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APPLICATION OF THE THORNTHWAITE WATER BUDGET TO THE HYDROLOGY OF THREE TENNESSEE WATERSHEDS

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ABSTRACT

Water budget analysis is a useful method for the study of water surplus and runoff in a drainage basin. The purpose of this paper is to apply the Thornthwaite water budget method to three selected rural Tennessee watersheds. The watersheds are the Loosahatchie River in West Tennessee; the East Fork of Stones River in Middle Tennessee; and the Little River in East Tennessee. The calculated runoff from the three watersheds, using Thornthwaite water budget methods, are compared with the measured runoff data to evaluate the validity of the water budget method and to determine the possible effects of watershed characteristics on total amount of surface runoff. The average monthly calculated runoff for the East Fork of Stones River for the 14-year period 1972- 1985 was very close to the average monthly measured runoff. The Little River in East Tennessee produced more runoff than calculated, while the Loosahatchie River in West Tennessee produced less runoff. The discrepancy for the Little River is due to the fact that the watershed lies in an area of greatly variable elevation and precipitation. There is no immediate explanation for the Loosahatchie's discrepancy. Water budget procedure does provide a useful means for understanding hydrology of the basins in this study.

INTRODUCTION

Water budget analysis is a useful method for the study of water surplus and runoff in a drainage basin (Mather, 1978). This study used the Thornthwaite water budget method to calculate water surplus and runoff in three non-urbanized Tennessee watersheds. Three rural watersheds were selected from each of the state's major regions: West, Middle, and East Tennessee. They are comparable in size, each covers between 260 and 270 square miles. While similar in size, each watershed lies in a different region of the state and hence possesses distinct characteristics of land use, vegetation, topography, soil, geology, and stream gradient. The purpose of this paper is to apply the Thornthwaite water budget method to the three selected rural Tennessee watersheds. The calculated runoff of these three watersheds are compared with the measured runoff by the U.S. Geologic Survey (U.S.G.S.) to evaluate the validity of the water budget method and to determine the possible effects of watershed characteristics on total amount of surface runoff.

STUDY AREA

The three Tennessee watersheds selected for this study are (a) the Loosahatchie; (b) the East Fork of the Stone River; and (c) the Little River (Figure 1). Descriptions and comparisons of the watershed characteristics are as follow:

Loosahatchie River:

The Loosahatchie watershed is in West Tennessee. The drainage basin of the river near Arlington, Shelby County, covers 262 square miles. The river begins northeast of Newcastle (elevation 539 feet) in Hardeman County. The stream gauge is 250 feet at Arlington, a difference of only 289 feet. Topography of the West Tennessee Plain and West Tennessee Uplands is gently rolling, interrupted by small ridges and drainage divides (Soil Conservation Service,1971). Some gullied topography and swampy conditions are found along the

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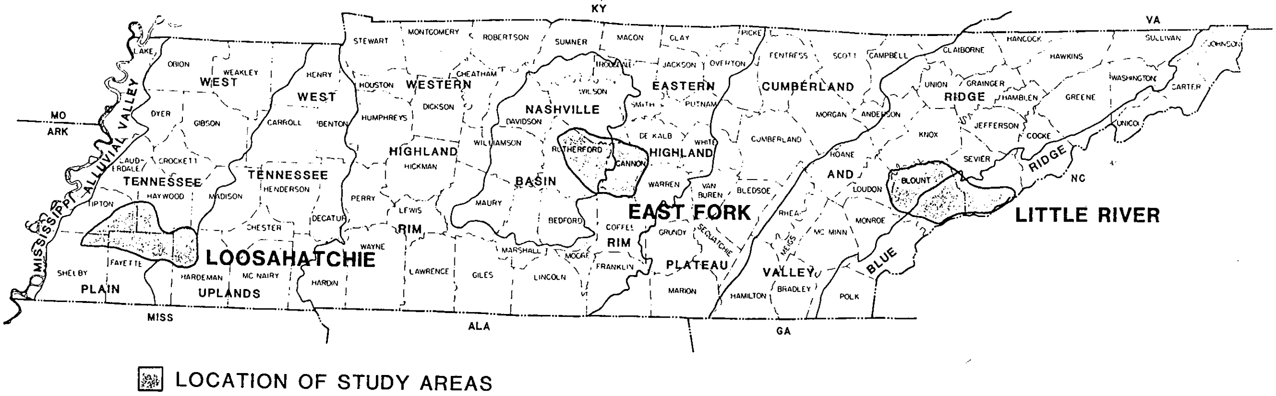

