UNIVERSITY OF MINNESOTA
ST. ANTHONY FALLS LABORATORY
Engineering, Environmental and Geophysical Fluid Dynamics

Project Report 376

Correlations Between Climate and Streamflow in the Little Washita River Watershed, OK

by

Laura L. Kletti and Heinz G. Stefan

Prepared in cooperation with

NATIONAL AGRICULTURAL WATER QUALITY LABORATORY
Agricultural Research Service
U. S. Department of Agriculture
Durant, Oklahoma

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Acknowledgements

The investigation described herein was conducted for the National Agricultural Water Quality Laboratory, Agricultural Research Service/USDA, as a part of a project to anticipate the possible effect of projected climate change on water resources and ecosystems. Dr. Frank R. Schiebe was the project officer.

Data were provided by J. Thurman of the Water Data Center, ARS/USDA Hydrology Laboratory.

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I. Introduction

Three substantially different methods have been used to relate the runoff in the Little Washita River, OK, to climate parameters. One method uses a detailed watershed runoff model SWAT, which integrates several well established hydrologic runoff model components. The second approach is based on a mean monthly water budget and calculates runoff as one of its components. The third approach simply correlates measured runoff with measured weather parameters. The timescales of these three methods are substantially different: daily, monthly, and seasonal (3-months) for the three methods, respectively. The timescale is the shortest for the most process oriented model and the longest for the purely statistical method.

The simplest of these three methods in terms of data requirement and computational effort is described herein and applied to the Little Washita Watershed. The other two are explained in reports by Mohseni and Stefan (1996) and Hanratty (1996).

The goal of the analysis reported herein was to find the simplest linear relationships between readily available climate parameters and long-term streamflow in the Little Washita River. The climate variables include air temperature (T_a), dew point temperature (T_d), precipitation (P), and wind speed (W). Daily data were available.

A linear relationship between runoff and the given climate parameters would be

$$R = A\cdot T_a + B\cdot T_d + C\cdot P + D\cdot W + E \tag{1}$$

This relationship has been slightly modified by combining the terms $B\cdot T_d$ and $D\cdot W$ into a term $B\cdot Evap$ where $Evap = W(T_a - T_d)$ represents an evaporation parameter. Equation (1) is therefore reduced to

$$R = A\cdot T_a + B\cdot Evap + C\cdot Prec + D \tag{2}$$

where R = runoff (in/mo), W = wind velocity (m/s), T_a = air temperature (°C), T_d = dewpoint temperature (°C), Prec = precipitation (in/mo), and A,B,C,D are coefficients of linear regression. They are given in units of A(in/mo)$(^\circ C)^{-1}$, B(in/mo)$(m/s)^{-1}$ $(^\circ C^{-1})$, C(-), and D(in/mo).

Equation 2 was applied in several alternative forms:

$$R = C \cdot \text{Prec} + D \tag{2a}$$

$$R = A \cdot T_a + C \cdot \text{Prec} + D \tag{2b}$$

$$R = B \cdot \text{Evap} + C \cdot \text{Prec} + D \tag{2c}$$

Values of D were allowed to be negative.

II. Little Washita River Watershed

The Little Washita River Watershed is located in southwestern Oklahoma. A map of the watershed is shown in Figure 1. Basic topographic characteristics summarized in Table 1 can be found in the work by Allen and Naney (1991) and in the USDA/ARS data files WS69015.TXT. The ARS data file is reproduced in the Appendix.

The landscape topography is described as rolling with a maximum relief of 600 ft. The drainage area used in this analysis was the one given in the data files. The mean land slope is fairly steep, and the watershed is described as well drained (Allen and Naney, 1991). Most of the agricultural crops are row crops (81% cotton and milo). Very little soil conservation measures are applied on the watershed. Depths to bedrock are fairly shallow. Deeper overburden (> 5 ft) occurs along the river beds and in the far western end of the watershed.

III. Streamflow and Weather Data

Daily streamflow in the Little Washita River and weather data representative of the Little Washita watershed in Oklahoma were used in the analysis. The locations of the weather station and the stream gaging station are indicated in Figure 1. Stream flow and weather data files used in the analysis are listed in Table 2. Daily values for the period from November 1965 to July 1983 were extracted from these files, and daily maximum/minimum air temperatures, daily wind velocities, and relative humidities were averaged for each month. Monthly precipitation values were the sum of event precipitation values reported for that month.

The daily runoff data set included instantaneous readings at various times during each day (24-hour clock). More frequent readings were taken when the flow rate was rapidly changing. Therefore each flow rate was weighted according to the time interval it represented. The daily runoff value was the sum of the weighted instantaneous readings. The monthly runoff value (cfs) was the sum of these daily values.

Data manipulations included conversion of air temperatures from °F to °C. Dew point temperatures were found using the relative humidities and air temperatures. Wind velocity was changed from miles/hr to m/s. Runoff values were converted from cfs to in/mo by dividing by the drainage area given in Table 1 and multiplying by the number of seconds per month. Mean monthly values of the climate parameters and runoff are given in Table 3. It is noteworthy that the annual runoff is only 1.94 in/yr, or 6.8% of the annual precipitation of 28.56 in/yr.

Seasonal and annual climate values were found from the mean monthly data. "Seasonal" data values were the mean of 3 months and "annual" data values the mean of 12 months. The mean monthly runoff and air temperatures have been plotted in Figure 2. Seasonal (3 month) groupings were chosen beginning with Dec/Jan/Feb (labeled 12,1,2) for winter and so on for the other three seasons following the pattern used in a previous, similar study (Kletti and Stefan, 1995). The winter (12,1,2) and fall (9,10,11) groupings are reasonable for runoff because of the small differences of values in the three individual months (see Fig. 2). Spring (3,4,5) and summer (6,7,8) groupings may not be the best for runoff.

IV. Regression Analysis

1. Analysis of the entire data set

The analysis was first performed using the entire data set. Equations 2a, 2b,and 2c were applied to the monthly, seasonal, and annual data values. The linear regression analysis using alternatively equations 2a, 2b, or 2c gave the coefficients listed in Table 4. Coefficients were obtained separately for monthly, seasonally and annually averaged data. The statistics of the three different regression equations applied to the three time scales (month, season, year) are given in Table 5.

Monthly Runoff

In Figure 3 the actual and regressed mean monthly runoff and the standard deviations (STD) of the actual runoff are plotted. Equation 2b predicts the spring runoff peak by one month and the fall runoff peak by two months too early. Predictions by Eq. 2a and Eq. 2c are virtually identical.

The coefficients in Table 4, and the statistics in Table 5, show little if any difference in the predictions by the three equations. If a choice had to be made, the authors would select Eq. 2c because it shows a positive value for D and has no lag to the observed runoff peaks (Fig. 3). Equation 2c includes evaporation which is a parameter sensitive to climate change.

Seasonal Runoff

Table 4 also gives coefficients from the regression analysis with seasonal (3-month) average data. The mean actual and regressed runoff values for each season are plotted in Figure 4. All regressed values are much closer and easily within one standard deviation of the actual value. Separate statistics for the seasonal analysis can be found in Table 6.

Annual Runoff

The annual analysis was for 14 years of data. Mean annual values of air temperature, precipitation, and actual runoff are plotted in Figure 5. Averages for the 14 years are also included. Dry years typically have lower annual runoff. This is shown in Figure 6 where the regression between runoff and precipitation is given. The fit of regressed annual runoff to actual runoff is shown in a timeseries plot in Figure 7. The 1981 values show the largest discrepancy; in that year precipitation was high and air temperature near the mean (Fig. 6), and yet the runoff is below the mean.

Statistics

The r^2 values in Table 4 are highest for the annual analysis. Accordingly the root mean square error (RMSE) values between regressed and actual runoff decrease going from a monthly to a seasonal to an annual data basis. Table 5 also gives the standard deviation (STD) of the mean regressed values. The mean actual and regressed runoff values are equal, as is to be expected for a linear regression. The regressions have, however, smaller STD values than the actual runoff. There is little difference between the STD values obtained by eqs. 2a, 2b, and 2c.

