA procedure because the procedure is usually applied to much larger watersheds. However, the results are useful in demonstrating which peakflow variable best reflects flows that have the potential to alter the channel.

The ECA model also incorporates a relationship that allows the user to estimate reductions in the initial water yield increase over time as vegetation regrows. This relationship, modified by habitat type, cannot be evaluated with only 5 years of data following harvesting in the Horse Creek watersheds.

STUDY SITE

The Horse Creek administrative-research site is in the Nez Perce National Forest in north-central Idaho, about 35 miles east of Grangeville. Two third order streams, the Main and East Forks of Horse Creek, drain the area toward the east, entering Meadow Creek several miles upstream from its confluence with the Selway River. Within the Main Fork basin are 15 gauged first and second order watersheds, 10 on the north side of the Main Fork and five on the south side (fig. 1). One watershed on each side of the Main Fork serves as an undisturbed control watershed. Roads have been constructed in 11 of the watersheds, and portions of four of these watersheds with roads have also been partially harvested.

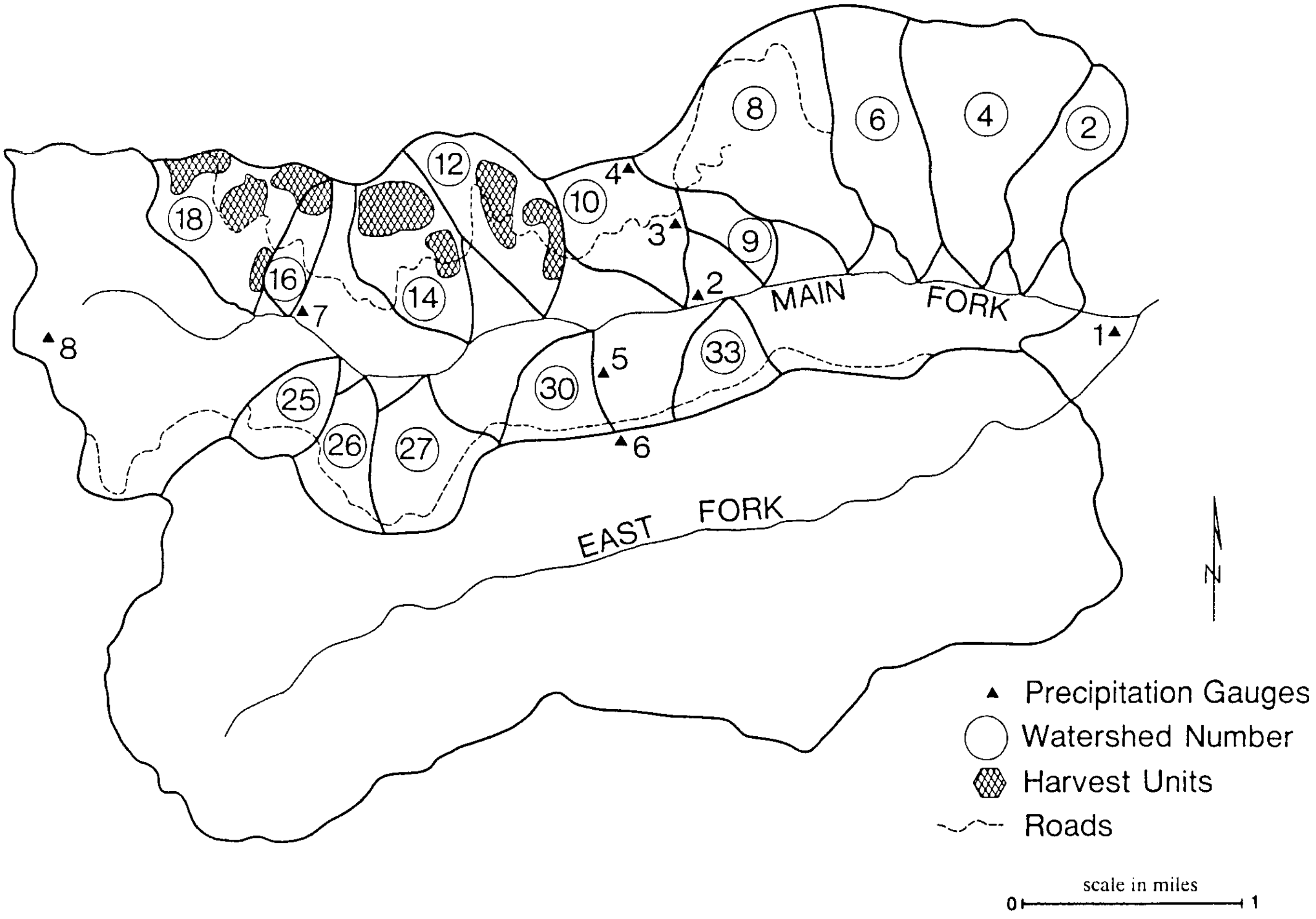

Figure 1—Map of the Horse Creek watersheds nested in the Main Fork drainage showing road, harvest unit, and precipitation gauge locations.

These watersheds are moderately dissected lands in the Selway subsection of the Northern Rocky Mountain Physiographic Province (Arnold 1975). Elevations range from 4,100 to 5,916 ft. Median side slopes are 31 percent, but slopes in excess of 65 percent are common adjacent to the main channel in the lower portions of the Main Fork watershed. The general aspect of the 10 watersheds on the north side of the Main Fork is southerly and for the five watersheds on the south side of the Main Fork, northerly. These small watersheds were completely covered, predominantly with grand fir (*Abies grandis* [Dougl.] Lindl.) and associated species. The most prevalent habitat types in these watersheds are western redcedar/ queencup beadlily (*Thuja plicata / Clintonia uniflora*) and grand fir/queencup beadlily (*Abies grandis / Clintonia uniflora*).

The average annual precipitation is about 46 inches, with about 70 percent occurring as snowfall during November through April. The winters are wet and moderately cold. Pacific air masses frequently affect the climate. In the winter months these warm moist air masses produce a heavy wet snow, and winter melt is not uncommon. Continental air masses also may affect the winter climate producing colder air temperatures and a drier snowfall. January is the coldest month with daily temperatures averaging 23 °F. The summers are hot and dry with only a few convective storms in July, August, and September. During the warmest month, July, average daily temperatures are 60 °F.

High streamflows generated by snowmelt or rain and snowmelt usually occur in April, May, and June, although the initial increase in streamflow is usually apparent by the middle of March. About 65 percent of the annual streamflow occurs in April through June. The snow water equivalent on April 1 averages about 58 percent of the total annual precipitation. The melt from the snowpack plus precipitation of about 10 inches in April through June produce spring streamflows that are 20 to 50 times as large as the lowest annual streamflows. The largest average daily streamflow measured on control watershed 6, 6.72 ft^3/s (16.8 $ft^3/s/mi^2$), was the result of 0.7 inch of rain on a melting snowpack in May 1976. Streamflows diminish over the summer months, and the lowest flows occur in September or October. Streamflow usually remains low throughout the fall and winter, gradually increasing in response to fall rains or winter melt. Infrequently a rain-on-snow event in late fall or winter may also generate high streamflows. For example, on the control watershed, watershed 6, over 12 years, only once has a late fall rain-on-snow event produced streamflow that exceeded the maximum streamflow during the following spring snowmelt. This particular storm produced about 3 inches of rain over 2 days. Air temperatures during the storm were in the 32 to 45 °F range.

