Analysis of Long-Term Precipitation for the Central Texas Blackland Prairie: 1939 to 1999

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Abstract

Historical data on precipitation occurrence, amount, intensity, and spatial and temporal variability are vital in water resource management. These data are beneficial in adapting agricultural, industrial, ecological, and domestic water supply management to best utilize the occurrence of natural rainfall events because rainfall ultimately determines surface and groundwater supplies. Therefore, knowledge of historical rainfall patterns is necessary to make informed decisions and predictions about future water supplies. In the Texas Blackland Prairie, an important agricultural region with a large and increasing urban population, drought and excess rainfall can be experienced throughout the year. With the diverse demands placed on water resources in this region and an increasing demand due to population growth, water resource management will be an even more important issue in the future. Faced with these demands, the continuous precipitation record from the USDA-ARS Grassland, Soil and Water Research Laboratory watersheds near Riesel, TX should prove valuable in water resource planning and management by providing information on long-term trends in rainfall amount intensity, and frequency.

Keywords: precipitation data, climate change

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Introduction

Our objective in this paper is to present the results of long-term analyses of precipitation data for the central Texas Blackland Prairie (1939-1999). These results should provide useful information to projects involving design of hydrologic structures such as dams, culverts, and detention basins, water supply and water quality modeling, and other hydrologic and water quality issues relevant to the region. The lack of adequate hydrologic data has been recognized for some time as a cause for failure of hydrologic structures but more commonly as contributing to unnecessarily conservative safety factors in structure design (USDA-SCS 1942). More recently, the importance of precipitation data in hydrologic modeling has been demonstrated (Favis-Mortlock 1995, Chaubey et al. 1999, Harmel et al. 2000).

In addition to presenting results from the precipitation analyses, it is hoped that this paper will publicize the availability of the precipitation data from Riesel. Recent publications by Hanson (2001) and Nichols et al. (2002) provide valuable regional precipitation analyses based on USDA-ARS experimental watershed data from Reynolds Creek, ID and Walnut Gulch, AZ. This publication will provide similar regional precipitation analyses within the Texas Blackland Prairie.

Site Description

The Blackland Prairie encompasses 4.45 million ha and is a major agricultural region extending from San Antonio 480 km north to the Red River (Figure 1). The area also contains the major metropolitan areas of Dallas, Fort Worth, Waco, Temple/Belton/Killeen, Austin, and San Antonio. Houston soils are the most extensive in the region and are noted for their strong shrink/swell potential.

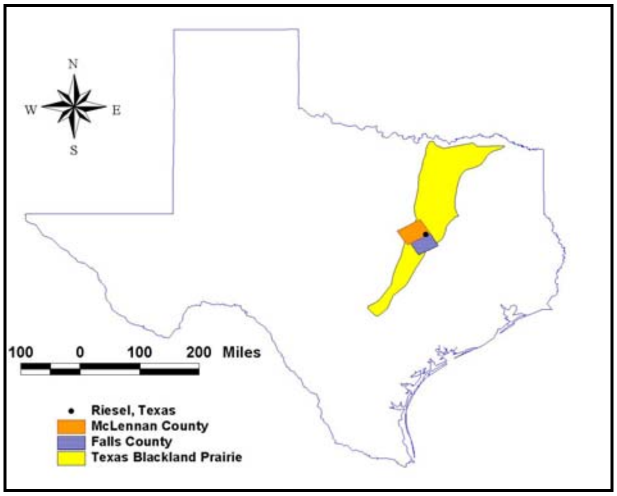

Figure 1. The Texas Blackland Prairie.

Long, hot summers and short, mild winters characterize the climate in the Blackland Prairie. The growing season lasts on average from mid March to mid November. Most rainfall occurs associated with the passage of Canadian continental and Pacific maritime fronts (Knisel and Baird 1971). Convective thunderstorms during the warmer months also contribute intense, short duration rainfall events. Tropical hurricanes can contribute substantial rainfall in rare occurrences. Frozen precipitation can occur occasionally but does not contribute significant moisture.