A physical interpretation of the regression coefficients in Table 4 can be attempted as follows: All **B**s are negative. This agrees with the nature of evaporation as a loss term in equation 2c. All **C**s are positive. This reflects the contribution of precipitation to runoff. Because **C** is always much smaller than one, only a small fraction of precipitation produces runoff, i.e. losses from precipitation are large. All **A**s are negative. The term $\mathbf{A}\cdot\mathbf{T}_a$, therefore, represents losses which become larger as air temperature increases. **A** is relatively small in the seasonal regression. **D**s are positive or negative and therefore indicate contributions or losses which are (statistically) not weather-related.

2. Analysis of data separated by seasons

Referring to Table 3, the seasonal precipitation is minimum in winter (3.4 in), maximum in spring (10.7 in) and almost the same in summer and fall (7 in). The corresponding runoff is minimum in fall and winter (0.3 in), maximum in spring (0.8 in) and average in summer (0.5 in).

Regressions were therefore made by analyzing the data in each season separately. The coefficients obtained from seasonal data sets (4) are listed in Table 7. Root mean square (RMSE) errors between actual data and regressions are also listed. Using a separate regression equation for each season improves the prediction considerably. The RMSE values range from 0.046 to 0.114 in/mo (Table 7) or a combined value of 0.085 in/mo when four separate equations are used, as opposed to an RMSE of 0.098 in/mo (Table 4) where only one equation is used. The improvement is largest in fall and winter. An average RMSE improvement of 0.049 in/mo can be calculated by using the sum of the squares of errors.

Equations 2a, 2b and 2c give similarly good fits. Within each season, the RMSE values differ by less than 4%, except in fall when the maximum difference is 15%. Equation 2c has a slight edge over the others, but requires more input data. Equation 2a gives slightly worse predictions than the others but requires only precipitation data as input. The linear regressions against precipitation (eq. 2a) are shown in Figures 8 through 11 for each season separately.

The final equations recommended for the separate seasonal analysis are eqs. 2a for winter, spring and summer and eq. 2c for fall, with the coefficients given in Table 7. The fit is shown in Fig. 12 where seasonal runoff values are plotted against time. Missing data (omitted from the analysis) are indicated by breaks. The r^2 value is 0.650 for the combined seasonal regression equations.

The recommended seasonal regression equations are

$$R = 0.059\ P + 0.035 \qquad \text{for Dec, Jan, Feb} \qquad \text{(winter)} \tag{3a}$$

$$R = 0.086\ P - 0.042 \qquad \text{for Mar, Apr, May} \qquad \text{(spring)} \tag{3b}$$

$$R = 0.161\ P - 0.236 \qquad \text{for Jun, Jul, Aug} \qquad \text{(summer)} \tag{3c}$$

$$\begin{aligned} R = &- 0.014\ W\ (T_a - T_d) \\ &+ 0.051\ P + 0.093 \end{aligned} \qquad \text{for Sep, Oct, Nov} \qquad \text{(fall)} \tag{3d}$$

where R = runoff (in/mo), P = precipitation (in/mo), W = wind velocity (m/s), T_a = air temperature (°C), T_d = dew point temperature (°C).

Input and output values are three-month (seasonal) averages.

The coefficient associated with precipitation in equations 3a to 3d are less than 0.10 except for summer (June, July, and August). This indicates that less than 10% of the seasonal precipitation contributes directly to the seasonal runoff except in summer. In other words, 90% of the seasonal precipitation either evaporates or infiltrates. By comparison, rivers in Minnesota receive an average of 25% and a maximum of 52% of precipitation as runoff (Kletti and Stefan, 1995).

The constant in equation 3a can be thought of as the contribution of the base flow to the Little Washita River runoff in winter, on average about 35% of the total runoff. The constants in equations 3b and 3c are indicators of losses which in comparison to the total runoff have particular significance in summer. Because constants are negative, equations 3b and 3c are limited to precipitations of more than 0.49 in/month and 1.47 in/month, respectively. This would indicate that the river goes dry (ephemeral river) when precipitation becomes very low. The constant in equation 3d is indication of a positive contribution to runoff which is not related to weather, possibly baseflow.

VI. Summary

An analysis similar to the one of Kletti and Stefan (1995) was done for the Little Washita River Watershed, OK. Monthly, seasonal, and annual runoff averages were regressed against climate parameters, specifically precipitation, air temperature, dew point and wind speed. A data set from a gaging station and a weather station within the watershed (Fig. 1) were used. The record extended from 1966 to 1983. Linear regressions were run on the entire year-round data set as well as on separate seasonal data sets. The separate seasonal regression produced an r^2 of 0.65 and included 66 data points. The separate regressions for winter, spring, and summer used precipitation as input, while fall used air temperature, dew point temperature, and wind speed in addition to precipitation. The combined seasonal RMSE was 0.085 in/mo which is one-half of the mean actual runoff of 0.16 in/mo. The lowest RMSE of 0.058 in/mo was obtained for the annual timescale, but the low number of data points (14) clouds this annual RMSE value. Overall, the separate seasonal regressions given by Eqs. 3a to 3d and illustrated in Figure 12 are considered at this time to give an approximate statistical fit of the Little Washita River runoff data.

References

Allen, P. B. and Naney, J. W. 1991. Hydrology of the Little Washita River Watershed, Oklahoma: Data and Analyses. United States Department of Agriculture, Agricultural Research Service, ARS 90.

Gu, R. and Stefan, H. G., 1993. Validation of Cold Climate Lake Temperature Simulation. Cold Regions Science and Technology, 22: 99-104.

Hanratty, M. P. Using the IDRISI Geographical Information System to Determine Watershed Model Inputs, University of Minnesota, St. Anthony Falls Laboratory, Project Report No. 388, April 1966, 91 pp.

Kletti, L.L. and Stefan, H.G., 1995. Empirical Relationships Between Runoff and Climate Parameters: An Analysis For Minnesota. University of Minnesota, St. Anthony Falls Laboratory, Project Report No. 374, 121 pp.

Mohseni, O. and H. G. Stefan. A Methodology to Estimate Climate Effects on Monthly Stream Runoff with Application to Minnesota and Oklahoma, University of Minnesota, St. Anthony Falls Laboratory, Project Report No. 384, February 1966, 100 pp.

Thurman, J., 1995. USDA/ARS Water Data Base Files, Hydrolab.arsusda.gov.

TABLE 1. Little Washita Watershed Information

Area (mi^2)	207.8
Mean Land Slope (-)	0.05
Depths to Bedrock (% of area)	
Less than 5 ft	54
Greater than 5 ft	46
Soils (% of area)	
Sands	34
Loams	66
Land Use (% of area)	
Agricultural	34
Pasture/Range	26
Wooded Pasture	38

TABLE 2. USDA/ARS Water Data Base Files (L69=Little Washita)

HUM_124.DAT	Max, Min, Relative Humidity
WIND_124.DAT	Mean Wind (mph)
RG000124.L69	Event Precipitation (in)
WS69015.MMT	Max, Min Air Temperature (°F)
WS69015.L69	Streamflow (cfs)
Period Used	Nov '65 - Jul '83

TABLE 3. Mean Monthly Weather and Runoff Data

Month	Wind (m/s)	Dewpoint (°C)	Air Temp (°C)	Precip (in/mo)	Runoff Average (in/mo)	Runoff STD (in/mo)
1	1.86	-2.02	2.13	1.19	0.10	0.06
2	1.97	0.40	5.15	1.19	0.12	0.06
3	2.49	4.92	10.45	2.02	0.16	0.10
4	2.37	10.32	15.64	3.29	0.18	0.09
5	1.69	14.64	19.51	5.43	0.45	0.39
6	1.45	19.83	24.61	3.09	0.29	0.25
7	1.34	21.61	27.59	2.38	0.16	0.31
8	1.16	19.56	25.30	1.96	0.06	0.07
9	1.20	16.61	21.40	3.19	0.10	0.10
10	1.35	10.53	15.75	2.57	0.13	0.15
11	1.67	5.02	10.17	1.22	0.09	0.07
12	1.80	0.56	5.43	1.04	0.10	0.05
Average	1.70	10.17	15.26	2.38	0.16	0.14
Annual Total (in/yr)				28.56	1.94	

