1950

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Recommended Citation

Roberts, J. Kent, "The precipitation-runoff relationship on the Grand River Basin of Missouri and Iowa" (1950). *Masters Theses*. 4901.
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THE PRECIPITATION-RUNOFF RELATIONSHIP
ON THE GRAND RIVER BASIN
OF MISSOURI AND IOWA

BY

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A

THESIS

submitted to the faculty of the

SCHOOL OF MINES AND METALLURGY OF THE UNIVERSITY OF MISSOURI

in partial fulfillment of the work required for the

Degree of

MASTER OF SCIENCE IN CIVIL ENGINEERING

Rolla, Missouri

1950

Approved by E. W. Carlton
Professor of Civil Engineering

ACKNOWLEDGMENT

The author wishes to express his appreciation to Professor E.W. Carlton for much guidance and encouragement during the writing of this thesis.

Thanks are also offered to Mr. Harry Bolon and Mr. James K. Searcy of the Water Resources Branch, U.S.G.S., for their cooperation in making available the streamflow and precipitation records on file in the Rolla District office.

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INTRODUCTION

In the study of a drainage basin which is to be utilized for water supply or water power, there is frequently a dearth or complete lack of runoff data, though precipitation data are almost always available.

The Water Resources Branch of the United States Geological Survey maintains gaging stations on various streams and runoff records from these streams are available from their publications and offices. Many of these runoff records cover a considerable number of years, and are entirely sufficient for use in an analysis of any drainage basin covered by such data. Some of these gaging stations have not been in operation long enough for the records to be of direct use. Unfortunately the vast majority of small streams have no such gaging stations, so an engineer called on to investigate such a stream has little or no information on which to base his design. When this situation exists, the engineer has a natural tendency to overdesign the reservoir structure to such an extent that the project may be abandoned or may be more expensive than necessary.

Although the lack of runoff records is common, the United States Weather Bureau has operated rain gages for many years in almost every locality.

It is impractical for the Geological Survey to gage every stream or to anticipate 20 or 30 years in advance where runoff records will be needed. Therefore, there exists a need for a simple method of determining runoff from precipitation data with some degree of accuracy. The purpose of this study is to try to develop a method of supplying runoff records by using precipitation data.

It might be well at this point to review the movement of water as it relates to the earth or the "hydrologic cycle."

A diagrammatic representation of the hydrologic cycle is shown in <u>Figure 1</u>.(1) The major elements are clearly indicated, and only those relating directly to this study will be discussed further.

It may readily be seen that not all water reaching the earth as precipitation will appear as runoff in an adjacent stream. Some of it infiltrates into the ground, some runs off over the surface, and some evaporates or is transpired back into the atmosphere.

The amount that infiltrates into the ground will vary greatly depending on several factors which may be constantly changing. These factors are the openings in the soil, the temperature, and the previous water content of the soil. If the ground is frozen or the soil almost saturated, very little additional precipitation will be admitted. Of the total infiltration, some is utilized by vegetation and transpired back into the atmosphere, some may continue to percolate

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(1) Thorndike, Saville, Basic Principles of Water Behavior, Headwaters Control and Use, U.S.D.A., Washington, D.C., Pt. I, April 1937, pp. 1-10.

