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FLOW FREQUENCY RESPONSES TO HARDWOOD-TO-GRASS CONVERSION AND SUBSEQUENT SUCCESSION

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ABSTRACT

A 8·9 ha (22 acre) catchment at the Coweeta Hydrologic Laboratory in western North Carolina was cleared of hardwood forest in 1958 and 1959 and seeded to Kentucky 31 fescue grass in 1959 and 1960. Grass production was high in years when fertilizer was applied and water yield was very similar to that expected from the original forest cover. As grass production declined, so water yields rose, with important increases in the magnitude of both low frequency flows and, particularly, in baseflow. In 1967 and 1968, when all vegetation was deadened in the catchment, the discharge levels in all flow frequency classes were higher. Natural revegetation was then allowed and water yields gradually declined towards the expected level, although there remained a tendency for winter flows to remain higher, and for summer flows to be lower than expected. This paper updates the earlier work of Hibbert (1969) and uses flow duration curves to extend his results.

KEY WORDS Flow frequency Forest hydrology Coweeta Land use change

INTRODUCTION

There have now been a sufficient number of catchment experiments aimed at describing the change in water yield caused by forest cutting that Bosch and Hewlett (1982) were able to produce regression models to summarize these results. The cause of such changes have been successfully related to micrometeorological factors (Gash and Stewart, 1975), and using such information, preliminary attempts to model changes in evapotranspiration and streamflow have been made (Huff and Swank, 1985). Nevertheless, most attention has been devoted to the gross changes in water yield which accrue. Few reseachers have directly examined the detailed record of streamflow in the cleared catchment to discover what changes in the pattern of runoff accompany a given change in water yield. A notable exception was the paper of Hewlett and Helvey (1970) which considered changes in the size and shape of storm hydrographs. Otherwise, changes in streamflow have been noted only by implication, where monthly or seasonal differences in runoff volume have been examined (Douglass and Swank, 1972), and there has been no way of judging in which flow range the major changes have occurred. In updating the work of Hibbert (1969), this paper seeks to go beyond his (and other) studies of water yield, through the use of flow frequency analysis, in order to discover in which flow classes the significant changes in streamflow occur, following forest removal. Because of the nature of the data (discharge values grouped into frequency classes), it was not appropriate here to consider changes in the shape and timing of storm hydrographs; this analysis is confined to a consideration of changes in flow frequency.

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SITE DESCRIPTION AND HISTORY

Hibbert (1969) described in some detail a paired catchment experiment at the Coweeta Hydrologic Laboratory in western North Carolina. This paper extends his original analysis which was concerned only with the forest-to-grass conversion and did not discuss the complete deadening of vegetation which followed the first treatment, nor the subsequent revegetation. The study is located on Watershed 6 (WS 6), a 8·9 ha north-facing catchment at Coweeta Hydrologic Laboratory in western North Carolina, U.S.A. Climate of the 1626 ha Coweeta Basin is classed a perhumid, mesothermal with water surplus in all seasons (Swift *et al.*, 1988). Precipitation consists of frequent, small, low-intensity rains in all seasons with little snow. Occasional large storms are associated with severe thunderstorms or inland influences from hurricanes. March is typically the wettest month (20 cm) and October is the driest month (11 cm).

