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HYDROLOGIC CHARACTERISTICS OF WALKER BRANCH WATERSHED[1,2]

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ABSTRACT--Walker Branch Watershed, a 97.5 ha deciduous forest catchment on dolomitic terrain, received annual precipitation averaging 151.1 cm over a six-year period from 1970-1976. Approximately 57% of this precipitatin left the watershed as streamflow. Soil evaporation and canopy interception with subsequent evaporation loss were well represented by relationships derived for eastern hardwoods and amounted to about 12% of precipitation. Transpiration accounted for the remainder (31%) of the water loss from the watershed. Seasonal precipitation-streamflow balances show that precipitation is relatively uniformly distributed throughout the year, while streamflow varies seasonally with high flows from December through May and low flows from June through November. Baseflow discharge patterns from the two subcatchments are different, the smaller basin yielding relatively more than the larger one. This difference is thought to be due to groundwater exchange between the two through channels in the dolomitic bedrock. The hydrologic data base is used extensively in nutrient and trace element cycling studies and in development of mechanistic hydrologic models.

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DISCLAIMER

INTRODUCTION

Experimental watersheds have been in existence for over 50 years and originally were used to gain an understanding of water yield and erosion in natural and managed ecosystems. Today the role of experimental watersheds in understanding ecosystem function is much broader, and within the past decade many watershed research programs have included studies of nutrient and toxic element movement. The Walker Branch Watershed project has addressed many aspects of ecosystem function, especially with regard to biogeochemical cycling of elements. These have been summarized earlier in this volume by Harris (1977).

Water is the dominant carrier of elements from a catchment as well as being a major factor controlling biological activity within an ecosystem. Therefore, an assessment of biogeochemical cycles of watersheds requires a quantified, understanding of the hydrologic cycle. In fact, the primary reason for conducting element cycling research on experimental watersheds is because hydrologic data are available and element concentrations can be applied to these data to generate element balances for the landscape. While this is an important use of the hydrologic data for Walker Branch, the information is also used in formulation and validation of mathematical models of water use and transport within forested ecosystems. This paper discusses the hydrologic characteristics of Walker Branch and summarizes hydrology data for the period from 1970-1976. Other papers contained in this proceedings have utilized this data base for studies of trace element inputs (Lindberg et al. 1977), trace element export (Turner et al. 1977), nutrient discharge (Henderson et al. 1977), organic matter transport (Comiskey et al. 1977) and hydrologic modeling (Huff et al. 1977).

WATERSHED DESCRIPTION AND INSTRUMENTATION

A detailed description of Walker Branch is given earlier in this volume by Harris (1977). Briefly, the watershed is 97.5 hectares in area and consists of two subcatchments. The bedrock is dolomite, vegetation is predominantly deciduous forest and soils are deeply weathered typic paleudults. The watershed has remained relatively undisturbed over the past 35 years. Streambed morphology differs between the two subcatchments. The smaller West Branch (38.4 ha) flows aboveground throughout the entire extent (370 m) of its perennial flow and much of this is over exposed bedrock. In contrast, between the limits of perennial flow and the weir (760 m) the East Branch flow is completely subterranean in two reaches (sometimes totaling 335 m) at low flow rates. The East Branch stream channel is characterized by extensive sand and gravel deposits and little exposed bedrock is evident.

Precipitatin gauges, Fisher and Porter Model 1548 automatic recorders, are located at five sites on the watershed (Fig. 1). The rain gauge network permits the input to a given subwatershed, weighed by the Thiessen technique (Curlin and Nelson 1968), to be determined by at least three stations on that subwatershed. Data are recorded at five-minute intervals; while the instruments detech changes of 0.025 in. (0.064 cm) of precipitatin, the data are recorded in 0.1-in. (0.25 cm) increments.

