CHANGES IN SNOWMELT RUNOFF CAUSED BY REFORESTATION 1/

By

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Hydrologists have known for many years that snow cover in forested areas responds differently to wind, sun, and temperature than that in open fields. The ultimate effect, of course, of any change in the manner of accumulation or disposition of snow is a change in the regimen of streams in the affected area.

Many studies have been made, and others are now in progress, to explore more fully the complex relations between snowmelt and streamflow, and to measure them quantitatively. In a recently-completed study of reforestation effects in New York State, several interesting changes in streamflow were found. Total runoff on a yearly basis has been reduced by about 8½ inches. During the dormant season, the reduction is 5½ inches, or about 31 percent; during the growing season, the reduction is 3 inches, or about 52 percent. The changes in the dormant season, taken as the six-month period ending April 30, reflect primarily the effect of the forest development upon the accumulation and disposition of snowfall in the area, and are discussed in detail in this paper. In the study areas, the accumulated snow has completely melted by the end of April of each year.

The study area

In 1932, a cooperative program between the U. S. Geological Survey and the New York State Conservation Department was begun to determine the effect upon streamflow of a major reforestation program then in progress in New York State. An experimental area of 3.12 square miles in the Shackham Brook watershed near Truxton, New York was selected for the study. The watershed is located in the glaciated areas of central New York State about 30 miles northeast of Ithaca. Shallow Pleistocene deposits of glacial till cover a bedrock of shales and limestones to depths ranging from less than 2 feet along the ridges to about 20 feet in the valleys.

Between February 1931 and April 1933, 58 percent of the Shackham Brook watershed - 1,146 acres - was reforested. The reforestation followed an irregular pattern, being bounded by the landlines of the State-acquired tracts, as shown in Figure 1. More than one and a quarter million trees were planted in about the following proportions: 40 percent Norway spruce, 21 percent white pine, 16 percent Scotch pine, 11 percent red pine, 6 percent European larch, 4 percent balsam fir, and 2 percent black cherry and black locust. However, early mortality rates were high, and replantings of about one-third of the original totals were made between 1934 and 1939. The trees were permitted to grow without cutting or thinning. A field survey in 1958 indicated that the various plantings ranged from 4 to 7 inches in diameter and from 18 to 30 feet in height. The survey also indicated that almost complete crown closure had been obtained.

A control for the Shackham Brook area was originally established in an area drained by Fall Creek near Ithaca, New York, but was abandoned after several years because of poor correlation of the streamflow records with those of Shackham Brook. In 1938 a new control area was established in the Albright Creek basin, located about 8 miles southwest of Shackham Brook. The Albright Creek area is 7.08 square miles, and similar to the Shackham Brook area in topography, soils, geology, and other basin characteristics. Land use, consisting of about 20 percent second-growth deciduous woodlots and about 80 percent pasture and cropland, has not changed significantly during the study period.

Analyses of winter flows

In central New York, precipitation in the form of snow may occur at any time from November through April. The seasonal pattern of snowfall is quite variable but generally follows a pattern of snowfall in November followed by melting, then a variable accumulation of snow during mid-winter with some occasional melting, followed by the major release of snowmelt in March or April. Weather records indicate that snowfall in the Shackham Brook area averages over 80 inches per season, and has occasionally exceeded 120 inches.

Selection of study period.-

Because of the dates when snowfall may be expected in the Shackham Brook area, streamflow for the period November 1 to April 30 was studied to detect changes attributable to the effect of the reforestation on the

