HYDROLOGIC CHARACTERISTICS OF AN UNDISTURBED HARDWOOD WATERSHED IN EASTERN KENTUCKY

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Abstract.--Precipitation and streamflow were monitored over a five year period (1972 - 1976) on a 93.70 ha second-order watershed in the Eastern Mountain and Coalfield physiographic region of Kentucky. The watershed was covered by a second-growth stand of mixed hardwoods, 50 - 55 years of age, in relatively undisturbed condition. Precipitation averaged 136.07 cm for the period of study. Mean annual streamflow was 80.20 cm and represented 59 percent of the mean annual precipitation. Although only 53 percent of the annual precipitation was received during the dormant season, 82 percent of the annual streamflow occurred during this period. Quickflow (stormflow) accounted for 44 percent of the total streamflow. The quickflow volumes, coupled with a relatively steep-sloped flow duration curve, categorizes the watershed as flashy from a hydrologic viewpoint. This hydrologic characterization of an undisturbed hardwood covered watershed provides some implications for water yield management in this region.

Keywords: Hydrology; forested watersheds; water yield; stormflow.

INTRODUCTION

In recent years increased attention has been focused upon the quantity and quality of streamflow emanating from forested watersheds in the eastern third of Kentucky. Floods and the associated sedimentation, as well as water shortages, have resulted in accusations of land misuse throughout the area. The Eastern Mountains and Coalfield Region, which is part of the Cumberland Plateau physiographic province, contains the primary watersheds for more than half of Kentucky, and is primarily forested. The Kentucky, Licking, Big Sandy, and Cumberland Rivers, that originate in this region, provide water for industrial and public use for the eastern half of the state. Several studies (Kentucky Department of Commerce 1975, Krieger et al. 1969) have shown that approximately 96 percent of the water used in the Eastern Mountains and Coalfield Region and 79 percent of the water used in the Bluegrass Region is in the form of surface water. This demonstrated dependency upon surface water supplies strongly suggests that land use practices in the headwater areas can greatly affect the quantity, quality, and timing of flow of that vital resource.

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If the forested watersheds of the eastern third of the state are going to contribute positive benefits to the future of Kentucky, several important questions must be addressed. First, how are the prevalent forest practices contributing to problems of water quantity and quality? Second, what changes could be made in these practices to make them compatible with desirable water yield objectives? Third, what are the potential forest practices that will likely cause water yield problems?

To evaluate the current status of forest practice - water yield relationships we need to know the baseline or background values of water quantity and quality produced from undisturbed forested watersheds. Such values are essential criteria in any evaluation of environmental degradation.

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

STUDY AREA

Robinson Forest, a 6,075 ha facility of the University of Kentucky, is located in Breathitt and Knott Counties, 40.23 km south of Jackson, Kentucky (Figure 1). The University acquired the tract in 1923 following logging of the virgin hardwood stands. There has been no extensive logging on the area since that time. This portion of the Cumberland Plateau is naturally dissected with varying relief of narrow, winding ridges, steep valley walls, and narrow stream bottoms. Elevations generally range between 260 - 460 m above sea level, with local relief approximately 200 m. The area is underlain primarily with rocks of the Pennsylvanian geologic period. The Breathitt Formation (Middle Pennsylvanian), which dominates the study area, is composed of alternating layers of sandstones, siltstones, shales, and coal (Welch 1958). This formation has weathered to form a dendritic drainage pattern, with steep side slopes, ranging from 35 - 90 percent, and averaging approximately 45 percent.

Soils on the sideslopes have developed from colluvium of variable thickness overlying alternating layers of resistant and non-resistant strata. This has resulted in complex, benchy, and/or dissected sideslopes. The soils are quite variable in depth, ranging from very shallow near rock outcrops to several meters or more near the uphill sides of benches. The predominant soils of the area are the Shelocta and Rigley series, comprising approximately 75 percent of the soils found on Robinson Forest (Hutchins et al. 1976). Rigley soils, which are sandier than Shelocta, occur more frequently on south-facing slopes and the upper slope positions on northerly aspects. The finer-textured Shelocta soils occur on north aspects and in concave "cove" locations. There are several other less extensive soils on the area, including Gilpin, Steinburg, and Pope. The Gilpin series is found on drier upper slopes, while the Steinburg series occurs on upper slopes and ridges exhibiting rock outcrops. The Pope series are alluvials found in some of the wider stream bottoms (Graves et al. 1977).

