# RAINFALL VARIABILITY AND SPATIAL PATTERNS FOR THE SOUTHEAST

**D. D. Bosch**
*Southeast Watershed Research Laboratory*
*USDA-ARS*
*Tifton, Georgia*

**F.M. Davis**
*Southeast Watershed Research Laboratory*
*USDA-ARS*
*Tifton, Georgia*

## ABSTRACT

The Southeastern region of the United States holds significant agricultural and hydrologic importance. Rainfall patterns, although highly variable from year to year, show rainfall to be greatest in the midsummer months with high intensity, convective thunderstorms. Thirty years of rainfall data from the Little River Watershed near Tifton, Georgia have been analyzed. The summer storms were found to be more intense, shorter, yield less volume, and occur more frequently. For summer storms, gages separated by 1.9 km or less are likely to be highly correlated ($r \geq 0.9$) while this increases to 9.2 km for the winter. The seasonal data provided here will be useful in planning planting times and agrichemical management. This analysis indicates that extrapolation of precipitation data collected at off-site locations will have little utility for prediction or modeling purposes unless the off-site gage is located closer than 2 km to the site of interest.

## INTRODUCTION

Rainfall is a key factor in shaping the vegetation, hydrology, and water quality throughout the earth. Rainfall is particularly critical to agriculture. Along with temperature, the occurrence and variability of precipitation, to a large extent determine which crops can be grown in different regions throughout the world. As additional insight into precision farming is gained, the importance of rainfall variability becomes more apparent. An accurate understanding of precipitation characteristics and soil variability is critical to optimizing farm production and to precision farming.

The Southern Coastal Plain of the U.S. is a physiographic region with a wide range of soil types and crop management systems. The Southern Coastal Plain extends over 285,000 km$^2$ (USDA Soil Conservation Service, 1981). Land use in this region is approximately 69 % woodland, 17 % cropland, 11 % pastureland, and 3 % urban (Mills et al., 1984). The Southern Coastal Plain is situated within the humid eastern part of the United States and is largely in the moderate to warm southern portion of this region.

In 1967, as a means to study this unique region and to provide measurements

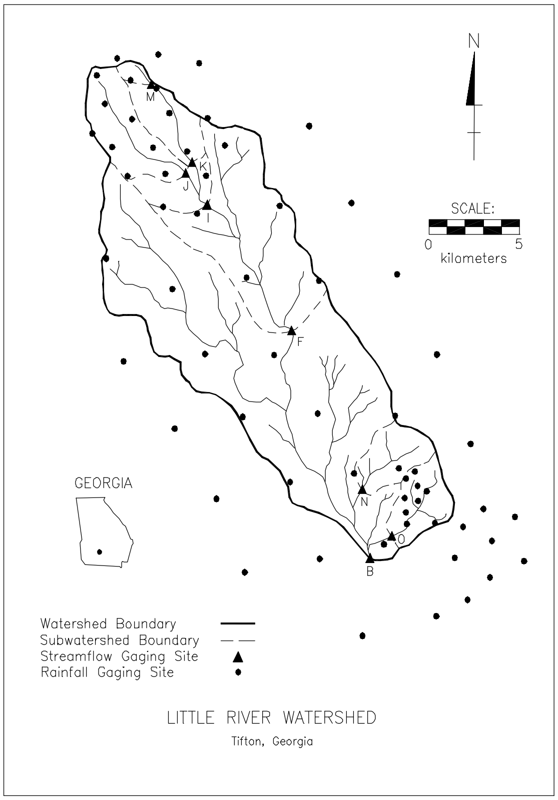

Figure 1. Streamflow and precipitation gage network on the Little River Watershed.

of selected hydrologic variables important to water supply and qualitative predictions, the Agricultural Research Service of the U.S. Department of Agriculture instrumented the 334 km$^2$ Little River Watershed (LRW) near Tifton, Georgia (Mills, 1971) (Fig. 1). The LRW is instrumented for measuring rainfall input and streamflow output for the total area and for subwatersheds that range in size from approximately 16 km$^2$ to 115 km$^2$ (Fig. 1). The measurement network provides a unique opportunity to characterize rainfall. The instrumentation was installed in the late 1960's and early 1970's and has been in continuous operation since that time. The principal objective for measuring hydrologic variables on the LRW is to provide data for analyzing coastal plain watershed processes and ultimately for developing and testing prediction methodology for ungaged watersheds.

