Trans. Ky. Acad. Sci., 39(1–2), 1978, 31–38

Some Hydrologic Characteristics of a Small Forested Watershed in Eastern Kentucky

EVERETT P. SPRINGER AND GEORGE B. COLTHARP
Department of Forestry, University of Kentucky,
Lexington, Kentucky 40506

ABSTRACT

Evaluation of land use–water yield relationships requires knowledge of baseline or background hydrologic characteristics of relatively undisturbed watersheds. Hydrologic data were collected in 1972–1976 on a 93.70-ha undisturbed forested watershed in the Eastern Mountain and Coalfield region of Kentucky. During that period, precipitation averaged 136.07 cm annually. Total water yield (runoff) averaged 80.20 cm or 59 percent of the average annual precipitation. Mean annual stormflow (quickflow) volume comprised 44 percent of the mean annual runoff. Steeply sloping flow duration curves coupled with a high percentage of the total annual runoff that occurred as stormflow characterizes the watershed as having "flashy" hydrologic response.

INTRODUCTION

In recent years, increased attention has been devoted to the quantity and quality of surface water that drains from forested watersheds. The Eastern Mountain and Coalfield Region is mainly forested, and contains the primary watersheds for more than half of Kentucky. The Kentucky, Licking, Big Sandy, and Cumberland rivers, that originate in the region, provide water for industrial and public use for the eastern half of the state. Several recent reports (Kentucky Department of Commerce 1975, Krieger et al. 1969) show that approximately 96 percent of the water used in the Eastern Mountain and Coalfield Region and 79 percent of the water used in the Bluegrass Region is in the form of surface water. With this demonstrated dependency upon surface water supplies, land use practices in the headwater areas can greatly affect the quantity and quality of flow of that vital resource.

In order to evaluate the current status of land use–water yield relationships, we need to know the baseline or background values of water quantity and quality produced from relatively undisturbed forested watersheds. Such values are essential yardsticks in any evaluation of environmental degradation.

Forest hydrology studies currently underway at the University of Kentucky Robinson Forest in eastern Kentucky are providing some of these much needed baseline data. Several small forested watersheds have been monitored since 1971, and this paper summarizes some of the pertinent hydrologic characteristics of one of those areas.

METHODS AND MATERIALS

Study Area

over 75 percent of the soils of Robinson

Robinson Forest lies 40.23 km south of Jackson, Kentucky, in the Eastern Mountain and Coalfield Physiographic Province. The University of Kentucky acquired the 6,075-ha tract in 1923 following logging of the virgin stands; there has been no extensive logging since acquisition. The bedrock is comprised of alternating layers of sandstones, siltstones, shales, and coal from the Pennsylvanian Age (Hutchins et al. 1976). Some layers of the bedrock are more resistant to weathering than others, therefore, the resulting slopes are dissected by benches. The deepest soils occur along the upslope sides of benches and in cove sites, while rock outcrops are common along slopes and the outslope edges of benches. From a hydrologic viewpoint, those soils are classified as shallow. The Shelocta and Rigley series, found on slopes, comprise

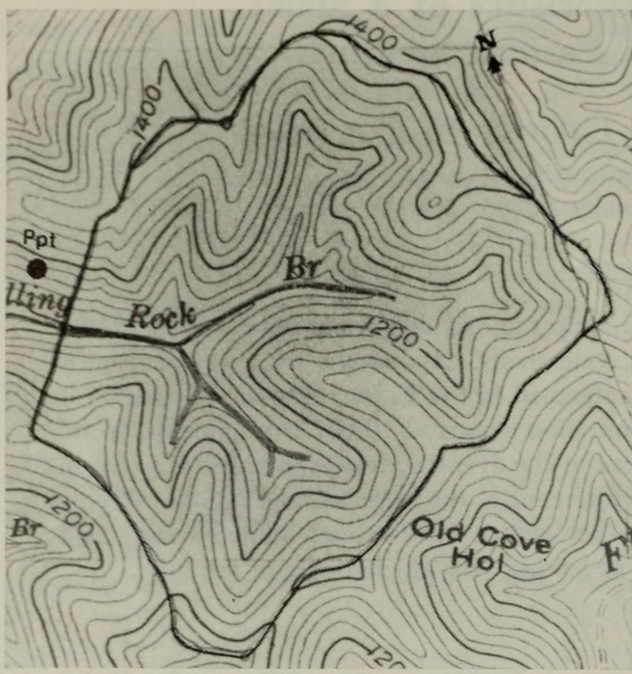

FIG. 1. Topographic map of Falling Rock Watershed.

