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ASPEN CLEARCUTTING INCREASES SNOWMELT AND STORM FLOW PEAKS IN NORTH CENTRAL MINNESOTA[1]

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ABSTRACT: Clearcutting aspen from the upland portion of an upland peatland watershed in north central Minnesota caused snowmelt peak discharge to increase 11 to 143 percent. Rainfall peak discharge size increased as much as 250 percent during the first two years after clearcutting, then decreased toward precutting levels in subsequent years. Storm flow volumes from rain during the first two years increased as much as 170 percent but declined to preharvest volumes in the third year. Snowmelt volumes did not significantly change. Snowmelt peak discharge occurred about four to five days earlier after clearcutting, but the timing of storm flow from rainfall was not changed.

Snowmelt peaks remained above precut size for nine years after clearcutting on an area undergoing natural regeneration to aspen saplings. Partial cutting – up to approximately one-half of the watershed – reduced peak snowmelt discharge because melt was desynchronized in cleared and forested parts. Clearing more than 2/3 of the watershed caused snowmelt flood peak size to double during years with snow packs in excess of seven inches of water that remained until a day when maximum air temperatures exceeded 60°F.

(KEY TERMS: floods; land use; peak discharge; Lake States; logging.)

INTRODUCTION

The effects of clearcutting forests on flooding remains controversial, largely because of the lack of a consistent response from one clearcutting experiment to the next. Summaries by Lull and Reinhart (1972) and Anderson, *et al.* (1976), indicate that clearcutting generally increases water yield, but may increase, decrease, or have no effect on flooding. Storm flow characteristics such as peak discharge size and storm flow volume from rains have increased following commercial clearcutting in West Virginia (Reinhart, *et al.,* 1963; Reinhart, 1964; Patric and Reinhart, 1971). Peak flow increases were below 14 CSM (cubic feet per second per square mile) and occurred mostly in the growing season. Partial selection cuts produced smaller increases in peak flow size. Clearcutting a 33-acre low elevation watershed at the Coweeta Hydrologic Laboratory did not increase the size of peak discharge (Hoover, 1945; Hewlett and Hibbert, 1961); however, clearcutting a 108-acre high elevation watershed increased peak flow size an average of 9 percent (Hewlett and Helvey, 1970). Clearcutting a 39-acre watershed that was kept denuded by herbicides in New Hampshire caused peak size to double (Pierce, *et al.,* 1970; Hornbeck, 1973). Clearcutting one-third of an oak-hickory watershed in Missouri did not affect storm flow (Settergren, *et al.,* 1980). In Oregon, peak flow size from rains was not affected by clearcutting a small headwater basin (Harr and McCorison, 1979). In Alberta rain peak flow increased 1½ to 2 times after extensive patch cutting (Swanson and Hillman, 1977). In Arizona Baker, *et al.* (1971), found that peak discharges on a recent clearcut and heavily thinned (75 percent) ponderosa pine watershed increased 2.2 times over control areas after a 100-200 year rainfall. Authors generally conclude that clearcutting will not affect downstream flooding if only a small portion of a forested area is cut each year.

The effects of clearcutting on stream flow from snowmelt also vary among studies. At the Hubbard Brook Experimental Forest in New Hampshire, clearcutting caused snowmelt peaks early in the season to increase and those late in the season to decrease, indicating that the time of snowmelt is different in open and forested areas. The largest peak flow increase from the clearcut area was double that from the forested area (Hornbeck, 1973). On the Frazer Experimental Forest in Colorado, strip cutting high elevation conifers increased snowmelt peak size up to 50 percent in some years and decreased it by 23 percent in 1 year. In Oregon, several studies of clearcutting without soil disturbance showed no increases in snowmelt peak size (Rothacher, 1973; Harris, 1973, 1977; Harr, *et al.,* 1975), and one showed a 32 percent reduction in snowmelt peak size (2-year return period) from numerous melt periods (Harr and McCorison, 1979). Apparently melt was more rapid in conifer areas caused by more condensation convection melt on tree crowns than in the open area. Other studies in Oregon showed that peak flow size increased as much as 50 percent where either soil disturbance was greater than 12 percent of the area or slash was burned (Harr, *et al.,* 1975; Harr, 1976). Snowmelt peak flows from extensive patch cuts in Alberta appeared to increase two to three times (Swanson and Hillman, 1977). Most small watershed studies have measured peak flow rates with less than 25-year return

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intervals; controlled tests of clearcutting effects on large peaks have not been made.

Anderson and Hobba (1959) analyzed 54 watersheds in the Northwest and concluded that forest cutting would not drastically affect major floods from large basins because only 1 percent of a watershed would be harvested each year. For a 100-year flood the peak rate would increase 6 percent. For a mean annual flood the peak rate would increase 20 percent. Harr (1975) estimated that total storm flow from a large area would not increase more than 1 or 2 percent. Patric (1978) in a summary of studies in the eastern hardwoods felt that harvesting trees on a sustained yield basis would not affect downstream flooding unless there was region-wide cutting followed by fire, grazing, or agriculture that eliminated forest regrowth and destroyed the forest soil structure. Black (1966) showed that California's Eel River experienced floods of increasing magnitude and frequency following accelerated logging of old growth redwood and Douglas-fir since 1921. In Pennsylvania Reich (1972) showed that reducing the amount of forest by 75 percent in 5 to 200 square mile watersheds doubled the mean annual flood peak.

