Long-Term Rainfall and Runoff Characteristics of a Small Southern Piedmont Watershed

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Abstract

The long-term hydrologic response of a small (7.8 ha) zero-order Southern Piedmont watershed were analyzed from 1940-1984. Four land use phases occurred during this period: row cropping (5-yr), kudzu (5-yr), grazed kudzu mixed with rescuegrass (7-yr), and grazed coastal bermudagrass (28-yr). Land use and rainfall variability influenced runoff characteristics. Row cropping produced the greatest runoff, percentage runoff, and peak flows. Kudzu reduced spring runoff and almost eliminated summer runoff, as did a mixture of kudzu and rescuegrass; however, rainfall was reduced during these two phases. Peak flows were also reduced during these two phases. Bermudagrass reduced runoff more than row cropping but not as much as kudzu or kudzu mixed with rescuegrass. Peak flows increased during grazing of bermudagrass but stayed below those during the cropping phase. Monthly rainfall-runoff regression relationships were developed and R^2 greater than 0.60 were found for: cropping phase - summer, spring and winter; kudzu phase - spring and winter; kudzu-rescuegrass phase - summer, spring, winter; and bermudagrass phase - summer and spring. Long-term information such as this is needed for various environmental and management decisions faced by land managers today.

Keywords: experimental watershed, rainfall-runoff, Southern Piedmont, kudzu, bermudagrass

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Introduction

The USDA-Agricultural Research Service has been operating a network of geographically distributed experimental watersheds of various sizes since the early 1950s. Some were established in the 1930s by the Soil Conservation Service. These watersheds are resources of historic hydrologic data and knowledge (Goodrich et al. 1994). Part of this network is the 7.8 ha (19.2 ac) zero-order watershed known as W1 established in 1939 near Watkinsville, GA. The topography, soil, and land use characteristics of W1 are typical of many sloping fields throughout the Southern Piedmont, a 16.5 million ha (40.7 million ac) region in the southeastern United States (Carreker and Barnett 1953). The region is one of the most severely eroded parts of the United States as a result of over two centuries of row crop agriculture, frequent intense summer storms and easily erodible soils. The need to study the rainfall-runoff characteristics of typical Piedmont fields under varied cropping systems in order to develop predictive capabilities and recommendations for land management and conservation measures spurred the establishment of W1. In this paper we summarize 45 years of rainfall-runoff data under 4 different land uses lasting 5 to 28 years each, and focusing on monthly, seasonal and annul relationships.

Methods

Data sources

Data were acquired for the 1940 to 1984 period from various sources, including ARS Water Data Center, Hydrology Laboratory, Beltsville, MD, annual reports (e.g., SPCRU 1970), and several miscellaneous USDA-ARS annual publications (e.g., Burford et al. 1982).

Watershed description and history

The zero-order W1 watershed is pear shaped with slopes from 3 to 10% and an average of about 7%. Moderately eroded Cecil and Pacolet soils occupy about 69 and 31% of the watershed, respectively (R.R. Bruce, unpublished report). The Pacolet soil is confined to the upper part of the watershed. Both soil series have developed in residual felsic igneous and metamorphic parent material such as granite, granite gneiss, mica gneiss, and mica schist (Radcliffe and West 2000). The Pacolet soils have less thickness than those of the Cecil but the properties of the two soils are similar otherwise. The soils generally have brownish-gray sandy loam to red clay loam surface horizons overlaying red clayey argillic horizons. The Bt horizon at W1 begins less than 36 cm from the surface in the Pacolet, but is 36 to 66 cm from the surface in the Cecil (R.R. Bruce, unpublished report). The subsoil in both soils is underlain by a C horizon, several meters thick, of porous decomposed rock material resting on solid rock at 5 to 30 meters from the surface.

When established in 1940, W1 had residual vegetated bench terraces constructed several decades earlier by farmers and used for row crop farming. Terraces were removed in 1957 by spreading the spoil over the immediate area. Land use was as follows: 1940-44, cotton-oats-cowpeas on a two year rotation; 1945-49 kudzu with corn in the first year; 1950-56 kudzu mixed with rescuegrass with light controlled summer kudzu and winter rescuegrass grazing; and 1957-84 grazed coastal bermudagrass and winter annuals.