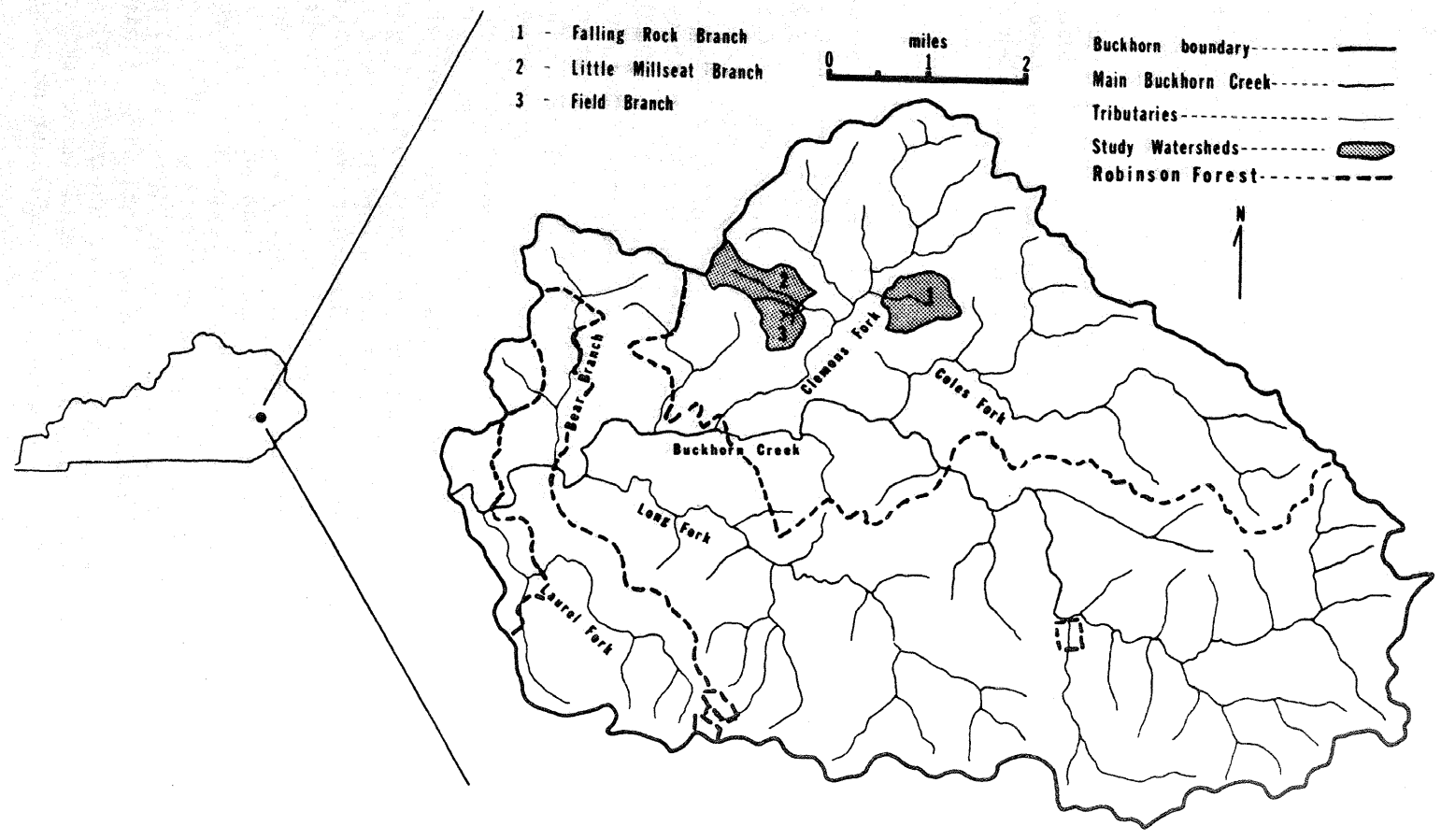

Figure 1.--Location of Buckhorn Creek Basin, Robinson Forest, and experimental watersheds.

The vegetation is typical of the mixed hardwood forests indigenous to the Cumberland Plateau of eastern Kentucky. The predominant hardwoods are oaks (*Quercus* spp.), hickories (*Carya* spp.), and yellow-poplar (*Liriodendron tulipifera* L.). The conifers, comprising less than 10 percent of the forest cover, are mainly eastern hemlock (*Tsuga canadensis* L.) and several pines (*Pinus* spp.). Carpenter and Rumsey (1976) have published a complete checklist of species on Robinson Forest.