Effects of clearcutting on storm flow and snowmelt have not been measured in northern Minnesota where flooding can result from summer rains or from snowpacks that accumulate without appreciable melt throughout the winter.

The expansion of the timber industry in Minnesota will lead to aspen clearcutting of up to 105 square miles per year in the headwater areas of the Red Lake, Big Fork, and Upper Mississippi river basins. Probable changes in storm flow runoff need to be identified so that knowledgeable land-use and public policy decisions are made.

This paper summarizes an 18-year paired watershed study of rainfall and snowmelt response to clearcutting the upland part of an upland-peatland watershed in north central Minnesota. During the first year of this study one-half of the watershed was clearcut resulting in a 31 percent increase in annual water yield but a 35 percent reduction in the size of snowmelt peak discharge (Verry, 1972). This paper reports the nine-year response of: (1) peak discharge, (2) storm flow volume, and (3) timing of peak discharge following clearcutting. Both snowmelt and rainfall runoff events are evaluated.

SITE DESCRIPTION

The paired watersheds are located in the Marcell Experimental Forest and are typical of upland-peatland watersheds in northern Minnesota. Both watersheds are contiguous, round, and have no predominant aspect.. The highest elevation on the two watersheds is 1,436 feet with a range of 31 feet on the clearcut watershed and 52 feet on the control; upland slopes average 10 percent and bog slopes 0.1 percent. Each watershed has centrally located bogs (Histosol) surrounded by sandy loam (Alfisol) uplands. The soils of the area developed in glacial till 8 to 12 feet thick. Mature aspen (*Populus tremuloides* Mich.) that were harvested averaged 70 to 75 feet in height. Black spruce (*Picea marina* (Mill.) B.S.P.) of 25 to 35 feet in height occurred in the bogs.

Water tables in the bogs of both watersheds are elevated about 20 feet above the regional ground water table. Most of the annual precipitation on each watershed is evapotranspired, but 5 to 10 inches leaves as surface stream flow, and some percolates to the regional aquifer through 50 to 70 feet of till and buried sands. The hydrology and hydrogeology of these watersheds are discussed by Bay (1967, 1969, 1970). Eighty percent of the annual precipitation occurs from April 1 to November 1, mostly as rain. May through August are the highest rainfall months, each averaging about 4 inches. Snowfall averages 5.2 inches water equivalent, much of which is converted to water yield.

The control watershed often exhibits a double peak for larger runoff events or when the water table is high in the bogs. The control watershed has a second small bog located at a higher elevation which controls the runoff from approximately one-sixth of the watershed. This bog stores water during small events or dry antecedent conditions, but contributes to storm flow during large events or when its water table is high.

METHODS

Precipitation and stream flow data have been collected since 1962 on paired watersheds designated No. 4 (treated) and No. 5 (control). Stream flow was measured with type H flumes and stage recorders. Eighteen years of stream flow from paired watersheds 4 and 5 were examined. After nine years of calibration, clearcutting began in December 1970 on the aspen upland of watershed 4. One-half of the watershed was clearcut before snowmelt in 1971, and the remainder of the upland or 71 percent of the watershed before the growing season in 1971. All merchantable aspen was removed.

Rainfall events that produced at least 0.02 area-inches of storm flow volume were examined. The size of peak discharge, storm flow volume, and timing of the peak were analyzed.

Separating base flow from storm flow (or quick flow) was difficult because of the extremely drawn out recession limb of most storm flow hydrographs. Such hydrograph characteristics are typical of upland-bog watersheds which exhibit temporary storage and gradual release of water to streams. Baseflow was separated by connecting a straight line from the beginning of hydrograph rise to a point on the recession limb defined by $N = A^{0.2}$, where N is the time (days) after peak, and A is the area in square miles (Linsley, et al., 1958). Storm flow was terminated 52 hours after peak for the control watershed and 42 hours for the clearcut watershed.

Linear and nonlinear regression equations were developed for the preharvest calibration period (1962 to 1970) and postharvest period (1971 to 1979) for rainstorm analysis of instantaneous peak discharge, storm flow volume, and time to peak. Nonlinear relations were developed for rainfall events because of the temporary storage effect of the small second bog on the control watershed. The relation giving the best fit for rain events in the calibration period was:

$$(\text{clearcut}) = b_0 + b_1 (\text{control})^{0.25} \quad (1)$$

TABLE 1. Characteristics of Control and Clearcut Watersheds Before Clearcutting (from Verry, 1972).