Mean monthly rainfall for the watershed is 1200 mm (Mills, 1971), with a minimum monthly average of 51 mm for November and a maximum of 145 mm for July. Rainfall patterns indicate rainfall amounts are greatest in the midsummer months with high intensity, convective thunderstorms. Frontal storms with moderate rainfall amounts are typical of the winter through spring months. Essentially all of the precipitation in the region comes from rainfall.

The original rain gage network was designed to obtain a correlation coefficient of 0.9 between measurements of the nearest gages (Mills, 1967). Gages in the headwater area were spaced approximately 2.4 km apart while those in the central portion were about 4.8 km apart (Fig. 1). Using 14 years of daily rainfall data collected with the LRW rain gage network from 1968 to 1981, Mills et al. (1984)

examined the patterns of correlation coefficients between daily rainfall measured at different gages throughout the LRW and a rain gage located at the watershed center. Their analysis indicated that for the March-May season the 0.9 correlation lines were achieved for rain gages separated by distances from 7.8 to 14.5 km or less, while for the summer season from June-August this distance was from 1.8 to 2.6 km or less. The fall and winter periods behaved similar to the spring season, with these representative distances for September to November of 4.7 to 6.2 km, and for December to February, approximately 12 km. Mills et al. (1984) concluded a 2.4 km spacing was needed to assure a correlation coefficient of 0.9 for catches of adjacent gages throughout the entire year (Mills et al., 1984).

The analysis of Mills et al. (1984) assumed each storm occurred during the 24 hr period coinciding with a given day. However, natural rainfall events are frequently less than 24 hr in duration, and do not conform to a 24 hr clock. Sorman and Wallace (1972) who studied precipitation patterns on the LRW during 1968, 1969, and 1970, found that most rainfall cells lasted on the average, 53 min., and that most storms consisted of approximately 5 cells which occurred either simultaneously or consecutively. Work from other locations also indicates that storm cells normally last approximately 20 to 30 min., with a maximum duration of 90 min. (Sorman and Wallace, 1972). Thus, the assumption of a storm event conforming to a 24 hr time period is unrealistic.

Approximately 30 years of precipitation data have been collected on the LRW. This data set represents an excellent opportunity to examine rainfall characteristics while examining actual rainfall durations. The objectives of this analysis were:

1) Characterized storm patterns over the LRW based upon actual event data.
2) Establish seasonal rainfall distributions determined based upon storm period.
3) Examine spatial correlation scales of the precipitation events.

## METHODS

Rainfall on the LRW is measured in both time and space. Recording rain gages that continuously measure rain are spaced over the watershed at various intervals ranging from 2 to 8 km. Rain gages installed in 1967 were weighing-type digital gage-recorders (Brakensiek et al., 1979). These gages consisted of a collector for catching and storing rainfall and a device for weighing the rain water. The device recorded rainfall volume on 5 min. intervals to the nearest 2.54 mm. The original gage network was designed to provide a relatively dense spatial measurement of rainfall on the small headwater subwatersheds and the extreme low eastern section of the basin and more sparse measurement on the remaining part of the basin (Fig. 1). A total of 55 gages were initially installed on the watershed. The justification for the original rain gage design was to provide more accurate measurement of rainfall variability on the small drainage areas where it would be more likely to cause runoff variability.

Two major changes have occurred to this rain gage network since 1968. The first occurred in 1982, when after 14 years of data collection, the network was reduced to 31 gages in order to lower costs. The dense rain gage network was retained on the headwater area to minimize the impact of reduction in instrumentation on ongoing hydrologic studies. The second major changed occurred in early 1993, when the original weighing-type gages were replaced by tipping-bucket type gages. With the tipping-bucket rain gages, each 0.254 mm of rainfall is measured as the bucket tips. Mills et al. (1993) compared precipitation data collected with the two different types and found no significant difference between the two. Also in 1993, part of the dense network of rain gages in watershed O was reinitiated and some perimeter gages removed.