The parent material in the area is classified as border zone material adjacent to the Idaho batholith. The majority of the parent material is metamorphosed sedimentary material correlated with the Belt Super Group. This metasedimentary material is varied and intergrades from quartz-biotite-plagioclase gneisses and schist to biotite-plagioclase quartzites (Greenwood and Morrison 1973). These rocks consist primarily of micaceous gneissic material with large proportions of quartz, plagioclase, muscovite, and biotite. The soils are moderately deep, well drained, loam to sandy loam with a surface layer of loessial silt. The two most extensive soil types are Andic Dystrochrepts and Typic Vitrandepts. The loessial surface layer has a loam to silt loam texture and extends to depths of 7 to 21 inches. The subsoil, extending to depths of 22 to 28 inches, has a loam to sandy loam texture, and the substratum, extending to depths of 40 to 61 inches, has a sandy loam to very gravelly sandy loam texture.

MANAGEMENT ACTIVITIES

In the summer of 1978, single-lane midslope logging roads were constructed in watersheds 18, 16, and 8 and in the summer of 1979, in watersheds 14, 12, and 10. The road tread is typically crowned or insloped with an inside ditch-relief culvert drainage system. The roads occupy from 3 to 5 percent of the watershed area (table 1). Clearcut harvesting, in patches ranging from 9 to 35 acres, took place in 1981 and cleared 20.9 to 32.6 percent of the area in watersheds 18, 16, 14, and 12. Tractor logging was done in watershed 18, 16, and 14, and skyline logging was used in watershed 12. The units were broadcast burned in the fall of 1981 except for the unit in the northwest portion of watershed 18, which was burned a year later. In 1983 and 1984 a ridgetop road was constructed in watersheds 25, 26, 27, 30, and 33. Table 1 and figure 1, respectively, describe the physical characteristics of these watersheds and the management activities and show the road and harvest unit locations.

METHODS

The streams draining the 10 small watersheds on the north side of the Main Fork were instrumented with H-type flumes and stage recorders and have provided continuous streamflow data since 1975. Those watersheds on the south side of the Main Fork have provided continuous streamflow data from 1979 through 1983. Stream stage was digitized from the stage recorder strip charts at hourly intervals, and mean daily stream discharge was calculated. The streamflow variables discussed in this paper were developed using mean daily stream discharge data, with the exception of the instantaneous peakflow, which represents the maximum instantaneous stream discharge.

In the Main Fork drainage are eight precipitation gauges (fig. 1). Table 2 gives the elevation and site characteristics of each gauge location. Subsets of these gauges were used to develop relationships between gauge elevation and annual precipitation for south and north aspect watersheds in Horse Creek.

The streamflow variables that were evaluated for the effects of vegetation removal by roading and harvesting were the annual stream discharge and several variables indexing high streamflows of different durations. Those variables were the maximum instantaneous stream discharge, the maximum mean daily stream discharge, the stream discharge equaled or exceeded 5 percent of the

Table 1—Selected characteristics of the Horse Creek watersheds

Watershed	Area	Mean elevation[1]	Stream order	Dominant aspect	Road area	Harvest area	Harvest and road area
	Acres	*Feet*		*Degrees*	*------ Acres*	*------*	*Percent*
2	143	4,940	1	200			
4	348	4,965	2	185			
6	256	4,950	2	166			
8	364	4,990	2	144	13.5		4.0
9	58	4,780	1	133			
10	161	4,990	2	144	4.2		3.1
12	207	5,165	2	161	8.4	67.4	36.6
14	154	5,235	2	134	3.4	41.5	29.2
16	54	5,443	1	198	2.2	11.3	25.0
18	213	5,458	2	177	9.2	61.9	33.4
25	79	5,320	2	44	3.0		3.8
26	95	5,255	1	13	3.6		3.8
27	168	5,180	2	9	5.1		3.0
30	92	5,015	2	34	3.7		4.0
33	82	4,902	2	358	3.3		4.0

[1] Average of the maximum and stream gauge elevations.

Table 2—Elevation and length of record for the Horse Creek precipitation gauges[1]

Station number	Elevation	First complete record year	Site characteristics
	Feet		
1	4,130	1966	Mouth of drainage
2	4,460	1977	Valley
3	4,910	1979	Midslope, south aspect
4	5,420	1978	Ridgetop
5	4,840	1979	Midslope, north aspect
6	5,250	1979	Ridgetop
7	5,000	1979	Valley
8	5,600	1966	Head of drainage

[1] Figure 1 shows locations of these precipitation gauges.

year, and the maximum mean monthly stream discharge. Subsequent to the analysis of these streamflow variables, the date at which half the annual streamflow is achieved was also evaluated for possible shifts following road building and harvesting.

Simple linear regressions were developed between the control and treated watersheds for each streamflow variable during the preroad calibration and the postharvest treatment periods. Data from the years when the road was in place, but prior to harvesting, were not used in the analysis. Thus, any changes in the streamflow variables are due to a combination of harvesting and roading.

Analysis of covariance was used to test for significant differences between the slopes and intercepts of the calibration and treatment regressions (Freese 1967), reflecting streamflow responses to the combination of roading and harvesting. The modifications in stream hydrologic factors due to just road building have been previously reported (King and Tennyson 1984).

Estimates of a change in any streamflow variable for the "average" water year were determined by comparing predicted values from the calibration and treatment regressions using the 12-year (1975 through 1986) average of the variable from control watershed 6 as the value of the independent variable. Estimates of the change in the "average" streamflow variables were used in the comparison with the ECA relationships because the ECA procedure is used to estimate average responses and is not driven by specific climatic events.

These watersheds are much smaller than those watersheds on which the ECA procedure is usually applied. However, the relationships in the procedure to estimate annual streamflow under undisturbed conditions and to estimate annual streamflow increases following harvesting and road building are "onsite" responses representing water yields per unit area of ECA disturbance and thus are not a function of watershed size. The increase in the maximum monthly streamflow or other variables describing highflows are related to the area of the watershed. Thus, the responses of the highflow variables from these small watersheds cannot be directly used to improve the relationships in the ECA procedure but will be used to evaluate several assumptions in this procedure.