Watershed 6 receives a mean annual precipitation of 185 cm, elevations range from 696 m to 905 m, and side slopes average 45 per cent. Soils are Ultisols and are represented by Typic Hapludults with Cowee-Evard and Trimont gravelly loam series being the predominant soils on the watershed. The Coweeta Basin was selectively logged between 1909 and 1923, after which the only disturbances to WS 6 were the chestnut blight of the 1930s, and cutting of the riparian zone of 1·1 ha in 1942 (Dunford and Fletcher, 1947). By 1957, the cleared area had completely regrown and the basin as a whole was covered by an oak-hickory stand of low quality, typical of north-facing slopes in the Southern Appalachians, with scattered openings of rhododendron, mountain laurel, and other low shrubby species (Hibbert, 1969). Conversion of grass began in 1958 when all saleable timber was felled and removed. Most of the basin was seeded between March and July 1959, with a final 1·6 ha sown in March 1960. Despite fertilizer application in 1959, a nitrogen deficiency became apparent in May 1960 and was corrected by use of ammonium nitrate fertilizer, applied at 200 pounds per acre. A dense growth of grass resulted, but in successive summers the grass became steadily poorer in quality as the effects of the single application of fertilizer were lost. The only treatment received by the grass during this time was use of a foliar spray to prevent growth of shrubs and other hardwood species. In March 1965, the grass had a further application of fertilizer (600 pounds per acre of 30–10–0 NPK and 150 pounds per acre of 60 per cent potash) and again grew vigorously. In 1966 and 1967, three herbicides were used to eliminate the grass cover on WS 6. Atrazine, paraquat, and 2,4–D were applied on the entire watershed except for a 3 m buffer strip on each side of the perennial stream. Thus, during the 2-year period, there was little living vegetation on the catchment. The dead grass was not removed from the site and so the infiltration capacity remained high throughout 1967 and 1968. Subsequently, from 1968 onward the catchment was allowed to revert to successional vegetation and in the first several growing seasons, the entire area was dominated by a dense cover of a variety of herbaceous species. By 1970, some woody shrubs became established and in the ensuing 6-year period covered by this report, woody vegetation increased in importance with the dominant species being black locust (*Robinia pseudo-acacia L*), blackberry (*Rubus* spp.), and numerous vines (*Vitis* spp., *Clematis spp.*, and *Smilax* spp.).

METHODOLOGY

Stream discharge leaving WS 6 is gauged using a sharp-crested 90° V-notch weir. In Hibbert's (1969) analysis, Watershed 14 (WS 14) was used as a control. However, we preferred to use Watershed 18 (WS 18) as the control, because the weir on WS 14 was under repair for part of the later period discussed here. Watershed 18 is also a valid control because it is located within 2 km of WS 6 and the two catchments are similar in size, topography, climate, and pretreatment vegetation. Also, Hibbert used a water year which began in April. We have used a water year which begins in *May*. This is now the standard period for the Coweeta hydrometric records: records of instantaneous flow are analysed (for each minute of the record) by computer at the University of Georgia, and a flow frequency analysis produced for the four seasons, for the summer and winter halves of the year, and for the year as a whole. The *flow duration curve* produced by the computer analysis shows the percentage of time that a specific discharge is equalled or exceeded, and is thus, effectively, a cumulative frequency distribution. For each flow period analysed, the first step is to sort the flow record among 90 flow classes, between 0 and 999·999 csm (cubic feet per second per square mile). Flow frequency is defined as the number of minutes of flow in each class interval. Then, each class frequency is divided by the total number of minutes in the period to convert it into a percentage of time. Finally, class percentages are cumulated, beginning with the highest class, to obtain the percentage of time that the flow equalled or exceeded the upper limit of its respective flow class.

A procedure outlined by Fallas (1982) was used to produce a statistical relationship between the treated watershed (WS 6) and its control (WS 18) during the calibration period. Using the cumulative percentages for each flow class, linear interpolation was used to estimate the flow equalled or exceeded at 12 fixed percentages of time: 1 per cent, 5 per cent, and thereafter at each decile between 10 per cent and 100 per cent. The regression model relating the control and treated basins was as follows:

$$Q6 = 0{\cdot}35 + 0{\cdot}72\, Q18 \tag{1}$$

where $Q6$ is the flow rate at the '*n*th' percentage of time on WS 6 and $Q18$ the flow rate on the control (WS 18) at the same percentage of time. Seven years' data were used for the calibration, giving 84 points for each regression equation. For the treatment period, the flow rate for a given percentage of time can be predicted for WS 6 using the flow duration curve for WS 18. The result can then be compared with the actual flow rate observed for that percentage of time on WS 6. Two comparisons have been made here: the absolute difference and the ratio of actual to predicted discharge. Another advantage of using flow duration curves is that the total water yield for the period being analysed can be obtained by integrating the area under the duration curve. Using the trapezoidal rule, the area under the curve (for a complete water year) is equal to:

$$Q_y = 0{\cdot}13578\,(3Q_1 + 4{\cdot}5Q_5 + 7{\cdot}5Q_{10} + \Sigma\, 10Q_{20-90} + 5Q_{100}) \tag{2}$$

where Q_y is the annual yield (in inches, since the flow rates are in csm); and Q_p is the flow rate (csm) at the percentage of time indicated by 'p' (Fallas, 1982). Precipitation and water yield data for watersheds 18 and 6 (actual and predicted) are given by water year in Table V.