The specific study watershed, Falling Rock, is a 93.7 ha tract selected as a control for future paired watershed experiments (Figure 1). It has a northwest orientation, with a mean weighted slope of 44 percent. The main channel is 670 m long and drops at a rate of 54.60 m/km (5.46%). The basin is somewhat rectangular in shape, with the long axis extending from southwest to northeast. The 100 percent forest cover has an average basal area of 20.20 m^2/ha.

METHODS

Gross incoming precipitation was measured with a standard 20.32 cm. dia. weighing-type recording gage located in a small forest opening near the stream gaging station. This information was supplemented by data from other gages in the sampling network for the forest. Precipitation data were reduced and analyzed by means of a computer program developed by Shanholtz and Burford (1967).

Streamflow was continuously monitored with a 3:1 side-sloped, broadcrested v-notch weir (143° notch) equipped with an FW-1 water stage recorder. The concrete weir cutoff wall was anchored in bedrock on either side and across the bottom, thus ensuring a rather reliable expression of total water yield. The weir had a maximum rated head of 0.9 m and a rated capacity of 4,825.70 liters/sec. Streamflow data were processed using the Coweeta streamflow program described by Hibbert and Cunningham (1967).

RESULTS AND DISCUSSION

Precipitation

The pattern of precipitation received on the study area is rather typical for this area of the United States; low intensity, long duration rainstorms predominate during the winter, and high intensity, convectional storms occur during the summer (Hill 1976). Snow has no significant effect on the hydrology of the area, hence it is not separated out. During the period of study (1972 - 1976) the mean annual precipitation was 136.07 cm; the range was from 117.85 cm in 1976 to 156.99 cm in 1974. An examination of mean monthly precipitation values (Table 1) indicates that March was the wettest month with 12.63 percent of mean annual total, while August was the driest, with only 4.99 percent of the total. Approximately 46 percent of the annual precipitation is received during the growing season (May - October). An average of 52 stormflow-producing precipitation events were received on the area each year.

Streamflow

Mean annual streamflow during the study was 80.20 cm, which was 59 percent of the average annual precipitation, an exceptionally high value! The highest

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	15.27	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

annual yield was in 1972 with 103.08 cm and the lowest yield was the following year with 51.96 cm (Table 2). The mean monthly data (Figure 2) indicate the temporal distribution of the mean annual flow. The period November - April, the dormant vegetation season, produces 82 percent of the annual streamflow. A similar relationship was found on the Fernow Experimental Forest in West Virginia (Reinhart et al. 1963). The relatively shallow soils do not have a large water storage capacity, and recharge occurs quickly. This lack of soil water storage space produces "flashy" or rapid streamflow response on these watersheds. This minimal soil water storage dictates that baseflow cannot be sustained during prolonged dry periods and the streams cease flow for brief periods during the year. Low flows occur primarily in July and August, periods of low precipitation and high evapotranspiration demand. The longest period without flow was an 11 day span in late August and early September, 1975.

A flow duration curve (Figure 3), representing the 1972 - 1976 period, indicates the distribution of flows and further substantiates the flashy nature of streamflow from the area. Morisawa (1968) indicates that flow duration curves allow characterization of runoff from watersheds. Those watersheds with deep permeable soils and large water storage capacity will exhibit flat flow duration curves, whereas watersheds with little or no storage have steeply sloped curves. The curve from Falling Rock watershed has a relatively steep slope, further evidence of lack of moisture storage within the soils of Robinson Forest.

Stormflows

Stormflow or direct runoff from relatively undisturbed forested watersheds consists primarily of subsurface flow, with little or no surface runoff in evidence. Numerous methods have been advanced for separating stormflow