Rainfall-runoff measurement

Rainfall was measured with a chart-based Fergusson-type weighting and recording rain gauge (Carreker and Barnett 1953). A 2 to 1 concrete broad-crested V-notch weir fitted with a chart-based Friez-type Fw-1 water-level recorder was used to record runoff. Calibration for the stage-flow relationship of the weir included correction for ponding. Data acquisition was discontinued after 1984. However, in June 1998, the weir was rehabilitated and data collection resumed with an automated system.

Data analysis

We used Excel, SigmaPlot, SAS and TableCurve3D to summarize statistical properties and establish relationships between parameters.

Results

Rainfall

Mean annual rainfall for 1940-84 was 1257 mm varying from a low of 853 in 1954 to a high of 1838 mm in 1964. Mean monthly rainfall was least in October (71 mm; CV 73%) and highest in March (149 mm; CV 45%). Seasonal rainfall decreased from winter (mean monthly 116.5 mm) to spring (April/May mean 105 mm) to summer (mean monthly 103 mm) and fall (mean monthly 80 mm).

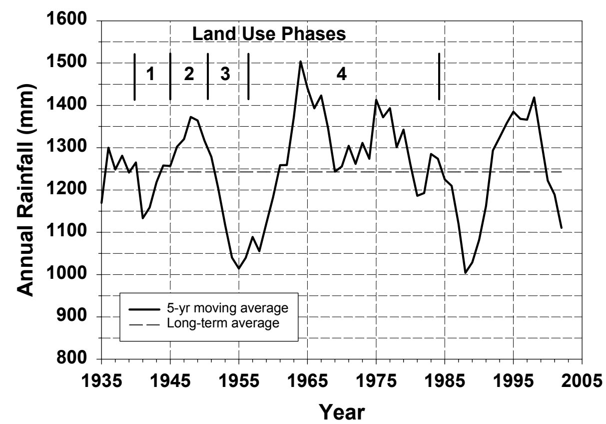

Figure 1. Five years moving average of annual rainfall starting in1935 for Watkinsville, GA.

During each of the four land use phases there were distinct rainfall patterns that influenced runoff as seen in the 5-yr moving averages (Figure 1). The 5-yr moving average of annual rainfall best reflected the trend in periodic drought and wet periods. The 1940-44 phase began with rainfall deficit compared to the long-term average but the deficit was eliminated by 1944. The next phase (1945-49) had above average annual rainfall, which led to rainfall surplus at the end of the period. Seven years of below average annual rainfall led to significant rainfall deficit during the next phase (1950-1956). The most severe drought in Georgia since official records began in 1892 occurred in 1954-55 (Plummer 1983). After 1957, a long period of average or above average rainfall ensued and lasted through 1984 with few years of below average annual rainfall.