WATER YIELD VERSUS PRECIPITATION

The ECA procedure estimates average annual water yield from a relationship with average annual precipitation developed by the Soil Conservation Service (Farnes 1972). This relationship was developed using data from about 100 mountain watersheds in Montana ranging in size from 10 to 2,000 mi^2. Average annual precipitation was extracted from mountain precipitation maps for Montana, developed by the SCS. Average annual runoff was obtained from U.S. Geological Survey streamflow records. In developing this relationship for the Horse Creek watersheds, estimates of annual precipitation were calculated by first developing a linear regression between precipitation gauge elevation and annual precipitation for each water year from 1975 through 1986, using annual precipitation records from seven climatic stations in the Main Fork drainage. Separate elevation versus annual precipitation relationships were developed for the watersheds on the north side of the Main Fork and those on the south side using different subsets of the seven climatic stations. Table 3 shows the linear regressions between annual precipitation and gauge elevation for each water year for the north and south aspect watersheds. In 1975 through 1978 not all of the precipitation gauges were installed, and regressions were developed using data from as few as two gauges. Precipitation gauges 1, 2, 3, 4, and 8 were used to develop the elevation versus annual precipitation relationship for the south aspect watersheds, and gauges 1, 2, 5, 6, and 8 were used for the north aspect watersheds (fig. 1). The annual precipitation for a watershed was then determined as the sum of the area weighted annual precipitation in 200-ft elevation zones. Average annual precipitation was calculated for the 1975 through 1986 period for the watersheds on the north side of the Main Fork and for the 1979 through 1983 period for the watersheds on the south side of the Main Fork. Stage recorders were removed from the five watersheds on the south side of the Main Fork at the end of the 1983 water year.

Figure 2 shows the relationship between average annual precipitation and water yield developed by the Soil Conservation Service. The figure also plots the estimated average annual precipitation versus water yield for the Horse Creek watersheds for the years of 1975 through 1986. Average annual precipitation and water yield for those years prior to management activities were adjusted to reflect averages for the 1975 through 1986 period based on the precipitation averages for control watershed 6. Except for watershed 18, these watersheds produced less runoff for a given amount of annual precipitation than would have been estimated using the SCS curve. In general, as the mean elevation of the watersheds increase, the data plot closer to the SCS curve. For watersheds 2 and 33, the two lowest elevation watersheds, use of the

Table 3—Annual linear regressions between precipitation gauge elevation and annual precipitation for the south and north aspect subwatersheds at the Horse Creek administrative-research site

Model: Annual precipitation (in) = $\beta_0 + \beta_1$ elevation (ft)

Year	$\hat{\beta}_0$	$\hat{\beta}_1$	*N*	R^2
South aspect regressions:				
1975	2.28	0.0103	2	—
1976	11.55	.0095	2	—
1977	-5.56	.0082	3	0.99
1978	22.72	.0057	4	.87
1979	2.55	.0065	5	.77
1980	23.14	.0044	5	.93
1981	30.11	.0024	5	.77
1982	35.26	.0022	5	.21
1983	20.36	.0034	5	.77
1984	24.87	.0054	5	.90
1985	25.18	.0023	5	.57
1986	20.21	.0042	5	.61
North aspect regressions:				
1979	-4.51	.0080	5	.74
1980	16.43	.0058	5	.66
1981	27.51	.0029	5	.61
1982	27.14	.0042	5	.65
1983	22.25	.0029	5	.42

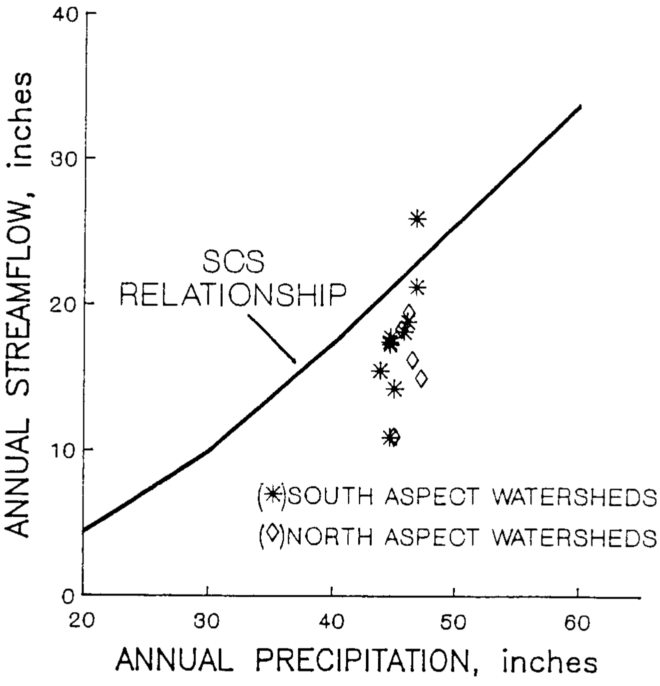

Figure 2—Relationships between average annual precipitation and average annual streamflow for the Horse Creek watersheds compared to a relationship developed by the Soil Conservation Service (Farnes 1972).

SCS curve would overestimate annual runoff by 9.9 and 10.5 inches respectively. On average the SCS curve overestimated water yield by about 4.5 inches for the Horse Creek watersheds. Because of the narrow range of the adjusted average annual precipitation for these watersheds, 44 to 47 inches, these data are not useful for comparison with the slope of the SCS relationship.

The data used to develop the SCS relationship between annual water yield and annual precipitation were from varied site conditions. Generally, those watersheds with deeper soils and a dense forest cover produce less streamflow for a given annual precipitation than those with thin soils or sparse timber. It is possible that the Horse Creek watersheds produced less yield than most of the watersheds used to develop the SCS relationship because of their relatively deep (4 to 6 ft) soils and dense tree cover.

The annual water yield varied considerably during the calibration period from only 4.45 inches from watershed 2 during the droughty year of 1977, up to 41.95 inches from watershed 18 during the extremely wet year of 1976. For the 12 years of annual streamflow measurements at the control watershed 6, the average and standard deviation are 17.2 and 6.03 inches, respectively. Estimated average annual streamflows for the four harvested watersheds, prior to any management activities, are 18.1, 18.8, 21.2, and 25.9 inches for watersheds 12, 14, 16, and 18, respectively. The portion of annual precipitation appearing as streamflow ranges from an average of 39 percent for watershed 6 up to an average of 50 percent for watershed 18, generally increasing with the mean elevation of the watersheds. Evapotranspiration and interception losses, estimated as the difference between average annual precipitation and streamflow, averaged about 23 inches on watershed 18 and between 27 and 28 inches on watersheds 6, 12, 14, and 16. Thus, there is a large potential to increase streamflow following activities that remove vegetation, reducing evapotranspiration and interception losses and altering snow accumulation and melt.