A computer program was developed to search through the LRW precipitation data base from 1967 to 1996 and select rainfall events meeting specified criteria. For each event, the rainfall data from each active gage was searched to evaluate when the event began and when it ended. An event was defined as beginning when rainfall was recorded at any rain gage on the examined watershed. Gages within the immediate watershed area were included in the analysis to include border effects. The event was defined as finished when no rain was received by any gage on the watershed for a period of one hour. Each event had to last over one hour to be considered in this analysis and the total volume measured by any one gage on the watershed had to be over 25.4 mm.

For each precipitation event, durations, maximum volumes, maximum 30 min. volume, weighted average volumes, and storm area coverage were calculated. The duration was calculated as the time between when the first gage in the watershed measured rainfall and the last gage ceased measuring rainfall. The maximum volume was the maximum at any gage within the storm coverage. The maximum 30 min. volume was evaluated as the maximum volume measured for any 30 min. period for any gage within the storm coverage. The coverage area was calculated by summing the area covered by participating rain gages. Any gage receiving precipitation was assumed to be covered by the storm.

Weighted average volume (WAV) for each storm event was determined using the inverse distance, or the reciprocal-distance weighting technique (Smith, 1992). The amount of rainfall at any ungaged point is a function of the measured rainfall and distance to nearby gages. Following this procedure, the watershed is divided into uniform grid boxes. The amount of estimated rainfall, $P_j$, at each grid box j is expressed by:

$$P_j = a \sum_{i=1}^{n} d_{ij}^{-b} P_i \qquad (1)$$

where $P_i$ is the measured rainfall at gage i, $d_{ij}$ is the distance from gage i to the center of grid box j, and n is the number of rain gages used to estimate $P_j$. The inverse of the sum of the inverse distance values for all of the gages, a, is:

$$a = \left(\sum_{i=1}^{n} d_{ij}^{-b}\right)^{-1} \qquad (2)$$

If m grid boxes cover the catchment, the mean areal precipitation is the arithmetic mean of the m estimates for the grid boxes. Dean and Snyder (1977) found that for widely spaced gages in the Piedmont region of the Southeast, an exponent of 2 gave the best results. Simanton and Osborn (1980) determined the exponent could range from 1 to 3 without significantly affecting the accuracy of the estimate. For this analysis we have set b equal to 2.

The area weighted averages were grouped according to seasonal period: Q1, December through February; Q2, March through May; Q3, June through August; and Q4, September through November. This seasonal grouping, based upon observed climatic and hydrologic patterns, has been used in explaining the response of hydrologic, sediment, and water quality parameters on Coastal Plain watersheds (Asmussen et al., 1975; Sheridan et al., 1982; Hubbard and Sheridan, 1983; Hubbard et al., 1984; Sheridan and Hubbard, 1987).

Basic statistical characterizations of precipitation events occurring during each season were made. Distributions of WAV, duration, maximum 30 min. volume, and storm size were determined. A correlation matrix was established by conducting an autocorrelation analysis between the storm volumes measured at each rain gage and determining a Pearson correlation coefficient (r) between each pair of gage volumes. These cross-correlations were calculated for the entire watershed, using all of the gage data. Using the gage coordinates, a separation distance between each pair of gages was determined. In addition, the angle between each pair of gages was determined. North was assumed to be 0°. Angles along the same axis were assumed to be equal, i.e. 45° was assumed equivalent to 225°, 90° the same as 270°, etc.. These data were used to examine the relationship between distance between rain gages, angle, and r.

## RESULTS AND DISCUSSION

### Basic Characteristics

For the period examined from 1969 to 1996, 1259 storms were identified. Basic statistical characterizations, mean, standard deviation, and coefficient of variations were calculated for the WAV's and compared for each season (Table 1). Based upon the 25.4 mm gage threshold criteria used in this analysis, the average storm size weighted over the entire watershed was 19.7 mm, while the average storm duration was 7.2 hrs (Table 2). The largest storms occur during Q1 while the smallest occur during Q3. The least variability in storm size is observed during Q1 while the most is observed during Q3 and Q4. On the average, the storms lasted 10.8, 8.4, 5.0, and 7.9 hrs during Q1, Q2, Q3, and Q4, respectively. The summer storms have greater intensity, are shorter, are smaller, and occur more frequently.