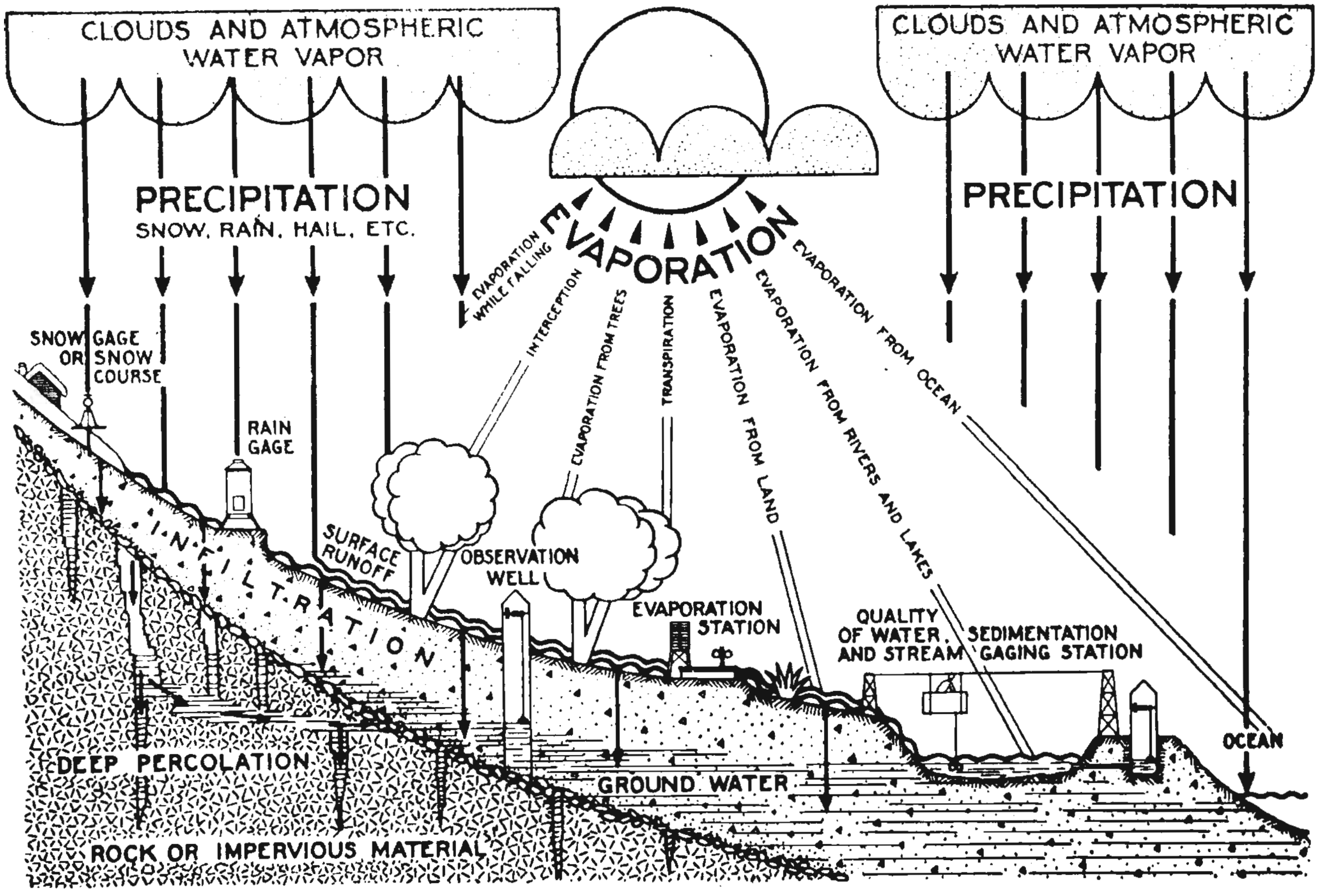

FIG. 1.—THE HYDROLOGIC CYCLE

into the ground water storage, some is subjected to evaporations as a result of capillary uplift, and some may return to the surface through lateral movement and result in a "delayed" runoff.

When the rate of rainfall exceeds the rate at which water is allowed to infiltrate, surface runoff will occur. This runoff water travels over the surface of the ground until it reaches the beginning of some stream system through which it passes until it is discharged into the ocean. Some runoff will be lost in this process due to evaporation and infiltration.

It can be seen from the foregoing discussion that the amount of runoff is subject to many complex and interconnected variations. These variables are such that it would be impossible to formulate a method of determining runoff applicable to all localities. However, by limiting the study to a relatively small area in which the drainage basin characteristics are essentially the same, these variables will be greatly modified. The author is of the opinion that by limiting the area under consideration, the precipitation-runoff relationship may be determined within the required limit of accuracy.

REVIEW OF LITERATURE

Various methods have been used in the attempt to determine the precipitation-runoff relationship, some to extend existing stream flow records, others to compile a complete record where none existed.

Where partial records are available, the method usually consists of correlating the runoff and precipitation data in a graphical form to obtain the desired relationship.

Where no stream flow records exist, the relationship is generally found by taking one or several nearby streams with record and making the correlation, taking into account the physical differences of the drainage basins.

Justin(2) has found that in the northeastern part of the United States, the following relationship will apply:

$$R = 0.934\, S^{0.155} \frac{P^2}{T}$$

in which R is the annual runoff in inches; P is the annual precipitation in inches; T is the mean annual temperature in degrees Fahrenheit; S is the slope of the watershed, which is the elevation of the highest point minus the elevation of the lowest point, divided by the square root of the area in square feet. Mr. Justin advised caution in applying this formula to other watersheds, as undoubtedly

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(2) Joel D. Justin, Derivation of Runoff from Rainfall Data, TRANSACTIONS, American Society of Civil Engineers, Vol. 77, pp 346.

the value of the constant and the exponent of S might vary somewhat in other sections of the country.

Mr. Justin recommends the use of this or a similar formula to determine runoff on a monthly basis for the purpose of constructing a mass diagram for use in determining reservoir capacity. While it will not give true runoff for any particular month, Mr. Justin found that the mass curve when plotted gives depletions which do not differ materially from those obtained when the observed monthly runoff is used in constructing the mass diagram.

The Hydrology Handbook(3) prepared by the Hydrology Committee of the American Society of Civil Engineers submitted the following formula for the estimation of runoff:

$$R = aP + bP_1 + C$$

in which R is the runoff in inches, acre feet, or mean cubic feet per second during a given year; P is the precipitation during the same year; and P_1 is the precipitation during the year immediately antecedent. The constants may be evaluated by graphical or least-squares technique.