CHANGES IN WATER YIELD

Changes in annual water yield are shown in Figure 1. Observed and predicted water yields were obtained by integrating the flow duration curves (see above). These results were confirmed by using regression analysis to relate the actual annual water yields for WS 18 and WS 6 during the calibration period and using this equation to predict water yields for WS 6 during the treatment period. A *difference* between observed and

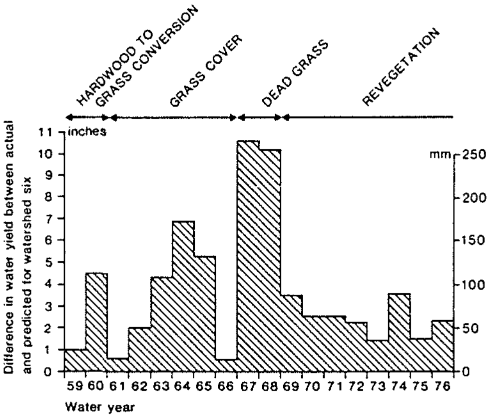

Figure 1. Changes in annual water yield from the predicted level for Watershed 6 at Coweeta for treatment phases as indicated

predicted water yield was obtained for each method and the 'paired' values were shown to be significantly correlated (at the 0·1 per cent level) with a Coefficient of Determination of 98·4 per cent. Thus, we can be confident that the water yields obtained by use of the flow duration curves are reliable. Figure 1 shows the way in which water yield increased following forest clearance; Hibbert's (1969) results are confirmed for the years with grass cover on WS 6. The dense growth of grass associated with the use of fertilizers (in water years 1961 and 1966) produced annual water yields very little different from the original forest. As the quality of the grass deteriorated between 1962 and 1965, so the observed annual water yield from WS 6 gradually rose above the predicted level. When all vegetation was deadened in the catchment, water yield rose more than 25 cm (10 inches) above the predicted level. Once vegetation began to recolonize WS 6, so the water yield gradually fell to approach the expected level.

In order to compare seasonal contrasts in water yield between the control and treated basins, regression analyis was used to produce calibration equations for each quarter of the year. These were then used to predict water yield for WS 6 during the treatment period. Data plotted on Figure 2 show the difference between the observed and predicted quarterly water yield for WS 6. These data confirm Hibbert's (1969) observation that in 1961 and 1962 the runoff in spring and early summer was less than predicted. It is not clear whether the (dense) grass began to use water earlier than the forest would have, or whether the grass used water at a greater rate at that time compared to the forest. Certainly both years had relatively dry springs, and grass is known to transpire at a greater rate than trees when the canopy is dry (Gash and Stewart, 1975). It is notable that this tendency for less runoff than expected in the period May through July consistently recurs throughout the time of forest recolonization after 1968, although this is counterbalanced by more runoff than expected in winter, a point which is further discussed below.

ANALYSIS OF FLOW DURATION CURVES

Variation in flow frequency due to climate

Flow duration curves are most conveniently plotted on probability paper. On such figures, flow may be plotted as an absolute value or a dimensionless value (flow divided by annual mean flow) to allow comparison between different years or between different basins. The shape of the flow duration curve gives a good indication of a catchment's runoff response to precipitation: a steeply sloping curve indicates very variable flow, usually from catchments with much quickflow and little baseflow; flow duration curves with a flat slope result from the dampening effects of high infiltration and groundwater storage (Burt, 1991).