Forest (Hutchins et al. 1976). The Gilpin and Steinsburg series are residual soils on ridgetops, and the Pope series has evolved from alluvial material along the bottoms (Graves et al. 1977).

Falling Rock Watershed is a 93.7-ha tract selected as the control watershed for future studies (Fig. 1). Its orientation is predominantly northwest, and the slopes average 44 percent. The main channel length is 670 m and slopes at a rate of 54.6 m/km. The basin is oval and the long axis runs from southwest to northeast. The 100 percent forest cover on the watershed has an average basal area of 20.40 m^2/ha, with the predominant species being oaks (*Quercus* spp.), yellow poplar (*Liriodendron tulipifera*), hickories (*Carya* spp.), and maples (*Acer* spp.). Carpenter and Rumsey (1976) published a complete checklist of species on Robinson Forest.

Measurements

Total incoming precipitation was measured with a weighing type gauge in a small clearing near the stream gauging station (Fig. 1).

Streamflow was measured continuously by a 3:1 side-sloped, broad-crested triangular weir equipped with an FW-1 water level recorder (Fig. 2). The weir cutoff wall is tied into shale on each side and across the bottom. The weir has a rated head capacity of 0.9 m, equivalent to 4,825.7 l/sec.

Data Reduction

Precipitation charts were point picked by hand, and the data transferred to computer cards. Reduction of the data to 2, 5, 10, 15, and 30-min and 1, 2, 6, and 24-hour intensities, for each event and daily and monthly totals, was accomplished by means of a previously developed computer program (Shanholtz and Burford 1967).

Streamflow charts were reduced by means of an Oscar-K chartreader available through the U.S. Forest Service, Berea, Kentucky. The Oscar-K utilizes an X–Y coordinate system, with time on the X axis and stage on the Y axis; the chartreader is interfaced with a keypunch so that values are punched directly into cards. The cards were processed into streamflow information using the Coweeta streamflow program described by Hibbert and Cunningham (1967). The output of the program includes (1) mean daily flow in lsm (liters per second per square mile), with monthly and annual summaries; (2) flow frequency by minutes; (3) stormflow information; and (4) stormflow summary by months, seasons, and years.

RESULTS AND DISCUSSION

Precipitation

The precipitation pattern is typical for this area of the United States; low intensity, long duration rainstorms predominate during winter, and high intensity, convectional storms occur in summer. Snow is an insignificant form of precipitation and no attempt has been made to determine its relative contribution (percentage of total). Mean annual precipitation for 1972–1976 was 136.07 cm; the driest year was 1976 when 117.85 cm fell and the wettest was 1974 when 156.99 cm fell. The amounts and distribution of the monthly and annual pre-

FIG. 2. V-notch weir used for measurement of streamflow.

cipitation for the study period (Table 1) indicate that March receives the highest mean monthly precipitation of 17.19 cm and August is the lowest, receiving 6.80 cm.

Streamflow

Monthly and annual streamflow for 1972–1976 are shown in Table 2. Mean annual streamflow was 80.20 cm, 59 percent of the

TABLE 1.—MONTHLY, ANNUAL, AND MEAN PRECIPITATION (CM), FALLING ROCK WATERSHED, 1972–1976

Month	Year					
	1972	1973	1974	1975	1976	$\bar{x}$
Jan	20.70	4.11	22.23	9.17	9.32	13.13
Feb	18.08	7.32	4.83	9.09	8.64	9.59
Mar	10.29	13.46	17.86	28.02	16.33	17.19
Apr	21.64	12.95	11.99	9.25	1.07	11.38
May	7.70	14.66	14.61	17.65	6.83	12.29
Jun	7.75	5.44	24.89	9.25	16.51	12.77
Jul	8.89	15.57	7.24	4.14	12.34	9.64
Aug	0.89	3.76	13.72	7.87	7.75	6.80
Sep	11.43	5.59	9.78	17.02	13.46	11.46
Oct	7.62	9.14	4.95	12.01	15.19	9.78
Nov	10.46	17.58	11.43	10.13	2.79	10.48
Dec	17.02	10.80	13.46	9.07	7.62	11.59
Annual	142.47	120.38	156.99	142.67	117.85	136.07

