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Canopy Interception, Stemflow and Streamflow on a Small Drainage in the Missouri Ozarks

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DAVID R. DEWALLE & LEE K. PAULSELL*

INTRODUCTION

This report presents an analysis of canopy interception, stemflow, and streamflow measurements collected for a number of years on the 12.48-acre Gum Springs Watershed at University Forest. Interception and stemflow data provide information used in determining amount of water evaporated from the forest canopy. Streamflow analysis gives timing and quantity of flow and when combined with climatic data in a budget can be used to estimate annual water losses.

University Forest is located in the southeastern Missouri Ozarks and is dissected by many first order, ephemeral streams. Oak-hickory timber of large pole size predominates on the small basins. Soils are red and yellow podzolics derived mainly from dolomite and limestone. Loess is found as a thin veneer on some ridge tops. Surface soil is a cherty, silt loam. Less chert and more clay are found in the subsurface horizons. Annual precipitation since 1949 averaged 46 inches. Mean annual temperature over the same period was 58°. The area of study has been under fire protection for about 30 years.

CANOPY INTERCEPTION

In the forest hydrologic cycle a major consideration is precipitation intercepted by the canopy. After rain begins, throughfall as a percentage of precipitation increases as the canopy is wetted and then reaches a nearly constant value. Wind and evaporation reduce the moisture retained on the vegetation and make further storage possible. Canopy interception is the difference between total precipitation above the forest or in a clearing and precipitation falling through and dripping from the canopy. Canopy interception may not be completely lost since intercepted water can reach the soil as stemflow. Also there is evidence that wetted foilage results in somewhat reduced transpiration rates. Stemflow is discussed in a later section.

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Study Areas and Design

Throughfall measurements during two studies at University Forest provided information on canopy interception in pole stands of oak-hickory. Canopy interception was the difference between mean throughfall and precipitation measured at University Forest weather station. The first study was conducted on a 0.13-acre ridge-top plot about 0.5 miles from the weather station. Four metal troughs 4 inches wide and 48 inches long were mounted about 2 feet above ground (Figure 1). Throughfall collected from the troughs in cans was usually measured after each storm, but occasionally only weekly. The troughs were moved to new random locations after several successive storms.

A second study was conducted on the 12.48-acre Gum Springs Watershed using nine triangular, plastic rain gages mounted 2 feet above ground (Figure 2). The gages constituted one row in a 72-point grid containing eight rows. The grid points and rows were spaced at 66-foot intervals and covered most of the watershed. Gages were moved systematically from row to row, back and forth across the watershed after every two or three successive storms. Throughfall for each storm was the average catch for the nine gages.

The watershed is adjacent to the weather station and is typical of many minor drainages on the forest. Table 1 compares stand characteristics on the plot and watershed. Basal area and average tree diameter are similar. Since the watershed supports much more understory vegetation along the intermittent stream channel than is present anywhere on the plot, stocking differences occur. The

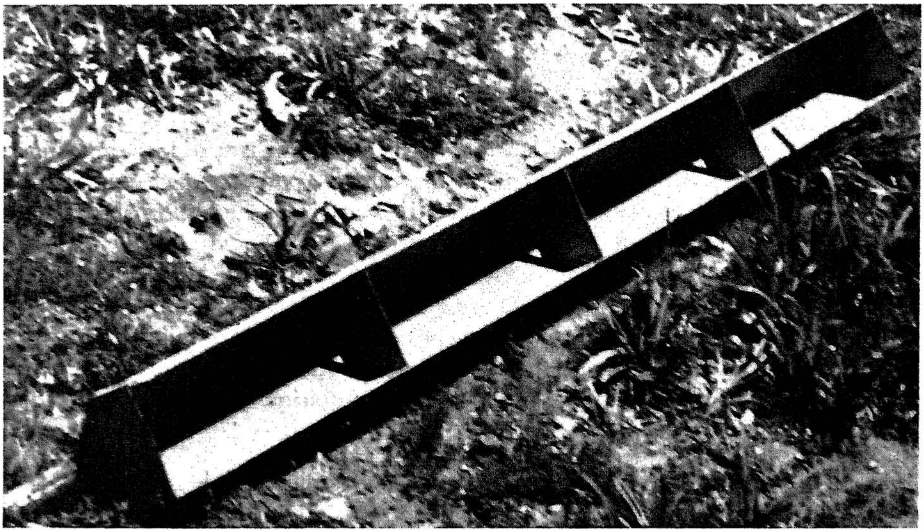

Fig. 1—Metal trough (without stand) used to measure throughfall on ridge-top plot.

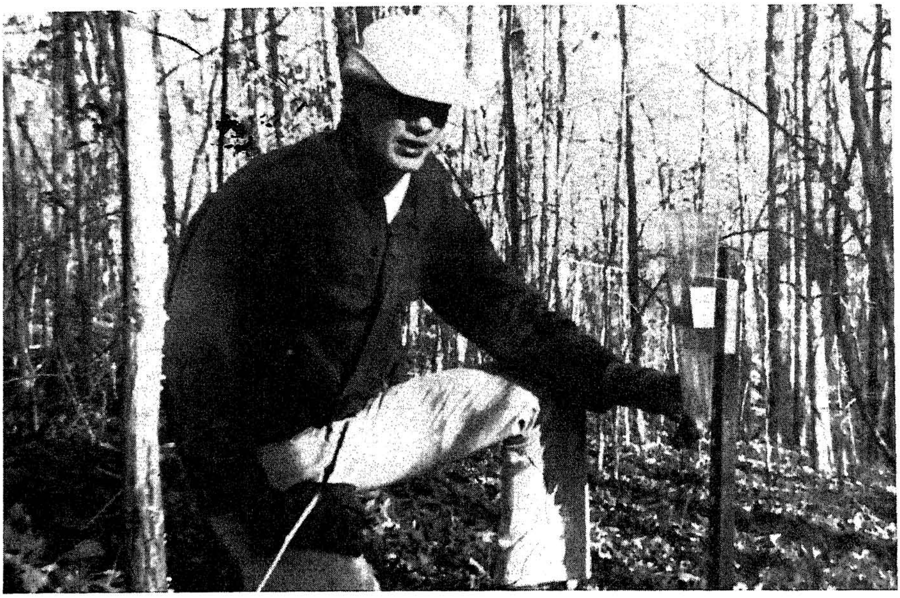

Fig. 2—Plastic rain gage used to measure throughfall on Gum Springs Watershed.

TABLE 1-COMPARISON OF OAK-HICKORY VEGETATION ON RIDGE-TOP PLOT AND GUM SPRINGS WATERSHED

	Ridge-top plot	Gum Springs Watershed
Basal area, sq. ft./acre	87.90	85.10
Average d.b.h. trees larger than 4.0 inches	8.1	8.5
Stocking, trees/acre	695.2	910.1

watershed supports a less dense stand on the drier upper slopes than occurs on the plot.

Results

On the plot 83% of precipitation from all storms reached the forest floor as throughfall. Less canopy interception occurred on the watershed with throughfall amounting to 89% of precipitation for all storms. Averages for all storms mask throughfall variation with storm size and season.