One complication in this study is that the relative distribution of high and low flows varies depending on whether a particular year is wet or dry. In dry years, low flows are large relative to mean flow so that the flow

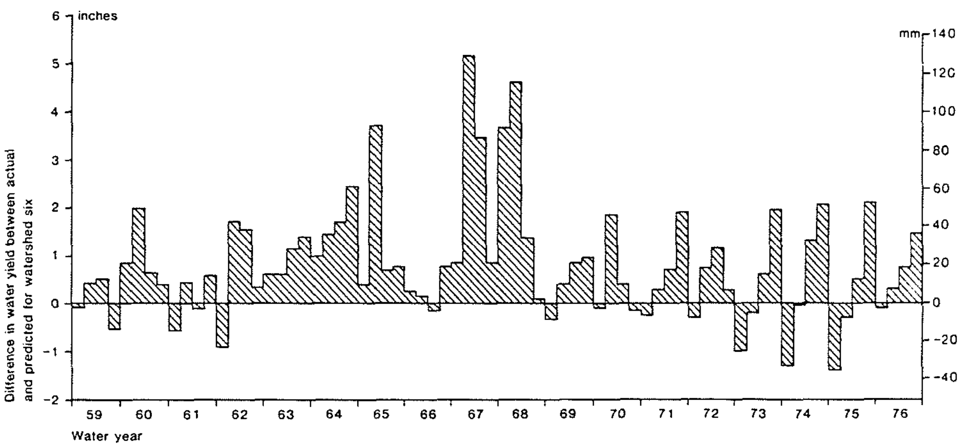

Figure 2. Changes in water yield for quarter-year periods from the predicted level for Watershed 6

duration curve appears steeper. In wet years, baseflow is relatively more important so that the flow duration curve is flatter, indicating a more uniform runoff response. This effect is shown for the control catchment (WS 18) in Figure 3(a). Given the uncontrolled nature of paired catchment experiments, this effect will be superimposed upon any variation due to changes in land surface cover. Thus, where possible, it is important to compare years with similar precipitation and runoff totals in order to minimize variations due to climate.

Annual flow duration curves during the study period

Using the method outlined above, for each year of the treatment period, the flow rate for a given percentage of time was predicted for WS 6 using the flow duration curve for WS 18 (Equation 1). This flow

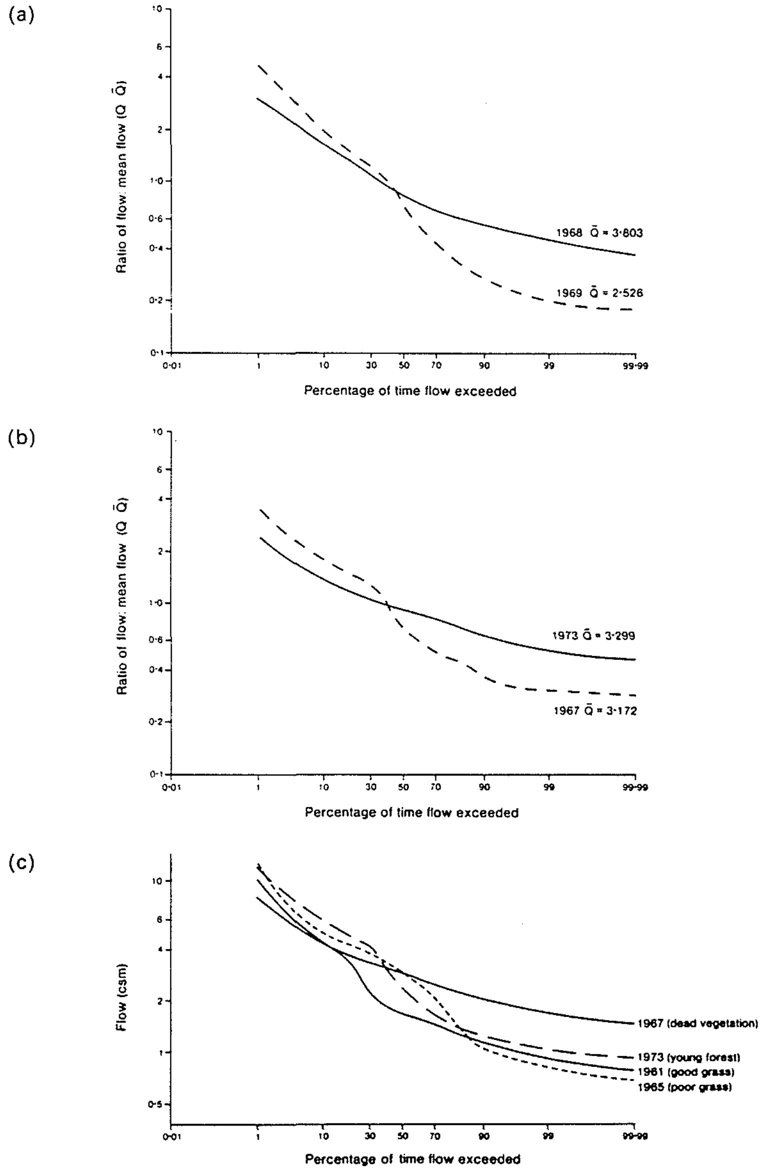

Figure 3. Flow duration curves for selected years during the study period for Watershed 18 (a) and for Watershed 6 (b and c)