Table 2.—Monthly, annual, and mean streamflow (cm), Falling Rock Watershed, 1972–1976

Month	Year					
	1972	1973	1974	1975	1976	$\bar{x}$
Jan	19.99	1.98	22.81	13.18	3.91	12.37
Feb	19.46	8.92	4.42	11.71	10.67	11.04
Mar	9.02	7.67	15.75	31.57	13.49	15.50
Apr	28.09	9.65	10.82	10.57	3.10	12.47
May	3.71	7.75	3.40	10.41	0.86	5.23
Jun	0.53	0.64	12.50	2.46	3.12	3.85
Jul	0.46	0.71	0.81	0.23	1.47	0.74
Aug	0.15	0.38	0.91	0.15	1.65	0.65
Sep	0.56	0.18	2.59	0.74	1.14	1.04
Oct	0.66	0.41	1.73	1.96	9.88	2.93
Nov	2.77	7.37	6.88	5.11	2.24	4.87
Dec	17.68	6.30	10.24	6.35	7.11	9.54
Annual	103.08	51.96	92.86	94.44	58.64	80.20

average annual precipitation, an exceptionally high value! The highest annual yield was in 1972 with 103.08 cm and the lowest yield was the following year with 51.96 cm.

The mean monthly data in Fig. 3 indicate the temporal distribution of the mean annual flow. On the average, the first 4 months of the year accounted for 64 percent of the annual runoff. If May and June are included, those 6 months produced 75 percent of the annual runoff. That period corresponds with the dormant vegetational