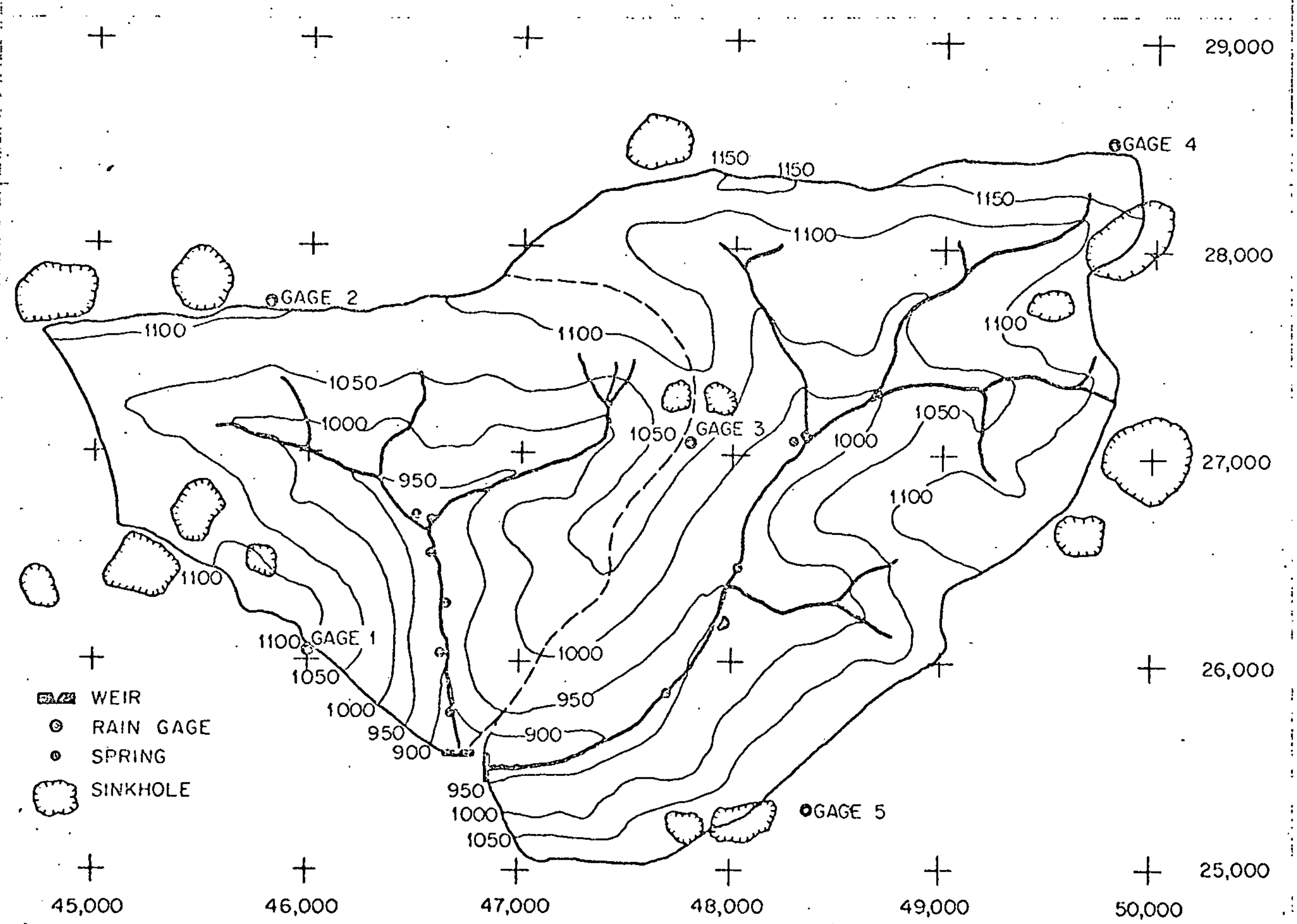

Fig. 1. Topographic Map of Walker Branch Watershed on the ERDA Reservation, Oak Ridge, Tennessee showing the location of gauging stations on the two subcatchments.

Streamflow from each subwatershed is monitored by sharp-edged, stainless steel 120° V-notched weirs (Nelson 1970). The height of the weir blade is 0.76 m so that streamflow as high as 1.2 m^3/sec can be measured. While this capability is adequate for normal conditions on Walker Branch, the concrete stilling basin forms a sharp-crested, rectangular weir above the V-notch which is used to extend estimates of streamflow during extreme storm conditions. The stage height above each weir is monitored continuously by Fisher and Porter water level recorders with a resolution of 0.001 ft. Data are recorded at five-minute intervals. The stage height recorders are periodically recalibrated with hook gauge measurements to minimize effects of instrument drift.