Riesel Precipitation Network

In the mid 1930s, the Soil Conservation Service (SCS) realized a need to analyze and understand hydrologic processes on agricultural fields and watersheds because of their impact on soil erosion, flood events, water resources, and the agricultural economy. As part of the SCS research program, the Hydrologic Division was created and a number of experimental watersheds were established across the United States. The primary functions of the facilities were to collect hydrologic data and to evaluate the hydrologic response from watersheds influenced by various agricultural land management practices (USDA-SCS 1942). One of those three original facilities, the Blackland Experimental Watershed, was established in 1937 in the heart of the Blackland Prairie near Riesel, TX (Figure 1). This experimental watershed facility later became part of the USDA-ARS Grassland, Soil and Water Research Laboratory with headquarters in Temple, TX.
Collection of rainfall data at the Riesel facility began in 1937 and continues through today. A total of 57 rain gauges were used at some time during the period of record. Historical data from these rain gauges (approximately 1400 rain gauge years) are available on the website: http://arsserv0.tamu.edu/hydata.htm. Rainfall estimates for individual watersheds can be calculated from Thiessen weights, which are also available. This site lists the stations and the years for which daily and sub-daily rainfall data are available. Currently, 15 rain gauges are in operation within the 340 ha watershed area (Figure 2). These operational gauges are instrumented with a tipping bucket rain gauge and datalogger to measure and record sub-daily precipitation. A standard non-recording rain gauge is also used at each site as a backup and calibration device.

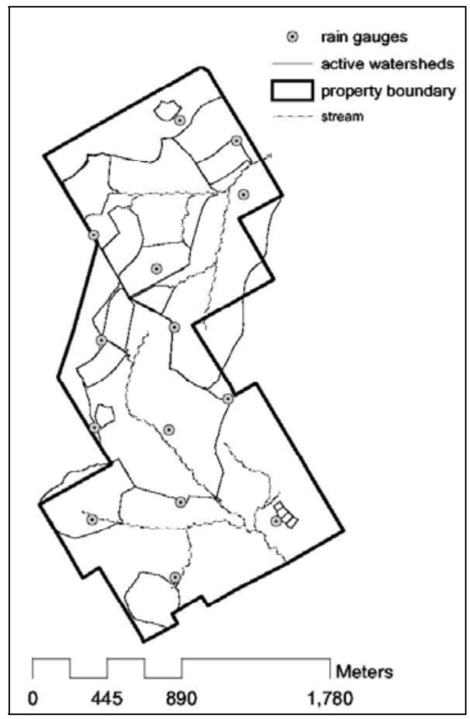

Figure 2: Active rain gauges at Riesel.

Methods

General rainfall characteristics

Descriptive statistics for measured monthly, seasonal, and annual rainfall were calculated for the period from 1939 to 1999 for the longest continually active gauges. Data from these four gauges were also used to compare the spatial variability of daily rainfall. Analyses of rainfall occurrence, amount, and variability were also conducted for a representative rain gauge.

Depth-duration-frequency relationships

To determine relationships between rainfall amounts, duration of rainfall events, and the expected number of events over a given time period, annual maximum rainfall amounts for 0.25, 0.5, 1, 2, 3, 6, 24, 48, and 72 hr durations were calculated. The return frequency for each of these depths and durations was then calculated as indicated by Haan (1977). The mean depth for each of these durations was in turn computed for 1 through 50 yr return frequencies for comparison with results calculated with the USGS depth-duration-frequency procedure for Texas (Asquith 1998) and estimates from the Rainfall Frequency Atlas of the United States or "TP-40" (Hershfield 1961). Return frequencies of seasonal and annual rainfall were also calculated.

Trend analysis

Monthly and annual means and standard deviations for all available rain gauges with continuous records were calculated to detect trends in rainfall amount and variability from decade to decade. Linear regression over time was conducted to evaluate long-term trends in monthly, seasonal, and annual rainfall totals. Trends in rainfall variability were examined with regression analyses on the absolute value of the residuals.

Results and Discussion

General rainfall characteristics

Mean annual rainfall for the four continuously active rain gauges was 880 to 900 mm. Typically, spring (defined as March, April, and May) is the wettest period with average rain of 270 mm. Fall (September, October, November) is also relatively wet averaging more than 220 mm. Winter (December, January, and February) and summer (June, July, and August) are relatively dry with approximately 190 mm of rainfall occurring each season. Average monthly rainfall ranges from 115 mm in May to less than 50 mm in July. In the wettest period, April through June, rainfall averages approximately 292 mm. In contrast the driest period, July through September, receives only 165 mm. On average, 90 days per year had measurable rain (greater than 0.25 mm), 72 days per year had rain amounts greater than 0.76 mm, and 11 days had rain amounts greater than 25 mm. It is interesting to note that the wetter months generally exhibit greater rainfall variability (Figure 3).

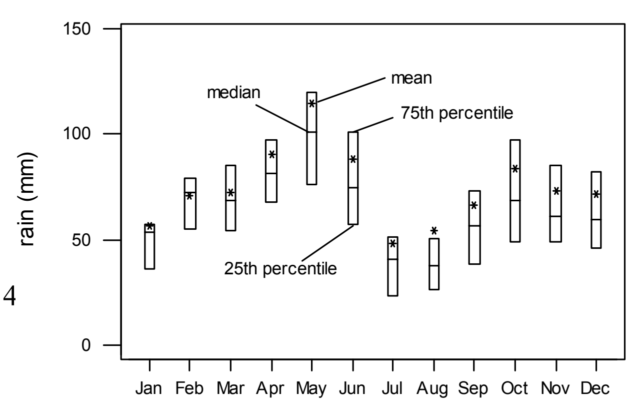

Figure 3: Monthly distribution of rainfall and rainfall variability.

