CHANGES IN SNOWMELT RUNOFF AFTER FOREST CLEARING ON A NEW ENGLAND WATERSHED

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ABSTRACT

Clearing a hardwood forest on a 39-acre watershed located in the White Mountains of New Hampshire advanced cumulative streamflow an average 4 to 8 days during periods of major snowmelt. Peak flows and high-flow volumes increased in the early part of the snowmelt season and decreased in the later part as a result of earlier and more rapid snowmelt on the cleared watershed. Total volume of streamflow for the entire snowmelt season was not significantly changed by clearing the forest. Results suggest that clearing as much as 25 percent of a hardwood forested area would not greatly affect the volume of downstream flows during the snowmelt season.

FORESTED WATERSHEDS in mountainous terrain are the headwaters for all the major rivers in New England. During an average winter these watersheds accumulate 3 to 4 months of precipitation in the form of snowpack. Spring meltwater from this snowpack frequently combines with heavy rainfall, and as much as 40 to 50 percent of the annual runoff may occur from mid-March to mid-May. The timing of this concentrated runoff from forest land determines whether or not a spring flood will occur.

At the Hubbard Brook Experimental Forest, located in the southwest corner of the White Mountain National Forest, small gaged watersheds are being used to explore the possibilities of influencing snowmelt runoff from forested areas. During December 1965, one of eight forested watersheds now being gaged at Hubbard Brook was cleared of all forest vegetation. Changes in runoff during the three snowmelt seasons since forest clearing were recorded.

This is the second paper about this Hubbard Brook study to be presented at the Eastern Snow Conference. Federer (1968) previously discussed the physical factors that influence snowmelt on the cleared watershed.

THE STUDY AREA

Two adjoining watersheds are being used in this experiment. Watershed 2, which has been cleared, covers 39 acres; watershed 3, used as an untreated control, covers 105 acres (fig. 1). Both watersheds have southerly aspects and average slopes of 20 to 30 percent. Elevations range from 1,600 to 2,400 feet.

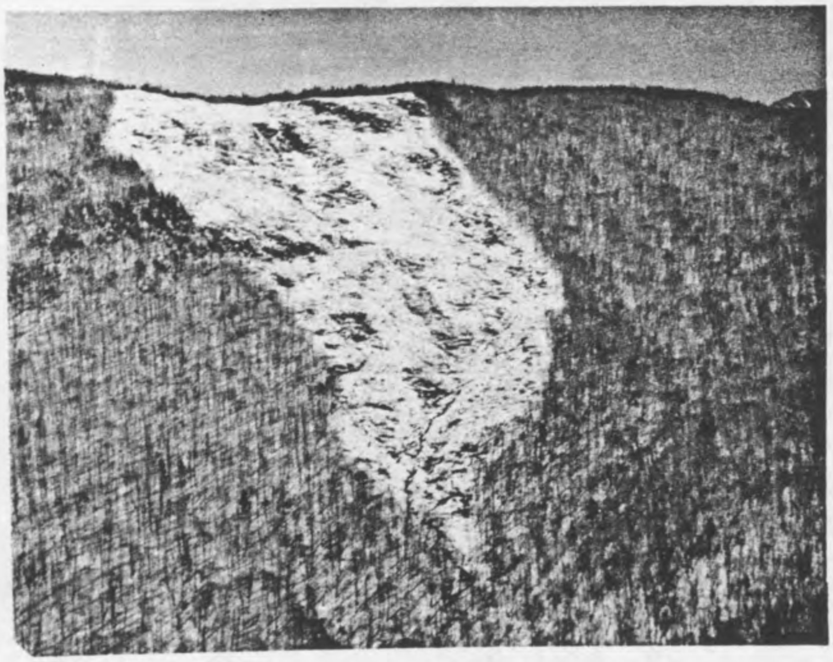

Figure 1.--Watershed 2 after forest clearing. The control watershed is adjacent drainage on right.

Precipitation averages about 48 inches annually, of which one-fourth to one-third occurs as snow. A snow cover usually persists from mid-December till mid-April; and a peak accumulation of about 40 to 50 inches, with 8 to 12 inches of water content, occurs in March. The continuous snow cover, together with the several inches of forest humus, insulates against the formation of soil frost. As a result, infiltration capacities remain high throughout the winter and spring; and practically all water that reaches the stream channels does so as subsurface flow.