Less canopy interception on the watershed was also evident when storm size was considered. Table 2 shows throughfall as a percentage of precipitation by storm size classes for each area. For all but the very large storms, more through-

TABLE 2-THROUGHFALL VARIATION WITH STORM SIZE IN TWO OAK-HICKORY STANDS

Precipitation (inches)	Throughfall (percent of precipitation)	
	Gum Springs Watershed	Ridge-top Plot
0.00 - 0.20	84.2	69.1
0.21 - 0.40	88.9	79.5
0.41 - 0.60	86.5	77.0
0.61 - 0.80	89.1	76.4
0.81 - 1.00	87.9	80.4
1.01 - 2.00	91.5	85.4
2.01 - 3.00	93.6	82.6
3.01 - 4.00	----	85.0
4.01 - 5.00	85.8	96.5
5.01 - 6.00	----	93.2
6.01 - 7.00	----	----
7.01 - 8.00	----	----
8.01 - 9.00	----	80.0

fall was measured on the watershed than on the plot. Data for storms with more than 3 inches of precipitation are probably misleading, since these storms sometimes represented several smaller throughfall events due to occasional weekly measurements on the plot. As expected, throughfall as a percentage of precipitation increased with storm size. This is because vegetation storage is a smaller percentage of large storm precipitation.

Since throughfall varies with season in deciduous forests, the data were separated by dormant and growing seasons on the basis of average dates of first fall and last spring frosts. The dormant season extended from October 31 to April 15, while the growing season extended from April 22 to October 24. Measurements made during the 7-day intervals between seasons were excluded. During the dormant season average throughfall amounted to 85% and 90% of precipitation on the plot and watershed respectively. During the growing season, the corresponding figures were 81% and 89%. One possible cause of the small difference between seasons on the watershed may be the tendency of post oak to retain dead foliage during winter. Post oak was more abundant on the watershed than on the plot. Sampling error may also exist.

Linear regression of throughfall and storm precipitation data by seasons was used to provide equations for estimating throughfall for each area. Table 3 presents results of the analysis. The equations again indicate that throughfall increases with storm size and decreases when foliage is present. The standard errors of estimate reflect the value of seasonal equations over equations for all storms combined. Seasonal equations of the two areas were significantly different at the 5% level. Differences might possibly be explained by the two widely differing

TABLE 3-CORRELATION-REGRESSION OF THROUGHFALL ($\hat{T}$) WITH STORM PRECIPITATION (P) BY SEASONS FOR TWO OAK-HICKORY STANDS IN INCHES

Area	Number of 1/ Storms	Equation	Correlation Coefficient r	Standard Error of Estimate (± inches)
Ridge-top plot				
Growing season	157	$\hat{T} = 0.8861P - 0.0906$	0.9755	0.0089
Dormant season	148	$\hat{T} = 0.9272P - 0.1056$	0.9678	0.0072
Combined	320	$\hat{T} = 0.9113P - 0.0990$	0.9689	0.2677
Gum Springs				
Growing season	109	$\hat{T} = 0.8909P + 0.0018$	0.9953	0.0079
Dormant season	55	$\hat{T} = 0.8909P + 0.0107$	0.9954	0.0021
Combined	167	$\hat{T} = 0.8906P + 0.0035$	0.9948	0.0749

1/ Storms occurring in 7-day periods between seasons were excluded in seasonal equations.

plot sizes (0.13 acres versus 12.48 acres), two different measurement techniques (troughs versus gages), and vegetation differences.

Since vegetation effects alone were probably not responsible for differences in data between areas, seasonal equations were derived for all data combined. Table 4 presents results of combined data analysis. The equations represent measurements of 469 storms and should describe throughfall in pole-size oak-hickory stands at University Forest. Figure 3 illustrates throughfall variation with storm size by seasons.

TABLE 4-CORRELATION-REGRESSION OF THROUGHFALL ($\hat{T}$) WITH STORM PRECIPITATION (P) BY SEASONS IN INCHES*

Season	Number of Storms	Equation	Correlation Coefficient r
Growing	266	$\hat{T} = 0.8755P - 0.0413$	0.9819
Dormant	203	$\hat{T} = 0.9135P - 0.0663$	0.9718

*Standard error of estimate not available

It is difficult to generalize about canopy interception in pole-sized stands of oak-hickory at University Forest. Storm size and, to a lesser degree, season affect interception percentage. Growing season interception amounts to about 12% of precipitation, while dormant season interception amounts to 9%.

One interesting feature of throughfall equations is the precipitation required to produce throughfall or the storage capacity of the canopy. An average of 0.06 inches of precipitation can be stored by the crown canopy according to combined equations. Storage capacity in the growing season was 0.05 inches and 0.07 inches in the dormant season. Greater storage in winter seems unlikely and the difference probably reflects sampling errors. Although a large number of storms were measured, the fixed-point grid on the watershed and small area on the ridge limited canopy variation encountered.

The regression equations are similar to those presented for mature mixed hardwoods of eastern United States (Helvey and Patric, 1965):

Growing season $\hat{T} = 0.901\ P - 0.031$
Dormant season $\hat{T} = 0.914\ P - 0.015$
$\hat{T}$ = estimated throughfall, inches
P = precipitation, inches.

However, University Forest data indicate somewhat greater interception during the growing season. Semago and Nash (1962), according to Helvey and Patric (1965), found for 21 storms in a large pole stand of oak-hickory:

Growing season $\hat{T} = 0.918\ P - 0.001$

This equation agrees more closely with Helvey and Patric's general equations.

STEMFLOW

To accurately evaluate interception losses in pole stands of oak-hickory, a measure of stemflow as well as canopy interception is needed. Stemflow provides