INCREASE IN ANNUAL WATER YIELD

The four watersheds that had road building and harvesting all had statistically significant increases in annual water yield ($\alpha = 0.01$). Figure 3 shows the annual streamflow relationships between the treated and control watersheds for the calibration and postharvest periods. For all four watersheds the slopes of the preharvesting and postharvesting regressions are similar, indicating a fairly constant volumetric increase in annual streamflow regardless of whether it was a low or high runoff year. For each water year, the increases in annual water yield were highly correlated with the watershed area in equivalent clearcut condition (fig. 4). The slope of the linear

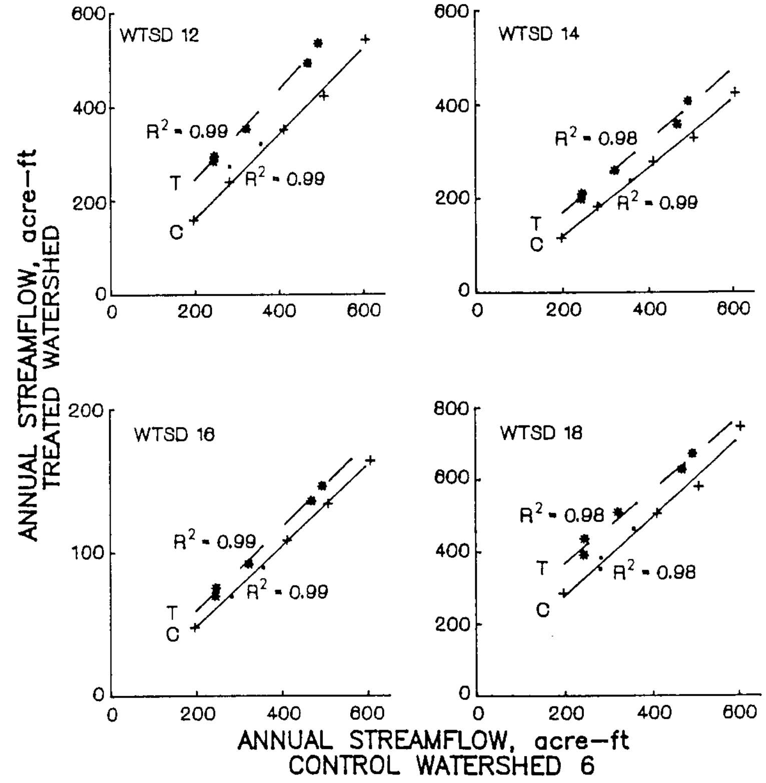

Figure 3—Calibration (C) and treatment (T) linear regressions for annual streamflow for the four Horse Creek watersheds in which road building and harvesting occurred. The data points with a solid dot symbol are for years between road building and harvesting and were not used in either regression.

regressions shown in figure 4 represents the depth increase in feet in annual water yield for the 5 years following clearcut harvesting (no intercept coefficient). Increases in annual water yield from the areas in harvest units and roads averaged 12.0 inches in 1982, 15.9 inches in 1983, 15.7 inches in 1984, 12.2 inches in 1985, and 14.6 inches in 1986. The solid line in figure 4 represents the linear regression through estimates of the average increases in annual water yield. These average increases were estimated using the 12-year average annual water yield from the control watershed as the independent variable, and calculating the difference between the predicted values from the calibration and treatment regressions. The slope of the solid regression line represents an average increase of 14.1 inches on the areas in roads and harvest units. For watersheds 12, 14, and 16 this increase is equal to about half of the 27 to 28 inches previously lost to evapotranspiration and interception. On watershed 18, an average increase in annual water yield of 14.1 inches is equivalent to 61 percent of the previous losses to evapotranspiration and interception. However, the streamflow increases are not only attributed to reductions in evapotranspiration and interception losses but also to modifications in snow accumulation and melt on the open areas. There were no measurements of soil water content or snow accumulation and melt to allow partitioning of the water yield increase by the processes being altered.

Increases in average annual water yield, on the areas with vegetation removed, are predicted in the ECA model as a function of the elevation of the areas in an equivalent clearcut condition (fig. 5). Because this relationship uses a percentage increase, it is important that estimates of the preharvesting average annual runoff be fairly accurate. The predicted increase in average annual yield increases with elevation in response to higher precipitation. At the elevation where tree density begins to decline and up into the alpine zone, the average annual yield increase declines with increasing elevation. For the elevation zone where road construction and timber harvesting occurred in the Horse Creek watersheds, the ECA curve predicts a 37 to 38 percent increase in the average annual water yield on the equivalent clearcut areas. Increases in average annual water yield, determined as the difference between the calibration and treatment regressions at the mean value for the control watershed were 52.0 percent on watershed 18, 51.2 percent on watershed 16, 78.7 percent on watershed 14, and 80.1 percent on watershed 12. These increases are substantially greater than those predicted by the ECA relationship. On average the water yield increase function in the ECA procedure underestimated the actual percentage increase by 44 percent.

An earlier evaluation of the ECA model was conducted on a 950-acre watershed on the Priest River Experimental Forest of northern Idaho (Belt 1980). A 98-acre clearcut and 19.2 acres of logging roads produced an extra 10 inches of annual streamflow over a 5-year postharvest period, compared to the adjacent forested land. Water yield increases on the cleared areas were about 66 percent

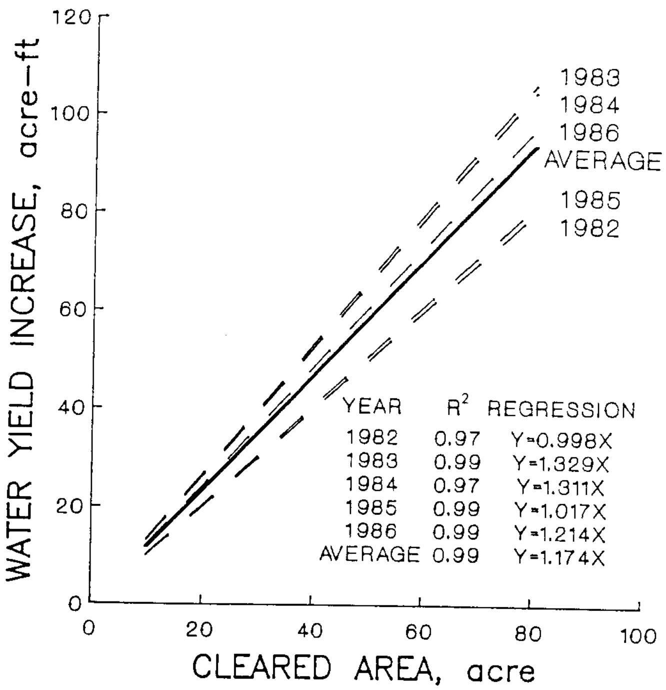

Figure 4—Relationships between the area of the Horse Creek watersheds in roads and harvest units and the increase in annual water yield.