Each event was assumed to end when a minimum of 1 hr had lapsed without any rainfall being measured in any gage within the watershed. Mills et al. (1986) assumed a 5 hr interval between storms in their analysis, but no apparent justification was made. Wischmeier (1959) assumed a 6 hr interval between storms. His assumption was based upon an optimum correlation between rainfall energy-intensity values and soil-loss. We examined different time intervals between events and evaluated the cumulative probability structure of the time interval between storm events. In order to examine this effect, the distribution of time between rainfall events based upon this 1 hr lapse time was plotted (Fig. 2).

Table 1. Basic statistics for the weighted average precipitation events for annual and quarterly time periods on the LRW.

| | Sample size | Mean | Maximum | Standard deviation | Coefficient of Variation |
|---|---|---|---|---|---|
| | | (mm) | (mm) | (mm) | (%) |
| year | 1259 | 19.7 | 137.4 | 18.9 | 95.7 |
| Q1 | 217 | 30.1 | 102.6 | 19.6 | 65.2 |
| Q2 | 251 | 25.9 | 96.3 | 19.9 | 76.8 |
| Q3 | 603 | 12.8 | 128.5 | 12.8 | 100.5 |
| Q4 | 188 | 21.9 | 137.4 | 23.6 | 107.9 |

Table 2. Average and standard deviation for the storm duration, maximum 30 minute volume, coverage area, and duration between rainfall events for annual and quarterly time periods on the LRW.

| | Duration | | Maximum 30 minute volume | | Coverage Area | | Duration Between Rainfall Events | |
|---|---|---|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | Mean | SD | Mean | SD |
| | hrs | hrs | mm | mm | $km^2$ | $km^2$ | days | days |
| year | 7.2 | 6.2 | 26.7 | 13.0 | 295.0 | 74.8 | 7.7 | 10.9 |
| Q1 | 10.8 | 6.2 | 16.8 | 8.5 | 315.9 | 64.9 | 12.2 | 15.3 |
| Q2 | 8.4 | 6.2 | 24.1 | 12.5 | 318.0 | 49.9 | 10.4 | 12.3 |
| Q3 | 5.0 | 4.8 | 31.8 | 12.7 | 277.1 | 81.5 | 4.0 | 4.8 |
| Q4 | 7.9 | 7.2 | 25.0 | 10.6 | 297.3 | 76.5 | 10.5 | 12.8 |

Approximately 10 % of the storms over the entire year are separated by less than 5 hrs. During Q3, 11 % of the storms are separated by less than 5 hrs and 36 % are separated by less than 25 hrs. Based upon this, it was determined that increasing the interval between storms would exclude valuable information about the summer storms.

The distributions for the time intervals between storms showed seasonal differences (Fig. 2). Substantially, less time was observed between storms during the summer quarter, Q3, than the remainder of the quarters (Table 2). The most time between storms occurs during the winter quarter, Q4. In addition, almost half of all of the storms occurred during Q3 (Table 1). During this and subsequent analysis, Q4