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

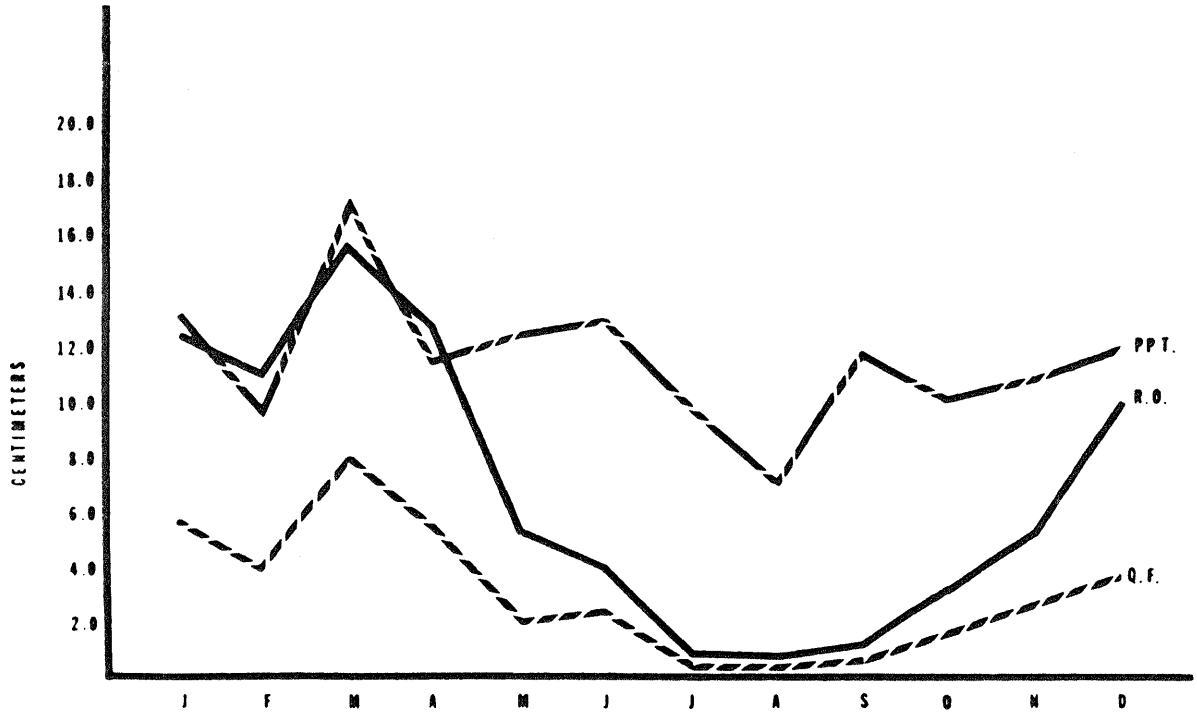

Figure 2.--Mean monthly precipitation, total streamflow, and quickflow, Falling Rock Watershed, 1972 - 1976.

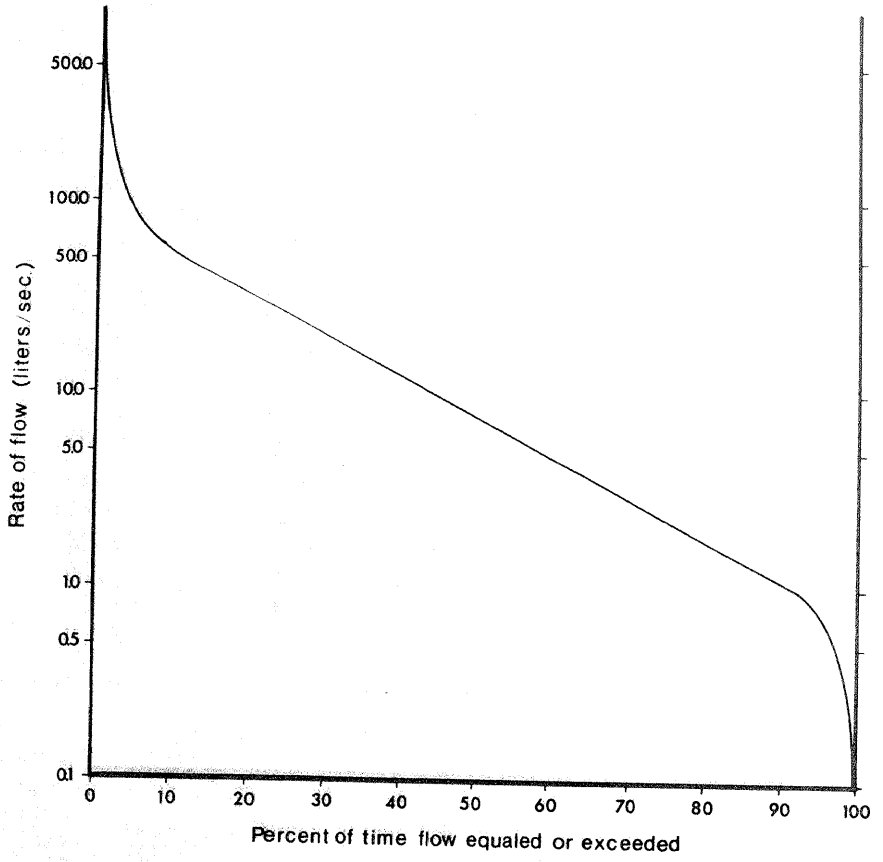

Figure 3.--Flow duration curve, Falling Rock Watershed, 1972 - 1976.