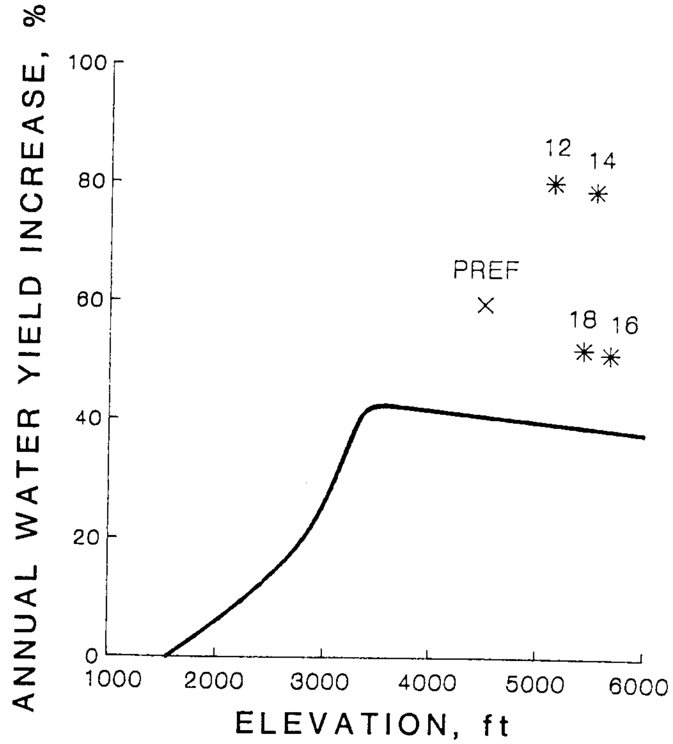

Figure 5—Observed increases in "onsite" annual water yield following road building and harvesting compared with the relationship used in the equivalent clearcut area procedure.

at an average elevation of 4,500 ft (fig. 5, point labeled PREF). In this case, the ECA relationship underestimated the observed increase in onsite annual water yield by 38 percent, which favorably compares with the 44 percent underestimation at the Horse Creek site.

The ECA procedure initially overestimated the average annual water yield from the undisturbed Horse Creek watersheds by about 4.5 inches. The procedure then increases this yield by a percentage that is too low. To some degree these inaccuracies, as compared to the Horse Creek data, compensate. However, inaccuracies in the predictions may also accumulate and lead to estimates of management effects on water yield that are not realistic. Thus, the need for a sound local data base for model calibration.

PEAK STREAMFLOWS

The timber cutting guidelines used with the ECA procedure place a limit on the allowable increase in the highest average monthly yield and in the channel impact period. The reasoning behind this restriction is that the increased energy associated with higher streamflows or the duration of high streamflows has the potential to alter the channel via channel bottom degradation and channel widening. In the ECA procedure the predicted increases in the annual streamflow are partitioned by month over the snowmelt hydrograph as a function of the elevation and aspect of the equivalent clearcut area to determine the increases in the highest average monthly yield. In scheduling harvest entries into a large watershed, harvest units can be spatially arranged on a wide variety of aspect and elevation combinations to minimize increases in the maximum monthly streamflow and stay below previously determined limits.

The modifications in maximum monthly streamflow from the Horse Creek watersheds with harvest units and roads cannot be compared with predicted responses in the ECA procedure because of the small size of the Horse Creek areas. The ECA procedure was developed for much larger watersheds and does not consider modifications in streamflow in headwater basins. However, streamflow responses in Horse Creek during the snowmelt period are useful in examining the appropriateness of two assumptions in the ECA procedure. Because the ECA procedure uses responses in third to fifth order streams, it assumes that limiting streamflow increases in the larger order streams adequately protects the channel system in the lower order streams. This assumption is not stated in any of the ECA literature but is inferred from the method of application in the procedure. The second assumption is that increases in the maximum monthly streamflows represent increases in streamflow sufficient to alter the channel. The responses in several streamflow variables representing different durations of highflows and previously developed relationships between bedload sediment transport and streamflow will be used to evaluate these two assumptions.

In 1975 and 1976 bedload transport rates were measured in selected Horse Creek streams during the snowmelt period and terminating in July. Bedload rating curves were developed regressing the logarithm of the bedload transport rate against the logarithm of stream discharge. Mean daily stream discharge for water years 1975 and 1976, ranked from highest to lowest, and the bedload transport rating curves were used to produce the relationships shown in figure 6 for control watershed These relationships demonstrate that the majority of annual bedload sediment is produced by relatively few days of high streamflows. The maximum mean daily flow generated about 10 percent of the annual load, and half the annual load is produced by the 7 or 8 highest flow days. Relationships for the other watersheds were similar in that relatively few days of the highest stream discharges transport most of the annual bedload. Thus, it is relatively few high flow days that have the potential for shaping the channel. Increases in short duration high flows following harvesting and road building are more important in terms of potential channel erosion and bedload transport than increases in longer duration high flows such as the maximum mean monthly streamflow or the channel impact period.

Megahan (1979) suggests that bank-full flows are large enough to have a major effect on channel form. Using a return period of 1.5 years for instantaneous bank-full flows (Leopold and others 1964), the bank-full flow for watershed 6 is 3.06 ft^3/s. The mean maximum monthly streamflow for watershed 6 is only 1.67 ft^3/s, much lower than the bank-full flows capable of altering the channel. The 12-year average maximum daily flow and average maximum instantaneous flow for this watershed are 3.68 and 4.10 ft^3/s, respectively. The maximum daily and maximum instantaneous flows for the average year are

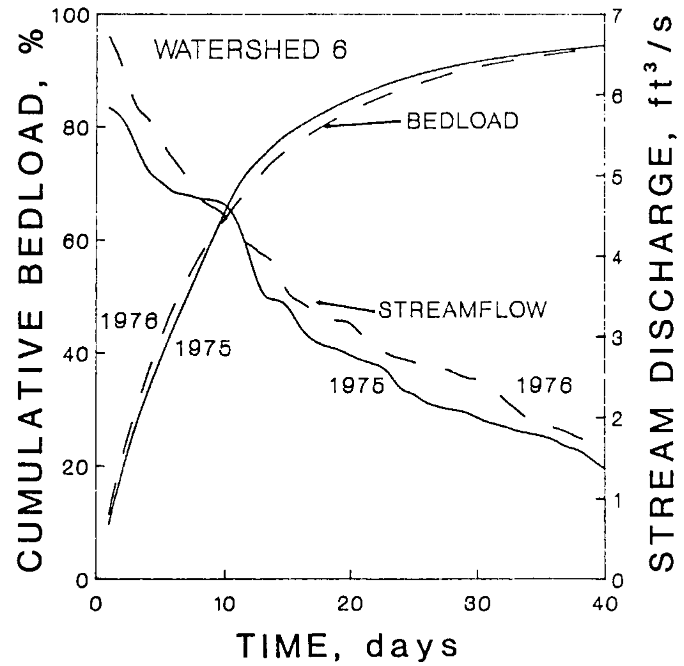

Figure 6—Cumulative bedload sediment production and mean daily stream discharge for the highest streamflow days, in decreasing order, for control watershed 6 during water years 1975 and 1976.

large enough to be shaping the channel. Using this approach to estimate the magnitude of channel-forming flows, only the 4 to 6 days of highest flows in an average year would exceed bank-full flow and have the capability to modify the channel. Even in the year of highest flows, 1976, bank-full flow was exceeded on only 20 days. This approach to defining channel-forming streamflows supports the previously discussed bedload transport approach in that relatively few days of highest streamflow have the potential to shape the channel. Therefore, increases in short-duration highflows are more important than longer duration highflows in shaping the channel, and any procedure to estimate streamflow responses and set limits on harvesting should focus on the expected changes in these shorter duration highflows.