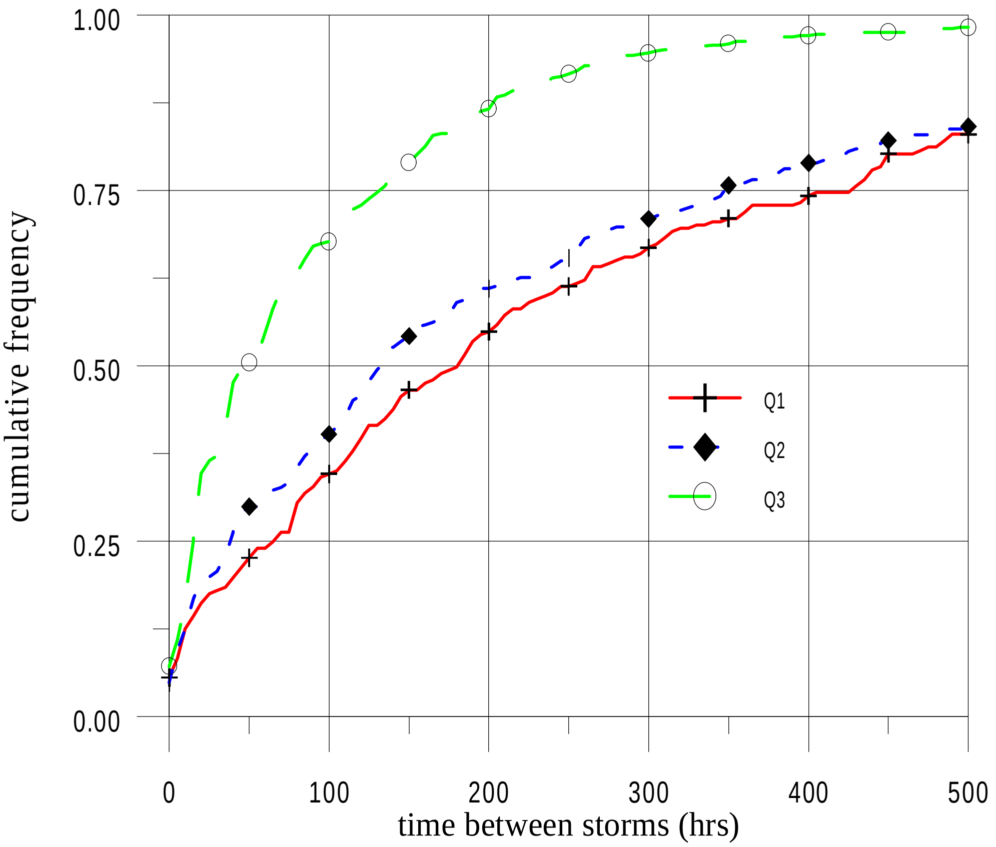

Figure 2. Cumulative probability distribution of the duration between storms for Q1, Q2, and Q3.

results were very similar to Q2 results and were excluded from the illustrations.

Cumulative distributions of the storm durations, maximum volumes, maximum 30 min. volumes, weighted average volumes, and storm area coverage were calculated for each seasonal period. Obvious differences were noted for Q3. The summer storms are smaller, shorter, and more intense (Fig. 3, 4 and 5).

## Spatial Correlation Structure

As expected, correlation between gage data is strongly dependent upon distance between gages (Fig. 6). An exponential relationship was fit to the data relating r to the separation distance:

$$r = e^{cd} \tag{3}$$

c is a fitting coefficient and d is the distance between gages (km). Coefficients for eq. 3 for the whole year, Q1, and Q3 were -0.0250, -0.0115, and -0.0548 respectively. Higher correlations extend over greater distances during the winter period than during the summer.

For summer storms, gages separated by 1.9 km or less are likely to yield r $\geq$0.9 while this increases to 9.2 km for the winter. For the entire year this distance is 4.2 km. The angle of the vector between gages also affects the correlation between precipitation data collected at these gages. There is a better correlation for gages along the 45° to 90° axis than along other angles. This is particularly true during the winter quarter. This coincides with the primary direction of storm travel.

The ability to make informed decisions regarding precision farm management depends upon an understanding of seasonal and spatial variability of rainfall. Our data indicate predictable seasonal rainfall patterns. For the LRW, precipitation volumes during June, July, and August are consistently higher than other months and during October and November volumes are consistently lower. Data presented here indicate that periods of drought are most likely during Q4. While the average duration between rainfall events is greater during Q1, 12.2 days, than during Q4, 10.5 days, the Q1 storms are consistently larger than those occurring in Q4.