Streamflow is calculated from the stage heights and the equation of Hertzler (1938) for 120° V-notch weirs,

$$Q = 4.43H^{2.449} \quad \text{for } H \leq 2.5 \text{ ft} \qquad (1)$$

or

$$Q = 41.779+66.8H^{1.47} \quad \text{for } H > 2.5 \text{ ft} \qquad (2)$$

where Q is discharge in ft^3/sec when the stage height, H, is in feet. Accuracy in the stream flow determination is dependnt on both the measurement of stage height and the extent to which the equations describe the weir discharge. Weir calibration at low discharge rates ($H < 0.5$ ft) was consistent with equation (1) with a maximum deviation of ± 5%. While the stage height is monitored to the nearest 0.001 ft., the accuracy of the recorder cannot be standardized closer than ± 0.002 ft. relative to the hook gauge measurements. For a 1-ft (0.305 M) stage height the uncertainty in the stage height recorder represents only 0.5% error in streamflow, but at 0.1-ft stage height (equivalent to a discharge of 0.015 ft^3/sec = 0.0042 m/sec) the uncertainty in streamflow is ± 5%.

RESULTS AND DISCUSSION

Annual Water Balance

The annual water balance has been quantified for Walker Branch Watershed for the period from September 1, 1970, to August 31, 1976 (Table 1). During these six water years precipitation averaged 151.1 cm, about 8% greater than the long-term annual mean of 140.1 cm for the Oak Ridge, Tennessee, area (ORATDL, 1972, and Supplements). Streamflow averaged 85.8 cm/yr during the period resulting in a net input (precipitation - streamflow) of 65.3 cm annually. This value is an estimate of the total evapotranspiration (ET) from the watershed providing our assumption that the watershed was neither gaining water from outside its boundaries or losing it through deep seepage is correct. This assumption appears valid based on the modeling analyses conducted by Huff et al. (1977).

The 65.3 cm annual evapotranspiration is less than the 76.5 cm potential evapotranspiration value estimated using Thornethwaite's methodology. However, there is considerable variation in ET among water years. ET for the 1972-73 and 1975-76 water years fell within 4 cm of the potential ET while during 1971-72 and 1973-74 ET was nearly 20 cm less than the potential value. The amount by which actual ET falls short of potential ET depends on the amount of precipitation from June through September. For the two water years when actual ET approached potential, precipitation was 3 to 6 cm above the long-term average during these months. On the other hand, June through September precipitation was less than normal for the other water years, and by 12 cm during 1973-74. Thus in spite of the fact that on an annual basis precipitation during the 1973-74 water year was 25% greater than normal, it was deficient during summer months and this resulted in one of the lowest amounts of ET during the six-year period.

In Table 1 separation of ET into its component terms, evaporation and transpiration, has been accomplished using the raltionships of Helvey and Patric (1965). Using experimental data from numerous hardwood sites in the eastern United States, Helvey and Patric developed equations to predict the quantities of throughfall, stemflow and canopy and litter (forest floor) interception for both the growing and dormant seasons. These equations require only inputs of total precipitation and the number of individual precipitation events. On Walker Branch we compared the relationships with the amount of throughfall in the four forest types found on the watershed. A summary of this comparison is shown in Table 2 and a more detailed presentation of the experiment is given by Henderson et al. (1977). We found that during both the growing and dormant seasons there was no significant difference among the four forest types in the amount of throughfall. Further the calculated throughfall was in close agreement with measured quantities. Therefore, since canopy interception accounts for greater than 80% of the evaporation losses from forested watersheds, we consider the Helvey and Patric (1965) equations for total interception to be valid for Walker Branch.

Table 1. Annual Water Balance on Walker Branch Watershed from September 1, 1970 to August 31, 1976.