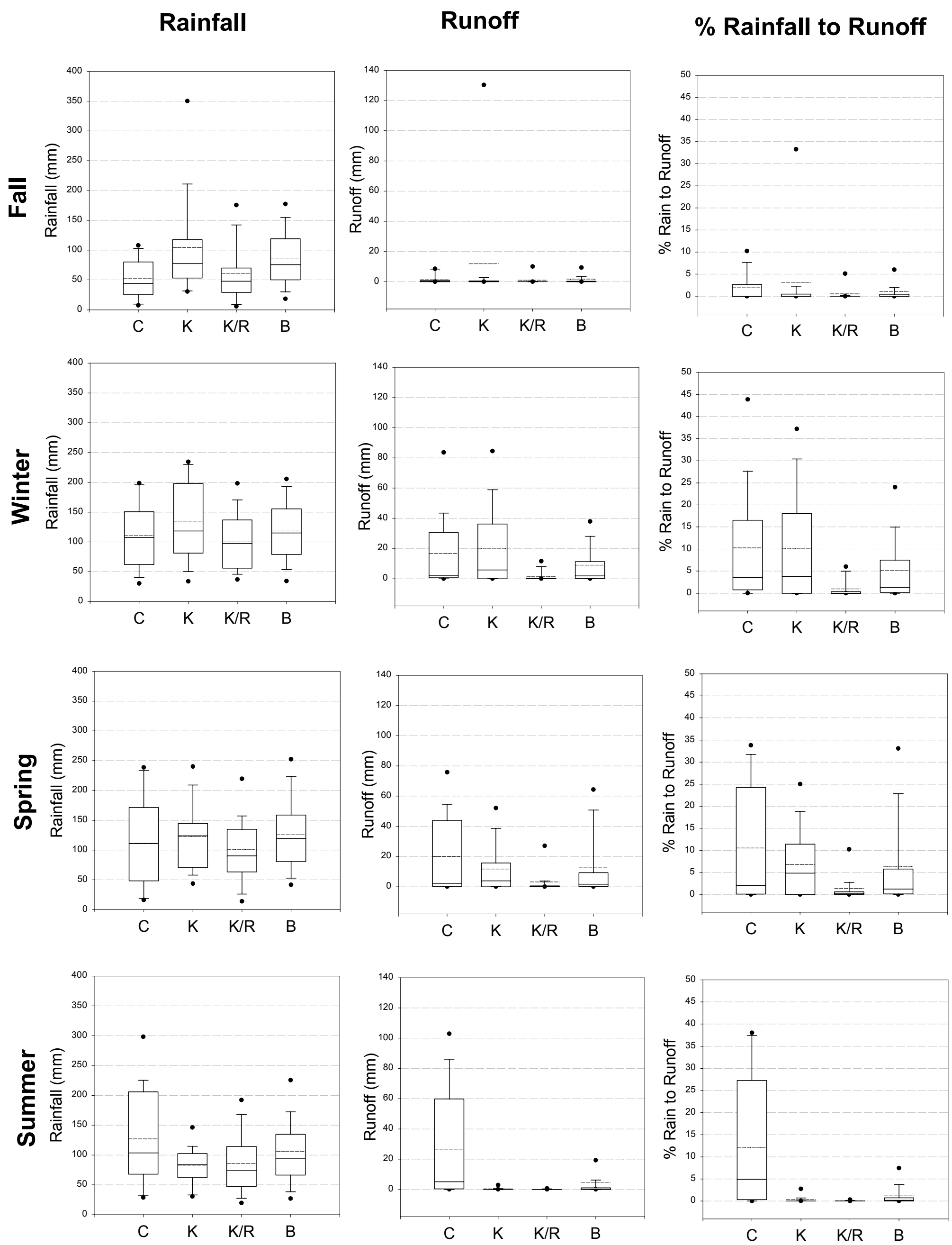

Figure2. Distribution of seasonal monthly rainfall, runoff, and percent runoff from 1940 to 1984, during each of four land use phases at W1 watershed. Land uses are designated as C for cropping, K for kudzu, K/R for kudzu-rescuegrass, and B for bermudagrass. September, October, and November are considered as fall season. December of a previous year, January and February are taken as winter season. Spring consists of March, April and May. Summer occurs in June, July and August. Each box shows the 25th percentile, median, and 75th percentile. Whiskers show the 10th and 90th percentile. Outliers up to the 5th and 95th percentiles are shown as dots. Means are shown as dotted lines inside boxes.

Monthly runoff

The distribution of seasonal monthly runoff for each land use phase (C = Cropping, 1940-44; K = Kudzu, 1945-1949; K/R = kudzu rescuegrass, 1950-56; B =

bermudagrass, 1957-84) interacted with rainfall (Figure 2). Seasons were taken as: fall - September, October and November; winter - December of a previous year, January and February; spring - March, April and May; and summer - June, July, August.

The cropping-based first phase exposed the soil to high intensity spring and summer storms, which led to high runoff. Winter rains saturated the soil and also produced runoff. The fall rains were generally below the threshold for initiating and sustaining runoff. Runoff was highest in summer (mean 26.6 mm) followed by spring (mean 20.0 mm), winter (mean 16.8 mm), and fall (mean 1.4 mm) during the first land use phase. Runoff as a percent of rainfall was highest also during the row crop phase. Means in mm were: summer, 12.5; spring, 10.6; winter, 10.3; and fall, 1.9.

After kudzu (1945-49) became fully established, summer runoff was dramatically reduced and spring runoff was reduced by almost half (runoff means: summer-0.3 mm, and spring-11.7 mm; percentage runoff means: summer-0.3, spring-6.7). The winter runoff was similar to the earlier phase, with slightly increased runoff during phase 2 (means: cropping-16.8, kudzu-20.2; runoff percentage about 10.2 for both). Fall runoff during the kudzu period was almost non-existent except for one extreme event (Fall-Runoff, Figure 2), despite a doubling of rainfall compared to the first phase. The reduction in runoff while in kudzu production is partly attributed to a reduced summer rainfall (mean 127 vs. 83 mm). During kudzu-rescuegrass (1950-56) production, a combination of good ground cover, and below normal rainfall led almost to no seasonal runoff. Annual runoff accumulation was 207.8 mm/yr during the row cropping ($r^2 = 0.99$), 127.8 mm/yr during the kudzu ($r^2 = 0.96$), but only 19.3 mm/yr during the kudzu-rescuegrass period ($r^2 = 0.97$). Corresponding annual rainfall accumulations in mm/yr were 1265, 1315, and 1044, respectively. Runoff was 3% or less in fall, spring and summer, and 5% or less in winter in 90% of the events.