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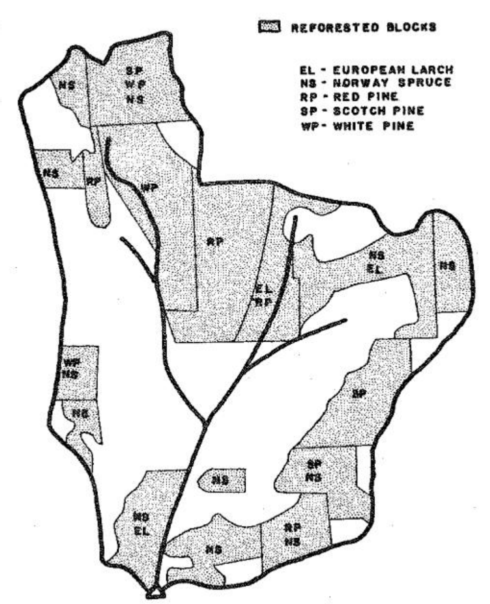
1/ Publication authorized by the Director, U. S. Geological Survey.
2/ U. S. Geological Survey, Washington, D. C.



REFORESTATION IN SHACKHAM BROOK AREA

Figure 1

interception and disposition of snow. Two studies were made; the first was a study of total runoff during the period, and the second a study of the peak discharges during the period.

Analyses of total runoff.-

Total runoff was studied by two methods. First, the runoff from the Shackham Brook area was compared with that of the control area, and second, the relation between precipitation and runoff for the Shackham Brook area was analyzed.

Because land-use in the Shackham Brook area changed gradually as the trees grew in the reforested areas, it was assumed that any change in streamflow also would be gradual and would be related to the growth of the trees. Time was therefore used as a variable to define the rate of change in the relationship between the flows of the experimental and the control area. A study of several model equations indicated that the equation best fitting the data was

$$R_S = a + b_1 R_A + b_2 TR_A \qquad (1)$$

in which R_S is the total runoff for Shackham Brook for the winter period, R_A is the runoff for Albright Creek for the same period, and T is the position of the period in a chronological sequence beginning with T = 1 for the first year of record. The selection of this equation was based on a comparison of the standard errors of estimate for the several model equations considered. The form of the equation indicates that the magnitude of a change in runoff is dependent upon the magnitude of the associated runoff from the control area as well as the time sequence.

A multiple-regression analysis based on equation 1 was computed as

$$R_S = + 0.76 - 1.17 R_A - 0.015 TR_A \qquad (2)$$

in which the b_2 coefficient of -0.015 was determined significant at the 5-percent level. The relationship shown graphically in figure 2 indicates that at the mean runoff for Albright Creek, runoff of Shackham Brook for the period of record was reduced by an average of 0.23 inch per year.

For the precipitation-runoff relation in the Shackham Brook area, a model similar to equation 1 was used, substituting precipitation on the Shackham Brook area for runoff from the Albright Creek area. The regression equation based on data for 1934-57 was computed as

$$R_S = + 14.76 + 0.89P_S - 0.011 TP_S \qquad (3)$$

The b_2 coefficient of -0.011 was determined significant at the 5-percent level. This relationship is shown graphically in figure 3. At the mean value of precipitation for the period of record, a reduction in runoff of 0.21 inches per season is indicated. This agrees very well with the figure of 0.23 inches per season determined by comparison of runoff with that of the control area. The equation also indicates that with average precipitation, the expected runoff for 1957 is 5.5 inches less than prior to 1934.