Watershed	Size (acres)	Soils: Uplands (sandy loam) (percent)	Soils: Uplands (sands) (percent)	Soils: Bog (peat) (percent)	Average Annual Precipitation (inches)	Average Annual Stream Flow (inches)	Volume of Timber Per Acre*: Upland, Aspen-Birch (cubic feet)	Volume of Timber Per Acre*: Bog, Black Spruce (cubic feet)
Control	130	73	10	17	30.5	4.2	3,820	1,440
Clearcut	84	71	0	29	30.4	7.6	3,040	1,100

*On stems > 0.5 inch d.b.h.

where clearcut and control are the respective hydrograph parameters peak discharge (cubic feet per second per square mile:CSM), or storm flow volume (area inches). Time to peak was evaluated to the nearest 0.5 hours from hydrograph rise to peak flow using a simple linear regression between clearcut and control watersheds.

The post-harvest period was divided into three periods (1971 through 1972, 1973 through 1975, 1976 through 1979) to compare changes immediately after harvesting with those accompanied by the regrowth of vegetation. An F-test was performed to evaluate the null hypothesis (H_O) that there is no difference between the slopes (β) of pre- and post-harvesting regression equations, H_O: $\beta 1 = \beta 2$ (Draper and Smith, 1966). All comparisons were made with $\alpha = 0.05$ (95 percent confidence level) determined as:

$$F = \frac{ss_W - ss\,\Omega/2}{ss\,\Omega/(n_1 + n_2 - 4)}$$

where ss Ω is the sum of the residual sum of squares of the preclearcutting and post-clearcutting regressions with $(n_1 + n_2 - 4)$ degrees of freedom and ss_W is a residual sum of squares of pooled pre- and post-clearcutting data with $(n_1 + n_2 - 2)$ degrees of freedom.

Effects of clearcutting and regrowth on the size of snowmelt peak flow was assessed with a linear regression relating nine years of peak flow (CSM) from the treatment and control watershed prior to logging. A 95 percent confidence interval for single values was constructed to which post-logging data are compared. The year 1971 is treated as a single value because logging was only one-half complete at the time of snowmelt. Two of the post-logging years (1973 and 1977) had so little snow that little runoff was produced. The remaining six years of post-logging data were then regressed (treatment on control) to test whether the entire post-logging period was different from the prelogging period. An F-test similar to that for rainstorm comparisons was used ($\alpha = 0.05$).

Changes in timing of snowmelt peaks were assessed with a simple tabulation of "date of peak" for both watersheds before and after logging. In our climate, snow usually accumulates from November throughout the winter with only minor melting at the surface. Melt normally occurs as one large event with minor daily fluctuations in April but rain on snow sometimes occurs.

Changes in snowmelt volume were assessed by linear regressions comparing the control and treatment watershed for nine years before clearcutting and nine years after clearcutting with $\alpha = 0.05$. Snowmelt volume was taken as March plus April stream flow. Snowmelt peak flows occurred between April 7 and April 28. When a snowmelt peak occurred in the last week of April the volume data were extended for seven days past the peak. This occurred in three of the 18 years.

Frequency of annual rainfall peak discharges before and after clearcutting were analyzed for both watersheds, using the log Pearson Type III distribution (U.S. Water Resources Council, 1976).

RESULTS

Snowmelt Runoff

During the spring of 1971, only one-half of the watershed was completely clearcut causing the snowmelt peak to decrease 35 percent below the predicted peak (Figures 1 and 2). This reduction was caused by a desynchronization of melt that resulted in two distinct peaks from the treated watershed. The first peak was from snow melting in the cut area; this was followed four days later by a slightly larger peak from the uncut area (Verry, 1972).

During subsequent years, measurable snowmelt peaks from the treated watershed increased up to 143 percent. All but the 11 percent increase in 1974 were significant at the 95 percent level (Figure 2). Some variables relating to peak snowmelt size are listed for both pre- and post-logging data in Table 2. The early melt response measured on the one-half cut watershed in 1971 continued for the completely clearcut upland in subsequent years; snowmelt runoff from the cut area peaked an average of five days earlier than the forested control. Similarly the number of days to peak (time from the day stream flow doubled the previous day's flow at the onset of melt to peak flow day) was reduced an average of five days by clearcutting. Rain on the snowpack (during April and before the peak flow) was 1.63 inches or less and probably did not cause substantial melt (U.S. Army, Corps of Engineers, 1960). Large soil water deficits in 1968 and 1977 kept snowmelt peaks low, and low winter precipitation kept snowmelt peaks low in 1963 and 1973. High winter precipitation in 1966 did not result in a high peak flow because alternating warm and cold periods about a week apart released the total snowpack slowly. The