The Hubbard Brook watersheds typify the erratic monthly distribution of streamflow that is common for most of New England. For the control watershed during the 10-year period 1958-67, an average 38 percent of annual flow occurred in April, while only 5 percent occurred over the combined growing-season months of June through September (fig. 2). A forest treatment that would distribute flow volumes more evenly would obviously be beneficial.

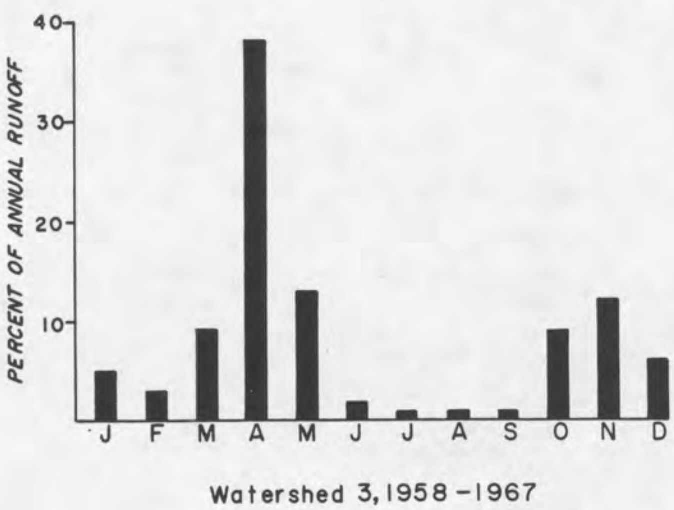

Figure 2.--Percentage of annual streamflow, by months, for the control watershed during the period 1958-67. Streamflow averaged 26.5 area-inches per year for the 10-year period.

Before clearing of watershed 2, the forest stand was predominantly 60-year-old northern hardwoods with widely scattered patches of red spruce. All trees were cut and left where they fell. Branches and stems were lopped to within 3 feet of ground level. Herbicides have been applied each summer since the 1965 clearing to maintain vegetation-free conditions as nearly as possible.

EFFECTS OF TREATMENT

The control-watershed concept has been used to determine the effect of forest clearing upon several streamflow quantities and characteristics. Streamflow records were collected from watersheds 2 and 3 under undisturbed forested conditions for the 8-year period 1958-65. Data from this calibration period were used to develop predictive equations in the form of straight-line regressions of watershed 2 on watershed 3 for various time periods and for peak flows.

After completion of forest clearing, streamflow values from watershed 3 were inserted in the regression equations to estimate what watershed 2 streamflow values would have been under undisturbed conditions. Differences between the estimated values and actual measured values for watershed 2 indicate the effect of treatment. The magnitude of the differences has been tested for statistical significance by using the t-distribution (Snedecor 1956, p. 138).

A logical and easy place to look first for the effects of forest clearing is in the streamflow totals for the months during which major amounts of snowmelt runoff occur. Differences in soil moisture storage between the two watersheds are relatively small during these months, so any changes in streamflow totals for the cleared watershed can be attributed directly to changes in snow water contribution.

In each of the 3 years after forest clearing, the major melt activity on the study watersheds has occurred around the end of March and the beginning of April, and snowmelt runoff may continue into early May. Analyses of streamflow totals for these 3 months show that timing of the snowmelt contribution was definitely changed by forest clearing (table 1). Streamflow increased in March as snow melted earlier and more rapidly from the cleared watershed than from the control watershed; streamflow then decreased in April and in two of the three Mays as snowmelt runoff caught up from the forested control watershed.

A note of caution should be added at this point. The magnitude of the monthly increase or decrease depends on the exact dates when the major melt activity occurs; thus it may not always completely illustrate treatment effects. For example, the above analyses showed an advance for the years in which snowmelt occurred in both March and April.

Table 1.--Effect of treatment on monthly discharge, in area-inches

Month	1966			1967			1968		
	Untreated estimate	Actual	Change	Untreated estimate	Actual	Change	Untreated estimate	Actual	Change
March	5.52	7.60	+2.08*	2.35	3.57	+1.22*	8.42	10.30	+1.88*
April	7.11	6.14	-.97	11.16	10.97	-.19	7.94	6.08	-1.86*
May	4.29	3.96	-.33*	5.13	4.37	-.76*	5.34	5.96	+.62*

* Significant difference at 5-percent level.