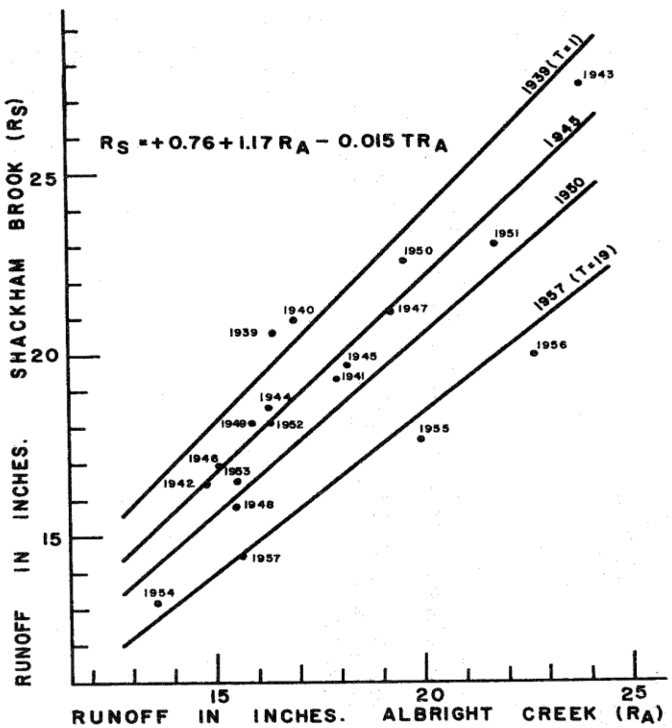
Analysis of peak discharges.-

Peak discharges for the period November 1 to April 30 were analyzed by correlating the peak discharge of Shackham Brook with the concurrent peak discharge on Albright Creek. The concurrent peak discharge on Shackham Brook was identified as that peak resulting from the same meteorologic event which caused the peak on Albright Creek. All peak discharges above 10 cfs per square mile on Albright Creek were used in the study. A total of 114 concurrent peaks were tabulated for the November-April period from 1939 to 1957.

A multiple-regression relationship using time as a third variable to describe changes was computed as

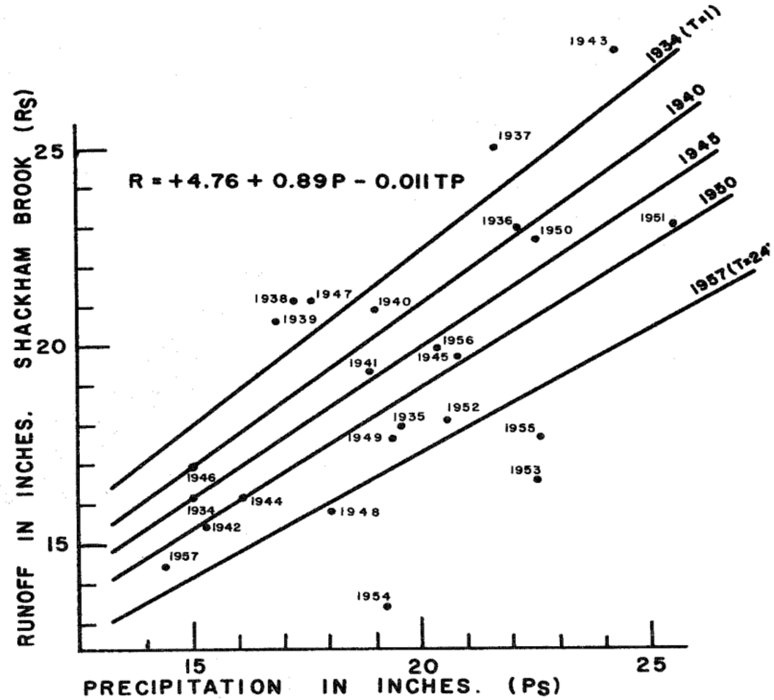
$$\log S = - 0.133 - 0.977 \log A - 0.012 T \qquad (4)$$

in which S is the peak discharge of Shackham Brook, A is the concurrent peak discharge of Albright Creek, and T is the period during which the peak occurred, listed chronologically (T = 1 for the period ending April 30, 1939). The coefficient of - 0.012 was determined significant at the 1-percent level. The relationship which is shown graphically in figure 4 indicates a reduction of 41 percent; that is, for a peak