Water Year[a]	Precipitation (P)	Streamflow (S)	Net Input (P-S)	Evaporation[b] (E)	Transpiration[c] (T)
	cm/year				
1970-71	139.5	74.5	65.0	17.8	47.2
1971-72	128.2	71.0	57.2	17.0	40.2
1972-73	187.5	114.8	72.7	22.3	50.4
1973-74	174.7	116.1	58.6	19.3	39.3
1974-75	146.4	83.1	63.3	17.9	45.4
1975-76	130.0	55.3	74.7	17.6	57.1
Six-year Average	151.1	85.8	65.3	18.7	46.6

[a]A water year extends from September 1 to August 31 of the following calendar year.

[b]Estimated with equations of Helvey and Patric (1965).

[c]Calculated as net input minus evaporation.

Table 2. Comparison of calculated and measured throughfall for Walker Branch Watershed during growing and dormant seasons in 1971 through 1973.

	Precipitation	Calculated* Throughfall	Measured Throughfall
	----------	cm	----------
Growing Season (May - Nov)	72.1	60.3	61.0
Dormant Season (Dec - Apr)	80.7	71.0	69.5

*Based on the relationships of Helvey and Patric (1965):

$TF = 0.901\ P - 0.079\ N$ (Growing Season)

$TF = 0.914\ P - 0.038\ N$ (Dormant Season)

Using the equations to separate evaporation and transpiration, it was estimated that about 70% of the evapotranspirative losses from Walker Branch occur as transpiration; the remainder being evaporation. Year to year variations were large for transpiration and in the same pattern as discussed earlier for total ET.

Annual Discharges from East and West Branches

As mentioned earlier, there is a distinct difference in channel characteristics between the East and West Branches of the watershed. There is also a difference in the water yield from these subcatchments. Even though the East Branch contains 50% more area, its annual discharge is only half that of the West Branch (Table 3). Later in this volume, Huff et al.(1977) demonstrate that this discrepancy can be accounted for by an exchange of baseflow from the east to the west subcatchments, possibly through solution channels in the dolomite bedrock.

Seasonal Precipitation and Streamflow

The seasonal distributions of precipitation and streamflow for Walker Branch Watershed (Fig. 2) are those which would be expected in warm subhumid

Table 3. Comparison of area-equivalent streamflow (cm) from the east and west branches of Walker Branch Watershed for 1970-1976.

Water Year[a]	Streamflow discharge East Branch	West Branch
	----------cm----------	
1970-71	52.3	108.5
1971-72	50.5	102.6
1972-73	90.8	151.6
1973-74	92.0	153.1
1974-75	61.8	115.9
1975-76	38.0	81.9
Six-year Average	64.2	118.9

[a]A water year extends from September 1 to August 31 of the following calendar year.

portions of the United States (Satterland 1972). Precipitation is generally well disturbed throughout the year with slightly greater amounts during winter and seasonally lower amounts in late summer and early autumn. Within any year, however, precipitation is quite variable, and it is not uncommon for the precipitation for a given month to be either half or double the average precipitation for that period. Snow accounts for a negligible fraction of the annual precipitation.

Precipitation occurs on one-third of the days in a year. Most of these days have relatively little rainfall. Of the days with rain, 55% total less than 1 cm and 90% of the days experience less than 3 cm (Fig. 3), although daily precipitation of almost 14 cm has been recorded during the six-year period. While large storms occur infrequently, they do account for a significant proportion of the total annual precipitation (Fig. 3). For instance, daily precipitation in amounts greater than 3 cm (10% frequency) accounts for 35% of the annual amount. Conversely, daily precipitation of less than 1 cm (55% frequency) accounts for less than 20% of the annual total. The precipitation pattern is thus characterized by numerous days with low daily amounts and a few larger storms which are important in determining the amount of annual precipitation and therefore the amount of streamflow.