Conceivably these same treatment effects would have been completely masked if weather conditions had restricted snowmelt and snowmelt runoff to a single month, say April. For this reason, it is better to study the snowmelt period day to day through its entirety rather than on a month-to-month basis.

Changes in timing of snowmelt runoff are better illustrated in figures 3 and 4, which are plottings of cumulative percentage of streamflow for March 1 through May 15 (the interval in which the effects of snowmelt may appear in the hydrograph). The graphs indicate two important bits of information for any selected date: first, the difference between percentage of cumulative flow that has passed from the watersheds; and second, the number of days cumulative flow is advanced by forest clearing.

The 1966 snowmelt interval (fig. 3) was punctuated by two major snowmelt periods separated by a prolonged cold spell. By the end of the first melt period, which occurred March 18-28, cumulative flow from the cleared watershed was about 14 percent higher than that from the control. This difference increased slowly until it reached 22 percent on April 14, the start of the second melt period. All remaining snow disappeared from

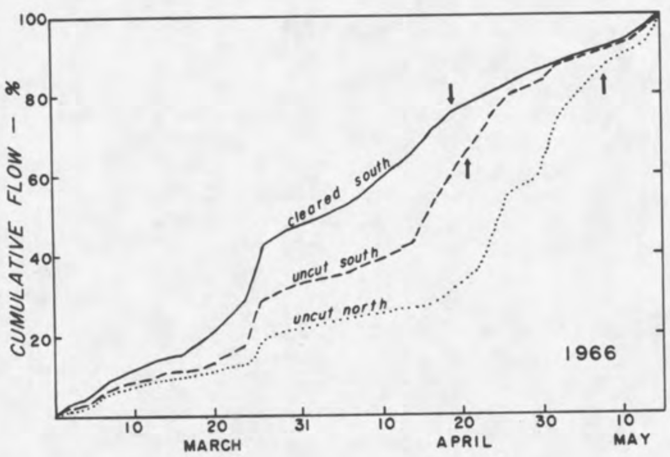

Figure 3.--Cumulative streamflow for 1966. Arrows denote date of complete snow disappearance.

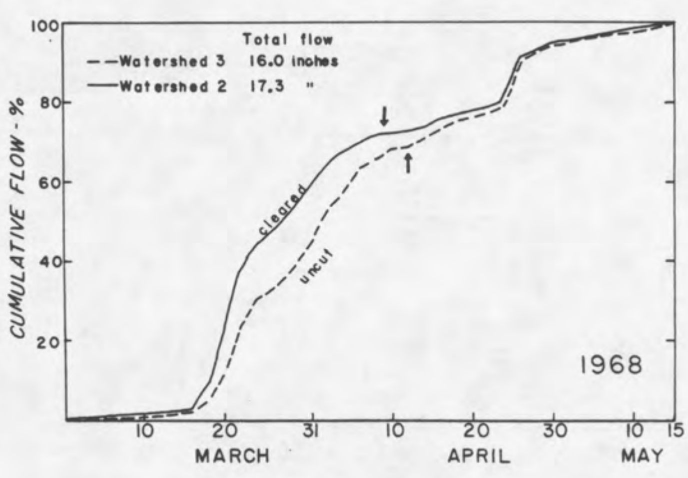

Figure 4.--Cumulative streamflow for 1968. Arrows denote date of complete snow disappearance.

both watersheds during the second melt period, but snow-water contribution was considerably greater from the control watershed as evidenced by the rapid convergence of the cumulative flow lines after April 14. Significantly, between the two melt periods, cumulative flow from the cleared watershed ran as much as 17 days ahead of the control. And from the start of the first major melt period on March 18 until complete snow disappearance on April 19, the cumulative flow-line for the cleared watershed ran an average 8 days ahead of the line for the control.

Figure 3 also includes cumulative flow for a forested, north-facing Hubbard Brook watershed. The delay in snowmelt runoff due to aspect provided a third distinctly different cumulative flow line that lagged as much as 21 days behind the south-facing control watershed and 28 days behind the cleared watershed.