from baseflow and most are arbitrary. Hewlett and Hibbert (1967), recognizing the hydrologic processes that operate in forest watersheds, reported on a hydrograph separation technique that was used in this study. They classified storm hydrograph volumes as either quickflow or delayed flow. Quickflow was distinguished from delayed flow by a line with a slope of 0.55 liters/sec./km^2/hr. projected from the rising limb to the falling limb of the hydrograph. The resultant monthly and annual quickflow volumes are presented in Table 3. Mean monthly quickflows are also compared with mean monthly precipitation and streamflow in Figure 2. The largest quickflow volumes usually occur during those months when there is a maximum of soil water storage and a minimum of evapotranspiration demand. There are exceptions of course, and June of 1974 is an example. Precipitation was in excess of monthly means for the March - June period, resulting in a quickflow volume approximately four times greater than the mean. A comparison of monthly streamflow volumes with quickflow volumes (Figure 4) reveals that July is the only month when quickflow was less than 30 percent of the mean monthly flow. During the study, quickflow averaged 44 percent of the mean annual runoff. If we assume that our streamflow measurements represent total water yield from the watershed, this 44 percent response is very high! Hewlett and Hibbert (1967), surveying forested watersheds in the eastern and southeastern U.S., found very few watersheds with quickflow responses as high as Falling Rock.

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

An examination of selected stormflow parameters (Table 4) reveals some additional hydrologic characteristics. The mean length of time for stormflow events was 25.42 hrs. A definite seasonal effect was evident, with a mean stormflow duration of 33.45 hrs. during the dormant season and 17.38 hrs. during the growing season. Similar seasonal effects were noted for time to peak, recession time, and peakflow rate. The highest yearly peakflow rates obtained during the study are presented in Table 5. In only one year, 1974, did the yearly peak occur during the growing season, and as previously noted, this was an atypical year.

SUMMARY

Precipitation and streamflow data were collected over a five year period on a small undisturbed hardwood-covered watershed in the Eastern Mountains and Coalfield region of Kentucky. Hydrologic characteristics were determined by analysis of the resultant data pool. Annual precipitation averaged 136.07 cm for the period. Mean annual streamflow or water yield averaged 80.20 cm, which represented 59 percent of the annual precipitation. Total streamflow and quickflow volumes were closely related, with quickflow accounting for 44 percent of the total yield. The relatively high contribution of quickflow to total flow volumes and a rather steeply sloping flow duration curve categorize the watershed as flashy, from a hydrologic viewpoint. Bryan and Hewlett (1979) indicate this area exhibits some of the highest storm runoff in eastern America.

This region has a very high potential as a wood fiber and energy producer, but it is imperative that these resources be obtained without jeopardizing the watershed resources. The rapid hydrologic response evident throughout this area suggests caution be exercised when utilizing either the timber or mineral resources.