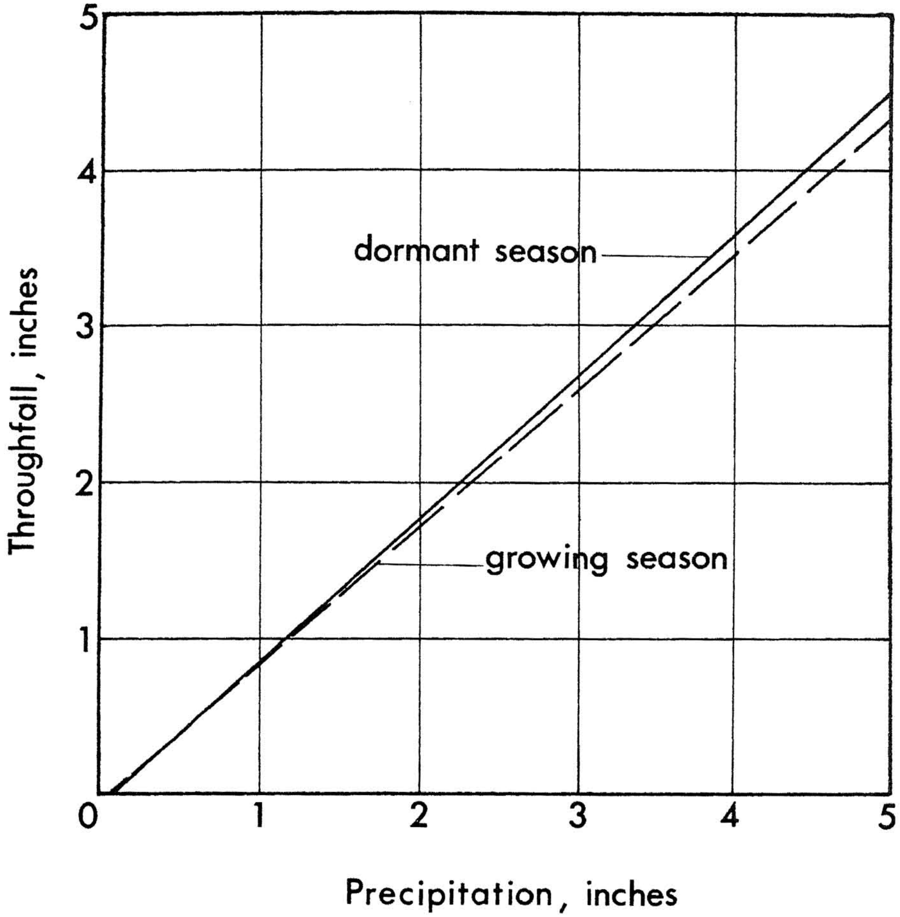

Fig. 3—Throughfall variation with precipitation by seasons for pole oak-hickory at University Forest.

a pathway for intercepted precipitation to reach the forest floor. Therefore throughfall measurements cannot be used to determine the amount of moisture evaporated from the canopy. True interception loss is total precipitation less both throughfall and stemflow. Addition of stemflow to a small zone of soil at the tree base may affect root distribution.

Methods

In some coniferous forests stemflow has been found to be negligible, but young, smooth-barked oaks can produce large quantities of stemflow. Therefore 32 trees on the Gum Springs Watershed, primarily black oak, with a wide diameter range were equipped for stemflow measurement. Screened 3.5-inch aluminum collars were sealed to the trees with roofing cement 4.5 feet above the ground. A plastic hose conducted water from the collar to a container where it was measured after each storm. Figure 4 shows the stemflow measurement installation. Crown area for each stemflow tree was computed from the mean of three projected crown diameter measurements. Species and diameter at breast height were also recorded for each tree. Table 5 lists stemflow tree characteristics.

TABLE 5-TREE CHARACTERISTICS AND STEMFLOW DATA

Tree Number	Species	Crown Area, (sq. ft.)	D.B.H. (inches)	No. of Storms	Stemflow (% of precipitation)
1	BO*	46.5	2.2	39	4.86
2	BO	54.1	2.8	36	3.49
3	BO	89.9	4.2	36	2.90
4	BO	89.9	4.5	36	4.17
5	BO	78.5	4.8	32	6.36
6	BO	83.3	5.6	30	2.61
7	BO	107.5	6.1	38	6.19
8	BO	201.0	6.7	34	1.57
9	BO	132.7	7.5	38	7.19
10	BO	176.6	7.9	29	4.79
11	BO	226.9	8.2	34	4.01
12	BO	218.9	9.8	23	3.18
13	BO	396.6	11.8	34	4.64
14	BO	572.3	12.0	34	5.28
15	BO	336.4	12.5	30	5.30
16	BO	478.9	13.3	35	6.02
17	BO	274.5	13.4	37	5.64
18	BO	628.7	14.6	32	3.67
19	BO	559.6	16.2	37	1.88
20	BO	739.9	16.5	31	2.30
21	BO	463.5	16.9	32	3.37
22	BO	891.5	17.5	30	2.34
23	BO	706.5	17.6	33	4.53
24	BO	839.4	19.3	35	4.21
25	H*	201.0	7.1	17	7.14
26	H	572.3	12.9	33	3.09
27	PO*	160.5	7.0	30	3.57
28	PO	559.6	13.7	32	5.13
29	SRO*	31.1	2.3	40	3.35
30	SRO	262.9	10.1	37	8.86
31	SO*	183.8	10.2	34	6.45
32	SO	854.9	20.4	38	1.97

*BO - Black oak; SRO - Southern red oak; SO - Scarlet oak; H - Hickory; PO - Post Oak.

Fig. 4—Stemflow collar, hose, and collection container for tree on Gum Springs Watershed.

Results

Total stemflow (inches depth over projected crown areas) for all trees amounted to 4.33% of total precipitation for 40 storms. Table 5 lists the mean stemflow percentage for each tree and the number of storms used to compute the mean. Stemflow as a percentage of precipitation varies with season, storm size, and tree characteristics.

With foliage present, stemflow for 32 trees averaged 3.83% of precipitation for 23 storms. Dormant season stemflow averaged 5.28% for 17 storms. Foliage apparently retarded the movement of intercepted precipitation to the trunk. Seasons corresponded to those used in throughfall analysis.

Since bark must be thoroughly wetted before significant stemflow begins, percentage stemflow should increase with storm size to a point. Table 6 shows percentage stemflow increasing in the smaller storm size classes. However, the trend is weak probably due to the low number of storms in each class.

Stemflow is known to vary among species and with tree age or size. Since the majority of trees used were black oak, species comparisons cannot be made. Table 5 shows no distinct trend of stemflow percentage with diameter within the black oak. The younger trees with smoother, less absorbent bark might be expected to have a greater stemflow percentage than the larger thick-barked trees. However this also depends on individual crown compactness and branching char-

TABLE 6-AVERAGE STEMFLOW FROM 32 TREES AS A PERCENTAGE OF PRECIPITATION BY STORM CLASSES

Storm Class (inches)	Storms (number)	Stemflow (% of precipitation)
0.00 - 0.20	4	2.48
0.21 - 0.40	4	3.26
0.41 - 0.60	8	3.17
0.61 - 0.80	6	5.07
0.81 - 1.00	4	3.22
1.01 - 1.25	5	4.44
1.26 - 1.50	2	3.94
1.51 - 1.75	1	5.85
1.76 - 2.00	3	5.41
2.01 - 3.00	1	5.51
3.01 - 4.00	0	----
4.01 - 5.00	2	4.70

acteristics. In the following analyses, data for all trees were expressed as a 32-tree mean for each storm.

Linear regression of average stemflow for 32 trees expressed in inches versus storm precipitation in inches depicts stemflow variation with storm size and season. Table 7 summarizes the analysis. The dormant season equation has a steeper slope, reflecting increased stemflow with absence of foliage. The amount of precipitation occurring before stemflow begins (P when S = O) varies considerably between seasons. During the growing season an average of 0.20 inches of precipitation is required, while -0.03 inches is indicated in the dormant season. Since negative precipitation has no physical meaning, the dormant season regression probably passes through the origin. Statistical analysis showed that the Y-intercept was not significantly different from zero. More dormant season data might give a regression which indicates some storage of precipitation by the bark. The growing season equation from a slightly larger sample size indicates 0.20 inches of canopy and bark storage. The intercept of this equation is significantly different from zero. Figure 5 shows variation of stemflow with storm size by seasons.