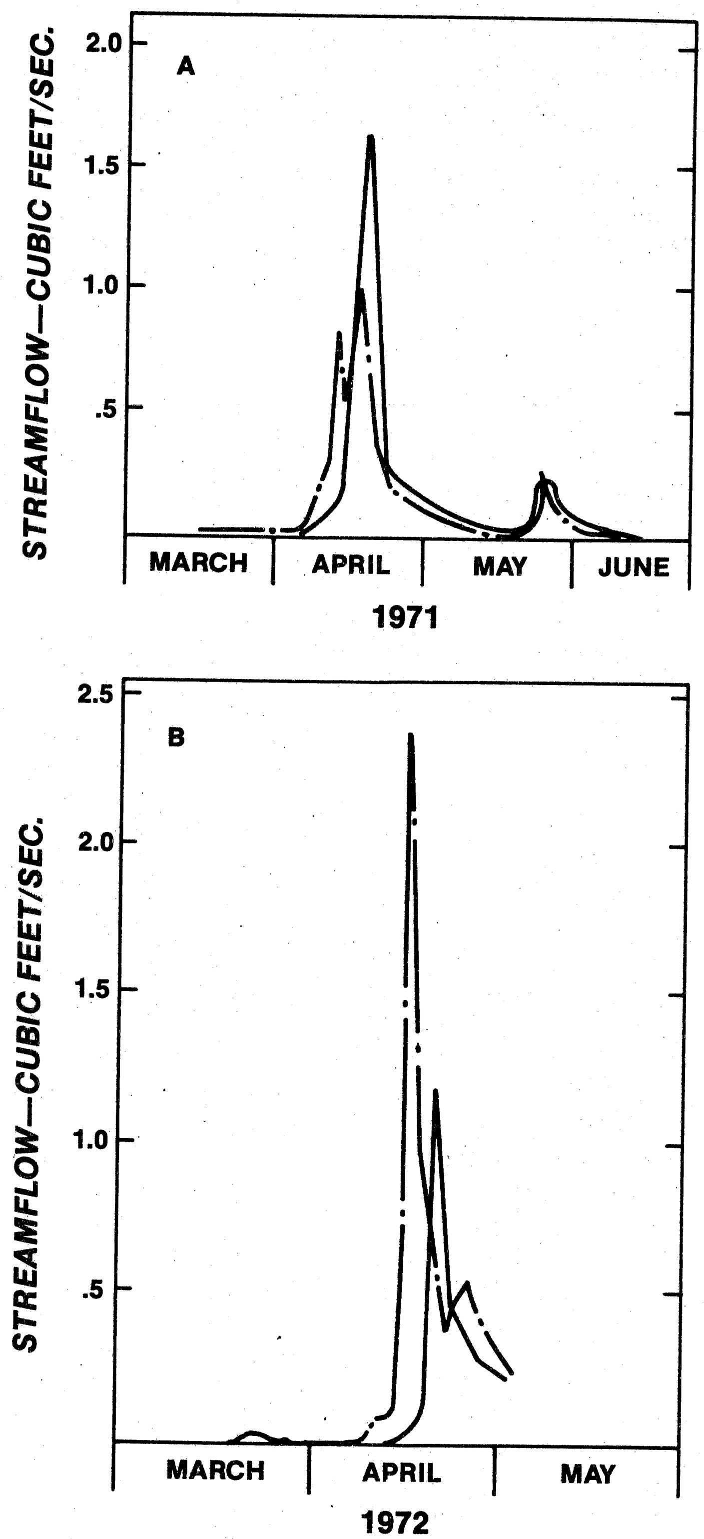

Figure 1. Snowmelt Peak Discharge From a Clearcut Watershed (broken line measured, solid line predicted from control): (A) With One-Half of the Watershed Clearcut, and (B) With the Entire Upland (71 percent of the watershed) Clearcut.

highest snowmelt peaks before logging in 1969 and 1970 and those showing the greatest response to clearcutting in 1972 and 1979 were associated with winter precipitation above 7 inches and maximum air temperatures above 60°F the day before or on the day of peak snowmelt. They also had at least one night above freezing before the peak.