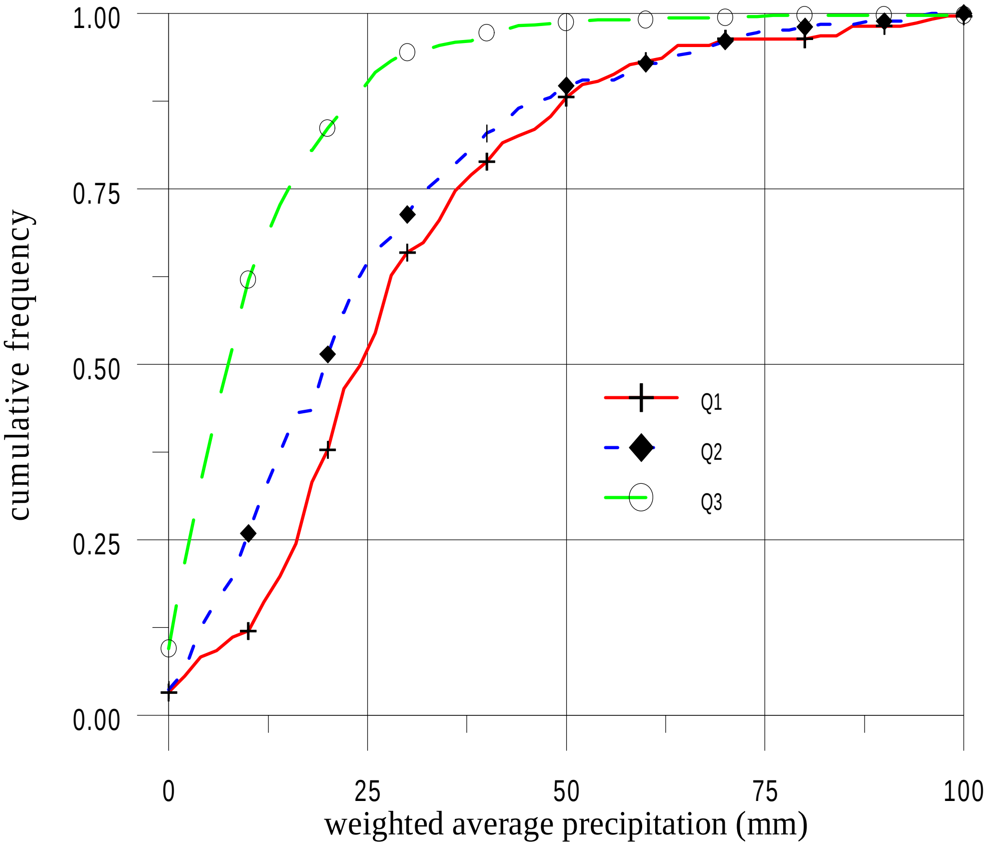

Figure 3. Cumulative probability distribution of the weighted average precipitation (mm) for Q1, Q2, and Q3.