rate was then compared to the observed flow rate for the same percentage of time using the actual flow duration curve for WS 6. These comparisons are given in Table I, which shows the absolute difference between observed and predicted (with a positive value where the former exceeds the latter), and on Table II, where the ratio of observed to predicted is given (the ratio is greater than 1 if the observed exceeds the predicted). As noted above, 12 points were calculated for each flow duration curve, but for simplicity only six of these are given on the tables. Apart from those years (1961, 1966) where there was a dense grass cover on WS 6, in almost every case the observed flow rate is greater than expected; this applied at all levels of flow. Selected annual flow duration curves are plotted on Figures 3b and 3c.

Table I. Comparison between actual and predicted flow duration curves for WS 6: absolute differences

	Frequency (%)					
Year	1	10	30	50	70	90
1959	+0·24	−0·09	−0·03	+0·15	+0·13	+0·14
1960	+0·47	+0·16	+0·39	+0·12	+0·53	+0·42
1961	+1·25	+0·12	+0·05	−0·02	0·00	−0·03
1962	+0·52	+0·15	+0·06	+0·40	+0·08	+0·15
1963	+0·75	+0·41	+0·36	+0·28	+0·25	+0·23
1964	+1·45	+0·55	+0·46	+0·58	+0·52	+0·36
1965	+3·83	+0·39	+0·25	+0·26	+0·31	+0·17
1966	+1·06	+0·17	−0·02	−0·04	−0·01	−0·02
1967	+0·70	+0·62	+0·61	+0·76	+0·96	+1·03
1968	+3·76	+1·23	+0·78	+0·52	+0·45	+0·40
1969	−0·25	+0·33	+0·08	+0·17	+0·18	+0·16
1970	+1·36	+0·09	+0·05	+0·09	+0·22	+0·30
1971	+0·98	+0·45	+0·18	+0·08	+0·06	+0·11
1972	+0·24	+0·24	+0·08	+0·10	+0·21	+0·20
1973	+1·34	+0·31	+0·24	−0·08	−0·06	−0·01
1974	+2·63	+0·91	+0·43	+0·20	−0·27	−0·24
1975	+0·49	+0·47	+0·06	+0·03	0·00	+0·02
1976	+1·69	+0·30	+0·23	+0·12	+0·05	−0·01

Table II. Comparison between actual and predicted flow duration curves for WS 6: relative differences

	Frequency (%)					
Year	1	10	30	50	70	90
1959	1·04	0·97	0·99	1·10	1·14	1·19
1960	1·03	1·03	1·12	1·05	1·38	1·40
1961	1·14	1·03	1·02	0·99	1·00	0·98
1962	1·05	1·03	1·02	1·15	1·04	1·11
1963	1·11	1·13	1·19	1·20	1·25	1·28
1964	1·13	1·10	1·17	1·37	1·48	1·46
1965	1·44	1·08	1·07	1·10	1·17	1·18
1966	1·11	1·05	0·99	0·97	0·99	0·97
1967	1·10	1·16	1·22	1·35	1·60	1·97
1968	1·44	1·26	1·24	1·20	1·21	1·21
1969	0·97	1·08	1·03	1·10	1·16	1·20
1970	1·22	1·03	1·02	1·04	1·11	1·19
1971	1·33	1·09	1·06	1·04	1·04	1·10
1972	1·03	1·06	1·03	1·04	1·12	1·17
1973	1·13	1·05	1·06	0·97	0·97	0·99
1974	1·17	1·14	1·09	1·06	0·82	0·72
1975	1·04	1·08	1·02	1·01	1·00	1·02
1976	1·17	1·06	1·07	1·05	1·03	0·99