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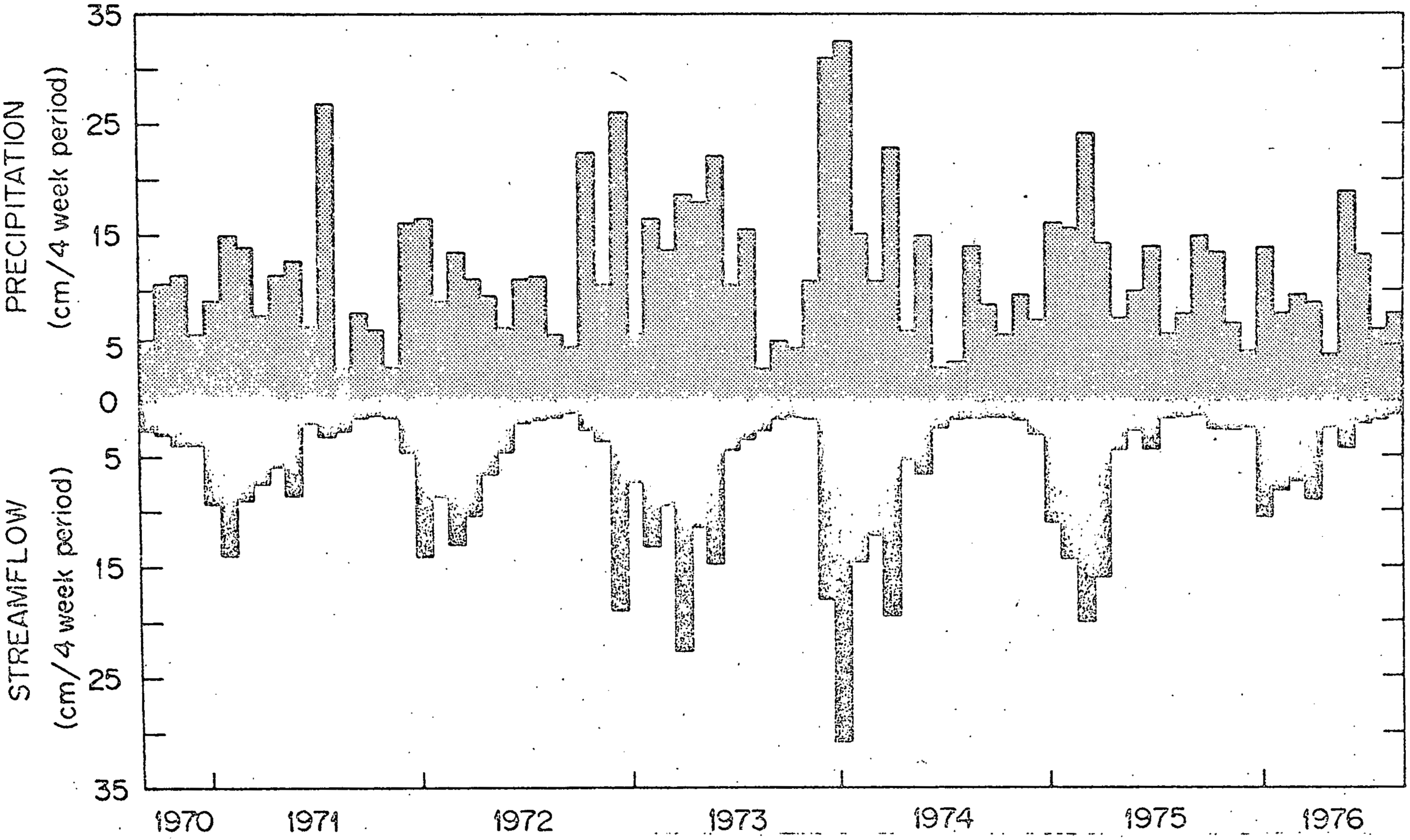

Fig. 2. Seasonal distributions by four-week intervals (13/year) of precipitation and streamflow for Walker Branch Watershed from September 1, 1970 through August 31, 1976. Values are expressed as cm of water over the total area of the catchment.