TABLE 4. Coefficient Summary - Entire Data Set

Time Scale (# pts)	**Eqn. No.**	**A (in/mo °C)**	**B (*)**	**C (-)**	**D (in/mo)**	**r^2 (-)**	**RMSE (in/mo)**
Month	2a			0.071	-0.007	0.536	0.138
(209)	2b	-0.023		0.074	0.021	0.545	0.137
	2c		-0.002	0.070	0.013	0.534	0.138
Season	2a			0.082	-0.034	0.518	0.099
(66)	2b	-0.003		0.089	-0.009	0.536	0.098
	2c		-0.005	0.081	0.017	0.534	0.098
Year	2a			0.154	-0.214	0.635	0.060
(14)	2b	-0.025		0.152	0.174	0.654	0.058
	2c		-0.006	0.034	-0.110	0.644	0.059

*(in/mo)(°C m/s)$^{-1}$

TABLE 5. Runoff Regression Statistics at Monthly, Seasonal and Yearly Timescales - Entire Data Set

	Month (in/mo)	**Season (in/mo)**	**Year (in/mo)**
Mean actual runoff STD of actual runoff	0.165 0.204	0.166 0.144	0.171 0.103
STD of Eq. 2a runoff	0.149	0.104	0.082
STD of Eq. 2b runoff	0.150	0.106	0.083
STD of Eq. 2c runoff	0.149	0.106	0.083

TABLE 6. Seasonal Runoff Regression Statistics

	Winter (in/mo)	**Spring (in/mo)**	**Summer (in/mo)**	**Fall (in/mo)**
Mean actual runoff STD of actual runoff	0.102 0.056	0.260 0.145	0.181 0.193	0.110 0.086
Mean of eq. 2a runoff STD of eq. 2a runoff	0.058 0.040	0.255 0.093	0.179 0.078	0.162 0.085
Mean of eq. 2b runoff STD of eq. 2b runoff	0.080 0.044	0.263 0.099	0.152 0.086	0.159 0.092
Mean of eq. 2c runoff STD of eq. 2b runoff	0.062 0.050	0.240 0.103	0.185 0.087	0.169 0.088

TABLE 7. Coefficient Summary - Seasonal Data Sets

Season (# pts)	**Eqn. No.**	**A (in/mo °C)**	**B (*)**	**C (-)**	**D (in/mo)**	**RMSE (in/mo)**
Winter (16)	2a			0.059	0.035	0.047
	2b	0.006		0.058	0.013	0.046
	2c		-0.002	0.053	0.059	0.047
Spring (18)	2a			0.086	-0.042	0.104
	2b	-0.019		0.100	0.191	0.101
	2c		-0.009	0.072	0.106	0.100
Summer (16)	2a			0.161	-0.236	0.114
	2b	0.025		0.173	-0.912	0.113
	2c		-0.011	0.142	-0.105	0.112
Fall (16)	2a			0.061	-0.035	0.055
	2b	-0.000		0.061	-0.029	0.055
	2c		-0.014	0.051	0.093	0.048

*(in/mo)(°C m/s)$^{-1}$

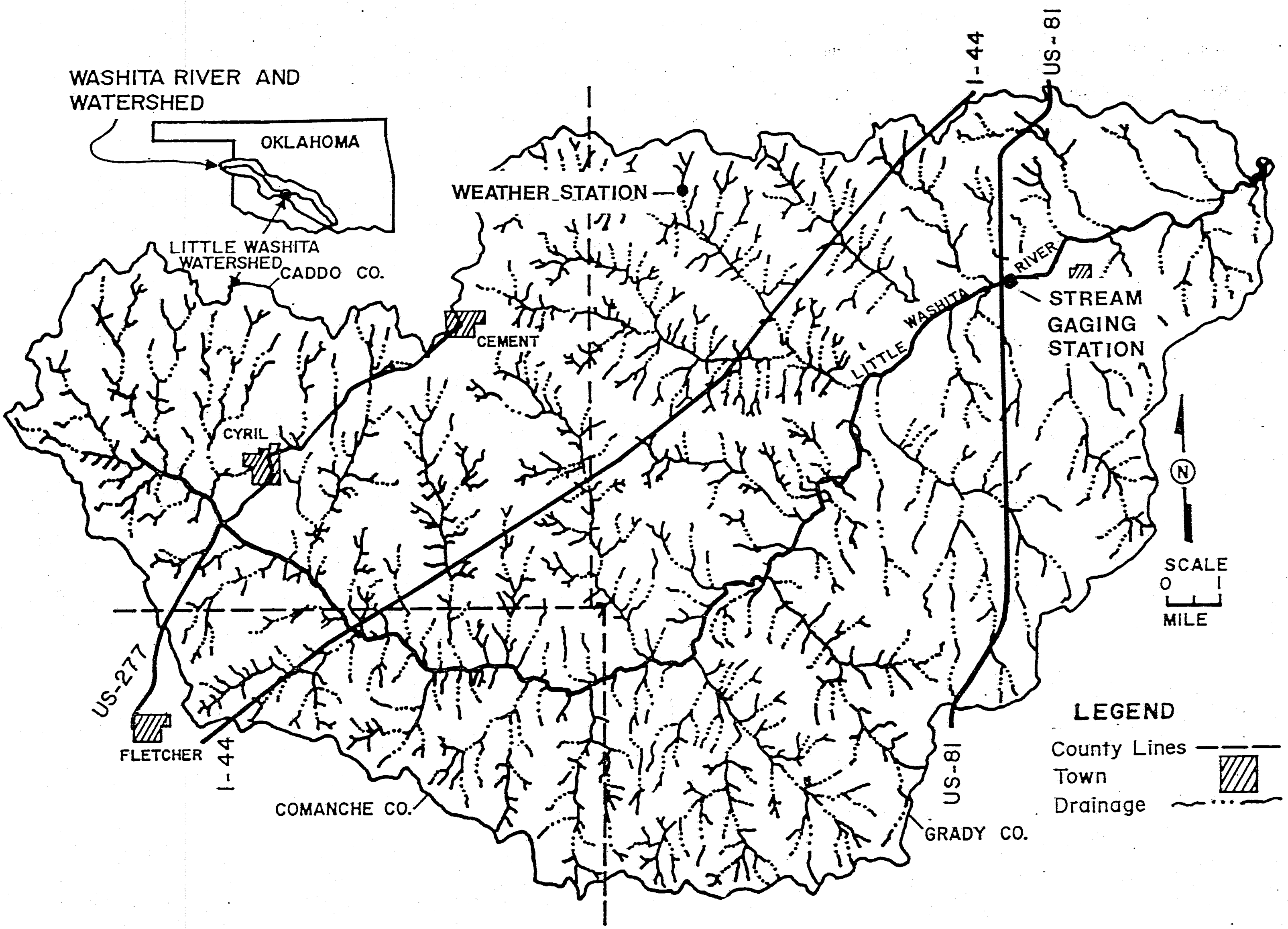

Figure 1 Location and map of the Little Washita Watershed. Location of the stream gaging station and the weather station used in the analysis are indicated.