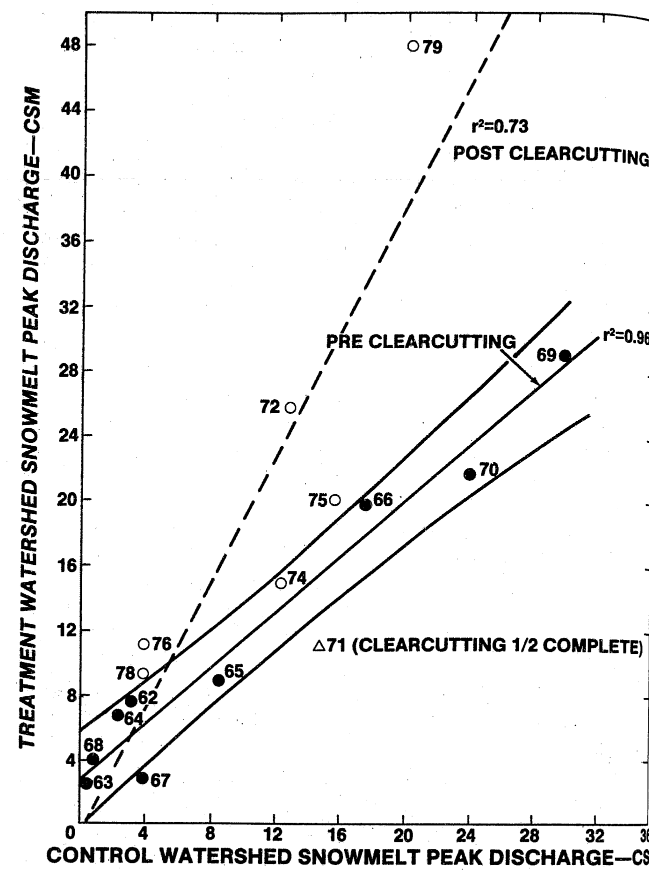

Figure 2. Changes in Snowmelt Peak Size Relation After Clearcutting and Regrowth. Solid line and circles are preclearcutting data with a 95 percent confidence band for individual values. Broken line and circles are post-clearcutting. The triangle (1971) is with one-half of the watershed clearcut. (There was no snowmelt discharge in 1971 and 1973.)

The regression of all snowmelt peaks following complete clearcutting and regrowth (between treated and control watersheds) also showed a significant increase in peak size between the pre- and post-logging (Figure 2). While clearcutting increased peak size snowmelt volumes (March through April flow) did not change.

Rainfall Runoff

Instantaneous peak discharges from rainfall on the clearcut watershed were significantly higher than before clearcutting for the entire 1971 through 1979 period (Figure 3a). By analyzing the 1971-1972, 1973-1975, and 1976-1979 periods separately, however, the peak flows during the last period were

TABLE 2. Treatment Watershed Variables Possibly Related to Peak Snowmelt Discharge, and Peak Timing Data Before and After Harvest (1962-70 mature aspen forest, 1971 clearcutting one-half done, 1972-1979 aspen regrowth).

	Treatment Watershed									Control Watershed
Year	Fall Soil Water Deficit (inches)	Rain Prior to Snowmelt (inches)	Overwinter Precipitation (inches)	Maximum Air Temperature Near Peak (°F)	Days to Peak (number)	Days Treatment Peak Occurred Before Control (number)	Peak Snowmelt Discharge (CSM)	Minimum Relative Humidity Near Peak* (percent)	Nights Without Freezing Before Peak (number)	Peak Snowmelt Discharge (CSM)
1962	--	0.85	6.94	58	11	0	7.5	50-68	2	3.2
1963	--	0.74	4.00	40	6	0	2.6	100-78	4	0.6
1964	--	1.63	5.75	52	10	0	6.7	42-26	0	2.8
1965	--	0.44	6.28	47	12	0	9.0	33-56	0	8.7
1966**	--	0.50	12.56	60	34	0	20.1	100-100	2	17.4
1967	--	0.55	6.96	60	11	0	2.9	20-70	1	4.0
1968	6.43***	0.90	7.51	64	10	1	2.8	24-15	1	1.1
1969	2.01	0.98	8.63	66	9	0	28.8	22-18	2	30.1
1970	2.77	0.68	8.79	67	21	0	21.6	60-50	1	24.2
1971	4.73	0.06	8.29	64	11	5,1	11.4	60-100	0	17.5
1972	0.61	1.07	7.06	61	7	5	25.9	18-18	1	12.9
1973	1.55	0.24	3.82	70	--	--	<0.1	--	--	<0.1
1974	1.19	1.14	5.54	51	6	3	15.1	19-30	0	12.5
1975	2.41	1.02	10.58	50	13	6	20.1	50-100	1	15.9
1976	3.47	0.41	5.48	57	10	5	10.8	28-40	1	4.2
1977	10.44	1.43	6.12	78	--	--	<0.1	--	--	<0.1
1978	0.22	1.10	5.98	55	9	9	9.0	34-32	0	4.4
1979	2.20	0.52	8.93	64	6	1	48.2	50-100	3	20.1

*On day of maximum air temperature and the following day.

**Double peak occurred on treatment and control watersheds caused by alternating warm and cold periods. Peaks occurred on April 16 and 24; table data is for the 16th.

***Soil water deficit not measured on designated treatment watershed 4; estimated from control watershed 5. Average field capacity for a 7.5 foot profile on the treatment watershed is 16.57 inches.

found to be no longer different from the preharvest period (Figure 3b).

Storm flow volumes increased after harvesting but the effects were no longer significantly different after 1972 (Figures 4A and 4B). The exact year that harvesting effects were no longer significant could not be determined as a year by year regression analysis would have had a limited number of sample points.

The timing to peak flow from rainfall events was unaffected by clearcutting.

Rainfall Runoff Frequency Analysis

Annual rainfall peak discharges from the clearcut watershed increased for recurrence intervals of 2 and 10 years, as determined from the eight-year period following clearcutting (Table 3). Annual peak discharges for the control watershed during this same post-treatment period, conversely, decreased for these same recurrence intervals. The implication is that the frequency curve shifted upward as a result of clearcutting and not as a result of higher runoff producing storms. Average annual and 10-year recurrence interval peaks were increased approximately 1.5 and 2.5 times the preharvest peaks.