Johnstone and Cross(4) present three forms of a straight

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(3) Hydrology Handbook, American Society of Civil Engineers, Manual of Engineering Practice Number 28, pp. 79.

(4) Don Johnstone and William P. Cross, Elements of Applied Hydrology, pp. 103-106.

line relationship between rainfall and runoff.

The first equation is:

$$R = pP$$

in which R is inches of annual or seasonal runoff, P is inches of annual or seasonal precipitation, and p is a percentage. This equation will give a straight line through the origin and would signify that the annual loss, as well as runoff, is a constant percentage of the annual precipitation amount. Little support for this form of an equation is offered by the authors.

The second equation discussed by Mssrs. Johnstone and Cross takes the form:

$$R = P - L$$

where L is a constant in inches. This is a straight line passing to the right of the origin and having a slope of 45°. It would signify that a certain minimum amount of rainfall is necessary before any runoff will occur and that for rainfalls greater than that minimum, the annual loss is constant. More support is given to this form of an equation but the authors really favor the third form, which is:

$$R = qP - C$$

where q is a percentage and C is a constant. This is a straight line passing to the right of the origin and having a slope of less than 45°. It would signify that a certain minimum amount of rainfall is necessary before any runoff will occur and that for rainfalls greater than that minimum the annual loss increases somewhat with an increase in the precipitation. By allowing the loss to increase somewhat with the precipitation, it recognizes the tendency of the plant cover to grow more luxuriantly--and therefore to transpire more--in wet years than in dry ones. It also recognizes the tendency toward higher ground-water levels in wet years.

Johnstone and Cross offer no values for any of the constants observing that they will differ for different drainage basins in different localities. It is up to the user to determine the constants from either partial records of the stream in question or from records of nearby gaging stations.

Foster(5) also recommends a formula of the same type as the third one presented by Johnstone and Cross.

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(5) Edgar E. Foster, Rainfall and Runoff, pp. 444.

DISCUSSION

After giving consideration to the various types of formulas suggested by several writers, the author was of the opinion that a relatively simple and sufficiently accurate determination of runoff from precipitation could be arrived at by using the form:

$$R = qP - C$$

in which R is the annual or seasonal runoff in inches, P is the annual or seasonal precipitation in inches, q is a percentage and C is a constant.

The values of q and C are to be determined from a correlation of existing stream flow and weather records on either a nearby drainage basin or partial records of the stream under study.

It would have been impossible to find values of the constants for any stream in the state or nation due to lack of time and probable complete differences of these constants for each stream.

The author decided to evaluate the two constants, q and C, for one large drainage basin in Missouri, using several small drainage basins within the large one, and in so doing, outline a procedure that could be followed if runoff data were desired elsewhere. After consultation with engineers of the United States Geological Survey, and an examination of stream flow records over the state, the Grand River Basin of Missouri and Iowa was selected as the large drainage basin. The Grand River basin as a whole contains nine stream gaging stations, most of which give 20 or more years of record; it contains a sufficient number of well scattered precipitation stations of even longer record.

It was deemed advisable to evaluate the constants not only on an annual basis but to correlate the data so that constants would be obtained for four quarterly seasons of the year. The first quarter is for the months of October, November and December; the second quarter for January, February and March; the third quarter for April, May and June, and the fourth quarter for the months of July, August and September. This definition of quarters is in agreement with the system used by the United States Geological Survey. The annual records would be taken for a "water year" of from October 1 to September 30, the number of the water year corresponding to the calendar year in which it ends.

The beginning of a water year is at a time when it is more likely that the stream flow will be at its lowest, and when the amount of ground water in temporary storage is least and likely to be most nearly the same from year to year.

The Grand River Basin is located in northwestern Missouri and southwestern Iowa, the bulk of its area being in Missouri. It is roughly elliptical in shape with the major axis in a generally north and south direction. (See Figure 2) Its extreme dimensions are about 150 miles long by approximately 90 miles wide.