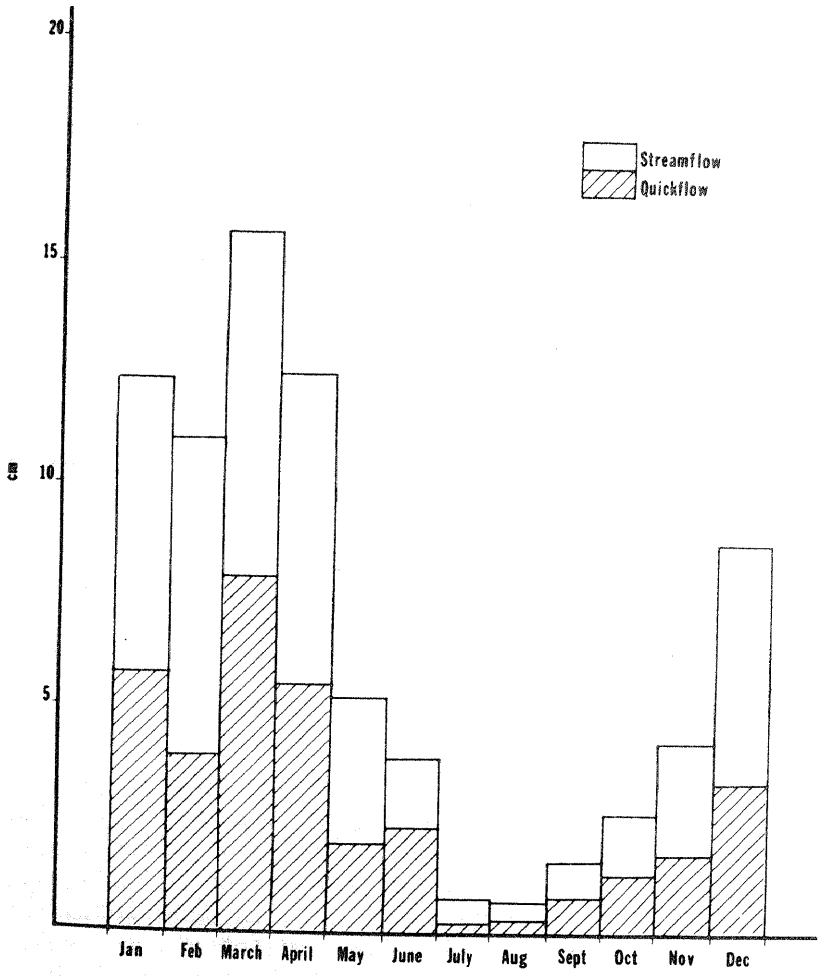

Figure 4.--Relationship of mean monthly quickflow and total streamflow, Falling Rock Watershed, 1972 - 1976.

Table 5.--Yearly maximum rate of flow (liters/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

Table 4.--Mean seasonal and yearly stormflow characteristics, Falling Rock Watershed, 1972 - 1976.

Period	Characteristic									
	Storm Duration	Time to Peak	Recession Time	Initial Flow	Peak Flow	Final Flow	Quick Flow	Delayed Flow	Total Flow	Response[b]
	min. (hrs.)	min. (hrs.)	min. (hrs.)	$l/s/km^2$[a]	$l/s/km^2$	$l/s/km^2$	cm	cm	cm	
Dormant (Nov - Apr)	2007.02 (33.45)	605.38 (10.09)	1401.63 (23.36)	17.12	196.17	35.51	0.99	0.48	1.47	0.67
Growing (May - Oct)	1042.94 (17.38)	223.36 (3.72)	819.57 (13.66)	7.67	163.29	17.10	0.23	0.09	0.32	0.72
Annual (Jan - Dec)	1524.98 (25.42)	414.37 (6.91)	1110.60 (18.51)	12.38	179.73	26.30	0.61	0.28	0.89	0.69

[a] Liters/second/kilometer^2

[b] $\text{Response} = \frac{\text{Quickflow}}{\text{Total flow}}$

LITERATURE CITED

Bryan, B.A., and J.D. Hewlett. 1979. The effect of strip mining on the headwater hydrograph of eastern Kentucky. pp.51-55. In Proc. of Symp. on Surface Mining Hydrology, Sedimentology, and Reclamation. Univ. of Ky., Lexington, Ky.

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. Jorden, 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. 159pp.

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. 813pp.

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. 813pp.

Hill, J.D. 1976. Climate of Kentucky. Ky. Agric. Exp. Sta. Progress Report 221. 88pp.

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 Sci. 121(4):234-241.

Kentucky Department of Commerce. 1975. Natural resources of Kentucky. Frankfort, Ky. 42pp.

Krieger, R.A., R.V. Cushman, and N.D. Thomas. 1969. Water in Kentucky. Ky. Geol. Surv., Lexington, Ky. 51pp.

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

Reinhart, K.G., A.R. Eschner, and G.R. Trimble. 1963. Effect on streamflow of four forest practices in the mountains of West Virginia. U.S. For. Ser. Northeast. For. Exp. Sta. Res. Pap. NE-1. 79pp.

Shanholtz, V.O., and J.B. Burford. 1967. Computer systems for reduction and analysis of hydrologic data. U.S. Agric. Res. Ser. ARS-41-132. 90pp.

Welch, S.W. 1958. Geology and coal resources of the Tiptop quadrangle Kentucky. U.S.G.S. Bull. 1042-P. 27pp.