Monthly, seasonal, and annual rainfall amounts and variability did not differ among the four rain gauges. This result was expected as the gauges are within 2500 m of each other with little change in topography. In terms of the maximum difference between the four rain gauges for each rainy day, relatively small differences were observed. On days with rain, spatial variability ranged from 0 to 54 mm with an average difference of 2.8 mm. However, 75% of values were within 3.3 mm and 90% were within 7.1 mm. Because of the small difference between these four rain gauges, rainfall characteristics and trends analysis are presented for a representative rain gauge.

Depth-duration-frequency relationships

Measured data and estimates derived from the USGS depth-duration-frequency procedure were similar at return frequencies greater than 1 yr for all durations. Although TP-40 results were similar to measured data for most durations for return frequencies greater than one year, TP-40 depths for the commonly used 24 hr design duration were considerably larger (approximately 25 mm). This difference represents a significant volume in hydrologic design and emphasizes the need for engineers to use the most up-to-date and extensive data sets and/or proven relationships when designing hydrologic structures.

These depth-duration-frequency results are valuable for hydrologic structure design, but seasonal and annual return frequencies are more important for water supply issues. Wet spring and fall seasons are much more frequent than wet summers and winters (Figure 4). Late fall through early spring rainfall is important because of increased likelihood of runoff into water supply reservoirs due to low evaporation and transpiration losses in this period.

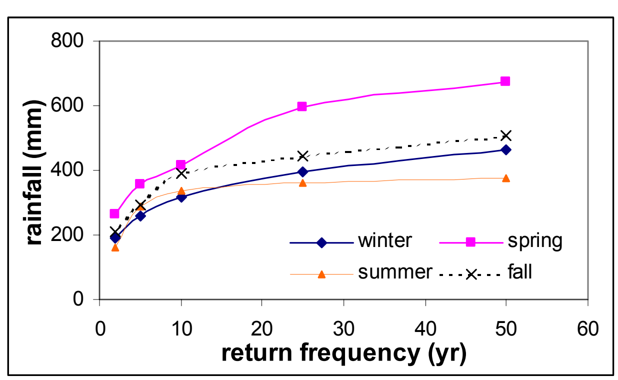

Figure 4: Seasonal return frequencies

Trend analysis

With two exceptions, the decadal monthly and annual rainfall totals from the 1940s to the 1990s seemed to fluctuate without any readily apparent trend. These two exceptions were detected through linear regression analyses and are presented in Table 1. The table also shows the general tendency of rainfall from the late 1930s through 1999. Regression analysis resulted in one statistically significant change in monthly, seasonal, and annual rainfall at $\alpha = 0.05$ and 0.10. The slope of the regression line (the change in monthly rainfall) for October rainfall was significant. October rainfall increased 0.89 mm (0.035 in) per year, which in terms of water supply is an important increase of over 50 mm in the 64 yr period of record. It is also interesting to note the relatively large increase in rainfall amounts for all seasons except spring and the overall annual increase of over 1.6 mm. When the influence of decreasing spring rains was removed, a significant increase in non-spring (summer, fall, and winter) rainfall of 2.19 mm per year was detected by regression analysis ($\alpha = 0.10$).

Because two significant trends in rainfall amount were determined, we wanted to determine whether the changes were due to changes in rainfall frequency and/or magnitude. Linear regression analysis resulted in statistically significant ($\alpha = 0.10$) increases in the number of summer and fall rainy days and also a significant increase in the total number of rainy days each year.

Table 1: Linear tendencies in rainfall amount from 1938 to 1999

time period	ave change (mm/yr)	time period	ave change (mm/yr)
jan	-0.03		
feb	0.15	winter	0.55
mar	0.43	spring	-0.57
apr	-0.67	summer	0.56
may	0.09	fall	1.07
jun	0.01		
jul	0.32	non-spring	2.19*
aug	0.24		
sep	0.01	annual	1.63
oct	0.89*		
nov	-0.20		
dec	0.39		

*statistically significant at a = 0.10.

A similar analysis was conducted on the frequency and magnitude of extreme rainfall events. From the 1940s to the 1990s, the number of days with rain exceeding 25.4 mm decreased for the spring (Figure 5). This observed decrease over time was statistically significant as determined with linear regression ($\alpha = 0.10$). This decrease in the number of spring days per year with rain greater than 25.4 mm did not, however, significantly affect the total annual number of days with excessive rain. No significant change in the number of days with rain greater than 50.8 mm of rain was evident from the 1940s to the 1990s. In terms of the magnitude of extreme rain events, linear regression determined significant decreases for the 75th percentile winter, spring, and fall rainfall events and the 95th percentile fall event.