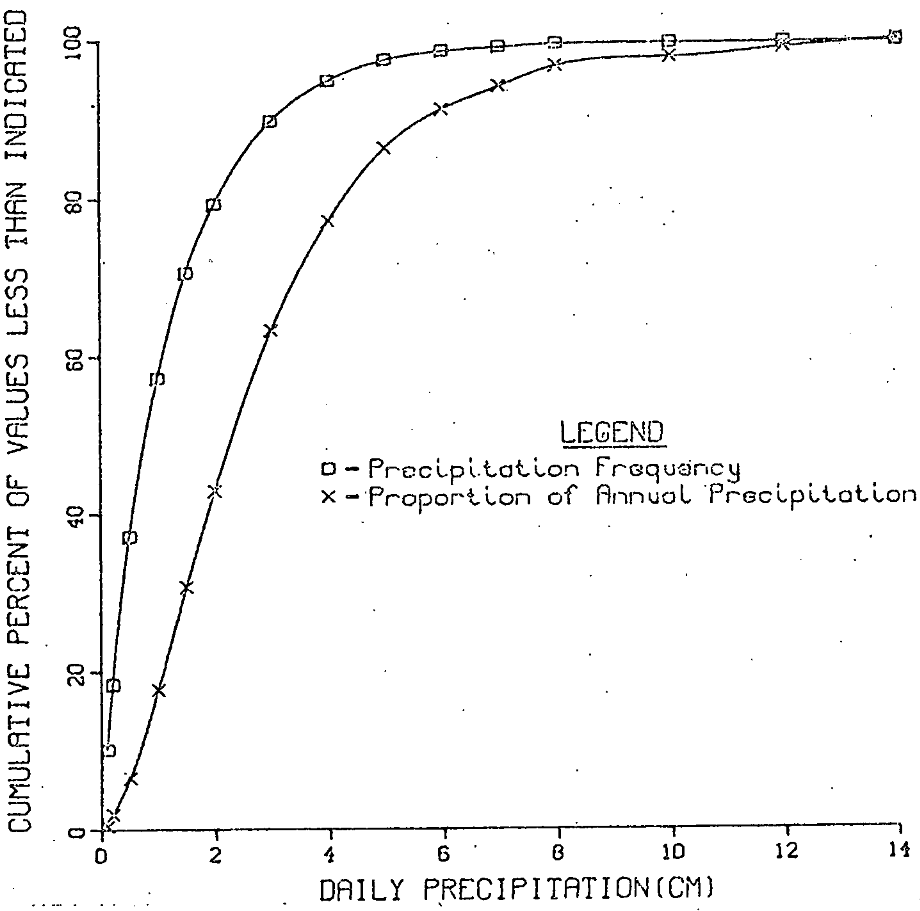

Fig. 3. Cumulative distribution of frequency and proportion of annual precipitation accounted for by daily precipitation of given amounts or less on Walker Branch Watershed for the period from September 1, 1970, through August 31, 1976.

Daily weighted average streamflow discharge rates ranged from 0.005 m^3/sec to nearly 1.1 m^3/sec for the six-year period from 1970 to 1976 (Fig. 4). However, the instantaneous peak discharge rate during this period was nearly 4.0 m^3/sec (2.3 m^3/sec for the East Branch and 1.7 m^3/sec for the West Branch). Periods of low flow (< 0.05 m^3/sec) occur about 90% of the time and account for 50% of the total water yield. Daily flow rates between 0.05 and 0.2 m^3/sec also contributed an important percentage of the annual yield (∿ 35%), even though they occurred only about 10% of the time. Daily flow rates greater than 0.2 m^3/sec occur considerably less frequently (only about 3 times a year) but account for 17% of the annual discharge. As Henderson et al. (1977) discuss, these relatively infrequent flow rate occurrences are of particular importance in the transport of some nutrients from the watershed.

When streamflow discharge is expressed on a precipitation equivalent basis (rate x time ÷ area), the pattern shown in Fig. 2 emerges. Streamflow is less variable than precipitation and is characteristic of the subhumid region which does not experience a snowpack accumulation. It is greatest during winter and spring months and lowest during summer and autumn (Fig. 2). This pattern is repeated annually with only minor deviations, and these are primarily associated with the amount of precipitation during any month. This pattern is controlled largely by the precipitation, evapotranspiration and water storage capacity of the soils as shown in Fig. 5. The low streamflow during summer and early autumn is due to depletion of stored soil water by evapotranspiration. Based on the studies of Peters et al. (1970) this storage amounts to only 4.6 cm in the upper 100 cm of the soil profile (rooting zone). As a result of this depletion, most of the precipitation during summer and fall satisfies soil water deficits. While soil water redistribution occurs continually during this period, it does not move through the soil profile to become streamflow but is retained within the rooting zone until adsorbed by vegetation and subsequently transpired. Soil water recharge takes place gradually during September and October as transpiration demands decrease. Thereafter streamflow responds to precipitation because little storage capacity exists within the watershed. Thus during winter and spring the amount of streamflow largely depends on the amount of precipitation. Since most of the winter precipitation occurs as rain rather than snow, high streamflow occurs throughout the winter season