The responses in four streamflow variables representing different durations of high streamflows were evaluated for the Horse Creek watersheds. These variables are the maximum instantaneous streamflow, the maximum daily streamflow, the streamflow equaled or exceeded 5 percent of the year, and the maximum monthly streamflow. Figure 7 illustrates the average response in these four variables following harvesting and road building. The open bars represent the predicted value for the watershed prior to disturbance, and the cross-hatched portion of the bars represent the increase observed after road building and harvesting for the average year. The calibration and treatment period regressions for these variables are included in the figures 8-11. In these figures the data points with a solid dot symbol are for those years between road building and harvesting and were not used in either regression.

The size of the increase in any of the peakflow variables is influenced to a degree by when the extra streamflow is produced from the harvest units and roads compared to the undisturbed portion of the watershed. In these south-aspect watersheds, patch clearcutting was an attempt to promote earlier melt in the harvest units such that increases in streamflow would be prior to the normal peakflows. An analysis of the date at which half the annual streamflow was produced indicated that only in watershed 12 were streamflow contributions significantly advanced in the water year. The half-flow date was advanced by about 8 days ($\alpha = 0.05$). The clearcuts in watershed 12 were free of snow about 2 weeks earlier than the clearcuts in the other watersheds. An algorithm developed by Swift (1976) was used to calculate the potential solar radiation received by the individual harvest units. The steeper, more southerly facing units in watershed 12 receive the highest potential solar radiation from October through March. The harvest units in watershed 12 are at lower elevations than the units in the other watersheds, both in terms of actual elevation and relative elevation within the watershed. Average ambient air temperatures are probably slightly higher in the harvest units in watershed 12 because of their lower elevation, which also may promote earlier melt.

The maximum instantaneous and maximum daily flows are usually the result of rain on an already melting snowpack for the Horse Creek watersheds. Increases in these

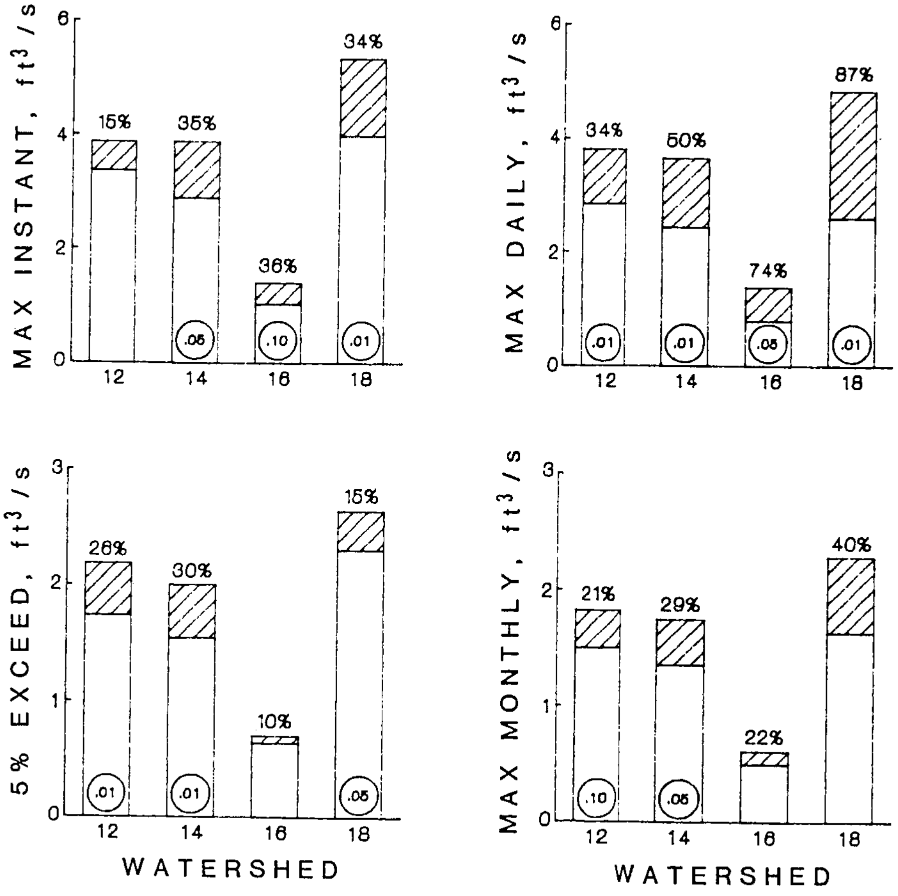

Figure 7—Average responses to road building and harvesting in variables indexing high streamflows for the four Horse Creek watersheds. The percentage above each bar is the average percent increase in that variable and the circled value is the alpha level of significance.

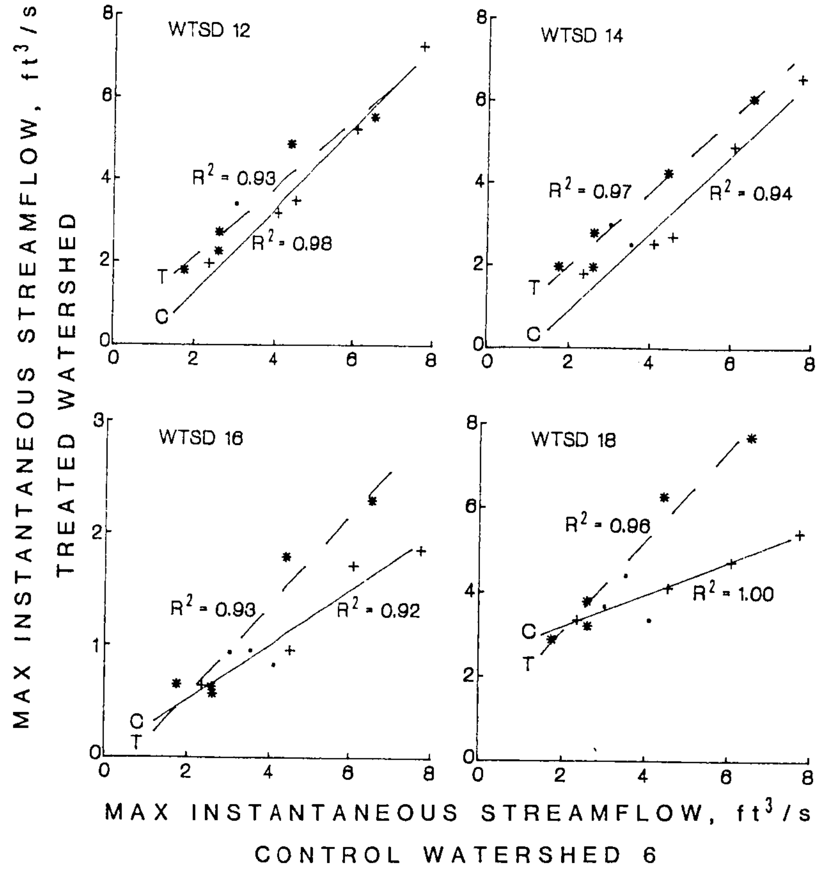

Figure 8—Calibration (C) and treatment (T) period regressions for maximum instantaneous streamflow for the four Horse Creek watersheds in which road building and harvesting occurred.