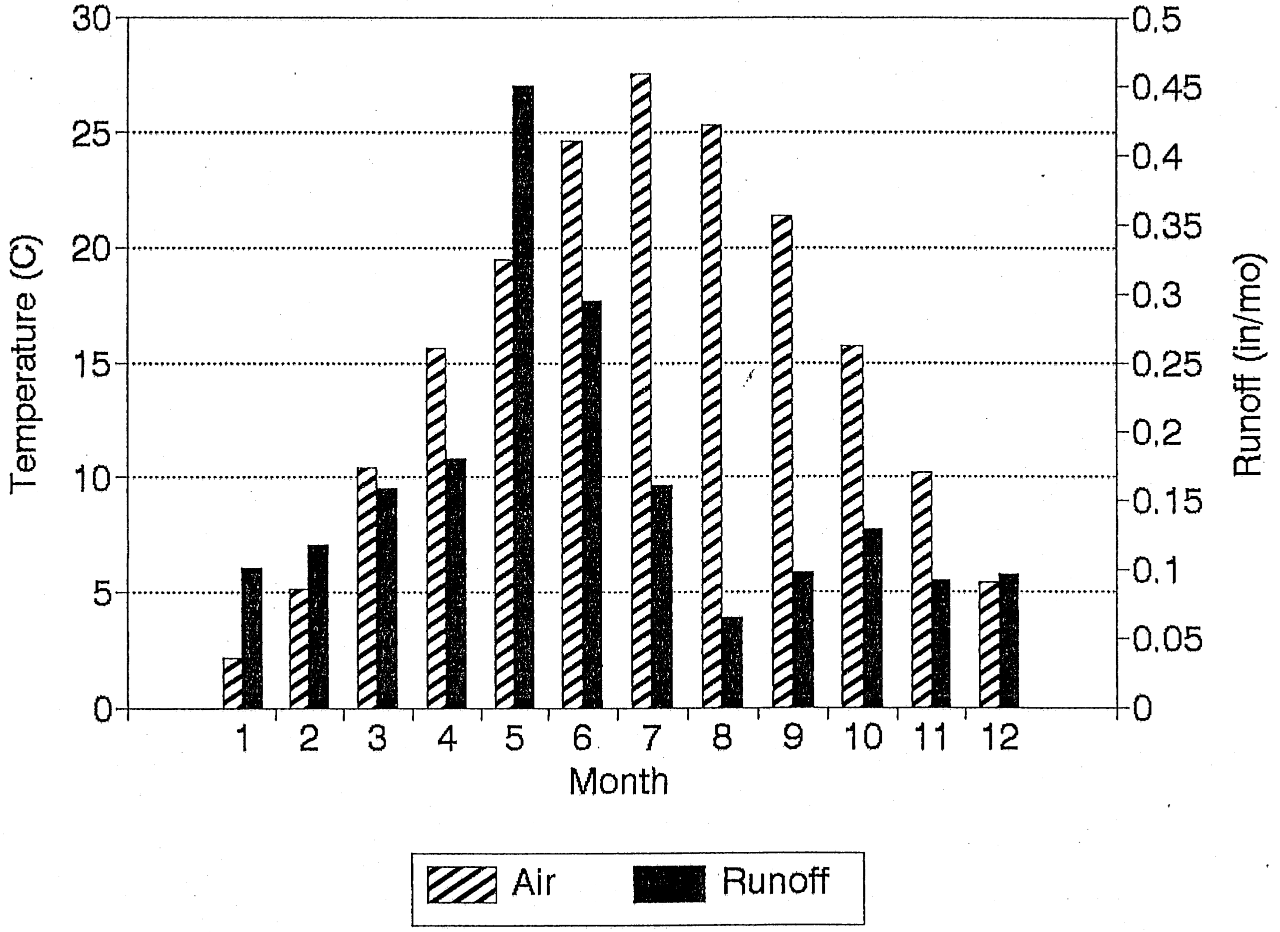

Figure 2 Mean monthly runoff and air temperatures.

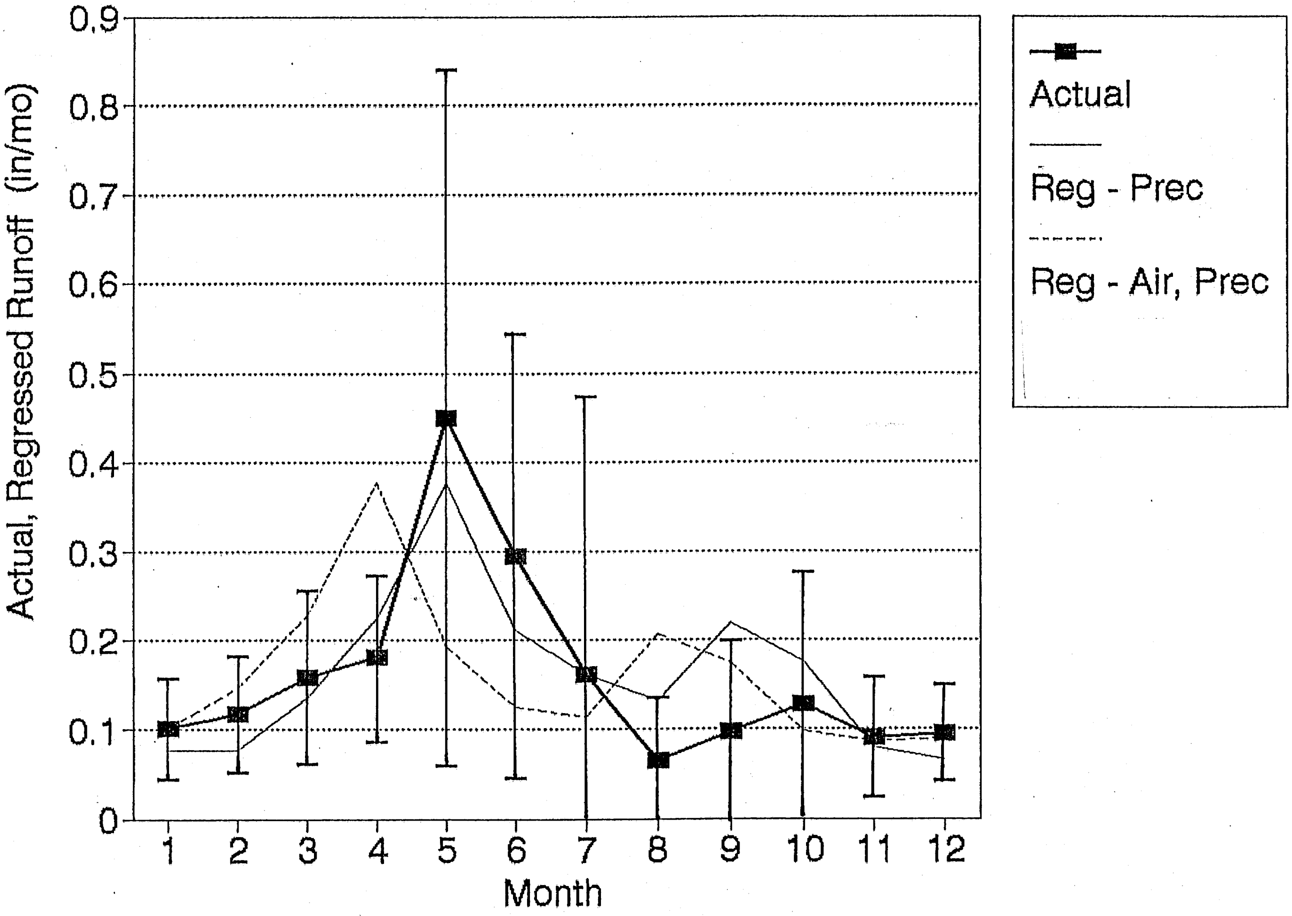

Figure 3 Actual and regressed mean monthly runoff. Regressions against precipitation (Eq. 2a) and against air temperature and precipitation (Eq. 2b) are shown. Standard deviations of actual monthly runoff from mean values over the period 1966-1982 are indicated by bars.