In 1961 and 1966, there was higher flow than expected for the less frequent, high magnitude flows, with slightly lower than expected baseflow. From 1973 onwards, baseflow tends also to be lower than expected, perhaps indicating that the regenerating forest vegetation has a similar pattern of water use to a dense grass cover. By contrast, in 1964 and 1965 there was a poor grass cover on WS 6 with the result that the low flows were larger than expected. The ratios given in Table II show that these small absolute increases in baseflow do, in fact, represent an extra 25 to 50 per cent flow. It is this, as much as raised level of low-frequency, high discharge flows which accounts for the overall increase in water yield for these years (Figure 1). Although there was a much higher water yield in both 1967 and 1968, the years when all vegetation was deadened, the reasons differ. The year 1968 was one of the wettest of the whole period, and not surprisingly, there was a marked increase in the level of low frequency 'quickflow' in that year; given generally wetter soils, it seems that both subsurface stormflow and saturation-excess overland flow were generated in much larger quantities than previously. Infiltration-excess (or 'Hortonian') overland flow was *not* generated, since the dead mat of grass encouraged high infiltration losses. 1967 was a year of average precipitation with fewer large floods compared to 1968. In 1967, the level of low flows was substantially higher than normal; baseflow accounted for a much larger proportion of total runoff than usual. Once the forest began to regenerate after 1968, there was a tendency for low-frequency, high-discharge flows to be larger than expected. As interception losses become more important, so baseflow declines in importance and quickflow constitutes a greater proportion of total runoff. By contrast, in 1967 the lack of live vegetation meant little interception and no transpiration losses; infiltration however remained high and large volumes of baseflow were generated. This contrast is shown in Figure 3b: despite very similar mean flows, the flow duration curve for 1973 is much steeper than that for 1967, indicating more uniform flows with a lower proportion of quickflow in 1967.

Selected annual flow duration curves for WS 6 are plotted in Figure 3c: absolute levels of flow are given for four years of similar runoff volume but with greatly contrasting land cover. As previously discussed, 1967 is characterized by large total runoff and high proportion of baseflow; thus the flow duration curve has a very shallow gradient. Although the curves for 1965 (poor grass cover) and 1973 (regenerating forest) are apparently similar, certain subtle differences can be detected: although the flow level exceeded 90–100 per cent of the time is lower in 1965, the flows exceeded between 40–90 per cent are higher than in 1973. This suggests that, apart from the very lowest flows, baseflow was generally higher for poor grass cover compared to forest. Thus, runoff yield for 1965 was 5·3 inches greater than expected in 1965 whilst only 1·4 inches greater than expected in 1973. Higher baseflow and total runoff under poor grass are reflected in a more uniform flow duration curve; under forest the runoff response is more variable with floods contributing more of the total runoff. The flow duration curves for dense grass (1961) and young forest (1973) are very similar in shape, with slightly lower runoff under grass, particularly for high-discharge, low-frequency flows.

Flow duration curves in winter and summer during the study period

Tables III and IV give the ratio of observed to predicted flows for the winter and summer halves of the year. Apart from 1961 and 1966, winter flows for all frequencies are higher than expected; this is confirmed on Figure 2. During the time of 'poor' grass cover, winter baseflow is very much increased. This probably indicates that any soil moisture deficit is more quickly removed under grass, compared to forest, so increasing flow in the early part of the winter (see also Douglass and Swank, 1972). This effect would be particularly encouraged, since, under grass, low flows in summer are also much higher than expected (Table IV), implying that soils remain wetter at that time also. It is notable that winter baseflow was much higher than expected in 1967, the first year with a cover a dead grass in WS 6. In 1968, in contrast, there was little increase in baseflow. This may be because 1968 was a very wet year; high flows would be expected whatever the vegetation cover under these circumstances; therefore, high flows account for a greater proportion of total runoff in the 1968 winter.