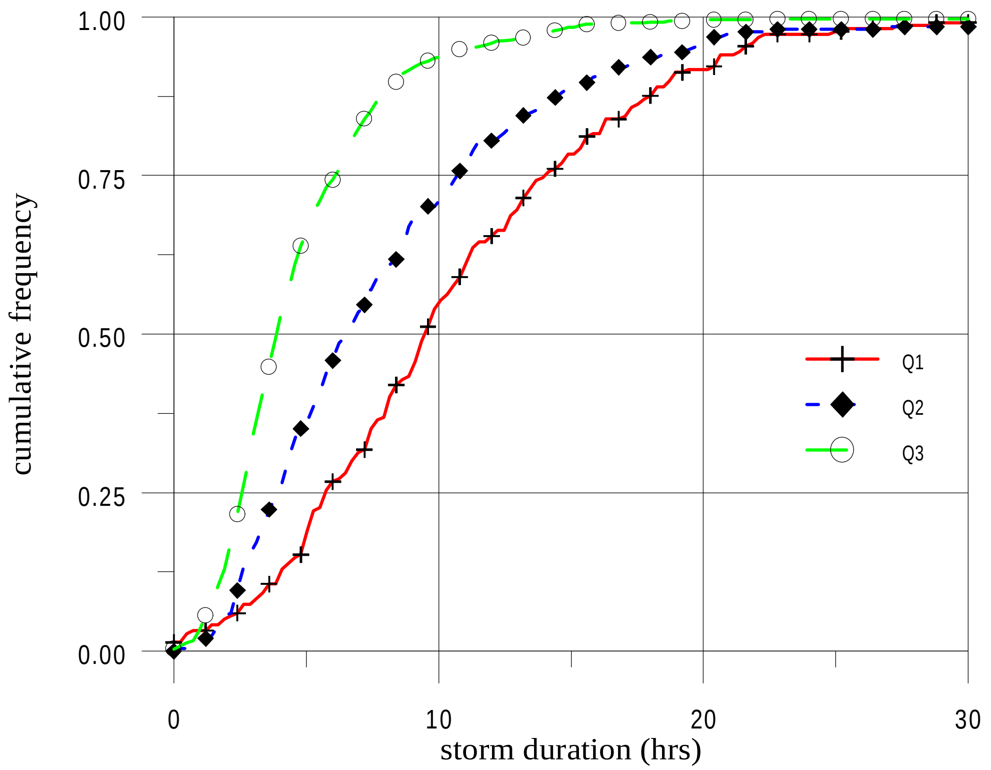

Figure 4. Cumulative probability distribution of the storm duration (hrs) for Q1, Q2, and Q3.

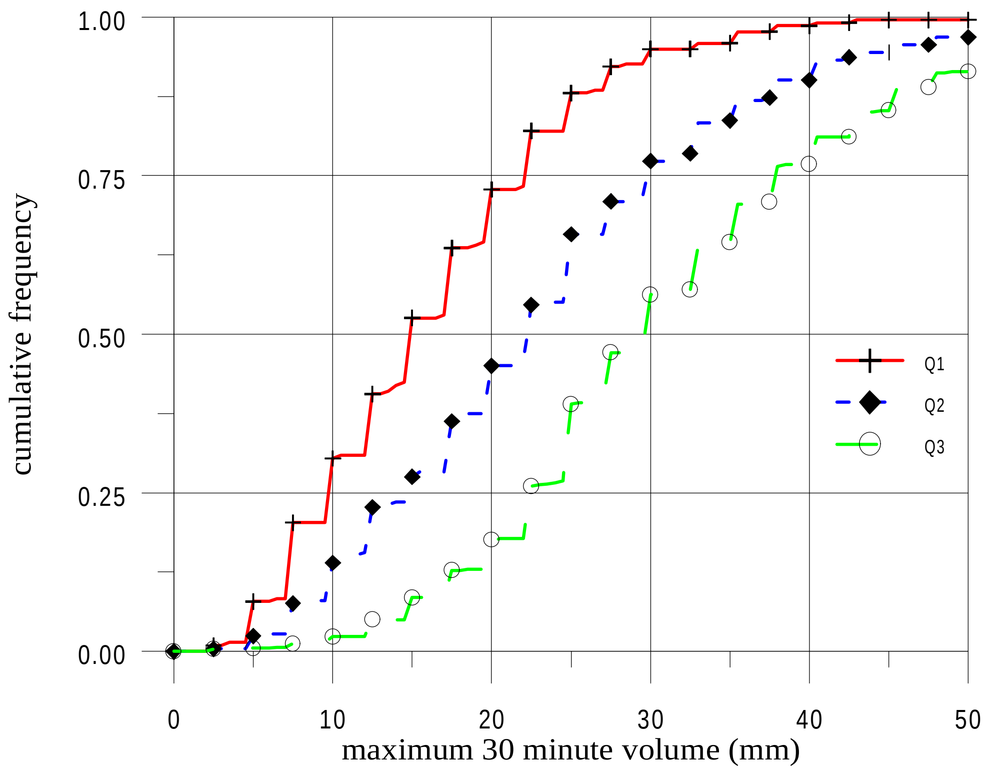

Figure 5. Cumulative probability distribution of the maximum 30 min volume (mm) for Q1, Q2, and Q3.