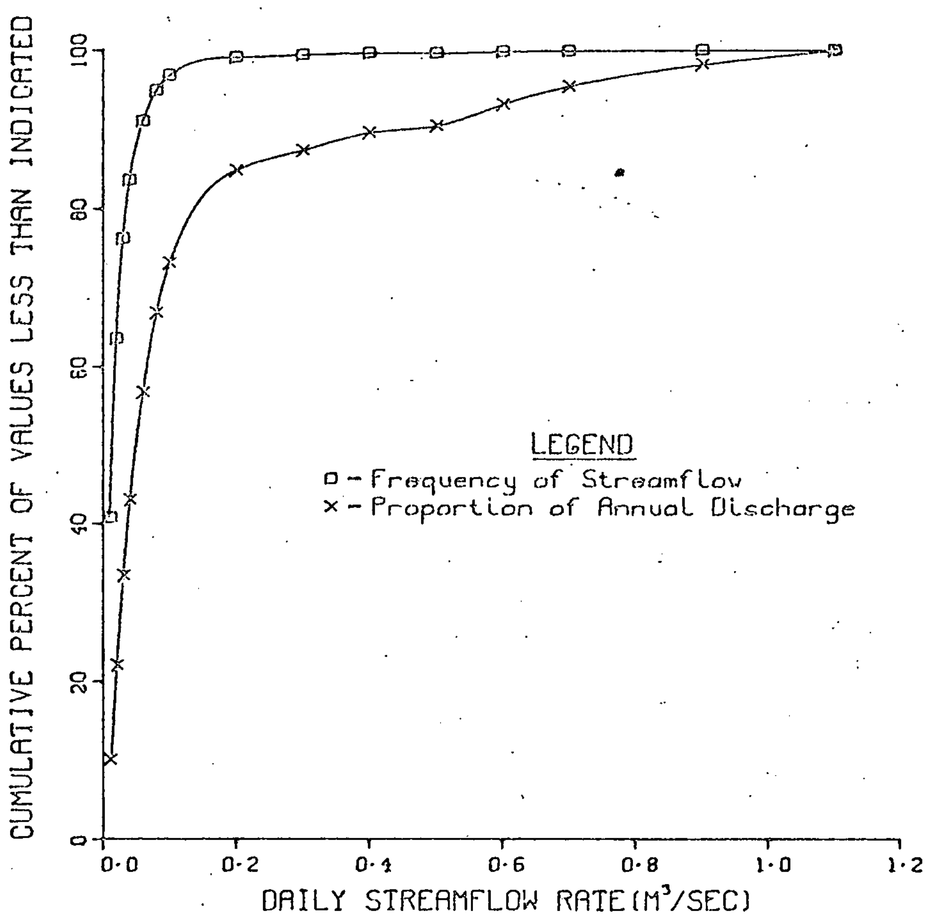

Fig. 4. Cumulative distribution of frequency and proportion of annual streamflow accounted for by daily streamflow discharge rates of given amounts or less on Walker Branch Watershed for the period from September 1, 1970, through August 31, 1976.

rather than being concentrated in spring as is characteristic of areas which accumulate snowpacks.

Figure 5 also shows why the June through September precipitation is so important in determining the actual amount of ET during individual years.