TABLE 7-CORRELATION-REGRESSION OF MEAN 32-TREE STEMFLOW ($\hat{S}$) WITH STORM SIZE (P) IN INCHES

Number of Storms	Season	Equation	Standard Error of Estimate (inches)	Correlation Coefficient (r)
23	Growing	$\hat{S} = 0.0482P - 0.0097$	0.0081	0.981
17	Dormant	$\hat{S} = 0.0016 + 0.0513P$	0.0153	0.971

Although the stemflow data are limited to 40 storms and primarily one species, the regression equations indicate the magnitude of stemflow over a wide diameter range by seasons. These equations can be used in pole-stands of oak-

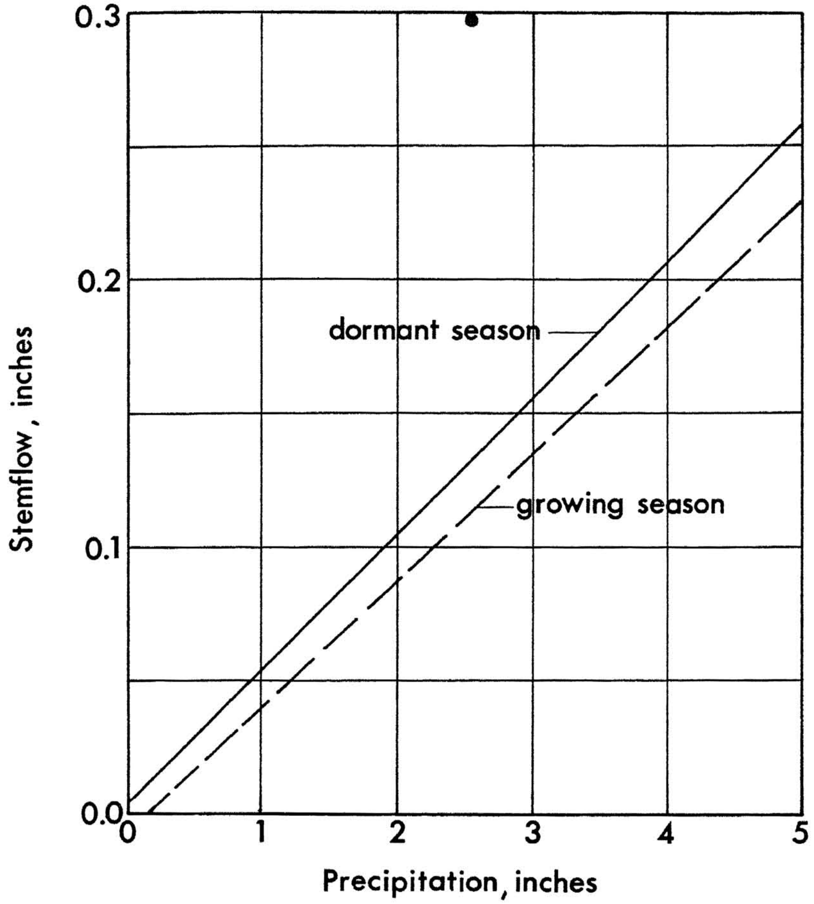

Fig. 5—Stemflow variation with precipitation by seasons for 32 trees.

hickory only if the 32 trees are representative of the stand and stemflow is expressed in inches over the crown areas. A correction for incomplete crown closure would be necessary also. However the equations are similar to the generalized equations given by Helvey and Patric (1965) for mixed hardwoods.

STREAMFLOW

Streamflow represents precipitation after evapotranspiration loss, soil-moisture storage gain, and ground-water storage gain are deducted. Runoff from forested basins differs from flow in agricultural watersheds in the Ozarks mainly due to the predominance of subsurface movement on forested areas. In the University Forest area many small springs also occur. Data concerning the quantity and tim-

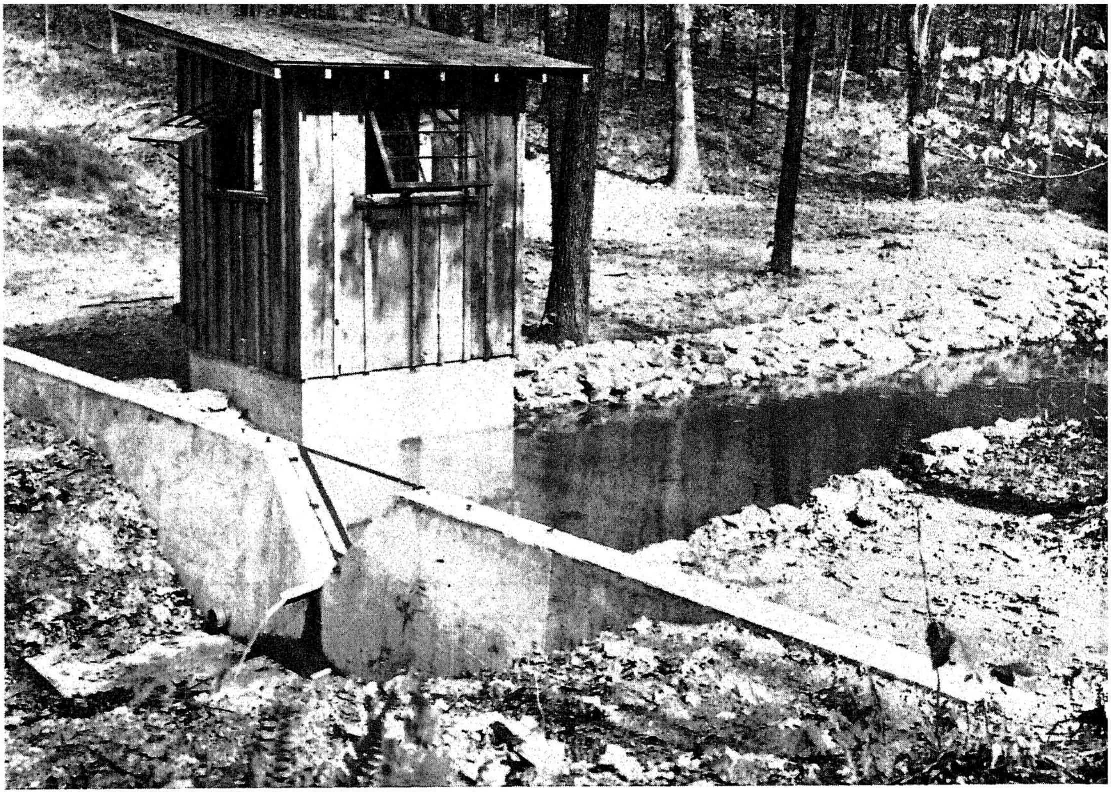

Fig. 6—Gaging station with modified 90° V-notch weir on Gum Springs Watershed.

ing of flow were derived from seven years of records on Gum Springs Watershed.