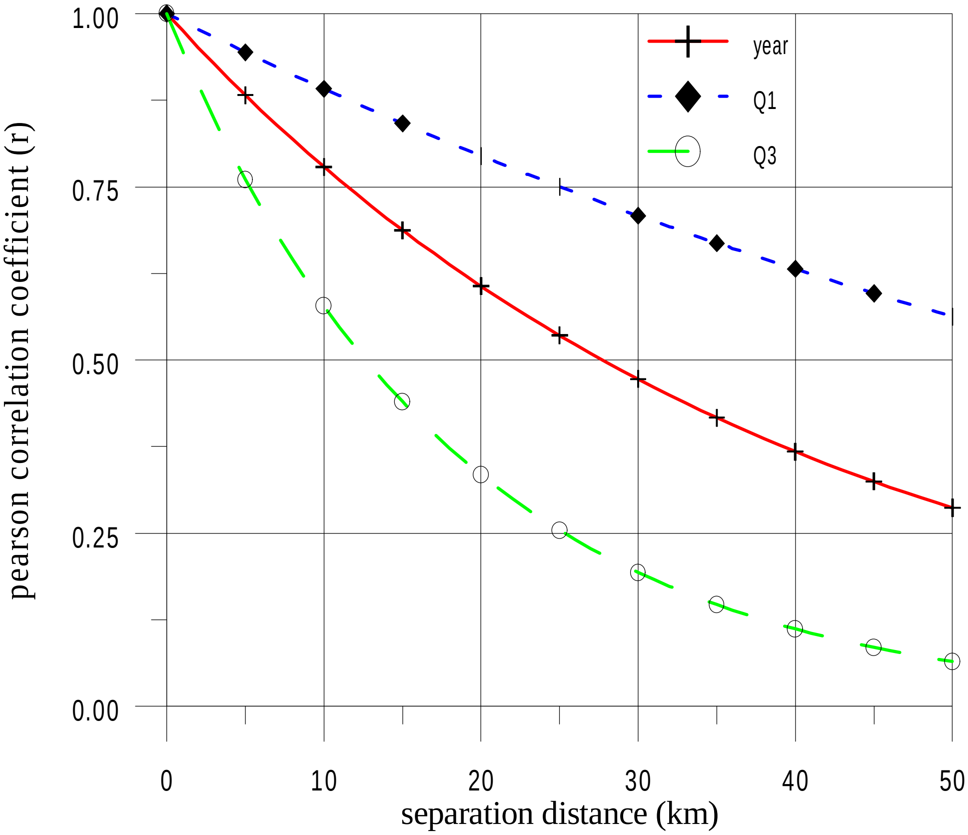

Figure 6. Relationships between the separation distance between rain gages and the correlation coefficient for the year, Q1, and Q3.

## CONCLUSIONS

An average storm for the LRW can be considered one which yields approximately 20 mm of rainfall, lasts 7.2 hrs, and covers 295 km$^2$. The greatest seasonal variation occurs during the months of June, July, and August. Storms during this period yield a smaller volume and are shorter, but occur more frequently. More importantly, the storms during this period are of greater intensity.

The correlation between rain gage data collected at different sites is higher over a greater distance during the winter period than during the summer. A high correlation coefficient ($r \geq 0.9$) can be expected for distances up to 9.2 km during December, January, and February, but only for distances up to 1.9 km during June, July, and August.

The spatial relationships presented here indicate that in order to obtain good correlation between rain gages they need to be separated by no more than 2 km. For this area, a fairly dense network of gages would be necessary to yield accurate on farm estimates of precipitation volume and rate. However, a cooperative effort involving farm owners and operators in a basin or watershed could establish such a network and obtain real-time estimates of precipitation for moisture-balance calculations. Correlation between gages can be improved by placing the gages on an axis parallel to the primary direction of moisture flux.

Data provided by this study support previous climatic studies in the Coastal

Plain area. In addition, this study provides detailed storm information previously lacking. The volume, duration, frequency, and intensity characteristics for precipitation events by season will be useful for hydrologic modeling. In the context of farm management and precision farming, the analysis of this study should be useful for making management decisions. The seasonal data provided here will be useful in planning planting times and agrichemical management. However, this analysis indicates that extrapolation of precipitation data collected at off-site locations will have little utility for prediction or modeling purposes unless the off-site gage is located closer than 2 km to the site of interest.

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