It is notable in the 1970s, when the forest was becoming established, that the water yield in autumn was always slightly above the predicted level, despite summer flows being below the expected level. This again suggests a rapid recharge of soil moisture at that time, providing a basis for much increased flow in the latter part of the winter. In 1961 and 1966, winter baseflow is slightly lower than expected, perhaps because of

Table III. Comparison between actual and predicted flow duration curves for WS6 for the winter half of the year: relative differences

Year	Frequency (%) 1	10	30	50	70	90
1959	1·21	0·91	0·92	1·04	1·12	1·11
1960	0·99	0·96	1·07	1·06	0·97	1·26
1961	1·06	1·02	1·01	0·92	0·98	0·98
1962	1·07	1·01	1·01	1·02	0·99	1·05
1963	1·16	1·13	1·18	1·22	1·30	1·29
1964	1·21	1·13	1·14	1·18	1·44	1·29
1965	1·12	1·04	1·03	1·02	1·01	1·18
1966	1·15	1·06	1·02	0·99	0·95	0·98
1967	1·17	1·15	1·16	1·22	1·25	1·34
1968	1·09	1·03	1·01	0·99	1·04	1·11
1969	1·02	1·08	1·11	1·08	1·18	1·26
1970	1·08	0·98	0·98	0·99	0·99	1·02
1971	1·12	1·09	1·11	1·09	1·07	1·08
1972	1·11	1·09	1·03	1·02	1·01	1·16
1973	1·18	1·09	1·07	1·07	1·06	0·99
1974	1·28	1·18	1·14	1·13	1·09	0·75
1975	1·16	1·08	1·10	1·07	1·06	1·07
1976	1·14	1·07	1·06	1·07	1·07	1·04

Table IV. Comparison between actual and predicted flow duration curves for WS 6 for the summer half of the year: relative differences

Year	Frequency (%) 1	10	30	50	70	90
1959	0·89	0·95	1·05	1·14	1·41	1·72
1960	1·11	1·03	1·01	1·35	1·51	1·66
1961	1·10	0·92	0·99	1·00	1·04	0·99
1962	1·09	1·02	1·04	0·98	0·98	1·06
1963	1·06	1·04	1·15	1·23	1·39	1·53
1964	0·91	1·06	1·28	1·35	1·65	1·89
1965	1·35	1·07	1·22	1·19	1·26	1·60
1966	1·20	0·90	0·98	1·09	1·12	1·23
1967	0·86	1·09	1·48	1·85	2·13	2·23
1968	1·36	1·47	1·40	1·31	1·23	1·23
1969	1·00	0·87	1·02	1·15	1·33	1·47
1970	1·13	0·98	1·04	1·15	1·19	1·19
1971	0·95	0·93	0·95	1·09	1·13	1·21
1972	1·01	0·96	1·02	1·07	1·16	1·27
1973	0·95	0·85	0·91	0·94	0·99	1·10
1974	1·01	0·92	0·93	0·90	0·87	0·80
1975	0·91	0·86	0·92	0·92	0·94	1·08
1976	1·03	0·98	0·98	0·99	1·07	1·20

interception losses from the dense grass cover. Throughout the study period, some of the highest ratios for winter flows are associated with the low frequency (1 per cent) flows. This suggests that surface runoff in the largest flood events may be more common for the disturbed WS 6 than for an undisturbed mature forest cover. As noted above, both saturation-excess and subsurface stormflow may be involved in generating these high flows.

Summer flows for the study period (Table IV) can be divided into two parts. Prior to 1969, low and high frequency flows were generally higher than expected. For the low frequency flows, this may show that forest-to-grass conversion encourages surface runoff in the largest storms irrespective of soil moisture levels. Flows occurring between 1 per cent and 50 per cent of the time were lower than predicted in years with a dense grass cover, but higher than predicted in years where the grass cover was of poorer quality. Here, soil moisture levels appear to be crucial in that a poorer grass cover tends to result in wetter soils, so producing higher flow levels than expected for this range of flow frequencies. It was noted above, in relation to Hibbert's (1969) observation, that flow levels in spring were lower than expected when the grass growth was vigorous (see 1961, 1962, and 1966 on Figure 2). The figures for the summer half of the year tend to hide this feature, since low flow in the first quarter of the water year is offset by higher flow in the second quarter (although the lower than expected 90 per cent flow in 1961, and the 50 per cent and 70 per cent flows in 1962, must equate with the low flow in the first quarter). As expected, flow during the summers when vegetation was completely deadened in WS 6 was much greater than predicted for all flow frequencies, except for the 1 per cent flows of water year 1967 which was a relatively normal year and perhaps lacked very large storms.