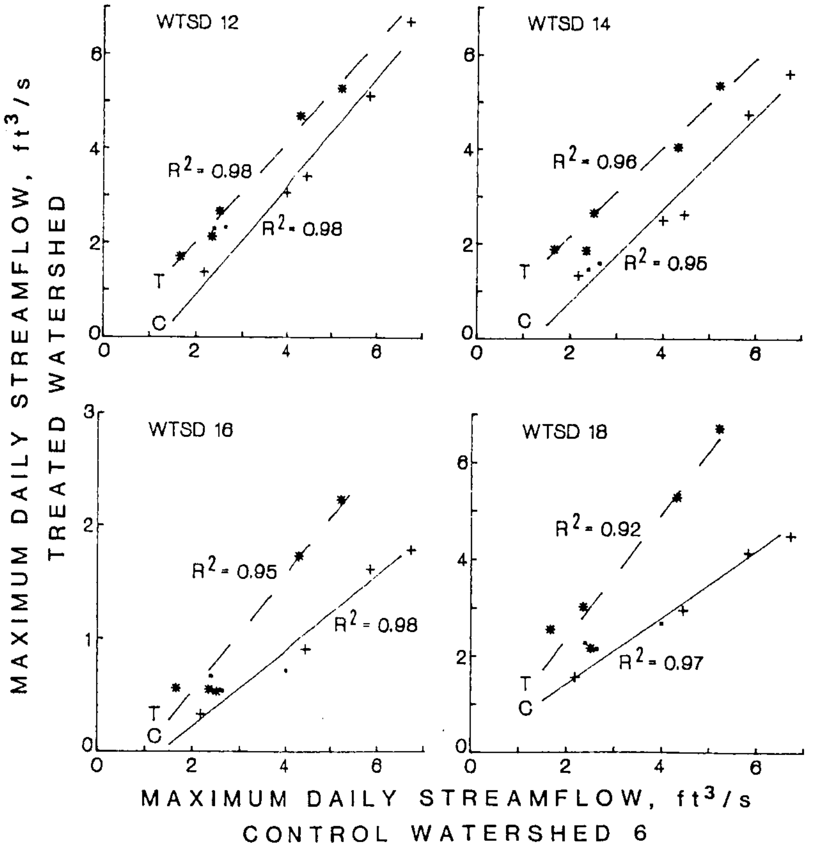

Figure 9—Calibration (C) and treatment (T) period regressions for maximum daily streamflow for the four Horse Creek watersheds in which road building and harvesting occurred.

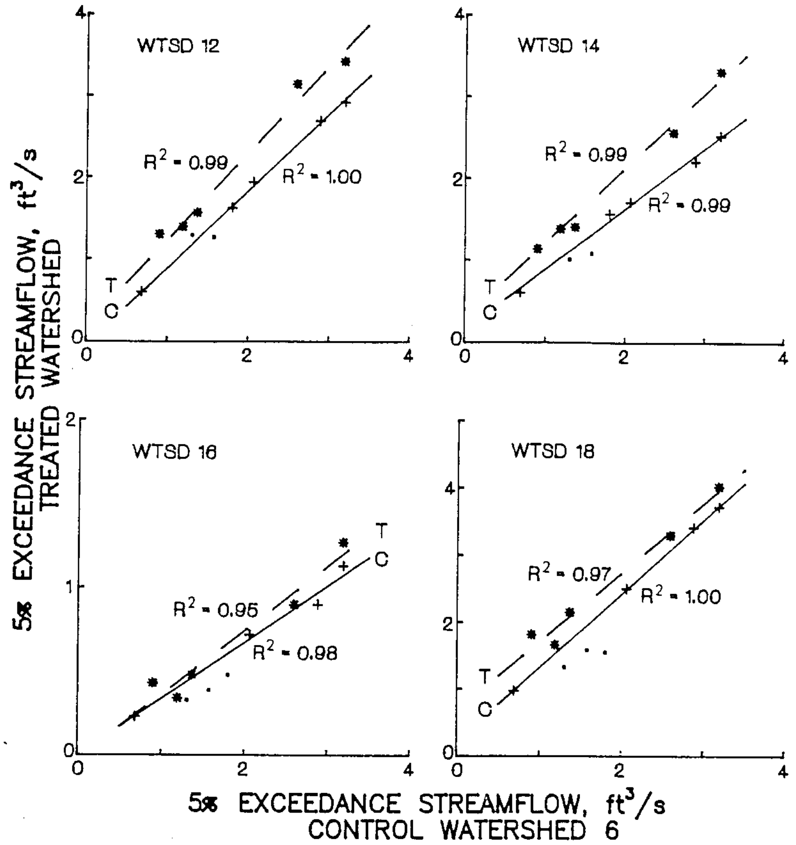

Figure 10—Calibration (C) and treatment (T) period regressions for streamflow equaled or exceeded 5 percent of the year for the four Horse Creek watersheds in which road building and harvesting occurred.

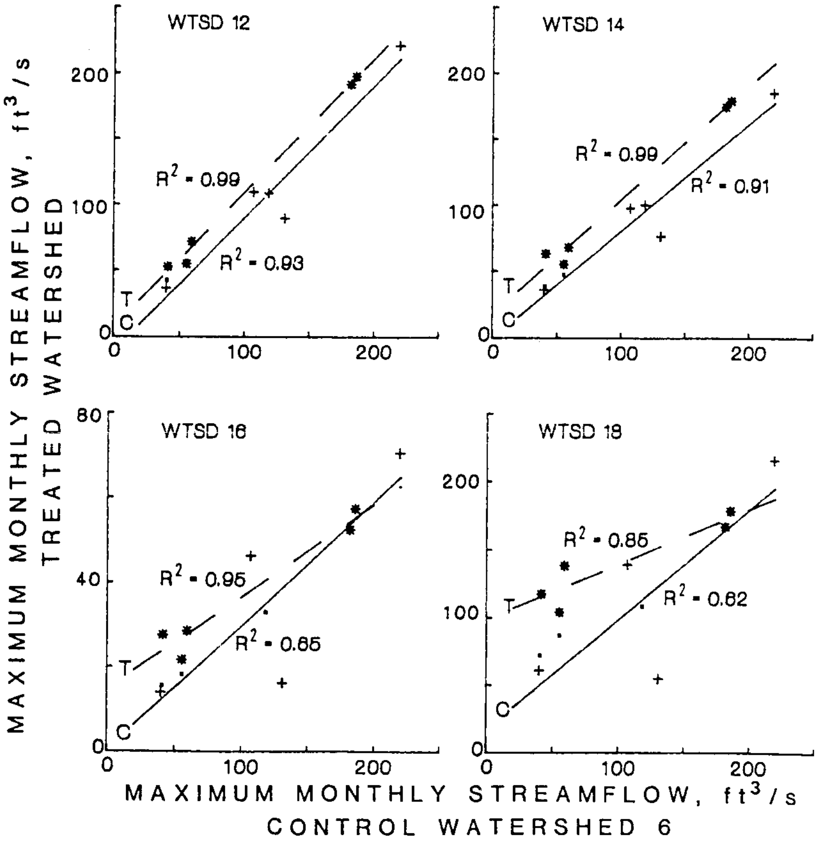

Figure 11—Calibration (C) and treatment (T) period regressions for maximum monthly streamflow (May) for the four Horse Creek watersheds in which road building and harvesting occurred.