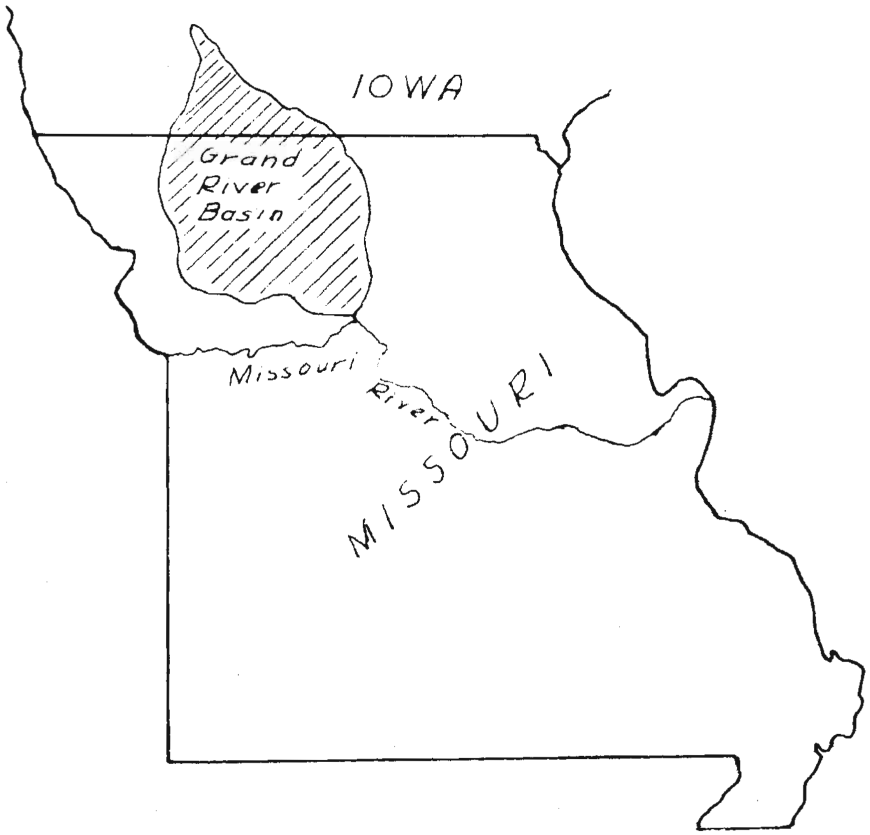

Fig. 2 Location and Shape of Grand River Basin

The area of the basin is about 7,900 square miles.

The Grand River is formed by its West, Middle and East Forks which rise in southwestern Iowa and flow in a southerly direction to their junction near Albany, Mo. Below this junction, its principal tributaries are:

Grindstone Creek, which rises near Maysville, Mo., and flows in a northeasterly direction to join the main river at Pattonburg, Mo.;

Big Creek, the west fork of which rises near Mount Ayr, Ia., and flows in a southerly direction to join the main river at Pattonsburg, Mo.;

The East Fork of Big Creek which rises in the vicinity of Lamoni, Ia., and flows in a southerly direction to join Big Creek near Bethany, Mo.;

Thompson River, which rises in Adair County in southwestern Iowa and flows southeast to the Iowa-Missouri line thence south to its junction with the Grand River near Chillicothe, Mo.; (The Thompson River was formerly known as Grand River and some may still refer to it by that name. The principal tributary of the Thompson River is the Weldon River which rises near Leon in Decatur County, Ia., and flows south to join the Thompson River near Trenton, Mo.)

Shoal Creek, which rises near Lathrop in Clinton County, Mo., in the southwestern corner of the drainage area and flows in an easterly and northeasterly direction, joining the Grand River just below Chillicothe, Mo.;

Medicine Creek, which rises near Corydon in Wayne County, Ia., and flows south to join the main river near Bedford, Mo.;

Locust Creek, which rises in Iowa near the Iowa-Missouri state line and empties into the Grand River in Chariton County near Sumner, Mo.;

Yellow Creek, which rises in Sullivan County, Mo., and flows south to join the main river in Chariton County, a short distance below Sumner, Mo.

The Grand River Basin varies in topography from a gentle, rolling plain near the mouth to rather rough, hilly land near the headwaters. The entire basin was originally a plain with a gentle slope to the south and east. Subsequently, the topography of this plain has been greatly modified by erosion.

The surface of the greater part of this section is mantled with a veneer of unconsolidated glacial deposits of clay, sandy clay, sand and gravel, or with loess deposits. Where these deposits have been carried away by the erosive action of the stream or otherwise thinned out, the underlying sedimentary rock formations are exposed. The underlying formations in this area are the sedimentary rocks of the Pennsylvanian Age.

Stream gaging stations are operated on the Grand River near Gallatin, Mo., and near Sumner, Mo.; on the Thompson River at Davis City, Ia., and at Trenton, Mo.; on the Weldon River near Mercer, Mo.; and at Mill Grove, Mo.; on the East

Fork of Big Creek near Bethany, Mo.; on Medicine Creek near Galt, Mo.; on Locust Creek near Linneus, Mo.

Records from each of these stations with the exception of Locust Creek near Linneus will be correlated with precipitation data to determine the constants in the formula selected. The records of Locust Creek near Linneus will be used to check the results of this study.

Precipitation stations whose records will be in this correlations are the following: Afton, Creston, Lamoni, and Mount Ayr in Iowa; Bethany, Chillicothe, Conception, Gallatin, Grant City, Kidder, King City, Lucerne, Milan, and Trenton in Missouri.

The Thiessen method(6) of approximating the equivalent uniform depth of precipitation over an area was used in this study.

The selection of this method came after considering it and two other methods, the unweighted mean and the use of isohyetal maps. The unweighted mean method, consisting of adding the precipitation reported by each of the stations and dividing by the number of stations, was not considered accurate enough as the precipitation stations are often irregularly spaced with respect to a particular drainage basin.