DISCUSSION AND CONCLUSIONS

Rain Storms

Storm flow peak size doubled after clearcutting but this effect lasted only three to five years. Storm flow volume also doubled, but this effect lasted only two years. These results are compatible with seven of the studies reported in the introduction and not compatible with four studies reported where cutting was partial or complete. The increases in storm flow peak size and volume are likely due to an increase in soil water and a subsequent decrease in available storage volume in the clearcut area (Verry, 1972). Flow delivery in these watersheds is subsurface to the bog and through the bog to an outlet stream. Road and major skid trail disturbance on the treated watershed was less than 2 percent. The decrease in treatment effect with time since logging is accompanied by aspen regrowth and is consistent with a return to prelogging levels of annual water yield evident in this experiment. Clearcutting aspen forests should not affect rain caused flooding in large watersheds because the effect is short lived and because aspen clearcutting on a sustained yield basis would not occur on more than 2 to 3 percent of an area in any given year. If clearcutting occurs extensively in a given watershed, then some consideration should be given to culvert sizes because peaks may be double those occurring for aspen stands five years and older.

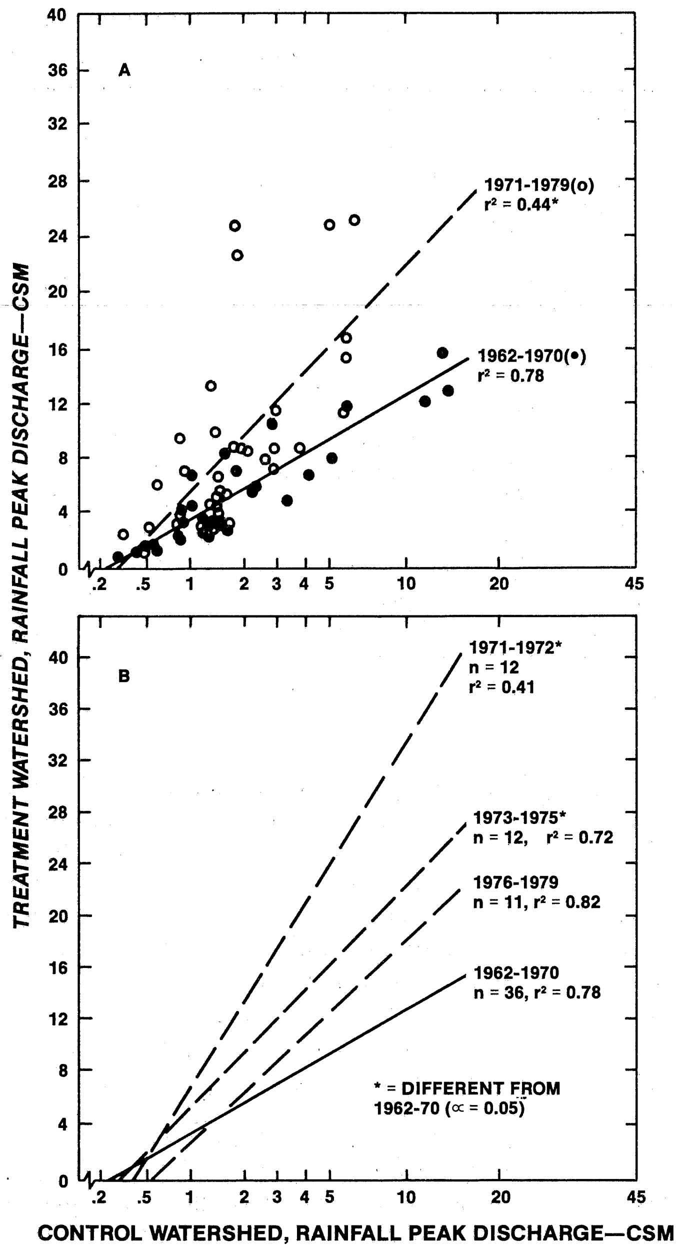

Figure 3. Relation Between Control and Treatment Watersheds for Rainfall Peak Discharge. (A) Nine years after clearcutting (broken line) and nine years before clearcutting (solid line). (B) Normal peaks tended to return to preclearcutting levels.

Snowmelt Peaks

Snowmelt peak discharge size is a function of energy and the amount of water in the watershed. Table 2 can be examined with reference to the five highest flows for the control watershed that occurred in 1966, 1969, 1970, 1971, and 1979 – years of regional flooding in northern Minnesota rivers. From these data, a sequence of events is hypothesized that will lead to regional snowmelt flood flows regardless of clearcutting conditions. First, fall soil water deficits are less than 3 inches; second, winter precipitation accumulates over 8 inches; third, at least one night temperature after the onset of melt stays above freezing followed by a maximum day temperature over 60°F; and fourth, the melt rate may be increased by condensation melt if humidities stay at or near 100 percent during the day as happened in 1966, 1971, and 1979. This hypothesis is for an area with a strong continental climate where snowpacks accumulate throughout the winter and snowmelt occurs all at once. In Minnesota, this is roughly the area north of 46°15′ latitude and may apply in similar areas of northern Wisconsin and Michigan and Canada. Variables such as temperature and relative humidity should not be interpreted as strictly causative factors. However, temperature is the result of net radiation, the primary driving force for snowmelt and high relative humidities suggest that condensation may be an important source of energy for snowmelt.