two variables were directly proportional to the cleared area on those watersheds where streamflow contributions were not advanced earlier in the year, watersheds 14, 16, and 18 (fig. 12). In these watersheds, increases in the maximum instantaneous and maximum daily stream discharge of 1 ft^3/s would require about 49 and 31 acres in cleared condition, respectively. The largest increases were in watershed 18 with 71 of its 213 acres in openings. In watershed 18 average maximum instantaneous flows increased by about 1.35 ft^3/s and average maximum daily flows increased by about 2.25 ft^3/s. In watershed 12 increases in these streamflow variables were smaller due to less snow present in the open area at the time of maximum flows. Increases in the instantaneous peak streamflows were not significant ($\alpha = 0.10$) for watershed 12.

Increases in the 5 percent exceedance streamflows were significant ($\alpha = 0.05$) on three of the four watersheds and ranged from 15 to 30 percent. On watershed 16, with only 25.0 percent of its area in equivalent clearcut condition, a significant ($\alpha = 0.10$) increase was not detected. Yet watershed 16 did have large increases in the instantaneous and maximum daily streamflows. Increases in the 5 percent exceedance streamflows were not proportional to the portion of the watershed in equivalent clearcut condition. The increases in the maximum monthly flow (May) were only significant ($\alpha = 0.10$) on watersheds 12 and 14 with 21 and 29 percent increases, respectively. Poor calibration equations (fig. 11) for watersheds 16 and 18 inhibited statistical detection of increases in this variable.

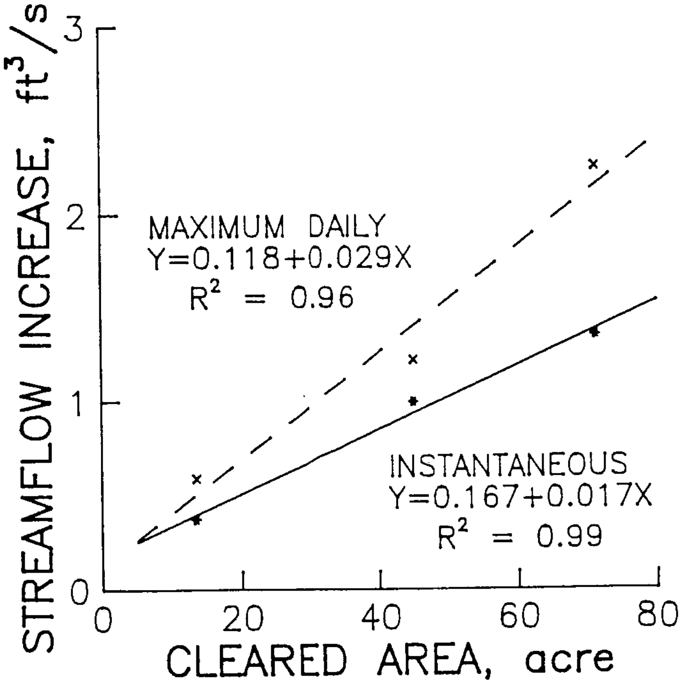

Figure 12—Relationships between area in roads and harvest units and average increases in maximum instantaneous and maximum daily streamflow.

SUMMARY AND RECOMMENDATIONS

Reliable local precipitation and streamflow data are required to develop accurate relationships between average annual precipitation and streamflow. The relationship developed in Montana by the Soil Conservation Service overestimated average annual streamflow for the Horse Creek watersheds by about 4.5 inches. If local data are not available, more accurate predictions may be achieved by using the relationship developed from the Horse Creek site. However, application of this relationship should be restricted to completely forested watersheds in the 4,000- to 6,000-ft elevation zone, with moderately deep well-drained soils in northern Idaho.

The increase in average annual streamflow following harvesting and road building was much larger than predicted in the ECA procedure. The original ECA document (USDA FS 1974, sec. 2, p. 28) suggests that increases of 6 to 13 inches in average annual water yield might result from harvesting in the 4,000- to 6,000-ft elevation zone in the Nez Perce National Forest in Idaho. Average increases were 14 inches in this same elevation zone in the Horse Creek watersheds. Based on results from the Horse Creek administrative-research site and the Priest River Experimental Forest, it is recommended that a 69 percent increase factor be used for moderately deep soils in the 5,000- to 6,000-ft elevation zone in northern Idaho.

High streamflows capable of altering the channel are of short duration in the average water year. For these small Horse Creek watersheds the largest 7 or 8 days of streamflow account for the majority of the bedload movement, with the single highest daily flow accounting for about 10 percent of the annual bedload production. Average monthly streamflows are usually not a good index of bedload transport, and "changes in average annual monthly peakflows have no meaningful effect on sediment transport" (Megahan 1979) and are thus poor indicators of changes in channel-forming flows. This would also hold true for the 5 percent exceedance flows in the average water year.

On south-facing first and second order drainages, advancing snowmelt through patch clearcutting was not readily achieved. Harvest units placed on those slope, aspect, and elevation combinations to maximize winter and spring solar radiation to the snowpack have the most likelihood of advancing melt. If melt is not advanced, increases can be expected in the instantaneous peak and maximum daily streamflows on the order of 0.2 and 0.3 ft^3/s, respectively, for every 10 acres in cleared condition. While it is not appropriate to suggest some absolute limit to harvesting in low-order watersheds, the results would indicate that harvesting in low-order watersheds that have channel conditions that may be sensitive to increases in short duration peakflows should proceed on a conservative basis. In many instances the channels may be stable enough to withstand fairly large increases in short duration peakflows without any channel alteration. Additional research is needed to understand how channels respond to both increased flows and sediment loads and how to identify channels that might be the most sensitive to change. There are other effects of increases in short-duration peakflows that should also be considered. Because sediment transport rate is usually exponentially related to streamflow, increases in peakflows could create a situation where accelerated sediment from roads or harvest units is more efficiently transported downstream. In certain situations, the increases in peakflows from small watersheds may be additive in the higher order stream channels (Harr 1986).

Current procedures for estimating the hydrologic responses to timber removal of third to fifth order streams often ignore what may be hydrologically important modifications in the low-order streams. Hydrologists should consider the potential modifications to headwater basins in scheduling harvest entries and locating harvest units, especially when conditions are such that the stream system is likely to be sensitive to streamflow modification.

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