Figure 1. Map of Tennessee showing three watersheds used in study.

stream valleys. The larger part of the watershed is characterized by alluvial deposits of sand, silt, clay, and gravel, and loess deposits of gray to brown clayey and sandy silt along the river. The West Tennessee Uplands lie on the Claiborne and Wilcox geologic formations. These formations exceed 400 feet in thickness of sand and served as the recharge area for the Claiborne and Wilcox sands aquifer. Livestock accounts for most of the consumptive use of surface water in this area. Stream water is also used by several sand and gravel operations (Soil Conservation Service 1971). Using the U.S. Army Corps of Engineers' flood profiles of the Loosahatchie it is estimated that the Loosahatchie's main channel descends approximately 204 feet over a 38-mile distance from the Fayette-Hardeman County line to the gauge at Arlington, producing an average stream gradient of 5.4 feet per mile (Federal Emergency Management Agency, 1983). Urban areas account for less than 5% of land use in the basin. Fifty-five percent of the Loosahatchie's 474,00 acres were estimated to be cropland, 27% forest, 15% pasture, and only 3% urban.

East Fork of Stones River:

The East Fork of Stones River is in Middle Tennessee south of Nashville. The drainage basin of the river near Lascassas, Rutherford County, covers an area of 262 square miles. The river's source is east of Woodbury, Cannon County, roughly 1000 feet in elevation. The U.S.G.S. gauge near Lascassas is 508 feet in elevation, a difference of 492 feet from the source to the gauge. Middle Tennessee is characterized by gently rolling to hilly terrain, with some level areas. The watershed overlies thick-bedded, fractured limestone. Alluvial deposits can be found in the stream valley, but most of the basin's soil is residual clay and averages about four feet in thickness. The area is dominated primarily by cropland, pasture, and forest. The major crops are corn and soy beans; and forests cover is 33.9 percent of the area. The area covered by lakes and ponds is negligible. The stream gradient at the U.S.G.S. gauge at Lascassas is 6.4 feet per mile, and the main channel length is 39.2 miles (May, Wood, and Rima, 1970).

Little River:

The Little River is in East Tennessee. The drainage basin of the river near Maryville, Blount County, covers 269 square miles. The Little River rises on the northern slope of Clingmans Dome (elevation 6642 feet) in the Great Smoky Mountains National Park. The U.S.G.S. gauge near Maryville is 850 feet in elevation, a descent of over 5790 feet between Clingmans Dome and the gauge. The Blue Ridge province consists of mountains and valleys of intensely fractured, metamorphic rock overlain by sandy or clayey soil, which averages about eight feet in depth and is thickest in the valleys and thinnest on steep slopes. The Ridge and Valley province consists of alternating ridges and valleys of fractured, folded sandstones, dolomites, limestones, and shales, overlain by clayey soils. Some alluvial deposits can be found in the stream valley. Much of the Little River drainage basin lies within the Great Smoky Mountains and is heavily forested (73.7%). Maryville is probably the most significant nearby urban area. Less than 0.1% of the basin area is covered by lakes and ponds. The stream gradient of the river at the U.S.G.S. gauge is 53.6 feet per mile, and the main channel length is 42.7 miles (May, Wood, and Rima, 1970).

DATA SOURCES, METHODS, AND PROCEDURES

To analyze the water budgets and to calculate the total surface runoff for these three watersheds, the WATBUG and WATINPUT software developed at Louisiana State University was used. Based on the Thornthwaite water budget model, this program required user inputs of average monthly temperatures, total monthly precipitation, heat index, latitude, and soil moisture storage capacity for each watershed studied (Thornthwaite and Mather, 1957).