A transition period occurred at the beginning of the final land use phase when terraces were removed in 1957 and coastal bermudagrass established. Full grazing of the watershed started in 1960. Winter annuals were used to supplement the summer bermudagrass grazing. The terrace removal would have contributed to the potential for increased runoff. Runoff increased compared to the 1950 to 56 period, but was less than the first 2 land use phases (except that summer runoff was larger than kudzu summer period also). Annual runoff accumulation after 1957 was 83 mm/yr ($r^2 = 0.96$) with annual rainfall accumulation of 1344 mm/yr ($r^2 = 0.99$). Runoff was minimal in the fall. Mean runoff was: summer, 1.2%; spring, 6.4%; winter, 5.1%; and fall, 1.1%.

Annual runoff and peak flow rates

The median annual runoff was 5% the annual rainfall. Annual runoff was 10% or less 75% of the time and only about 10% of the time did it reach between 15 and 25% of annual rainfall. Peak runoff rate reached 1472 L/s (52 cfs) and occurred in 1945. However, the median peak flow rate was about 300 L/s (10.5 cfs). Peak flow rates were highest during the 1940-46 period with mean of 954 L/s (33.7 cfs) and the coefficient of variation of 36%. This period included the first two years of kudzu when the plant had yet not achieved full ground cover. Mean peak flow rates plummeted to 119 L/s (4.2 cfs) with coefficient of variation of 76 for 1947-56. Peak flow increased during 1957-84 when mean peak flow rate was 380 L/s (13.4 cfs) and the coefficient of variation was 81%.

Rainfall-runoff correlation

Non-linear regression analysis showed that except for fall, relationships between monthly rainfall and runoff had R^2 greater than 0.6 (Figure 3). Coefficient of determination was highest for the cropping phase. The spring and winter bermudagrass phase data showed a larger scatter, which led to R^2 of 0.49 for winter. The scatter is expected because of the long duration of this phase. The steep rising arm of the fitted line for the kudzu-rescuegrass-spring correlation is largely the effect of a single influential observation.