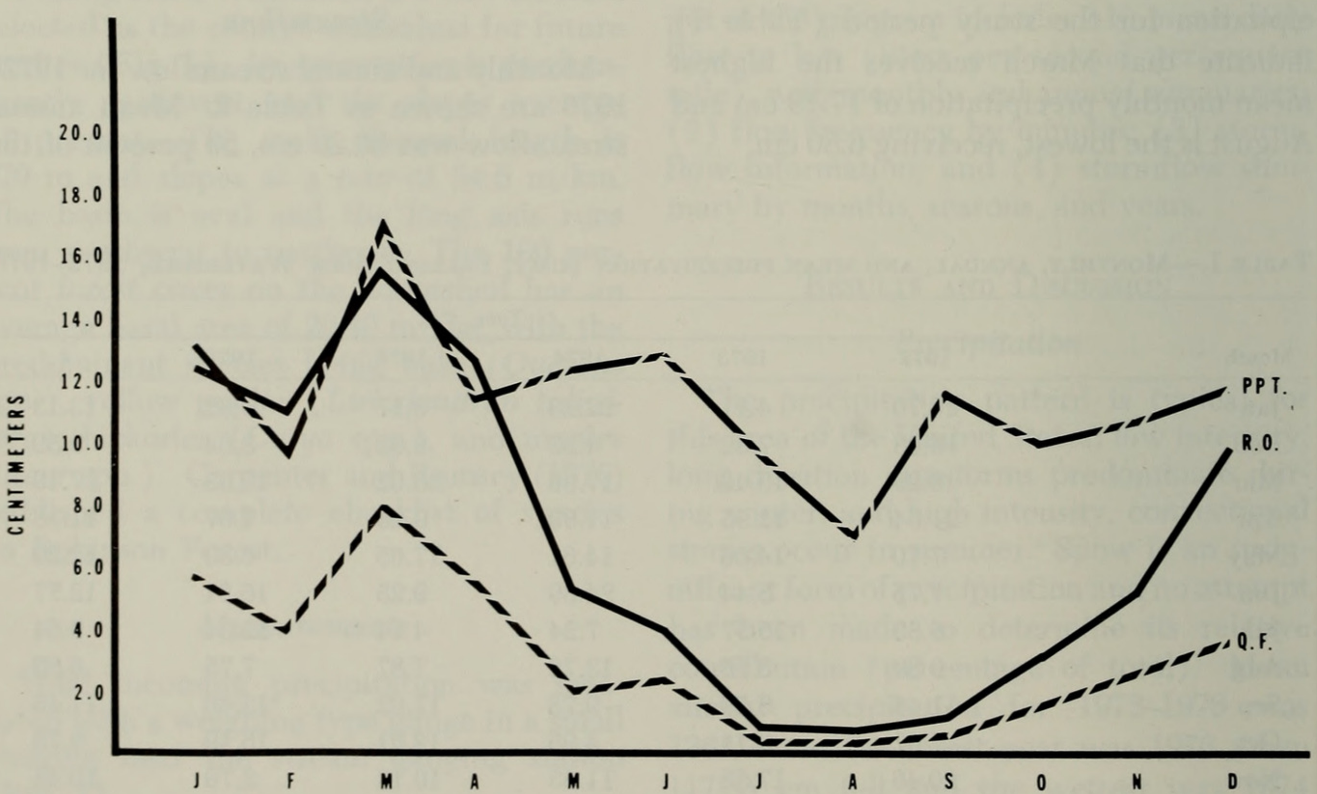

Fig. 3. Relationship between mean monthly precipitation, runoff, and quickflow for Falling Rock Watershed, 1972–1976.

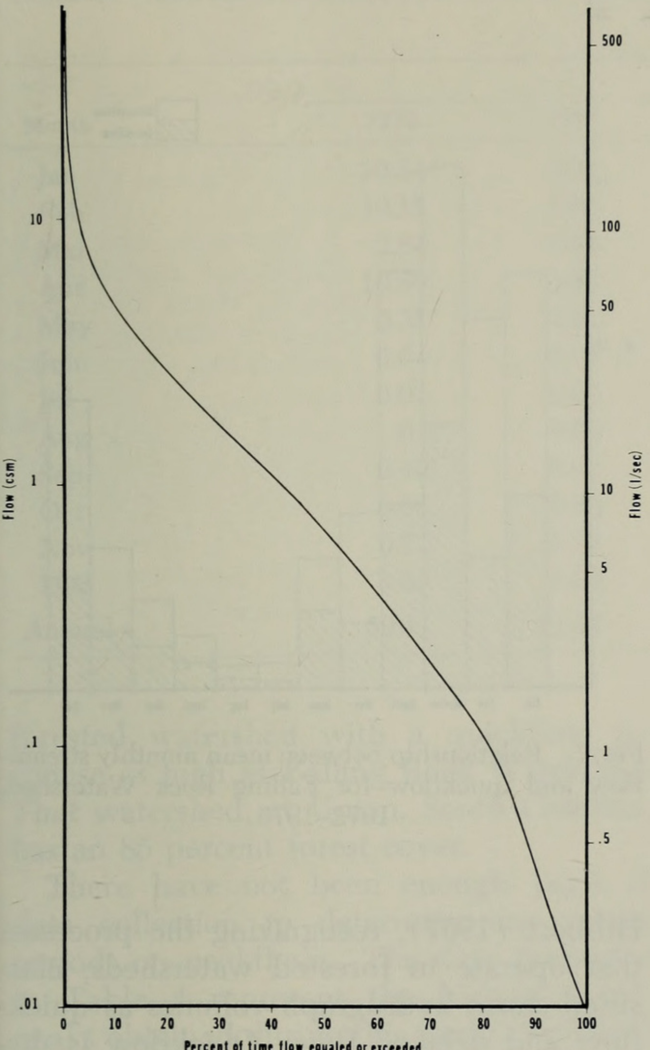

FIG. 4. Composite flow duration relationship for Falling Rock Watershed, 1972–1976.