Heat indices for the three watersheds were calculated for a 14-year period (1972-1985) by using the method in Thornthwaite and Mather's "The Water Balance" in Publications in Climatology X (1957), which required average monthly temperature data and the latitude of the weather station for the respective watersheds (Thornthwaite and Mather, 1957). The heat indices obtained were 83.78 degree Fahrenheit for Memphis (West Tennessee); 66.70 degree Fahrenheit for Murfreesboro (Middle Tennessee); and 69.34 degree Fahrenheit for Knoxville (East Tennessee).

For the study area, an average value of eight inches is assumed for soil moisture storage capacity for West Tennessee, seven inches for Middle Tennessee, and six inches for East Tennessee. This assumption was based on my previous research findings (Kung and McCabe, 1987), and Moisture Characteristics of Tennessee Soils (Longwell, Parks, and Springer, 1963).

The climatic data for the 14-year period, 1972 to 1985, were obtained from NOAA's Tennessee Climatological Data publications (National Oceanic and Atmospheric Administration, 1972-1985). The Memphis National Weather Service observations were used for the Loosahatchie River. Although other weather stations existed nearby, such as Bolton and Mason, none had 14 years of continuous data for both temperature and precipitation. The Murfreesboro station observations served the East Fork of the Stones River Basin, and the Knoxville National Weather Service station near Maryville was used for the Little River basin.

Measured runoff was obtained for the same period from the U.S.G.S. Water Resources Publication, Tennessee Water Resources Data (U.S. Geological Survey, 1972-1985). These measured stream runoff data in cubic feet per second (cfs) were converted to total surface runoff in inches. The tabulated runoff data are compared within the watersheds studied and are also compared with the calculated runoff to determine if deviations in runoff were random or if they occurred with any seasonality.

Analysis of Results

For the East Fork of Stones River, the average monthly calculated runoff (CRO) for the 14-year period was extremely close to the average monthly measured runoff (MRO). In fact, CRO was only 0.33% less than MRO. (Table 1) After careful examination, however, CRO appeared to consistently underestimate the peak MRO periods. This discrepancy may be due to the fact that the drainage basin is subject to rather severe flash flooding during the summer season. The most notable of these floods occurred during the period of record in March 1975. More recently a flash flood in September 1986 also caused extensive damage. It should be noted that the Little River, while experiencing slightly greater MRO for the 14- year period, did not appear to be subject to a dramatic runoff pattern.

Table 1. Comparison of Measured Runoff and Calculated Runoff in Inches in Three Tennessee Watersheds (1972-1985)

Watershed	Measured	Calculated	% Difference
Loosahatchie	19.60	24.24	23.67
East Fork	26.67	26.59	(0.30)
Little River	27.05	19.51	(27.87)

In the other two watersheds studied, CRO and MRO did not correlate well at all. For the Loosahatchie, CRO was almost 24% greater than MRO; but the CRO for the Little River was almost 28% less than MRO. In other words, the Loosahatchie experienced much less runoff than calculated, and the Little River experienced much more.

The average annual precipitation and measured runoff for the three watersheds were calculated as shown on Table 2.

Annual runoff for the Loosahatchie averaged 19.60 inches

Table 2. Average Annual Precipitation and Runoff for Three Tennessee Watersheds in Inches (1972-1985)

Watershed	Precipitation	Runoff	Loss	% Loss
Loosahatchie	56.68	19.60	37.08	65.4
East Fork	55.92	26.67	29.25	52.3
Little River	48.35	27.05	21.30	44.1

and ranged from 10.07 inches to 31.01 inches. The East Fork of Stones River runoff averaged 26.67 inches and ranged from 9.09 to 45.45 inches. The Little River runoff averaged 27.05 inches and ranged from 20.77 to 36.92 inches. Average total annual runoff constituted 34.6% of the average annual precipitation for the Loosahatchie, 47.7% for the East Fork, and 55.9% for Little River. It is interesting to note that for the three watersheds, the percent of water loss decreased from west to east. The Loosahatchie experienced losses of 65.4%; the East Fork lost 52.3%; and the Little River lost only 44.1%.