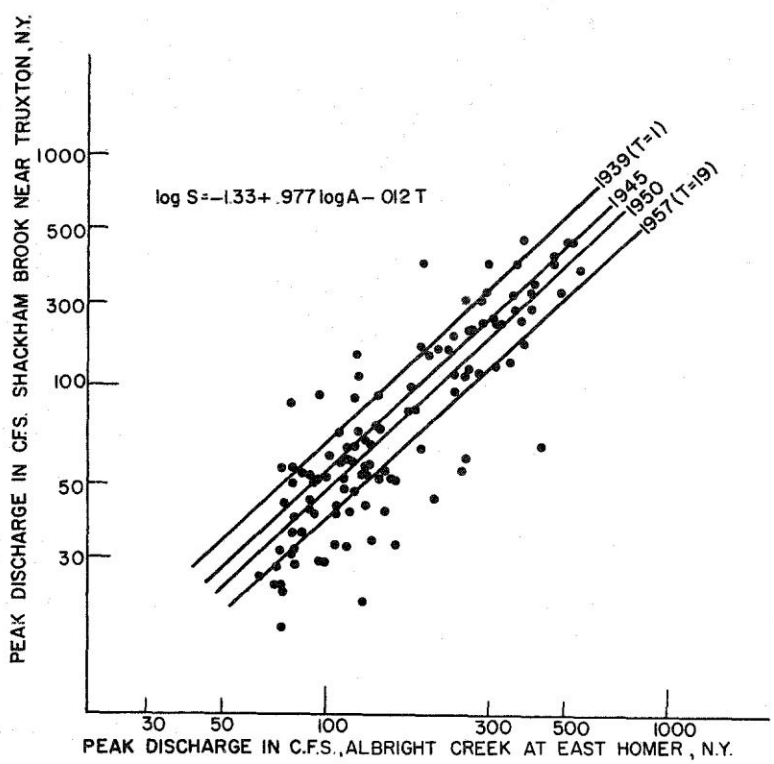
RELATION BETWEEN RUNOFFS FROM SHACKHAM BROOK AREA AND ALBRIGHT CREEK AREA FOR THE 6-MONTH PERIOD ENDING APRIL 30.

Figure 2



RELATION BETWEEN RUNOFF AND PRECIPITATION IN THE SHACKHAM BROOK AREA FOR THE 6-MONTH PERIOD ENDING APRIL 30.

Figure 3



RELATION BETWEEN PEAK FLOWS OF SHACKHAM BROOK AND ALBRIGHT CREEK FOR THE 6-MONTH PERIOD ENDING APRIL 30

Figure 4

discharge of a given magnitude on Albright Creek, the comparable peak discharge on Shackham Brook was 41 percent lower in 1957 than a comparable peak in 1939. Further analysis of the data by months also indicated an internal seasonal trend. Appropriate modification of equation 4 indicated that average variations by months are as follows:

Month	average reduction for month, in percent
November	66
December	59
January	51
February	41
March	30
April	16

In addition to these significant results, it was also noted that for the spring peaks occurring in March and April, discharges of Shackham Brook and Albright Creek correlated to a lesser degree for the latter part of the period of record than for the early part. Equation 4 indicated that the exponent of the relationship between peaks was essentially unity. This permitted the study of the spring peaks as a direct ratio of the peak on Shackham Brook to that on Albright Creek. Peaks for March and April of 1939-44 were used for the early group, those of March and April of 1952-57, the latter. The ratio in each group approximated log-normal distributions. A plotting of the cumulative frequency for each group showed the two curves crossing at the 85-percent point. This point was also verified mathematically. The two frequency curves are shown in figure 5. An analysis of the distributions indicates that although in general, peaks on Shackham Brook in the latter years of record have been substantially reduced by reforestation, about one out of seven peaks now is relatively higher than during the early years of record. No relationship was found between the ratio of peaks and the magnitudes, indicating that this one-peak-in-seven could be of any magnitude, large or small.