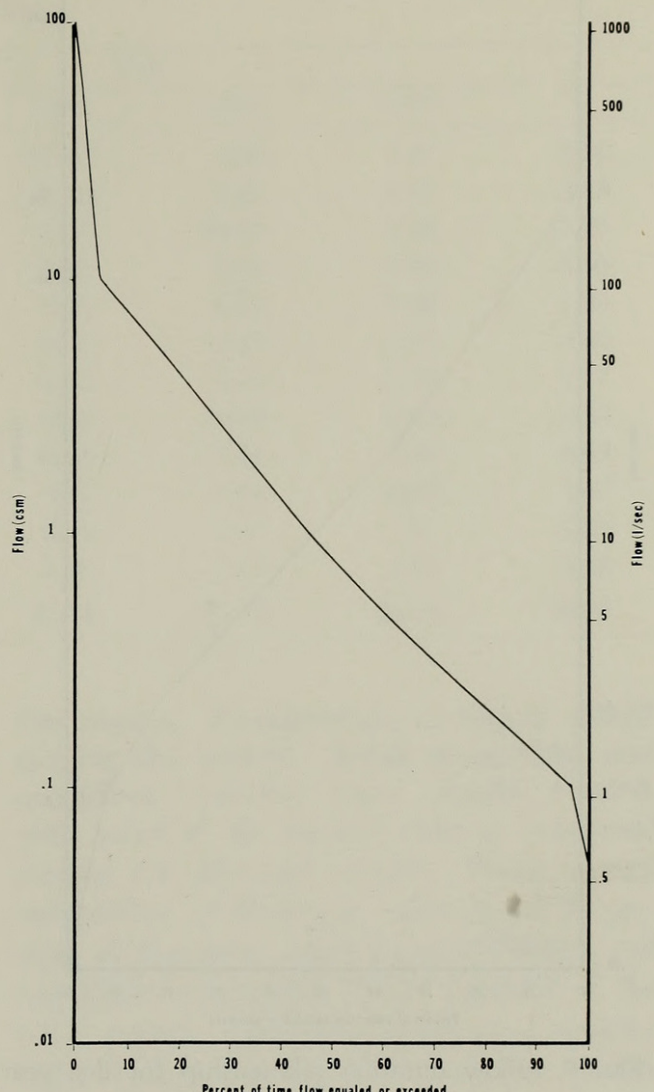

FIG. 5. Flow duration relationship for wet year 1974.

season and is characterized by full soil moisture recharge. Reinhart et al. (1963) found a similar relationship at the Fernow Experimental Forest in West Virginia. The relatively shallow soils do not have a large water storage capacity, and recharge occurs quickly. Such a lack of a large soil water storage reservoir produces "flashy" runoff conditions on those watersheds, and little or no storage dictates that baseflow cannot be sustained during prolonged dry periods, and the streams do not flow for brief periods during the year. Low flows occur primarily in July and August, periods of low precipitation and high evapotranspiration demand. For 11 days in late August and early September 1975 there was no streamflow.

Flow Duration

Flow duration curves (Figs. 4–6) are presented to indicate the distribution of flows and further substantiate the "flashy" characterization of the watershed. Fig. 4 represents the total 1972–1976 period when mean discharge was 7.00 l/sec. Fig. 5 represents 1974, characterized as a wet year, and it is obvious from the curve that flow was not less than 0.60 l/sec for any significant percentage of time during the year. Also, mean flow for that year was 8.20 l/sec, considerably above the composite mean of 7.00 l/sec. Fig. 6 represents 1976, a dry year when mean discharge was 5.20 l/sec, and during that year discharge exceeded 10.20

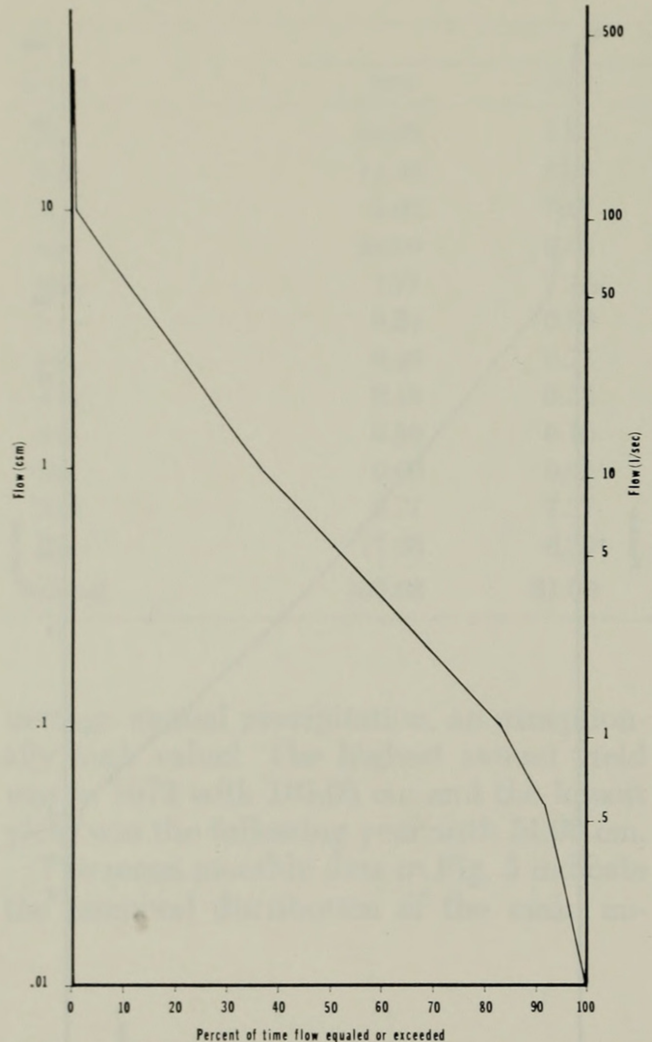

FIG. 6. Flow duration relationship for dry year 1976.