After 1968 when forest cover began to recolonize, flow levels in summer gradually fell below the expected level for all frequencies. This suggests that soils were drier, and that interception and transpiration rates were higher, than for a mature forest stand. As noted above, water yields in the first quarter of the water year (May–July) were much lower than expected (Figure 2). However, because of the higher than predicted flows in winter, the overall yield for the water year as a whole remained above the expected level until at least 1976.

Reduced low frequency flows in the summer during periods of dense grass and early regenerating forest may be due to shifts in vegetation phenology. Growth and development of grass, herbs, and pioneer woody species occurs much earlier than for mature hardwoods, thus initiating transpiration earlier in the growing season and decreasing soil water storage.

CONCLUSIONS

The effects of three treatments—forest-to-grass conversion, deadening of all vegetation, recolonization—on the water yield and pattern of runoff have been examined for WS 6 at Coweeta, using WS 18 as the control (Table V). At all stages of the treatment period, the annual water yield was higher than predicted, except when the grass cover was dense following the use of fertilizer and water yield was very close to that expected for a mixed deciduous forest. Analysis of quarter-year periods showed that lower than expected flows

Table V. Precipitation and water yield for watersheds 18 and 6 for the study period

Water year	Weighted precipitation WS 18	Water yield WS 18	WS 6 predicted*	WS 6 actual*	Difference (pred − act)
1959	64·35	27·24	24·30	25·27	+0·97
1960	82·68	44·12	36·61	41·11	+4·50
1961	66·37	38·04	32·08	32·68	+0·60
1962	91·31	56·75	45·86	47·88	+1·99
1963	66·94	26·42	23·99	28·33	+4·34
1964	77·92	41·03	34·46	41·35	+6·89
1965	78·55	47·94	38·16	43·44	+5·28
1966	68·54	30·12	26·38	26·94	+0·56
1967	68·21	38·32	32·48	43·09	+10·61
1968	85·54	51·63	41·82	52·00	+10·18
1969	71·53	34·34	28·50	32·02	+3·52
1970	76·06	41·50	34·58	37·14	+2·56
1971	81·51	43·31	36·21	38·79	+2·58
1972	74·22	41·05	34·50	36·74	+2·24
1973	92·95	53·56	43·39	44·81	+1·42
1974	90·18	53·58	47·97	51·52	+3·54
1975	86·98	50·45	43·92	45·37	+1·45
1976	80·46	42·26	38·71	41·01	+2·30

All units in inches
*calculated from flow duration curve (see text for details)

occurred for the first quarter of the water year (May–July) for the dense grass, and for recolonizing forest. Otherwise, water yields were higher than expected especially in late winter. Flow duration curves were used to show that flow rates at all flow frequencies were higher than predicted in winter, except when there was a dense grass cover. In summer, flow rates for all frequencies were generally lower than expected during the time of forest regrowth. During the earlier phase of the study, flows were higher where the vegetation was poor or non-existent, but with vigorous grass growth, the flow levels which are exceeded between 1 per cent and 50 per cent of the time fell below the expected level; both baseflow and the highest flood flows were greater than expected in summer.

The use of flow duration curves raises three points which deserve further attention:

1. Flow rates at the lowest flow frequencies were consistently higher than expected. This suggests that stormflow is being produced in greater quantities than normally is the case for a forested basin. Only field observations can show the source areas and types of runoff process involved, although it seems likely that both subsurface stormflow and saturation-excess overland flow are occurring.
2. For a dense grass cover, and for recolonizing forest, water use in the spring and early summer is greater than expected as shown by the levels of flow which occurred between 1 per cent and 50 per cent of the time. This response was probably due to earlier initiation of transpiration for these vegetal covers compared to mature hardwoods although field measurements of this process are not available.
3. It is clear, for all winters studied, and for some of the summers too, that baseflow was higher than predicted; this is important for both the yield and timing of runoff. In particular, high soil moisture levels lead to much higher flows in the late winter for all flow frequencies. How these changes relate to changes in evaporative losses or to changes in soil properties is not clear. Field studies are needed to monitor directly the pattern of soil water recharge, particularly in the early winter, and to relate this to the generation of both baseflow and floods.

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