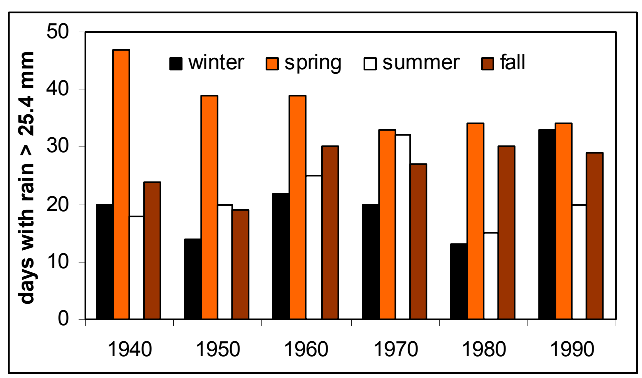

Figure 5: Number of days with rain exceeding 25.4 mm in each season.

The interaction of these changes in rainfall amount impact the overall trends presented in Table 1. The increases in October rainfall amount and the number of summer and fall rainy days contribute to increasing precipitation trends in summer and fall. This impact, however, is lessened by the decrease in extreme rainfall events in the fall. The decreases in both rainy days and days with extreme rainfall in the spring contribute to decreasing spring rainfall. When the influence of decreasing spring rainfall was removed, as was done for summer by Nichols et al. (2002), a significant increase in non-spring rainfall was determined. The lack of a significant trend in annual rainfall even though non-spring rains are increasing can be attributed to the decrease in spring rains, which contributed about 30 % of the annual rain total.

Trends of rainfall variability, as well as rainfall amounts, are important in water resource management, cropland and rangeland production, and other applications. Based on examination of plots of monthly and annual rainfall and residuals and decadal patterns, rainfall variability for certain months appears to be changing. The most noticeable observation was the pattern of decreases in the variability of November rainfall and increases in December rainfall variability from the 1940s to the 1990s. To test these initial observations, linear regression analysis was conducted on the absolute value of residuals of monthly rainfall. These tests indicated significant increases in February and August variability and a significant decrease in November variability ($\alpha = 0.10$).

Conclusions

This paper presents results of selected long-term analyses of precipitation data collected at the USDA-ARS Grassland, Soil and Water Research Laboratory, Riesel, TX since the 1930s. For this period, annual rainfall averaged 892 mm. In the wettest months (April, May, June, October) average monthly rainfall exceeds 85 mm, but for July, August, and January, rainfall averages less than 55 mm. On average 72 days per year have rain greater than 0.76 mm, and 11 days per year have rain amounts greater than 25 mm.

The depth-duration-frequency analysis yielded several notable results. The measured 24 hr storm depth, which is often used in hydrologic structure design, ranged from 89 mm for a 2 yr return period to 192 mm for a 50 yr return period. When the measured depth-duration-frequency relationship was compared to a USGS depth-duration-frequency procedure (Asquith 1998), results were similar for all return periods greater than 1 year for all durations. Measured depths were also generally similar to TP-40 results (Hershfield 1961); however, the 24 hr TP-40 depths were approximately 25 mm larger than measured depths. This difference can represent a significant volume in hydrologic design and emphasizes the need for engineers to use the most up-to-date and extensive data sets and/or proven relationships in design of hydrologic structures. Based on these results, the USGS depth-duration-frequency procedure (Asquith 1998) is a recommended alternative to measured data for hydrologic design in the central Texas Blackland Prairie region.

Although the general rainfall characteristics and depth-duration-frequency relationships are important, the analysis of possible changes in precipitation patterns due to possible global climate change has become a topic of intense speculation. In this study, we observed significant increases in October rainfall, non-spring rainfall, and the number of summer and fall rainy days; all which contribute increased rainfall. This impact, however, is lessened by decreases in the number of rainy days and extreme events in the spring and in the magnitude of extreme fall rain. These changes in rainfall are different from those observed in other regions. For instance, Nichols et al. (2002) reported increasing annual precipitation due to an increasing frequency in non-summer rains. These differing findings reinforce the need and value of regional, long-term precipitation analysis.

The long-term analyses included examination of general precipitation properties, depth-duration-frequency relationships, and trends in rainfall amount and occurrence. Results from these selected analyses, as well as additional analyses possible for the extensive database, should prove useful in hydrologic structure design, water supply and water quality management and modeling, and other hydrologic and water quality issues relevant to the Texas Blackland Prairie region.

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