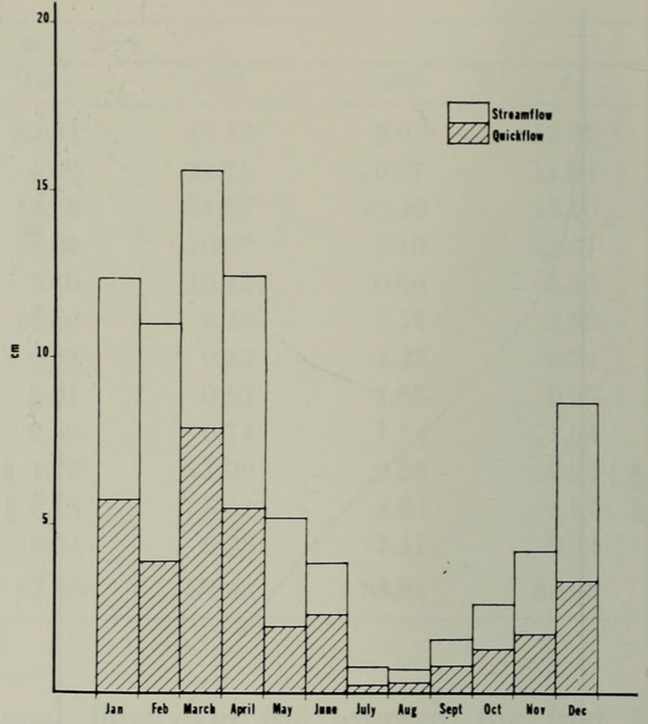

FIG. 7. Relationship between mean monthly streamflow and quickflow for Falling Rock Watershed, 1972–1976.

l/sec only 36 percent of the time, while the average for that interval was 43 percent.

Morisawa (1968) indicated that flow duration curves allow characterization of runoff from watersheds. Those watersheds with large storage capacity will exhibit flat flow duration curves, whereas watersheds with little or no storage have steeply sloped curves. The curves from Falling Rock Watershed have steep slopes, further evidence of lack of moisture storage within the soils of Robinson Forest.

Stormflows

Stormflow or direct runoff from forested watersheds consists almost entirely of subsurface flow, while overland flow or surface runoff is virtually nonexistent. Hewlett and Hibbert (1967), recognizing the processes that operate in forested watersheds, classified storm hydrograph volumes as quickflow and delayed flow. Quickflow is distinguished from delayed flow by a line with a slope of 0.55 $l/sec/km^2/hr$ projected from the rising limb to falling limb of the hydrograph. That method was used to analyze hydrographs from Falling Rock Watershed. The resultant monthly and annual quickflow volumes are presented in Table 3. The largest quickflow volumes usually occur during months of soil moisture recharge and little or no evapotranspiration. However, June 1974 had an abnormally high value of 8.97 cm that resulted from above average precipitation during March–June 1974. In Fig. 7, that presents monthly mean streamflow and quickflow for the study period, July is the only month where quickflow was less than 30 percent of the mean monthly flow. During the study, quickflow averaged 44 percent of the mean annual runoff. Hewlett and Hibbert (1967), surveying forested watersheds in the eastern and southeastern United States, found only 1

TABLE 3.—MONTHLY, ANNUAL, AND MEAN QUICKFLOW VOLUMES (CM), FALLING ROCK WATERSHED, 1972–1976

Month	Year					
	1972	1973	1974	1975	1976	$\bar{x}$
Jan	10.54	0.01	12.95	3.78	1.47	5.75
Feb	10.15	1.64	0.10	3.37	4.07	3.87
Mar	2.65	2.53	5.95	20.12	8.06	7.86
Apr	16.80	3.98	2.90	3.78	0.05	5.50
May	0.35	3.72	0.76	4.75	0.05	1.93
Jun	0.04	0.06	8.97	0.84	1.61	2.30
Jul	0.07	0.22	0.11	0.01	0.46	0.17
Aug	0	0.03	0.21	0.02	0.82	0.22
Sep	0.40	0.02	0.84	0.24	0.65	0.43
Oct	0.04	0.08	0.37	0.94	5.92	1.47
Nov	0.77	5.53	2.19	3.17	0	2.33
Dec	8.60	3.30	2.56	1.70	2.08	3.65
Annual	50.41	21.12	37.91	42.72	25.24	35.48

forested watershed with a quickflow response as high as Falling Rock Watershed. That watershed, at Union, South Carolina, has an 85 percent forest cover.