Little River's average annual loss of 21.3 inches is well below the average of 27.5 inches for the eastern part of the Tennessee Valley. The Chickasaw-Metropolitan Surface Water Management Survey Report of 1971 also noted the Loosahatchie's unusually low discharge when compared to the adjacent Wolf River basin. No detailed studies have been made to fully explain these differences, but it is assumed that the watershed characteristics such as slope, soil, and land uses are responsible. Also stream gradient is probably an important factor in the underestimation of runoff. The Little River falls in elevation from some 6000 feet at Clingmans Dome to about 900 feet at the stream gauge near Maryville in only 15 miles, an approximate gradient of 340 feet per mile, a great contrast to the Loosahatchie's estimated 5.4 feet per mile. However, variation in total amount of precipitation and precipitation distribution and frequency over the watershed is probably the single most important factor explaining the discrepancy between calculated and measured runoff. Although the Knoxville Weather Station is near Maryville, where the stream gauge is located where great variations in precipitation and temperature occur in the basin due mainly to the extremes in elevation. Annual precipitation on the highest mountain peaks of Tennessee, including Clingmans Dome, can reach 80 inches. Unfortunately, precipitation figures for these mountain peaks are not available for comparison with Maryville, where the average annual precipitation is 48.35 inches. Limited precipitation data was available for Newfound Gap for a 23-month period from July 1981 to May 1983. Monthly precipitation figures for Newfound Gap and Knoxville Weather Service at Maryville for the period of July 1981 to May 1983 were tabulated to illustrate the variation in precipitation. (Table 3) Newfound Gap averaged 6.70 inches per month for the 23-month period, and Maryville only 4.15 inches, a difference of 61 percent.

Such variation in precipitation cannot be used to explain the discrepancy in measured and calculated runoff for the Loosahatchie basin. Although the Memphis Weather ServiceOffice is by far the more distant weather station when compared to the weather stations used for the East Fork and the Little River, the use of precipitation data from Bolton would not have changed the findings. The precipitation data at the two stations were in close agreement (Table 4). Precipitation for the 13-year period from 1973 to 1985 averaged 56.51 inches per year at Memphis as compared to 54.72 for Bolton. This

Table 3. Monthly Precipitation for Newfound Gap and Knoxville (Maryville) in inches (July 1981 to May 1983).

Month/Year		Knoxville	Newfound Gap
July	1981	2.03	9.71
August		3.48	4.57
September		6.09	4.82
October		4.15	6.37
November		3.01	3.09
December		4.14	5.08
January	1982	6.03	7.27
February		4.88	10.97
March		6.36	6.28
April		3.26	7.13
May		5.52	5.15
June		3.93	4.85
July		6.60	9.05
August		2.68	4.06
September		2.68	4.95
October		2.66	6.57
November		5.21	8.98
December		4.89	10.78
January	1983	1.58	2.93
February		2.90	7.17
March		1.99	6.02
April		5.88	10.77
May		5.42	7.55
Total		95.37	154.12
Average		4.15	6.70

Table 4. Average Annual Precipitation and Runoff for the LoosahatchieRiverBasinUsing Two Different Weather Stations (inches) 1972-1985.

Weather Station	Precipitation	Runoff	Loss	% Loss
Memphis	56.51	19.63	36.88	65.3
Bolton	54.72	19.63	35.09	64.1

difference translated into a 65.3 percent loss for the Memphis data and a 64.1 percent loss for the Bolton data. The small difference between the two is not considered significant when considering the unusually large losses experienced by the Loosahatchie.

Conclusion

This study has found that Little River in East Tennessee has produced more runoff than was expected, and the Loosahatchie in West Tennessee has produced less. The discrepancy for the Little River is more readily explained by the physical characteristics of the drainage basin which lies in an area of highly variable elevation and precipitation. There is no immediate explanation for the Loosahatchie's discrepancy, but it is hoped that further research will resolve the problem. Stones River CRO and MRO are in close agreement.

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