Gaging Installation Description

Streamflow on Gum Springs Watershed was measured from October, 1959, to January, 1966. The discharge from the 12.48-acre basin was intermittent except for a small perennial spring above the stilling basin. The gaging station was equipped with a modified, 90-degree V-notch weir. A small 30-degree V-notch was cut in the apex of the larger notch to facilitate measurement of the perennial, though small, spring discharge. Due to the modified design, the weir was field calibrated volumetrically. Figure 6 presents a view of the gaging station. The retaining wall does not rest on bedrock, but is set into relatively impervious dense clay substrate.

Results

Annual discharge from the basin averaged 7.01 inches and ranged from 5.38 to 10.13 inches for the six complete years of record. Table 8 presents monthly and annual total discharge. Major streams in southeast Missouri average 16 to 18

TABLE 8-MONTHLY AND ANNUAL STREAMFLOW (INCHES) OF GUM SPRINGS WATERSHED

	Month												
Year	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
1959	----	----	----	----	----	----	----	----	----	0.21	0.23	0.49	-----
1960	0.54	0.46	1.26	0.71	1.66	0.27	0.23	0.24	0.16	0.21	0.31	0.50	6.55
1961	0.26	1.46	2.63	1.56	3.13	0.22	0.18	0.09	0.09	0.09	0.13	0.29	10.13
1962	0.78	1.49	1.76	1.32	0.45	0.16	0.09	0.15	0.09	0.11	0.08	0.10	6.58
1963	0.09	0.08	6.62	0.18	0.31	0.13	0.07	0.07	0.05	0.03	0.08	0.07	7.78
1964	0.16	0.19	3.06	1.43	0.22	0.08	0.05	0.06	0.08	0.02	0.16	0.16	5.67
1965	0.24	1.28	1.07	1.49	0.16	0.36	0.10	0.07	0.24	0.08	0.09	0.20	5.38
1966	2.08	----	----	----	----	----	----	----	----	----	----	----	-----
Mean	0.59	0.83	2.73	1.12	0.99	0.20	0.12	0.11	0.12	0.11	0.15	0.26	7.01

inches of streamflow annually (United States Geological Survey, 1965). This amounts to about 35% of annual average precipitation, while the University Forest basin mean discharge is only 15.35%.

Tables 9 and 10 give monthly and annual figures for precipitation and temperature respectively. Data were summarized from University Forest weather station records obtained adjacent to Gum Springs Watershed.

From comparison of streamflow and precipitation records the seasonal distribution of moisture can be inferred. Precipitation during winter months generally is used in satisfying soil moisture deficits, as indicated by low streamflow during November through February. During March through May, the soil was nearing saturation and much of the precipitation was yielded as streamflow. The June through October period was characterized by lower but more intense precipitation, heavy vegetational water use, and low streamflow. Growing season discharge was mainly from the spring with stormflow events (composed of surface runoff and rapid subsurface flow) occurring after major summer storms.

Hydrograph recessions during rain-free periods were of two major types, i.e. rapid, short-term recessions after major spring storms and gradual recessions noticeable during long, rain-free growing season periods. The former type was thought to be a result of rapid movement of water downslope through the noncapillary pores of the soil (subsurface flow). The latter was flow from the small spring.

Barnes (1939) showed that streamflow recessions plotted on semi-log paper define a straight line and fit the equation:

$Q_t = Q_o K^t$ where,

Q_t = discharge at end of time interval t

Q_o = discharge at beginning of interval

K = recession coefficient.

Each basin has a characteristic recession coefficient which varies inversely with permeability of material supplying water after surface runoff ceases. Springflow and subsurface flow recessions were selected from semi-log plots of streamflow during rain-free periods of at least five days. Two days were allowed after storm peaks for surface runoff to cease. Discharge was expressed in inches per day and time in days. Periods were averaged according to the method given by Johnson and Dils (1956). After averaging, a regression analysis was used to fit the exact equation. Since periods of subsurface flow included springflow as well, the springflow equation was derived first and extrapolated graphically beneath subsurface recessions. This permitted separation of the actual subsurface discharge above that contributed by the spring. Table 11 shows results of regression analysis.

The subsurface recession coefficient was 0.818. This coefficient is similar to those found by Whipkey (1958) for three partially-forested Ozark basins with soils similar to those at University Forest. Whipkey found coefficients of 0.83, 0.85 and 0.90 for what he termed baseflow on these ephemeral streams. It is quite possible that subsurface water movement provides "baseflow" on many small, up-

TABLE 9-MONTHLY AND ANNUAL PRECIPITATION (INCHES) AT UNIVERSITY FOREST WEATHER STATION

Year	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
1949	10.28	4.30	6.60	1.53	4.69	5.75	1.67	0.94	2.82	9.01	0.49	6.69	54.77
1950	15.36	6.84	3.99	5.80	6.11	3.28	3.90	5.42	3.83	2.13	4.15	0.75	61.56
1951	4.74	6.74	2.82	3.58	2.33	7.27	4.57	1.44	5.02	2.27	7.42	2.91	51.11
1952	4.16	3.52	6.87	3.36	2.85	0.00	2.98	3.01	1.79	0.45	5.05	3.41	37.45
1953	2.43	1.77	6.08	4.44	3.55	1.71	0.69	1.22	0.23	1.55	1.26	1.88	26.81
1954	5.03	3.77	3.48	1.99	4.72	4.58	0.83	2.53	3.57	3.91	1.49	6.97	42.40
1955	1.10	2.28	4.96	3.49	6.39	3.06	4.53	2.02	1.39	4.05	1.89	0.46	35.62
1956	1.84	7.19	3.47	3.82	3.27	4.88	3.08	3.18	1.77	2.21	3.73	2.04	40.48
1957	4.80	4.93	2.68	11.41	10.66	6.40	8.38	3.20	1.14	4.04	8.41	7.38	73.43
1958	2.73	2.04	8.24	4.50	5.88	3.08	6.66	3.27	4.69	1.01	6.72	0.13	48.95
1959	3.51	3.11	2.44	2.48	4.24	3.40	3.18	3.11	2.63	5.37	2.79	3.69	39.95
1960	2.76	2.32	2.99	1.87	6.12	3.28	3.81	4.85	1.14	2.53	4.61	4.29	40.55
1961	0.88	3.47	6.20	4.52	9.61	3.02	6.18	1.84	2.46	0.55	5.47	4.44	48.64
1962	4.73	6.32	4.51	3.04	2.53	4.32	2.37	6.70	3.12	3.21	1.09	2.24	44.18
1963	0.83	0.99	6.56	1.10	5.67	3.57	2.85	3.70	0.77	0.05	4.43	1.52	32.05
1964	1.15	3.72	12.58	4.03	2.14	3.59	2.63	5.47	6.22	0.00	4.91	3.49	49.93
1965	2.61	4.68	4.82	4.13	4.90	4.78	1.96	1.19	11.48	0.22	2.22	4.09	47.08
Mean	4.07	3.98	5.25	3.82	5.63	3.88	3.55	3.12	3.18	2.50	3.89	3.32	45.59