There have not been enough years of data collection to determine any return periods on peakflows. The data presented in Table 4 represent the highest yearly peaks obtained during this study. It should be noticed that 1973, categorized as a dry year, had the lowest peak value.

SUMMARY

Precipitation and streamflow data were collected over a 5-year period on a small undisturbed forested watershed in the Eastern Mountain and Coalfield Region of Kentucky. Hydrologic characteristics were determined from the data pool. Such baseline hydrologic information is lacking for the region. Precipitation averaged 136.07 cm for the period. Total streamflow and quickflow volumes were closely related, with most of the annual volume produced during the dormant season. Mean annual streamflow of 80.20 cm represented 59 percent of the mean annual precipitation, and quickflow accounted for 44 percent of the total runoff. Quickflow volumes coupled with steeply sloping flow duration curves categorize the watershed as flashy, from a hydrologic viewpoint.

The potential of the region as a lumber and energy producer is enormous, but it is important that those resources be obtained without destroying watershed values. To better understand such watersheds, experiments must be conducted to evaluate treatment effects on the water resource at Robinson Forest.

TABLE 4.—YEARLY MAXIMUM RATE OF FLOW (L/SEC), FALLING ROCK WATERSHED, 1972–1976

Date	Flow rate
12 Apr 1972	3,375
26 Nov 1973	1,195
22 Jun 1974	3,060
25 Apr 1975	1,818
21 Mar 1976	2,999

LITERATURE CITED

CARPENTER, S. B., AND R. L. RUMSEY. 1976. Trees and shrubs of Robinson Forest, Breathitt County, Kentucky. Castanea 41:277–282.

GRAVES, D. H., G. B. COLTHARP, M. C. HAMMETTER, D. C. JORDAN, C. L. SHILLING, AND R. F. WITTWER. 1977. Remote sensing of effects of land use practices on water quality. Final Report Contract No. NAS8-31006. 159 pp.

HEWLETT, J. D., AND A. R. HIBBERT. 1967. Factors affecting the response of small watersheds to precipitation in humid areas. Pp. 275–290. *In* W. E. Sopper and H. W. Lull (Eds.). International Symposium on Forest Hydrology. Pergamon Press, New York, N.Y. 813 pp.

HIBBERT, A. R., AND G. B. CUNNINGHAM. 1967. Streamflow data processing opportunities and application. Pp. 725–736. *In* W. E. Sopper and H. W. Lull (Eds.). International Symposium on Forest Hydrology. Pergamon Press, New York, N.Y. 813 pp.

HUTCHINS, R. B., R. L. BLEVINS, J. D. HILL, AND E. H. WHITE. 1976. The influence of soils and microclimate on vegetation of forested slopes in eastern Kentucky. Soil Science 121 (4):234–241.

KENTUCKY DEPARTMENT OF COMMERCE. 1975. Natural resources of Kentucky. Frankfort, Ky. 42 pp.

KRIEGER, R. A., R. V. CUSHMAN, AND N. D. THOMAS. 1969. Water in Kentucky. Ky. Geol. Surv., Lexington, Ky. 51 pp.

MORISAWA, M. 1968. Streams, their dynamics and morphology. McGraw-Hill Book Co., New York, N.Y. 175 pp.

REINHART, K. G., A. R. ESCHNER, AND G. R. TRIMBLE. 1963. Effect on streamflow of four forest practices in the mountains of West Virginia. USDA For. Serv. Res. Pap. NE-1. 79 pp. Northeast For. Exp. Sta., Upper Darby, Pa.

SHANHOLTZ, V. O., AND J. B. BURFORD. 1967. Computer systems for reduction and analysis of hydrologic data. USDA Agric. Res. Ser. ARS-41-132. 90 pp.