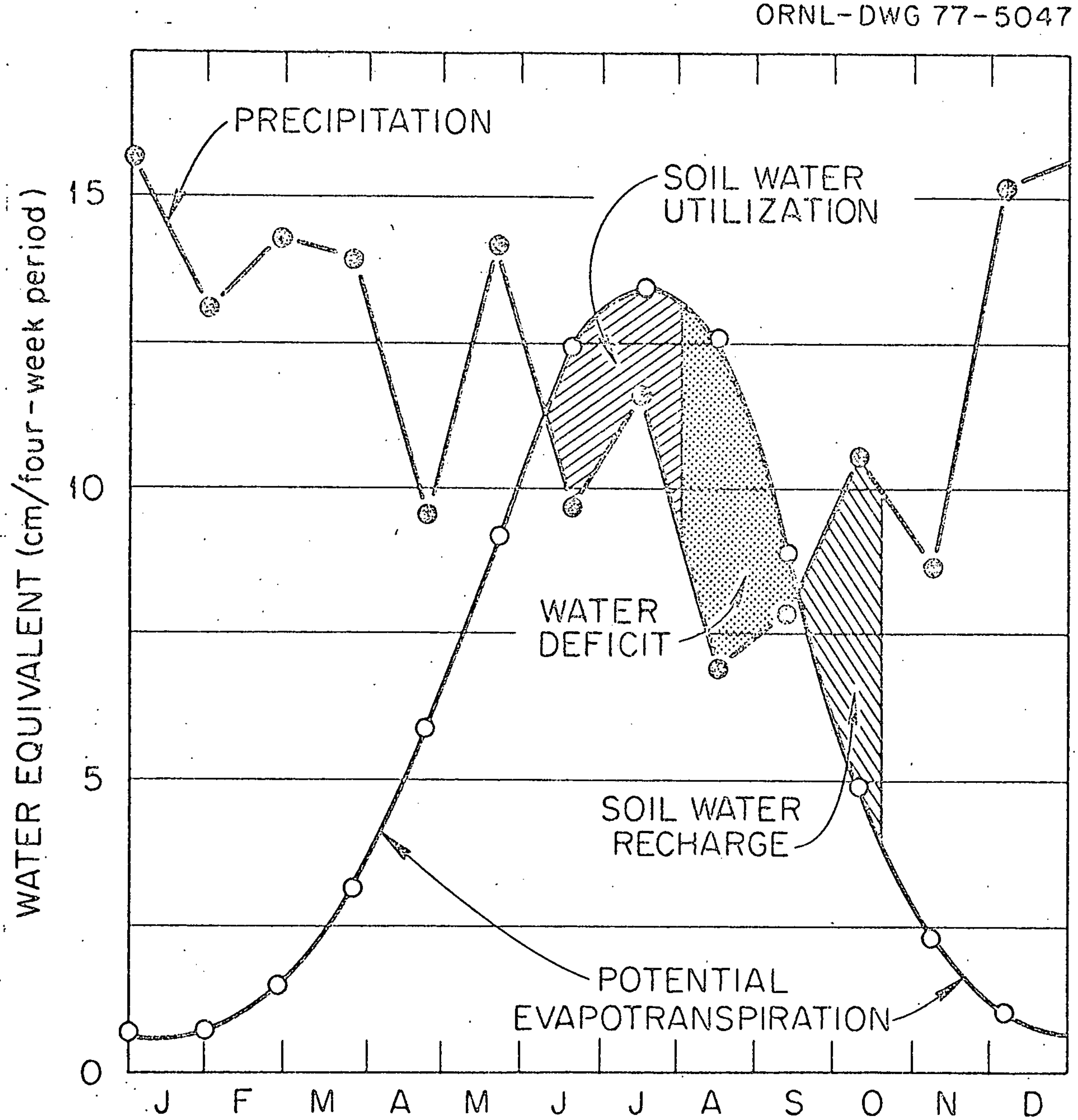

Fig. 5. Seasonal relationship between precipitation and potential evapotranspiration for Walker Branch Watershed showing periods of soil water utilization, water deficit, and soil water recharge. Precipitation values are averages over the September 1, 1970 to August 31, 1976 period potential evapotranspiration values are long-term averages using Thornethwaite's Methodology.

On the average precipitation is less than potential ET during this period and thus the six-year ET estimate falls short of the potential value (Table 1). However, if precipitation is greater than normal for any one year during summer the difference between the precipitation and potential ET lines will decrease (less water deficit) with the result being greater actual ET. Conversely, less than normal precipitation results in larger water deficits and lower actual ET during individual years. This figure also shows our rationale for delineation of a September 1 to August 31 water year. The September date is characterized by low precipitation and maximum soil water deficits. Therefore, from year to year at this date the soil water status will be consistently at a minimum and stable compared to other times of the year which receive more precipitation. Year to year variations in the amount of water stored in the soil profile are minimal during this period, leading to its selection as the start of the water year.

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