TABLE 10-MEAN MONTHLY AND ANNUAL TEMPERATURES (° F) AT UNIVERSITY FOREST WEATHER STATION

Year	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Mean
1949	39.00	41.55	46.52	57.58	69.62	75.87	80.83	77.44	66.09	61.00	48.73	41.51	58.81
1950	42.03	38.87	43.07	53.20	65.98	74.77	75.98	71.46	67.17	63.43	41.58	32.89	55.87
1951	36.77	38.16	45.90	54.28	67.53	73.88	77.05	78.48	68.30	60.69	39.69	37.45	56.52
1952	40.24	42.90	45.82	55.57	66.58	81.11	82.16	78.22	69.93	54.08	47.88	38.37	58.57
1953	38.19	42.59	50.65	54.43	67.58	81.18	80.09	80.09	73.86	61.93	49.12	37.31	59.75
1954	35.08	46.52	46.48	64.21	62.26	75.60	82.30	81.57	74.83	60.30	47.65	38.00	59.57
1955	37.27	39.88	48.89	63.16	69.07	70.02	80.24	78.71	74.91	59.00	45.57	36.14	58.57
1956	32.95	40.66	47.68	55.84	67.39	74.60	78.02	79.12	69.40	63.32	46.80	42.39	58.18
1957	30.71	42.91	44.88	58.71	66.82	74.22	76.62	75.79	68.88	57.42	45.80	43.28	57.17
1958	33.69	29.58	40.04	56.43	65.06	72.54	77.77	76.80	70.15	59.10	51.30	33.40	55.49
1959	33.33	38.76	47.45	58.23	69.74	73.77	77.46	79.67	72.11	57.98	43.13	41.02	57.72
1960	37.91	36.12	34.68	60.00	63.54	73.62	77.05	78.44	73.24	59.58	48.27	34.25	56.39
1961	31.79	43.61	50.28	54.91	60.20	72.48	76.87	74.35	70.05	60.42	46.73	36.13	56.49
1962	31.45	41.73	42.86	54.62	73.23	74.38	79.52	78.54	68.52	61.29	46.02	36.03	57.35
1963	26.96	31.43	52.30	63.89	66.70	75.68	77.18	77.02	70.88	66.52	51.50	28.67	57.39
1964	36.96	37.90	46.48	61.21	70.21	75.21	78.76	77.91	69.86	57.63	50.71	37.50	58.36
1965	37.58	34.83	40.98	61.11	70.50	74.25	77.07	75.84	70.00	57.50	52.74	40.66	57.76
Mean	35.41	39.29	45.59	58.08	67.18	74.89	78.53	77.62	70.48	60.07	47.25	37.35	57.65

TABLE 11-CORRELATION REGRESSION DETERMINATION OF SUBSURFACE AND SPRINGFLOW RECESSION EQUATIONS ON GUM SPRINGS WATERSHED

Type	Equation	Correlation Coefficient (r)	Standard Error (± log Se)
Subsurface Flow	$Q_t = Q_o 0.818^t$	0.994	±0.104
Springflow	$Q_t = Q_o 0.980^t$	0.991	±0.069

land Ozark basins. As Whipkey suggested, subsurface flow downslope may store water in alluvial deposits along streams which in turn provide water to the channel. The duration of this storage depends on basin size and may often be fairly short.

The subsurface recession equation integrated to infinity from maximum observed subsurface discharge of 0.1380 inches per day indicates a maximum storage of 0.688 inches. The half-life of the subsurface recession or time for discharge to decrease by one-half was 3.4 days. Figure 7 depicts the subsurface recession.

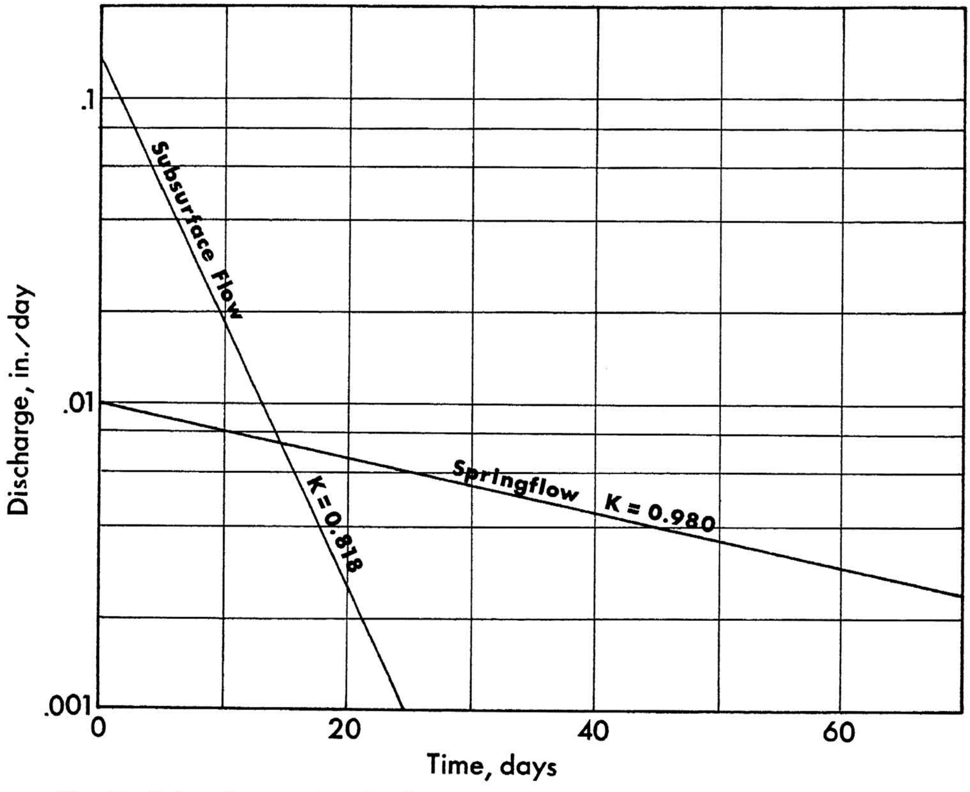

Fig. 7—Subsurface and springflow recessions on Gum Springs Watershed.

Springflow was characterized by a recession coefficient of 0.980. Storage, when the equation was integrated from maximum observed springflow of about 0.01 inches per day, was 0.495 inches. The true maximum springflow discharge occurred in spring, but was obscured by subsurface flow recessions. The maximum observed discharge used is probably a conservative estimate. Half-life of the springflow recession was 34.2 days. Figure 7 also illustrates the springflow recession. Covariance analysis shows the recessions are significantly different at the 1% level.

Subsurface flow may drain into bottoms along the stream on Gum Springs Watershed as evidenced by the near surface water table in soil pits along the stream after a major storm. Soil pits on slopes showed no standing water.

Springs in the University Forest area generally occur at the bases of slopes. Since outcrops of rock are not apparent at the spring site, hardpans known to occur in Ozark soils on flat ridges or very gentle slopes may be partially responsible. The source area for the spring could extend beyond the watershed.