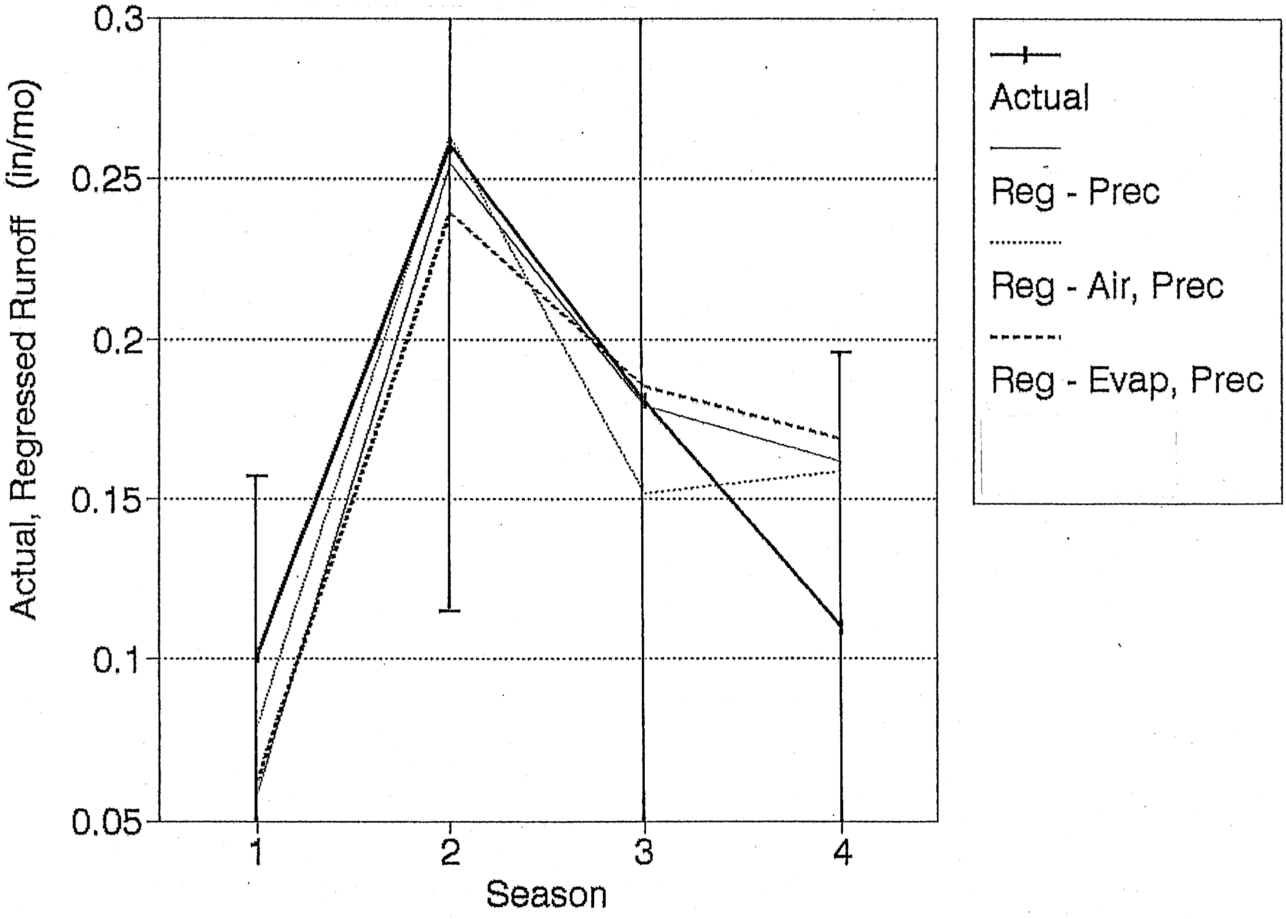

Figure 4 Actual and regressed mean seasonal (3-month) runoff. Regressions are against precipitation (Eq. 2a), against air temperature and precipitation (Eq. 2b) and against evaporation and precipitation (Eq. 2c). Standard deviations of actual seasonal runoff from mean values over the period 1966-1982 are indicated by bars.

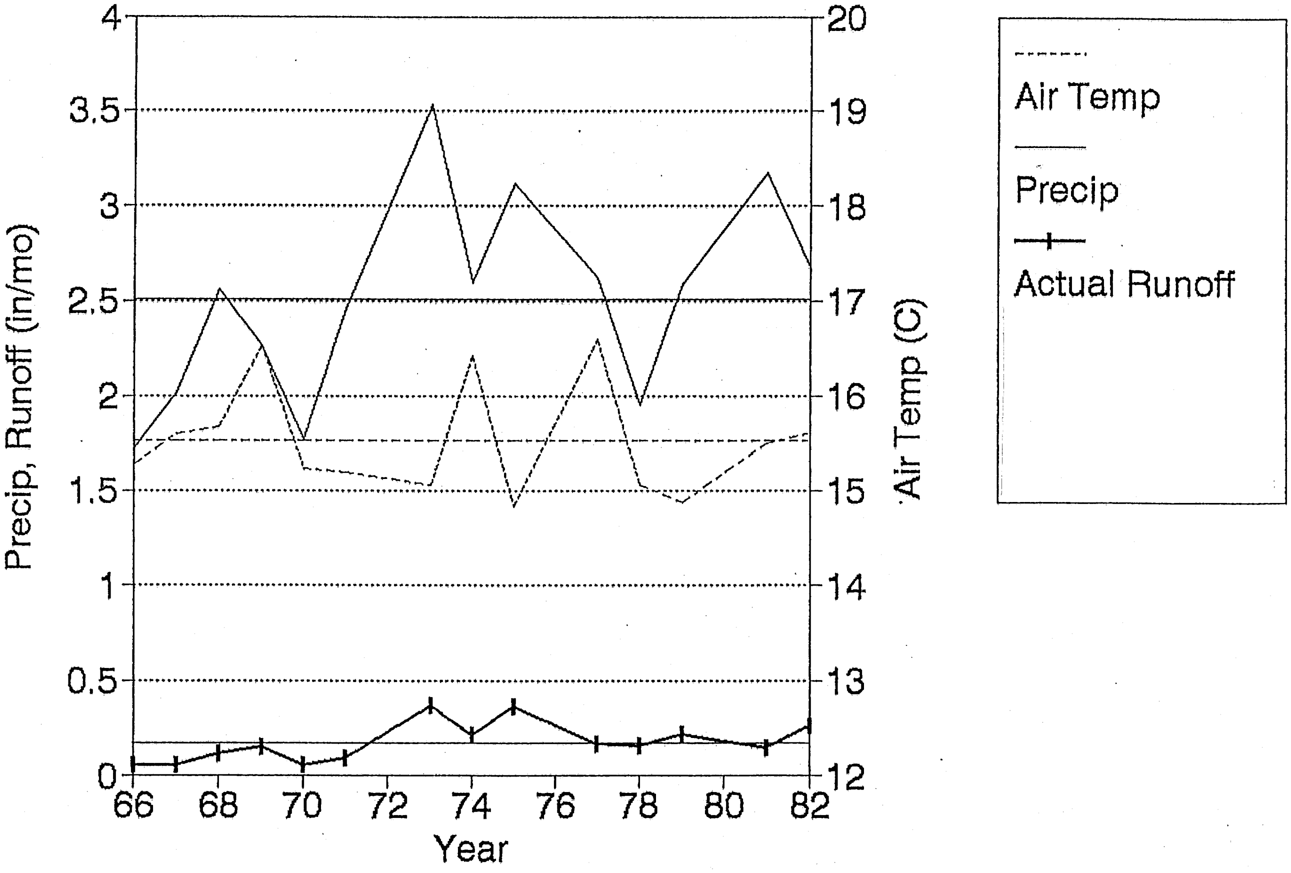

Figure 5 Actual mean annual air temperature, precipitation, and runoff from 1966-1986. Averages of the annual values are shown by straight lines through the data.