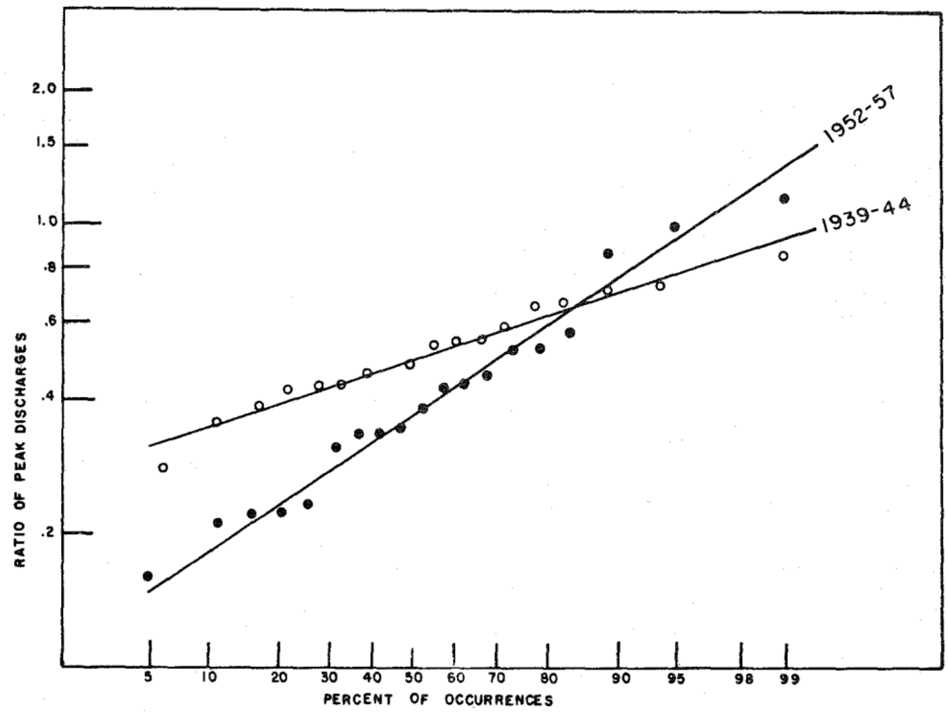
Discussion of Results

The effect of forest cover on snowmelt is complex, and may act in opposite directions. Forests may decrease the total runoff by intercepting greater amounts of snow and by increasing the capacity of the soil to absorb and store snowmelt. On the other hand, forests may increase the total runoff by reducing evaporation through their protection of the snowpack from wind and radiation. The New York study, as well as other similar studies, shows a net decrease in total runoff caused by forest effects. In the Shackham Brook area, the reduction in runoff is substantial - more than five inches in a 25-year period.

The effect of forest cover on the peak discharges is more difficult to interpret. Some peaks on Shackham Brook are now relatively lower than during the early years of record, while others are now relatively higher. The reduction in peak discharges is attributed largely to the delayed melting of that portion of the snowpack which is now protected by the forest cover. This results in a desynchronization of snowmelt from open and forested area. For example, studies in the Frazer Experimental Forest have shown that the snow cover disappeared from almost all of a 42-acre clearing while still covering about half of the area of the surrounding forest. Engineers' observations in the Shackham Brook area also indicate a retarding of snowmelt in the new forest areas, although no quantitative measures of the effect are available.

What happens to the snow in the forest area that is retarded from melting? First of all, a peak discharge is reduced because the snowmelt from the forest is retarded. The snow in the forest area then melts at a later date, and given the right condition, contributes to a peak discharge at this later date. In the Shackham Brook area, the later contribution of snowmelt from the reforested areas to the subsequent peak discharge is sufficient to make about one out of seven recent spring peaks high relative to a comparable peak during the early years of record.

Although the specific results of this study are limited to one small area in central New York State, the general results are believed applicable to other reforested areas in the State where snowfall is a major part of winter precipitation. However a better understanding of the complex effect on streamflow of the interrelations between forest cover and snow can be obtained only by exhaustive studies of this effect under various conditions of forest cover and snowfall, such as those now being conducted in experimental forests throughout the country.



CUMULATIVE FREQUENCIES OF PEAK DISCHARGE RATIOS FOR EARLY AND LATE PERIODS

Figure 5