Annual snowmelt peaks were approximately doubled and the timing was about five days sooner following clearcutting, but these changes were not accompanied by increases in snowmelt-runoff volume. Unlike rainfall induced peaks, the increased size of snowmelt peaks was primarily due to a change in heat transfer rather than reduced soil moisture deficits. Heat is transferred to the snowpack by absorbed shortwave (solar) radiation, net longwave (terrestrial) radiation, condensation, convection, conduction from the ground and the heat content of rain water. Usually the contribution of heat from the ground and rain is small (Reifsnyder and Lull, 1965). The remaining factors – shortwave and longwave radiation, condensation and convection – are thus the major sources of heat energy and are strongly affected by forest conditions. The greatest changes in heat flow are usually found when conifer forests, rather than hardwood forests, are clearcut. In our case, however, during the first summer after clearcutting, 41,000 stems per acre of aspen suckers were established. These grew to a height of 6 feet by August of 1971, and with natural thinning, to 20 feet before the 1979 melt. The crowns of mature stands extend from 35 to 75 feet above the ground. Although little change in shortwave radiation may be expected, longwave radiation to the snowpack from the dense, low growing sprouts is likely greater than that from mature canopies 35 to 75 feet above the ground. Convection and condensation may also change, but such sources of heat would usually not result in the observed changes in snowmelt peaks.

Our snowmelt results agree with the high values from Hubbard Brook (Hornbeck, 1973) and those of extensive patch cutting in Alberta (Swanson and Hillman, 1977). They differ from many other studies, probably because of the way environmental factors affect energy input and subsequent snowmelt. Hendrick, *et al.* (1971), evaluated the impact of elevation, slope-aspect, and forest cover using a snowmelt model with air temperature, dew point, solar radiation, cloudiness, and wind speed in large watersheds in New York and New Hampshire. They showed that spatial diversity in forest and open conditions, elevation and slope-aspect all contribute toward spatial diversity in snowmelt timing and rates. In mountainous watersheds of the Northeast, elevation and slope-aspect factors can override vegetation effects, even though forest-open diversity helps to spread melting (Federer, *et al.*, 1972).

For the eastern United States Hendrick, *et al.* (1971), concludes that (1) drainage basins consisting of mostly open, low, and flat lands are most prone to snowmelt flooding; (2) watersheds of large elevation range or highly varied forest cover are relatively safe from snowmelt flooding; (3) meterological conditions most likely to produce snowmelt flooding are combinations of high temperatures with high dew points and strong winds; and (4) strong solar radiation, will seldom, by itself, produce snowmelt flooding. These conditions are not unlike those presented in Table 2.

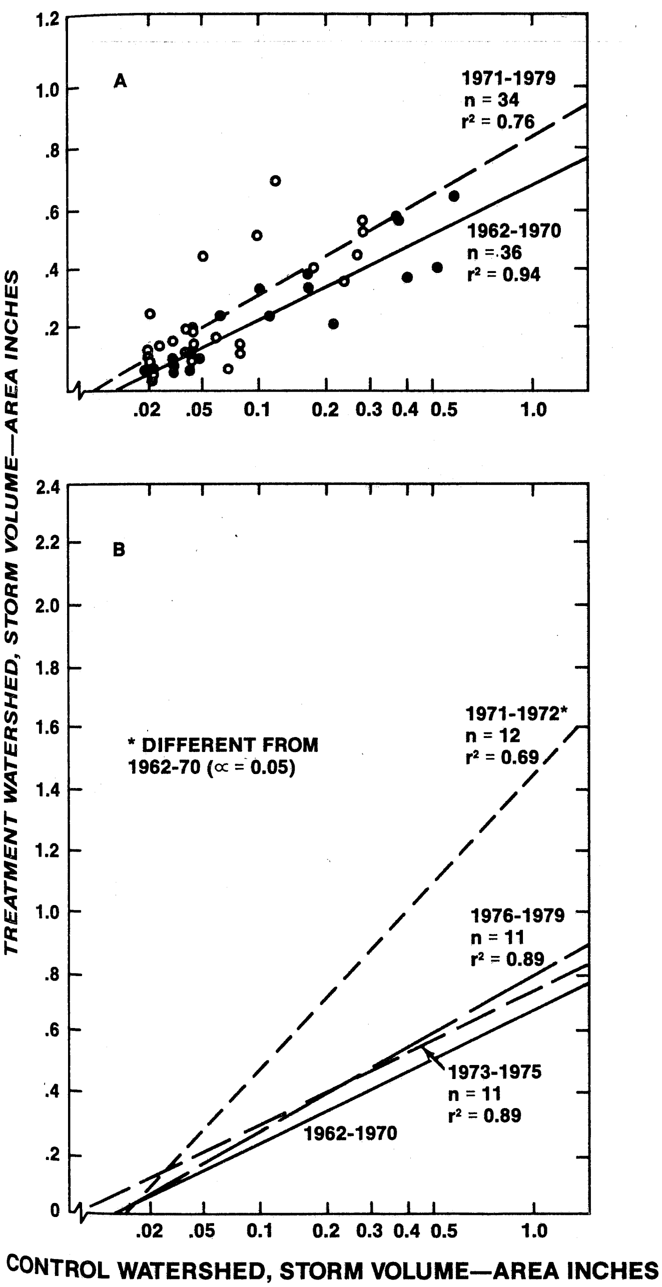

Figure 4. Relation Between Control and Treatment Watersheds for Rainfall Storm Volume. (A) Nine years after clearcutting (broken line), and nine years before clearcutting (solid line). (B) Normal volumes tended to return to preclearing levels.