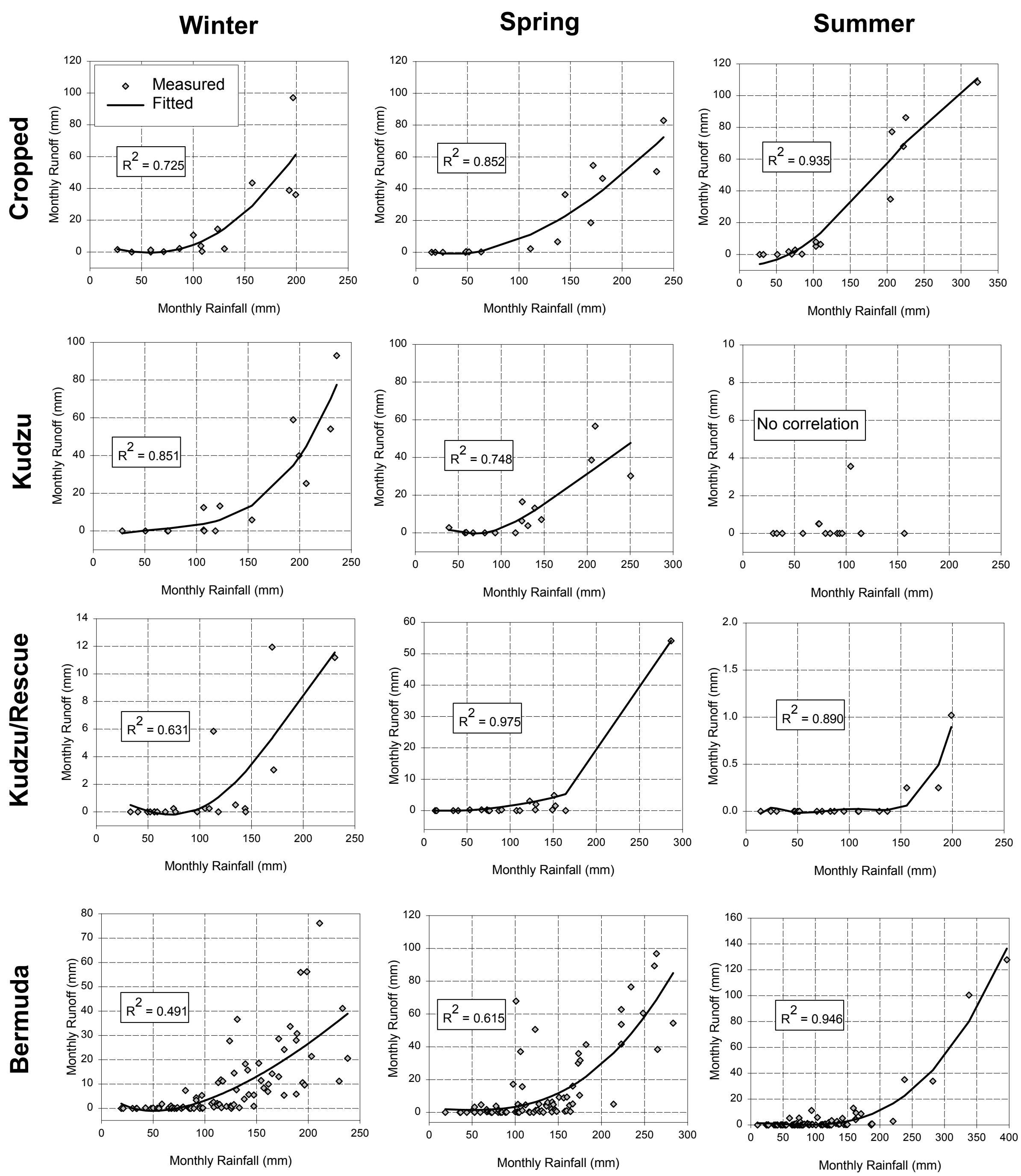

Figure 3. Relationships between seasonal monthly runoff and rainfall at W1 watershed from 1940 to 1984, during each of four land use phases. Coefficient of determination R^2 is given for each correlation. The diamonds and solid lines represent measured and fitted values, respectively.

Recent rainfall-runoff monitoring

Land use at W1 has continued as bermudagrass and winter annual-based grazing since 1984. Runoff has been limited since monitoring resumed in 1998, because of another relative drought in the Southeast from May 1998 through the end of 2002 (Figure 1).

Conclusions

Although this analysis is limited by the relatively short records for some of the land uses, it is clear that relatively subtle differences in land use have significant hydrologic ramifications at the small watershed scale. The data demonstrate how land use can be utilized as a management tool for resources protection. In Southern Piedmont, clean-tilled row cropping has clearly the potential for high runoff and consequently for land degradation. Year round ground cover offers the best protection for Southern Piedmont farm lands. This is particularly true in spring and summer when ground cover can be used to absorb part of the energy of the typically high intensity rainfall of these seasons and reduce potential runoff. Rainfall variability is an inherent part of the environmental attribute of Southern Piedmont. The seven years of below normal rainfall during the kudzu/rescuegrass phase contributed to the reduced runoff. What would have been the response had W1 been in row cropping? Hendrickson and Barnett (1963) reported on runoff research done from 1940 to 1954 on 6.32 m (20.74 ft) wide by 21.34 m (70 ft) long plots of 7% slope in continuous cotton located in close proximity to W1. They found that average annual runoff was 22% of the annual rainfall during the 15-yr period. Average runoff equivalent to phases 1, 2 and the first 5 of the 7 years of phase 3 of this paper were 22.7%, 21.3%, and 21.8%, respectively. There was no runoff reduction from these plots. While there are scale differences between the plots and W1, it is reasonable to conclude that runoff would have been much more from W1 during phases 2 and 3 had these phases been in cropping. Runoff however still occurs even under full ground cover as born out by the 28-yr data of the bermudagrass phase. The median annual percent runoff was 5% with 10% probability for 16% or higher runoff peaking at 23%. We analyzed only monthly, seasonal and annual rainfall and runoff data and did not go into individual storms. Nevertheless, long-term information such as this is needed for various environmental and management decisions faced by land managers today.

Acknowledgments

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