The use of isohyetal maps was rejected as being too

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(6) A. H. Thiessen, The Precipitation Averages for Large Areas, Monthly Weather Review, July, 1911, pp.1082

time consuming considering the number of stations and years of record. This method would most probably give results that would be the nearest correct of the three methods, but it was felt that this accuracy was not justified.

The Thiessen method attempts to make allowance for irregularities in gage spacing by weighing the report of each gage in proportion to the area which that gage is assumed to represent.

The area that any specific gage is assumed to represent is the area comprising all points that are closer to that gage than to any other. These areas are determined graphically as follows:

(a) Draw a set of triangles connecting adjacent gages.

(b) Construct the perpendicular bisectors for all sides of a triangle. These bisectors define a set of polygons, one for each gage, and each polygon contains only points that are closer to the gage at its center than to any other.

Figure 3 shows the constructed Thiessen polygons for the entire Grand River Basin.

After constructing the polygons for the Basin, the next step was the computation of the equivalent uniform depth of precipitation, for each drainage basin with a stream flow record, for each quarter of each year of record. Needless to say, these computations are too lengthy to be included in this thesis, and only a sample will be presented.

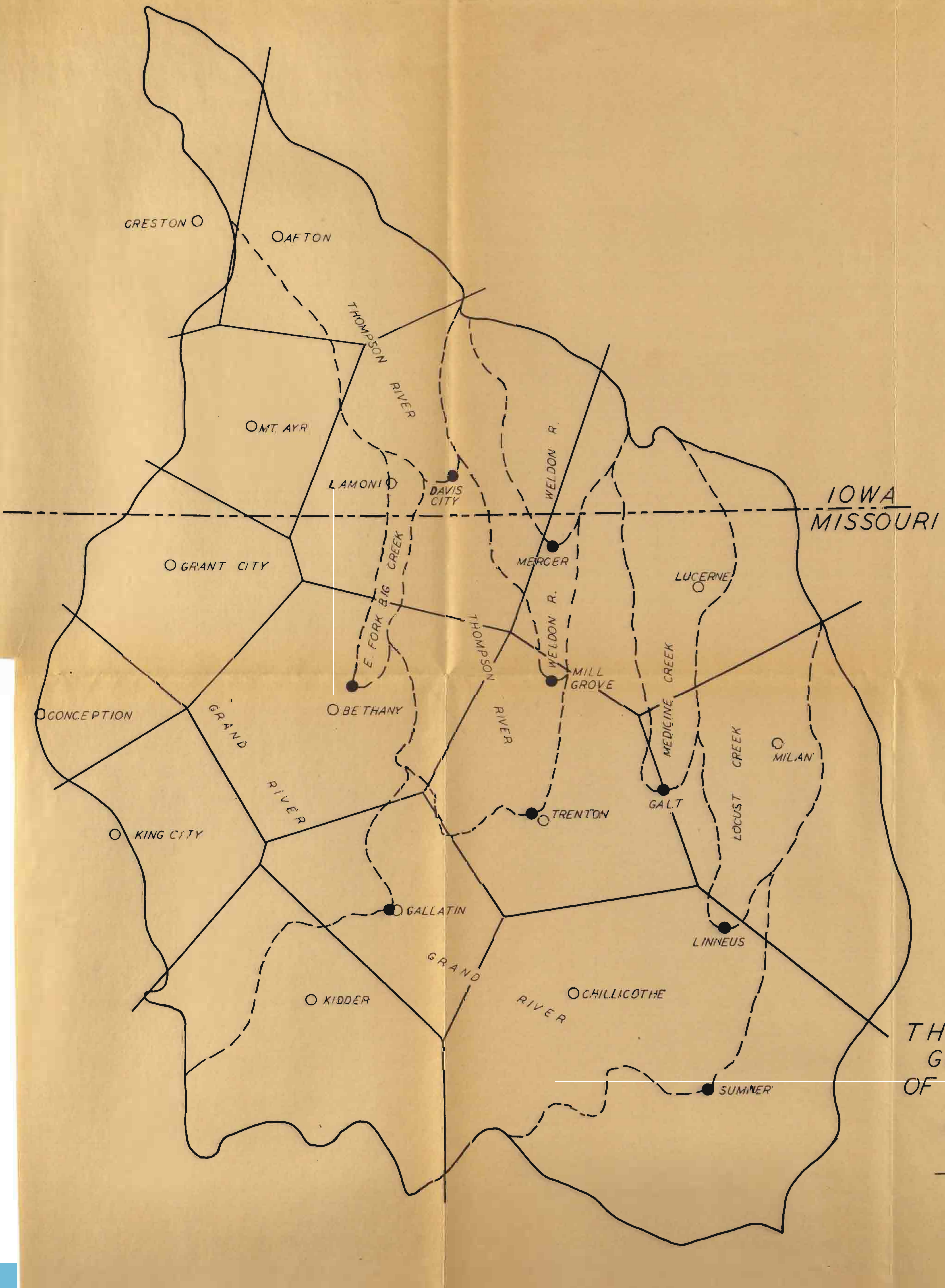