TABLE 3. Changes in Recurrence Intervals for Rainfall-Runoff Peaks on Control and Clearcut Watersheds Following Clearcutting.

Recurrence Interval	Control Before* (CSM)	Control After** (CSM)	Harvested Before (CSM)	Harvested After (CSM)
10 Year	13.9	11.8	19.0	51.0***
2 Year (average)	3.0	2.9	7.2	11.5***

*Based on the 1962 through 1970 period before clearcutting the treatment watershed.
**Based on the 1971 through 1978 period following clearcutting.
***Exceed the 0.05 limit curve developed from preharvest period (1962-1970).

In northern Minnesota, elevation and slope-aspect diversity are low, thus forest/open conditions provide most of the environmental diversity. The large increase in snowmelt peak in 1972 and 1979 with recent clearcutting and the reduced peak in 1971 associated with a one-half clearcut give us limited data to address the concept of forest/open diversity. We hypothesize the relation of cover diversity to snowmelt peak size in Figure 5. If mature forest conditions are used as a base, clearcutting up to 60 percent of a watershed may reduce or not significantly affect snowmelt peak discharge. Clearing more than 60 percent of a watershed may double the size of snowmelt peaks.

Under normal cutting cycles in sustained yield forests clearcuts and 10-year-old clearcuts would exist on 20 to 25 percent of a watershed and the snowmelt peak may actually decrease below that of mature forests. Extensive clearing may occur where conversion to agriculture or preparation for mining takes place in addition to timber harvesting. When this exceeds 60 percent of a watershed, snowmelt peak flows will increase when soil water and weather conditions follow the flood producing sequence. If clearcut harvesting results in over 12 percent of an area being heavily disturbed with roads, skid trails, etc., this may also increase peak flows temporarily (Harr, *et al.,* 1975; Harr, 1976). In watersheds where extensive forest clearing or soil disturbance occurs, the increased flooding and associated damage will also depend on the size of the river channel and floodplain and the presence of structures to regulate flooding. Increases in peak discharge were measured in the present study from a watershed containing 20 percent peatland. This fact alone can decrease the size of peak flows (Conger, 1971); thus our results should be considered conservative if applied to watersheds not containing wetlands.

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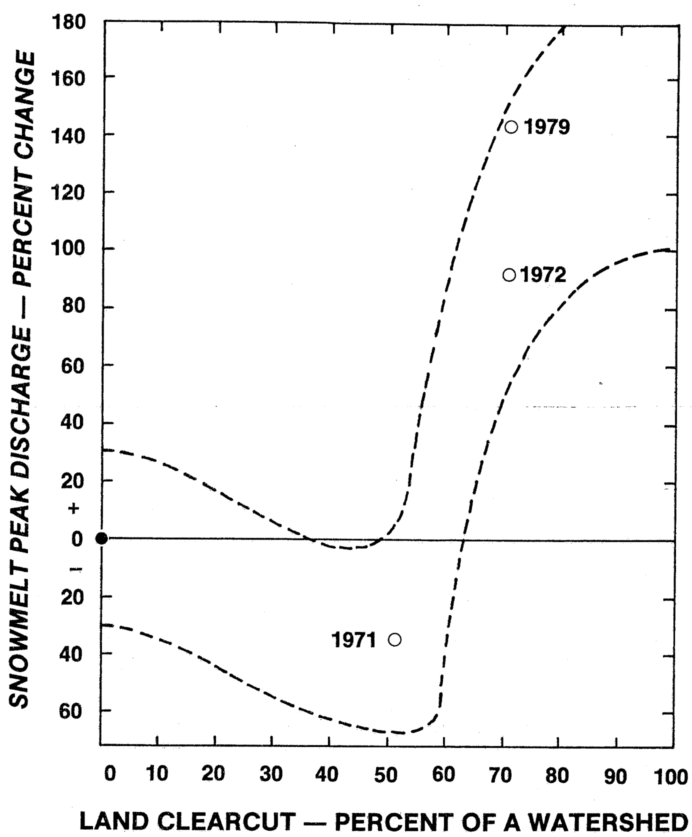

Figure 5. Relation Between the Portion of a Watershed Clearcut (with regrowth for at least nine years) and the Change in Snowmelt Peak Discharge Size Compared to Mature Aspen Forest Conditions. Circles are measured; lines hypothesize an envelope of response for northern Lake State conditions.

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