Differences in cumulative flow during 1967 (not shown) and 1968 (fig. 4) were much smaller than in 1966. In both 1967 and 1968, cumulative flow from the cleared watershed ran an average 4 days ahead of the control during periods of major snow-water contribution, and the maximum advance during either year was only 8 days. The year-to-year differences are due largely to the rapidity of snowmelt. In 1966, snowmelt was more gradual and spread over a relatively long time span, permitting the cleared watershed to advance well ahead of the control. In 1967 and 1968, much of the snow cover on both watersheds melted during a short span of warm, rainy weather, thus tending to minimize any differences in snowmelt runoff.

Cumulative streamflow data have also been analyzed statistically to insure that the differences shown by figures 3 and 4 are due to effects of forest clearing and not to other physical differences between watersheds. The statistical analyses were based on number of days required to pass selected percentages of flow for the March 1 to May 15 interval. Results for 50 percent of cumulative flow are shown in table 2; the number of days has been converted to dates for convenience. The advances of 11 days in 1966, 4 days in 1967, and 5 days in 1968 correspond exactly to values picked from the cumulative flow plottings, indicating that the effects of forest clearing can be portrayed graphically. This is not surprising in view of the fact that the maximum difference in the 50-percent flow dates for the two watersheds during the 8-year calibration period was only 2 days. The 50-percent flow dates are useful in that they occurred within a few days of the

Table 2.--Statistical analysis of 50-percent flow dates, based on March 1 to May 15 interval

Year	Date 50 percent of cumulative streamflow passed		Advance in cumulative flow
	Untreated estimate	Actual	Days
1966	April 15	April 4	11*
1967	April 9	April 5	4*
1968	April 1	March 27	5*

* Significant at 5-percent level.

peak of major melt activity, when we are most interested in knowing the effects of forest treatment.

High-flow events occurring during the snowmelt season also reflect advances in timing of snowmelt runoff. Table 3 shows results of an analysis of instantaneous peaks for snowmelt runoff events in which discharge exceeded 20 cubic feet per second per square mile (c.s.m.) on the control watershed. Early-season peaks were increased due to the speedup in snowmelt contribution from the cleared area. Peaks occurring later in the melt season after snow water had been depleted were often greatly reduced.

Table 3.--Effect of forest clearing on instantaneous peaks that occurred during the snowmelt season

Date	Peak flow		
	Untreated estimate	Actual	Change
	C.s.m.	C.s.m.	C.s.m.
1966			
March 25	58.59	79.15	+20.56*
April 17	33.53	11.56	-21.97*
1967			
April 2	62.24	72.73	+10.49*
April 10	41.31	44.11	+2.80
May 3	41.31	24.43	-16.88*
1968			
March 22	39.16	46.69	+7.53*
April 1	48.57	27.65	-20.92*

* Statistically significant at 5-percent level.

The total volume of discharge above 20 c.s.m. for individual high-flow events has also been analyzed. Events were included when discharge on both the control and cleared watersheds exceeded 20 c.s.m. for at least 60 minutes. Table 4 shows data for all three post-treatment years, but the effects of forest clearing are perhaps best illustrated by 1968. For the first high-flow event of 1968 (March 18-22), the actual volume of flow above 20 c.s.m. was more than twice the untreated estimate. However, in the subsequent high-flow events of 1968, volume above 20 c.s.m. was less for the cleared watershed, apparently because most of the snow water had already passed during March 18-22.

Despite the advances in timing of snowmelt runoff and accompanying increases and decreases in high-flow events, total volume of streamflow from the cleared watershed for the snowmelt interval was little changed. Discharge during all three post-treatment intervals was slightly higher than estimated (table 5), but the largest increase was not statistically significant. Though these changes in total flow are minor, it is interesting to speculate about what might have caused these values to increase or decrease. For example, interception losses must have been reduced after forest clearing.

Table 4.--Effect of forest clearing on individual high flow volumes above 20 c.s.m., in area-inches

Date	Total discharge above 20 c.s.m.		
	Untreated estimate	Actual	Change
1966			
March 24-25	0.44	0.80	+0.36*
1967			
April 1-3	2.50	2.18	-0.32
April 10	.33	.25	-.08
May 3	.15	.02	-.13
1968			
March 18-22	2.45	5.23	+2.78*
March 23-24	.52	.36	-.16
April 1	.84	.24	-.60*

* Statistically significant at 5-percent level.