Combined maximum subsurface and springflow recession storage amounts to 1.183 inches of water. The storage materials are effective reservoirs for rapidly infiltrating water. Surface runoff and erosion are held to a minimum. Annual semi-log plots of streamflow indicate the subsurface reservoir is recharged several times each year, while the springflow recession seldom peaks more than once each year in spring.

Flow duration information gives percentages of time certain discharge rates are equaled or exceeded. This type of information is used in various hydrologic design problems. Five years of flow frequency data from Gum Springs Watershed are given in Figure 8. Discharge is in inches per hour with time in percentage of hours in which these rates are exceeded each year on probability scale. In all but one year the flow rate occurring 50% of the time (median) was less than 0.0003 (–4.48 on log scale) inches per hour. A very low median flow is probably due to the presence of the spring. Discharge rates of 0.1 inches per hour were seldom equaled or exceeded. The general curve shape probably is similar on other basins with subsurface flow. The data for 1963 and 1964 have a somewhat steeper slope indicating more variable flow (Searcy, 1959). From monthly totals of streamflow (Table 8), 1963 and 1964 had above average March discharge which may indicate intense storms which are not present in other years. A detailed study of frequency of rainfall intensities each year may show similar trends.

HYDROLOGIC BUDGET

Precipitation less streamflow corrected for changes in ground-water storage for the water year gives an estimate of annual evapotranspiration loss. The water year is chosen as the sequence of months giving the smallest net change in soil moisture storage. Often the October 1 - September 30 sequence is chosen since late growing-season soil moisture is normally at its annual low point and has the highest probability of being the same from year to year. Actual representative

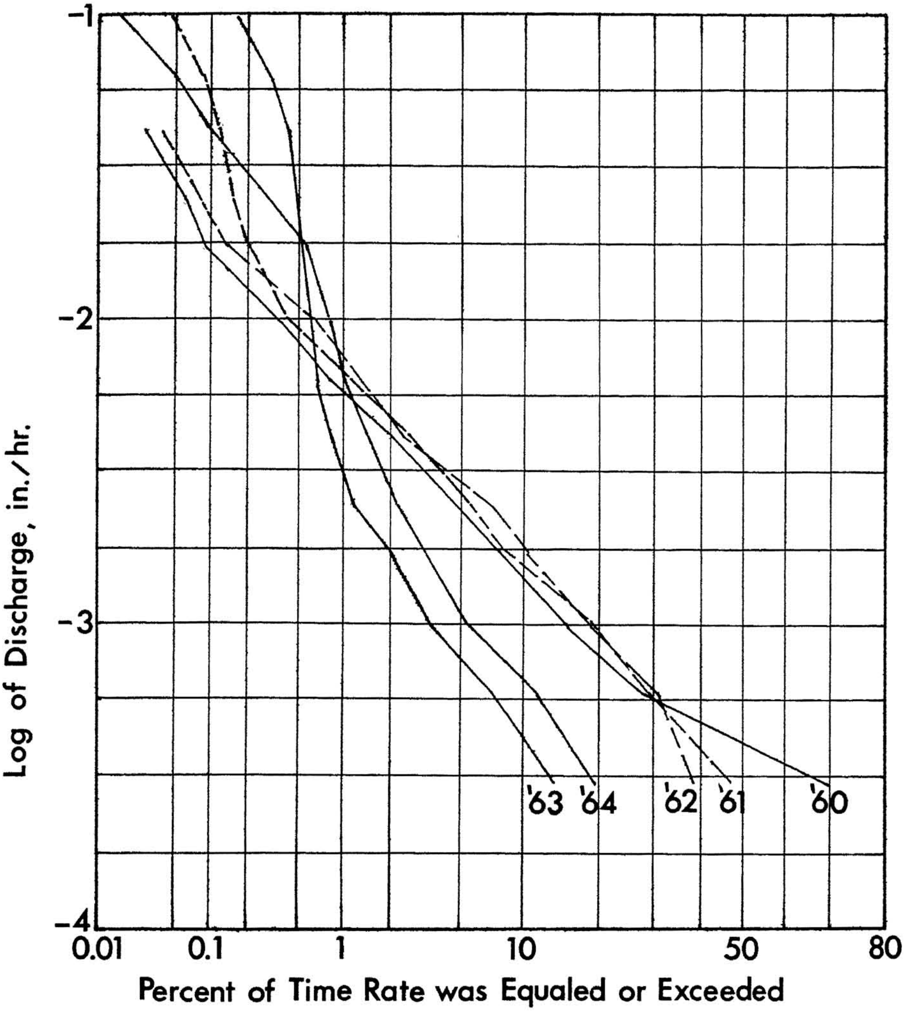

Fig. 8—Flow duration curves for 1960-1964 on Gum Springs Watershed.

field measurements of soil moisture changes on a basin can eliminate concern over the water year. A basic assumption inherent in most hydrologic budgets is that no deep seepage losses occur.

Methods

In a regression analysis, streamflow had best correlation with precipitation on Gum Springs Watershed for the March 1 - February 28 water year. However, missing records for March 1, 1961 and the necessity of using certain assumptions to compute ground-water storage during periods with subsurface flow and springflow combined forced use of the standard October 1 - September 31 water year. Also, no water year had a correlation coefficient above 0.633 which indicated other factors required consideration in the relationship. It is interesting to note that the better correlation for the March 1 - February 28 water year implies the soil was at a more constant moisture level early each spring, probably at the maximum storage capacity (again a constant from year to year).

Changes in ground-water storage were changes of storage in zones producing subsurface flow and springflow. Exponential equations fitted to subsurface flow and springflow recessions were integrated from daily stream discharge to infinity to obtain ground-water storage. Differences between storage at the beginning and end of a water year was the change in ground-water storage.

Since mean annual streamflow in southeast Missouri is considerably higher than measured on Gum Springs Watershed and no water year gave a good correlation between streamflow and precipitation, deep seepage losses were thought to occur. Thus evapotranspiration estimates from the budget would include seepage losses. As a check on evapotranspiration estimates, Thornthwaite's potential evapotranspiration loss was calculated from mean monthly temperatures (Thornthwaite and Mather, 1957) for each year.

Results

Table 12 shows precipitation less streamflow corrected for changes in ground water storage for October 1 - September 30 water years. Evapotranspiration estimates averaged 5.74 inches higher than potential evapotranspiration. Potential evapotranspiration calculated by Thornthwaite's method represents maximum losses that could occur if soil moisture were not limiting. Actual evapotranspiration losses in southeast Missouri are generally less, ranging between 25 and 30 inches per year (Whipkey, 1958; McQuigg and Decker, unpublished data; Williams et al., 1940). Thus the difference between actual annual evapotranspiration loss and the budget estimates was probably even greater.

Precipitation data taken from the weather station adjacent to the small basin were believed representative. Streamflow data were less accurate due to periodic gaging difficulties caused by a clogged weir screen and frozen stilling well. Annual streamflow records however, were probably within 10% of the actual value. Even errors of 20% or 1.45 inches of average annual streamflow do not account for the large discrepancy between estimated and potential evapotranspiration. Deep seepage losses probably account for the differences between potential and estimated evapotranspiration. These losses could be vertically downward to deep strata or laterally beneath the gaging station. The magnitude of the loss appears to vary by years.