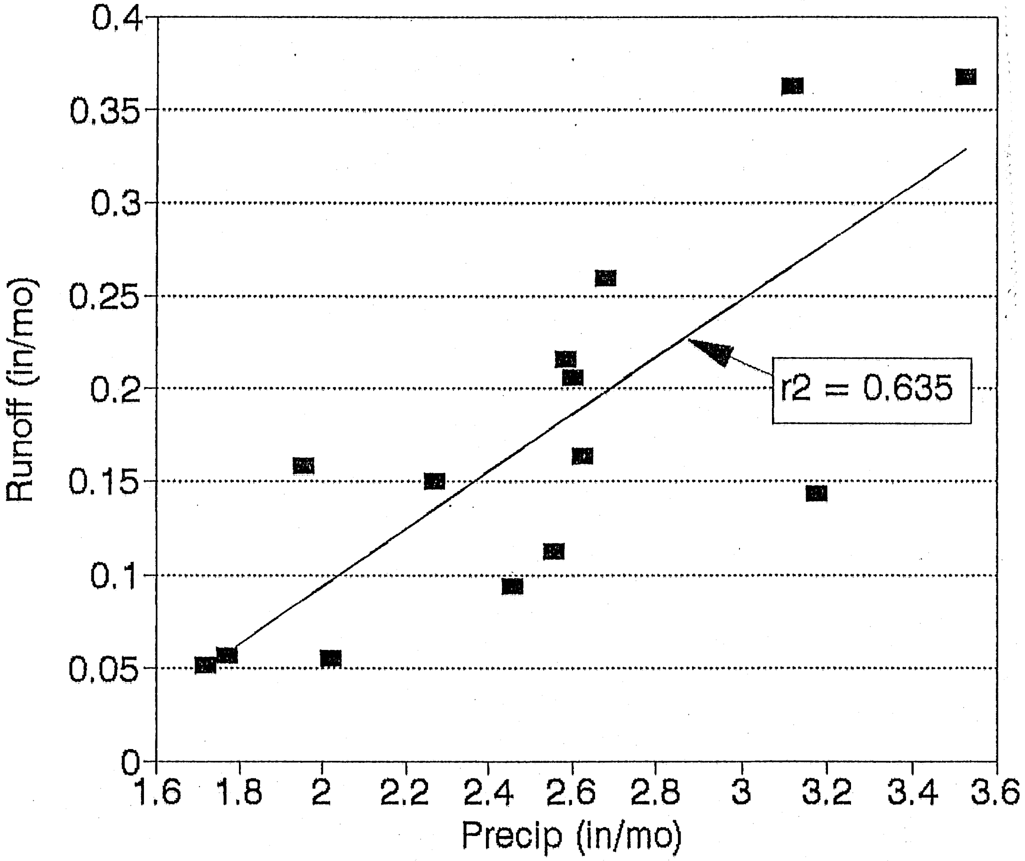

Figure 6 Annual runoff versus annual precipitation. Regression for period 1966-1982.

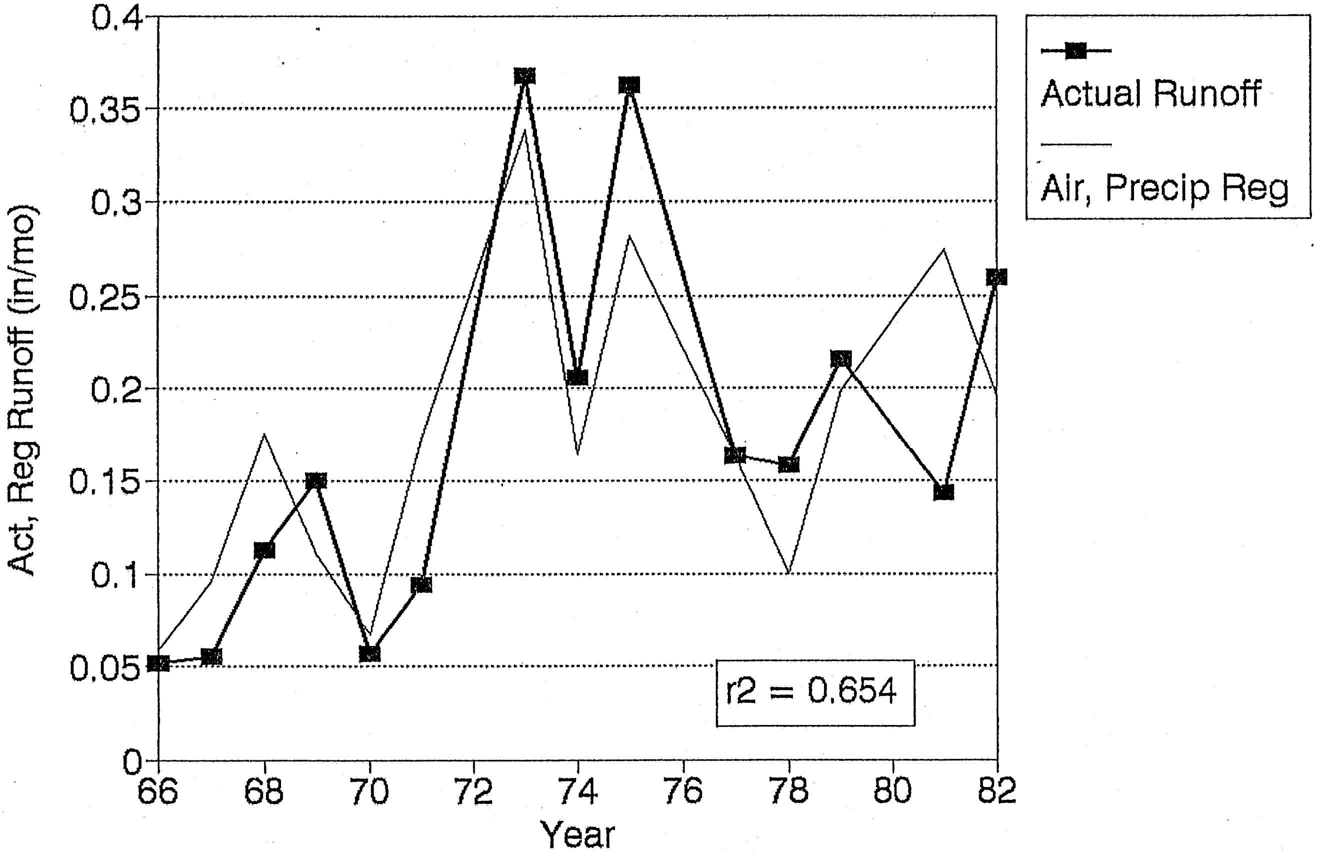

Figure 7 Actual and regressed annual runoff for the period 1966-1982.

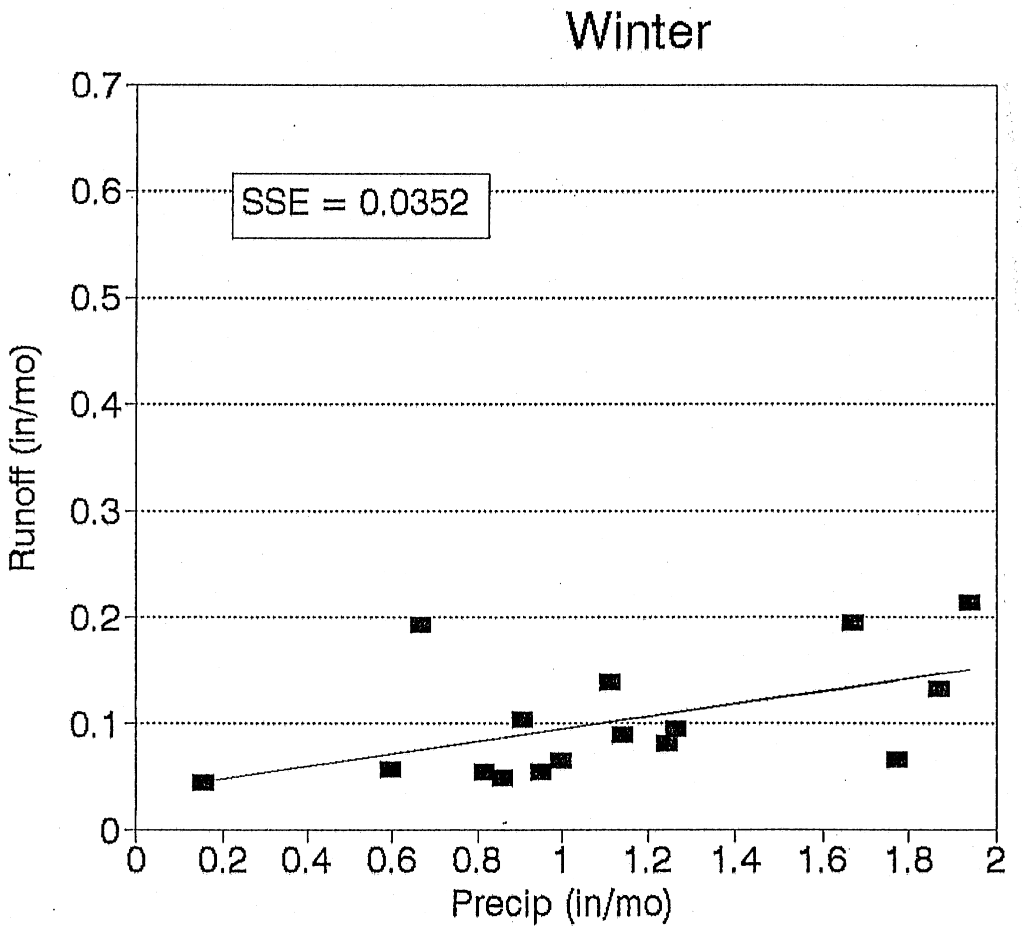

Figure 8 Winter (Dec., Jan., Feb.) runoff versus winter precipitation. Regression for period 1966-1982.