Table 5.--Effect of forest clearing on total flow during the March 1 to May 15 snowmelt interval, in area-inches

Year	Total flow for March 1 to May 15		
	Untreated estimate	Actual	Change
1966	15.20	16.06	+0.86[1/]
1967	16.63	16.97	+.34
1968	17.31	17.33	+.02

[1/] Changes in total flow not statistically significant.

In a study conducted at Hubbard Brook, Leonard (1961) found that 12 percent of the precipitation that occurs when the hardwood tree canopy is bare of leaves was intercepted. On watershed 2, decomposition and compression of slash was such that by winter 1967 there was very little opportunity for interception, especially after the snowpack reached a depth of 2 feet or more. On the other hand, we must consider the possibility that sizable amounts of snow may have blown off the watershed in the absence of a forest stand. Also sublimation, evaporation, and condensation rates at the snow surface must have been affected by forest clearing. It is entirely possible that these factors compensate each other, resulting in no significant change in total volume of streamflow.

DISCUSSION

The above results show three important effects of forest clearing on snowmelt runoff:

1. Cumulative streamflow was advanced by an average of 4 to 8 days, and by as much as 17 days during the period of major snowmelt contribution.

2. Earlier and more rapid snowmelt on the cleared watershed caused peak-flow volumes to increase in the early part of the melt season and decrease in the later part.

3. Total volume of streamflow for the March 1 to May 15 interval was not significantly changed.

The first two points reflect changes in timing of snowmelt runoff. These are important, particularly in light of how they might affect downstream flows.

The relative influences of changes in timing of runoff from the 39-acre watershed are quickly lost when this runoff joins streams from untreated areas. However, streamflow data from this study are useful for demonstrating the downstream changes that could be expected if a large percentage of a given area were cleared.

To illustrate, figure 5 shows a plotting of daily flows for watersheds 2 and 3 combined for the 1968 snowmelt interval. Each daily point was obtained by adding together the area-weighted daily flow from the two watersheds. The dotted line connects estimated values for daily flow from the combined watersheds if forest clearing had not been performed. The watershed 2 values used in plotting this line were estimated from a relationship established during the calibration period. The solid line connects actual daily flow from the combined watershed areas; thus this line includes any changes due to the forest clearing performed on the 27 percent of the total area occupied by watershed 2. Nearly all snowmelt contribution took place from March 16 through April 13; aside from this period, the two sets of daily-flow values were nearly equal, and only one line is shown.

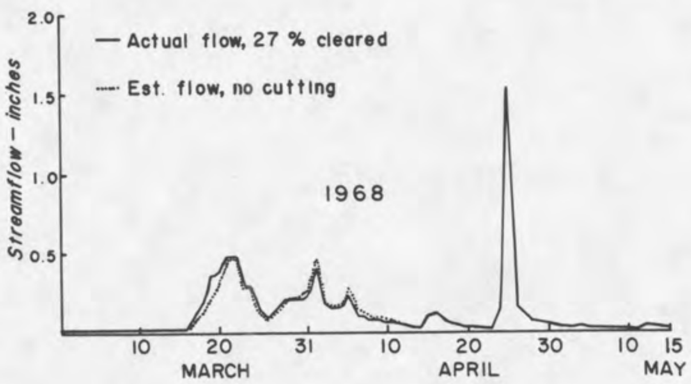

Figure 5.--Daily streamflow for watersheds 2 and 3 combined for 1968.

The nearness of the two lines during the periods of snowmelt contribution shows that forest clearing on 27 percent of the total area on a south aspect had surprisingly little effect. Daily streamflow totals increased, and advanced slightly during the early melt period that occurred around March 20; these streamflow totals were correspondingly reduced during the melt period that extended from March 30 through April 13. The maximum daily difference between the two plotted lines was only 0.10 area-inch (or about 2,750 gallons per acre per day), and for most of the March 16 to April 13 period the lines seldom differed by more than 0.02 area-inch. From these values we concluded that clearing as much as 25 percent of hardwood forest land on south aspects of large watersheds would probably not affect downstream flood conditions.

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