Figure 9 shows accumulated estimated and potential evapotranspiration for the period October 1, 1960 to September 30, 1965. The area between the curves represents potential accumulated seepage loss. Greater seepage losses seem to be

TABLE 12-HYDROLOGIC BUDGET (IN INCHES) ON GUM SPRINGS WATERSHED FOR OCTOBER 1 - SEPTEMBER 30

Water year	Precipitation (P)	Streamflow (Q)	Change in Ground Water Storage (± ΔSg)	Estimated Evapotranspiration (ET)	Potential Evapotranspiration P(ET)
1960 - 1961	49.61	10.64	-0.09	38.88	30.44
1961 - 1962	48.10	6.80	-0.03	41.27	33.05
1962 - 1963	32.58	7.89	-0.06	24.63	33.45
1963 - 1964	47.53	5.51	-0.01	42.01	33.18
1964 - 1965	48.95	5.35	+0.08	43.68	31.62
Mean	45.35	7.24	-----	38.09	32.35

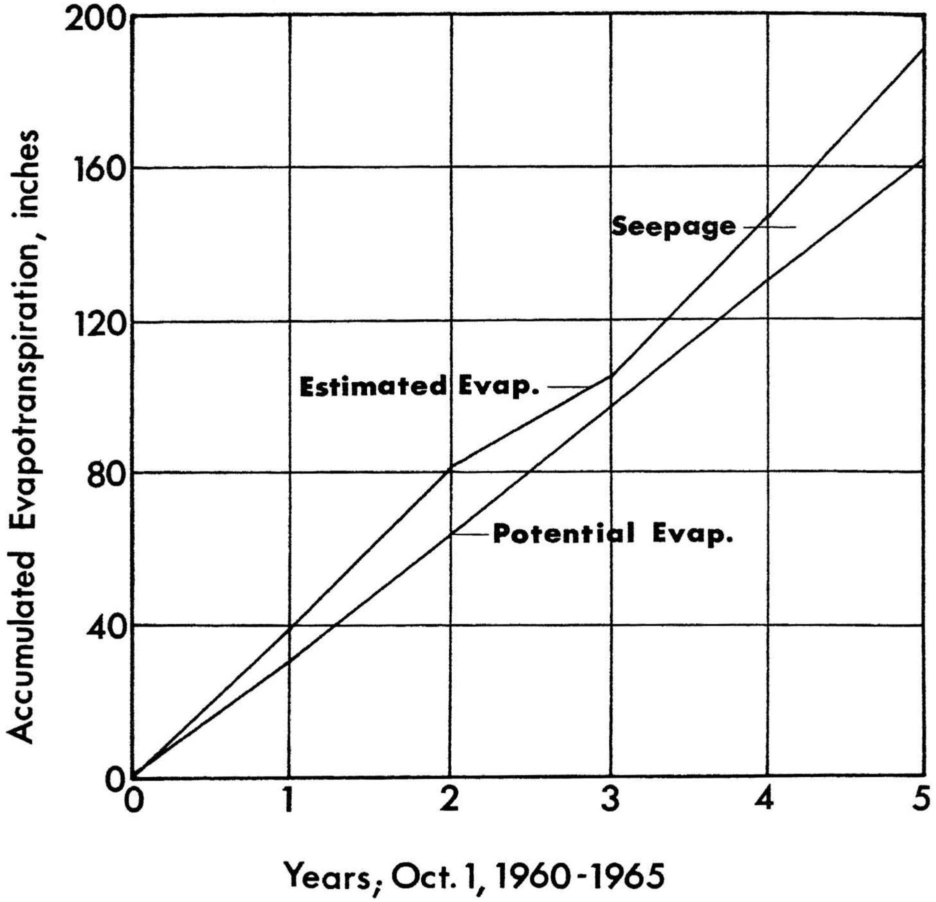

Fig. 9—Accumulated potential and estimated evapotranspiration for five years on Gum Springs Watershed.

associated with higher precipitation. The 1962-63 water year with below average precipitation apparently had no seepage loss. The evapotranspiration estimate for that year appears reasonable. Infiltration studies show that moisture moves downward as a wetting front with a high moisture content (Baver, 1956). Thus years with higher precipitation would be required to extend the wetting front to any depth. For there to be any appreciable deep seepage loss this wetting front must be in contact with the water table. Distribution of storms rather than total annual precipitation is probably more important in determining seepage losses. A year of low annual precipitation but with precipitation concentrated in several weeks might allow the wetting front to extend to considerable depths. Early spring wet periods without high vegetative water use would be most effective in producing seepage losses.

SUMMARY

The amount of precipitation falling through the forest canopy to the litter varies with storm size and season. Equations derived for predicting throughfall from storm size based upon throughfall measurements for 469 storms in two stands of large, oak-hickory poles were:

Growing Season $\hat{T} = 0.8755P - 0.0413$
Dormant Season $\hat{T} = 0.9135P - 0.0663$.

Mean canopy interception amounted to about 12% of precipitation in the growing season and 9% in the dormant season. Canopy storage averaged 0.06 inches for either season.

The quality of stemflow produced also depended upon storm size and season. Mean stemflow for 32 predominantly black oak trees for 40 storms was used to derive equations for prediction of stemflow from storm size. The equations were:

Growing Season $\hat{S} = 0.0482\ P - 0.0097$
Dormant Season $\hat{S} = 0.0513\ P - 0.0016$

Combined canopy and bark storage of precipitation was about 0.20 inches for the growing season. Stemflow as percentage of precipitation averaged 3.83 in the growing season and 5.28 in the dormant season. Percentage stemflow showed no consistent trend with tree diameter for 23 black oaks ranging from 2.2 to 19.3 inches d.b.h.

Mean annual streamflow on the gaged University Forest basin was 7.01 inches, compared to 16-18 inches for major streams in southeast Missouri. A major portion of mean annual streamflow occurred in the March-May period. Discharge was low in winter and late summer due to soil moisture deficits caused by evapotranspirational losses and low rainfall.

Streamflow recessions were separated into relatively rapid subsurface flow recessions and gradual springflow recessions. Exponential equations describing the recessions were:

Subsurface Flow $Q_t = Q_o\ 0.818^t$
Springflow $Q_t = Q_o\ 0.980^t$

Maximum combined subsurface flow and springflow storage was 1.183 inches over the basin. Time required for flow to decrease one-half was 3.4 days for subsurface flow and 34.2 days for springflow.

Flow duration curves for the basin indicated a very low median flow. In four of five years analyzed, median flow rate (occurring 50% of the time) was less than 0.0003 inches per hour. Peak rates were about 0.1 inches per hour.

Hydrologic budget estimates of evapotranspiration for the October 1 - September 30 water year were an average 5.74 inches high compared to Thornthwaite's potential evapotranspiration. Deep seepage losses were probably the cause of high evapotranspiration estimates.

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