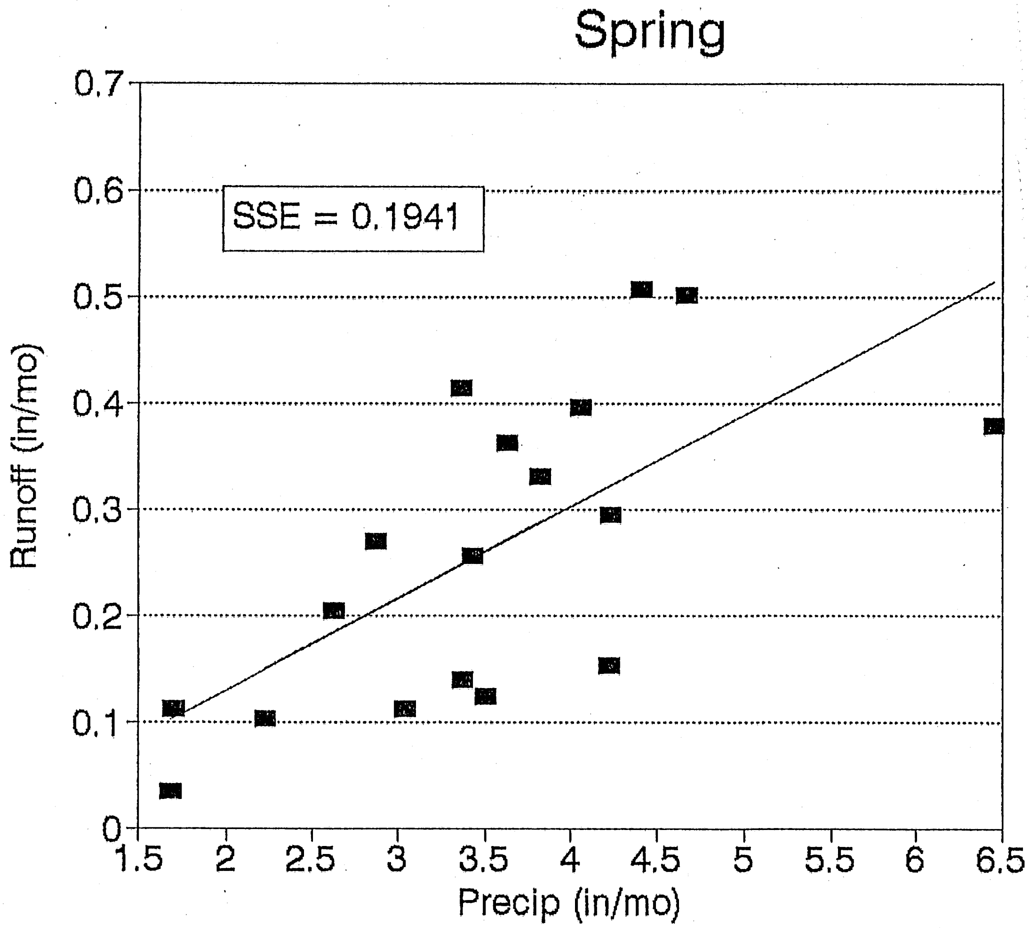

Figure 9 Spring (Mar., Apr., May) runoff versus spring precipitation. Regression for period 1966-1982.

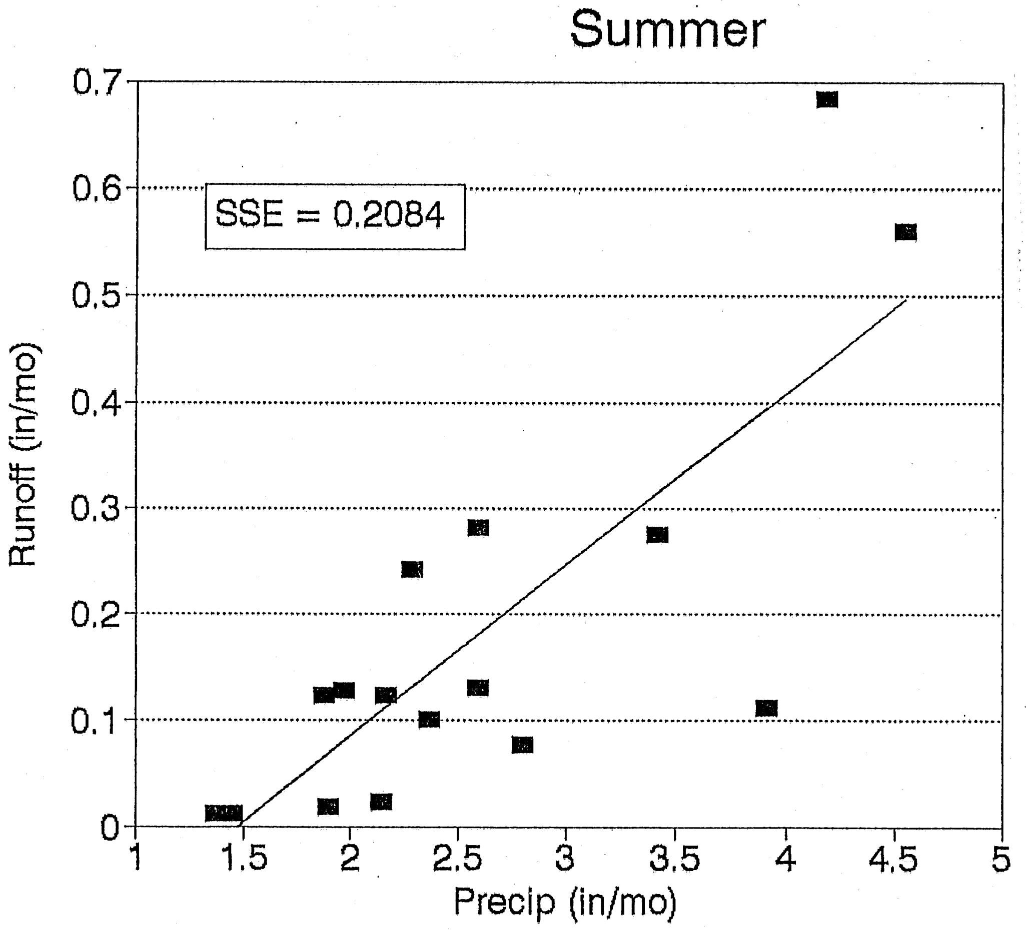

Figure 10 Summer (Jun., Jul, Aug.) runoff versus summer precipitation. Regression for period 1966-1982.

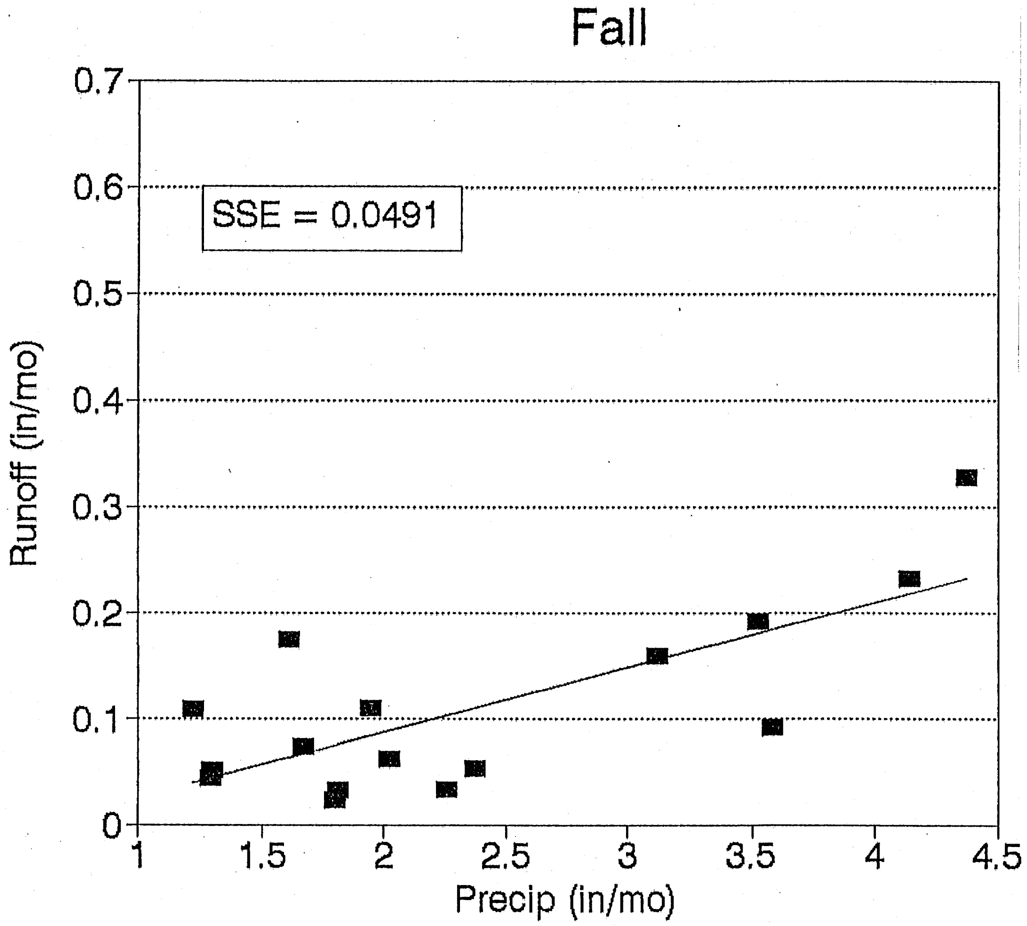

Figure 11 Fall (Sep., Oct., Nov.) runoff versus fall precipitation. Regression for period 1966-1982.

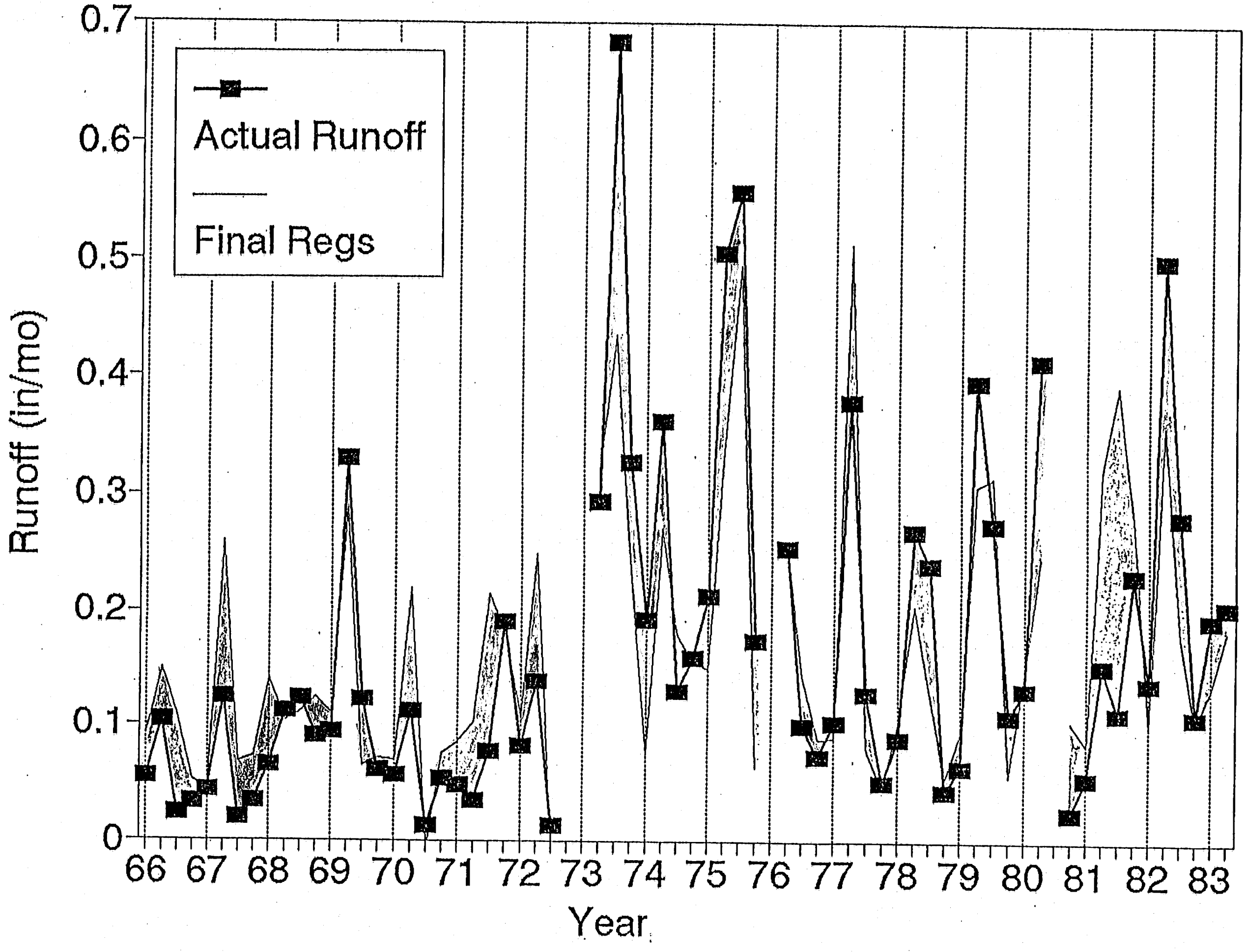

Figure 12 Actual and regressed seasonal runoff for the period 1966-1983. Regressions use Eqs. 3a, 3b, 3c and 3d for winter, spring, summer and fall, respectively.

Appendix

USDA/ARS Text File WS69015.TXT

WS69015.TXT

69015 522 CHICKASHA OK
Acres: 132990.
On-line: 1963-85
Dates of operation: 05/01/63-Present
Latitude: 345700 Longitude: 975700
Rain gage(s): 000146

Watershed conditions: Approximately 8% of the cropland is farmed to a rotation off small grain, alfalfa, and cotton. The remainder (approximately 92%) is farmed to sorghums, cotton, peanuts, watermelons, and other truck crops. There are very few structural conservation measures such as terraces, farm ponds, and grassed waterways applied. Much of the land preparation of row crops is by listing of bedding. Most of the land which is planted to row crops is planted during the winter. Fertilization is usually based on recommendations determined by soil tests. There is less than 1 farm pond per sq. mile.

Land use: Cultivation - 34%, pasture or range - 26%, wooded pasture - 38%, miscellaneous - 2%. Percent of cultivated land: alfalfa - 5%, sowed crops (wheat, oats, barley) - 14%, row crops (milo and cotton) - 81%.

Flow character: perennial, continuous.

Slopes: 0-1% - 10% of area
1-3% - 15% of area
3-5% - 25% of area
5-8% - 29% of area
8-12% - 20% of area
>12% - 1% of area

Soils: The residual soils derived from sandstone are deep sandy soils on gently rolling to rolling slopes and the deep to moderately deep loamy soils are on gently rolling gently sloping areas.

Instrumentation: Precipitation: Weather Bureau substations plus recording weighing type gages installed on 3-mile square grid.
Runoff: Stevens A-35 recorderr and bubble gage servo-manometer on left bank.