FIG. 3

THIESSEN POLYGONS
GRAND RIVER BASIN
OF MISSOURI AND IOWA

● STREAM GAGING STATION
○ PRECIPITATION STATION
- - - DRAINAGE AREA BOUNDRIES

SCALE $\frac{1}{500,000}$

Consider the Thompson River at Davis City. (See Figure 4) It will be noted that the polygon representing the precipitation gage at Mount Ayr has been eliminated. This was deemed desirable as this polygon represented only 2% of the total area.

The areas of the polygons in the Basin were determined by using a planimeter. The units of area were not determined but the planimeter readings used direct.

The area of each polygon was divided by the total area, which gave a coefficient of area assignable to each gage. The coefficients thus obtained were:

Creston..........	0.3
Afton............	0.5
Lamoni...........	0.2
Total............	1.0

By multiplying the precipitation reported for the quarter by each gage times the coefficient of area for that gage, then adding the values thus found, the equivalent uniform depth of precipitation over the drainage basin was determined.

All precipitation records used in this study were taken from the Climatological Review, Annual Summary, Iowa Section and Missouri Section, published by the United States Weather Bureau.

The Annual Summary, published separately for each state, gives monthly precipitation, temperature and miscellaneous data for each weather station in the state.

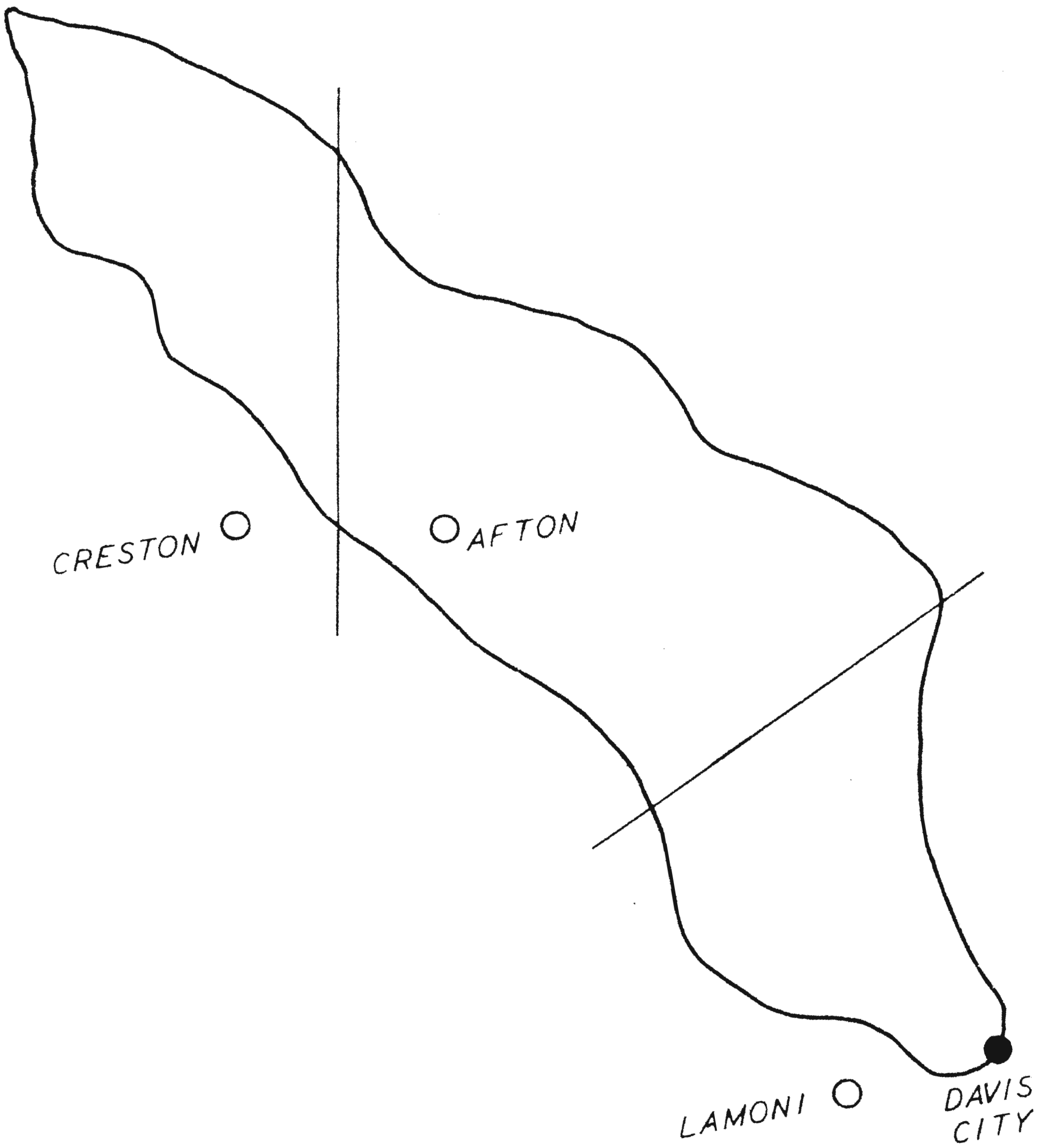

FIG. 4
THOMPSON RIVER AT DAVIS CITY

The following tabulation will serve to demonstrate the procedure followed:

TABLE I

PRECIPITATION COMPUTATION PROCEDURE

Thompson River at Davis City

First Quarter, 1919 water year.
(Oct., Nov., Dec., 1918)

Station	(1) Coef. of Area	(2) Inches Precip.	(3) (1) x (2)
Creston	0.3	5.84	1.75
Afton	0.5	6.80	3.40
Lamoni	0.2	7.03	1.50
Equiv. Uniform depth of precipitation (sum of col. 3)			6.55

This equivalent uniform depth of precipitation will be hereafter referred to as precipitation.

With the precipitation data all computed, the correlation of precipitation and runoff was presented graphically for each drainage basin for each quarter and also annually.

The correlation is shown for the first quarter in Figures 5 - 12, for the second quarter in Figures 13 - 20, for the third quarter in Figures 21 - 28, for the fourth quarter in Figures 29 - 36, and for the water year in Figures 37 - 44.

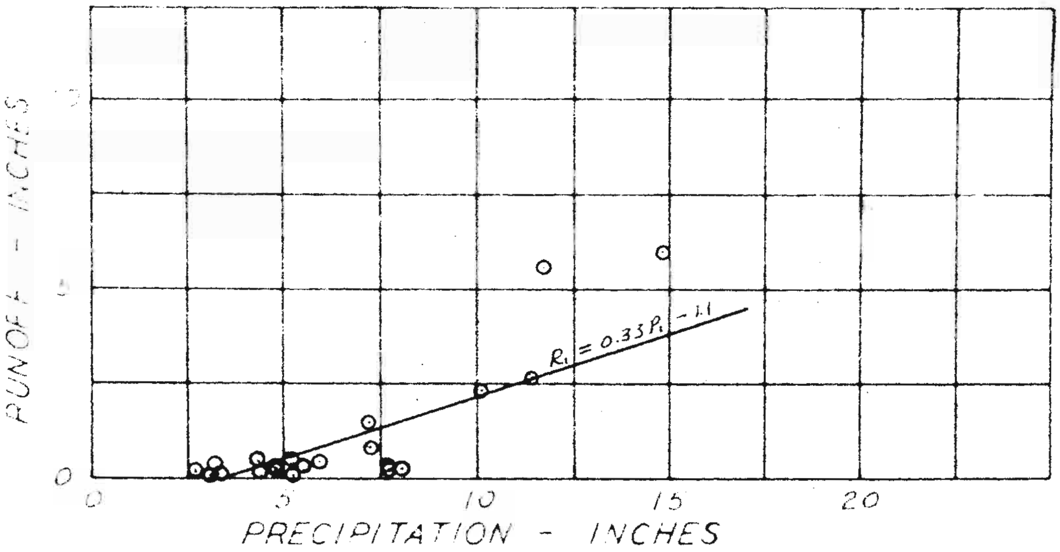

Fig. 5 PRECIPITATION - RUNOFF RELATIONSHIP
FIRST QUARTER, GRAND RIVER NEAR GALLATIN

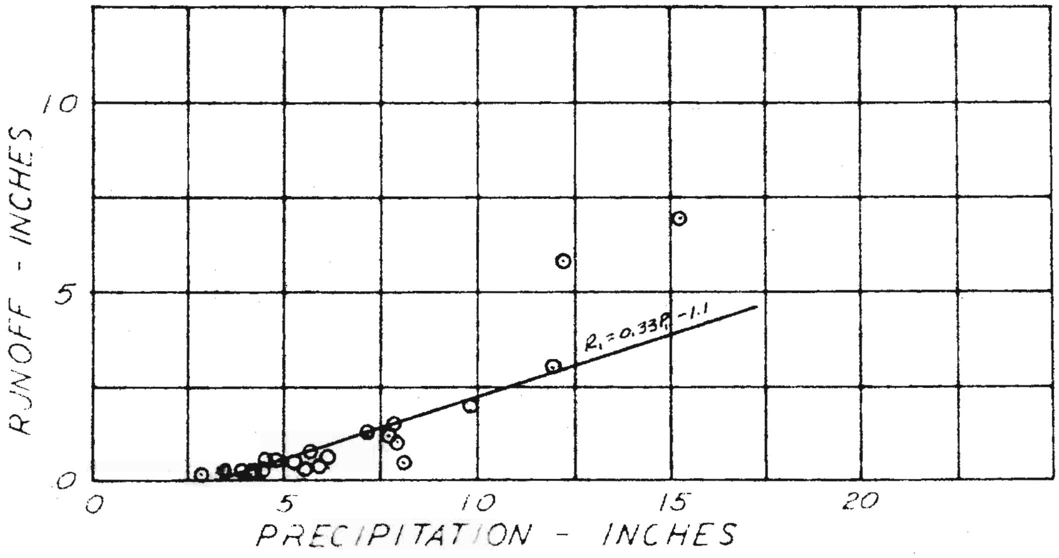

Fig. 6 PRECIPITATION - RUNOFF RELATIONSHIP
FIRST QUARTER, GRAND RIVER NEAR SUMNER

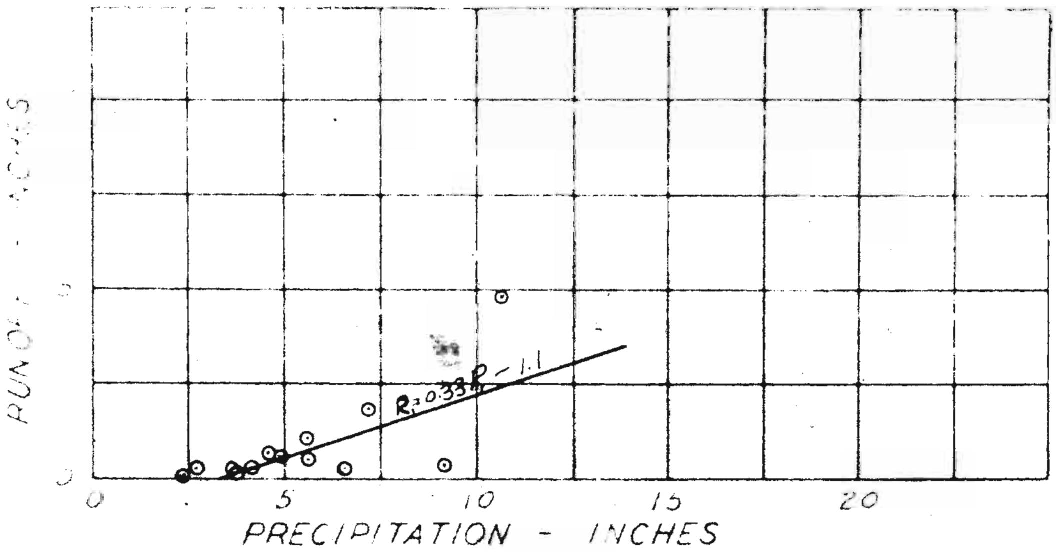

Fig. 7 PRECIPITATION - RUNOFF RELATIONSHIP
FIRST QUARTER, THOMPSON RIVER AT DAVIS CITY

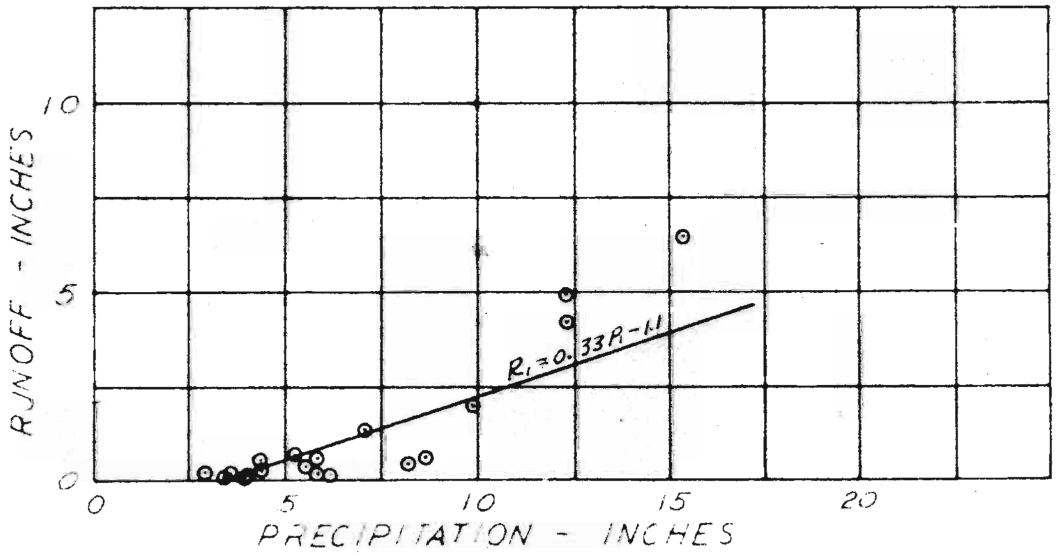

Fig. 8 PRECIPITATION - RUNOFF RELATIONSHIP
FIRST QUARTER, THOMPSON RIVER AT TRENTON

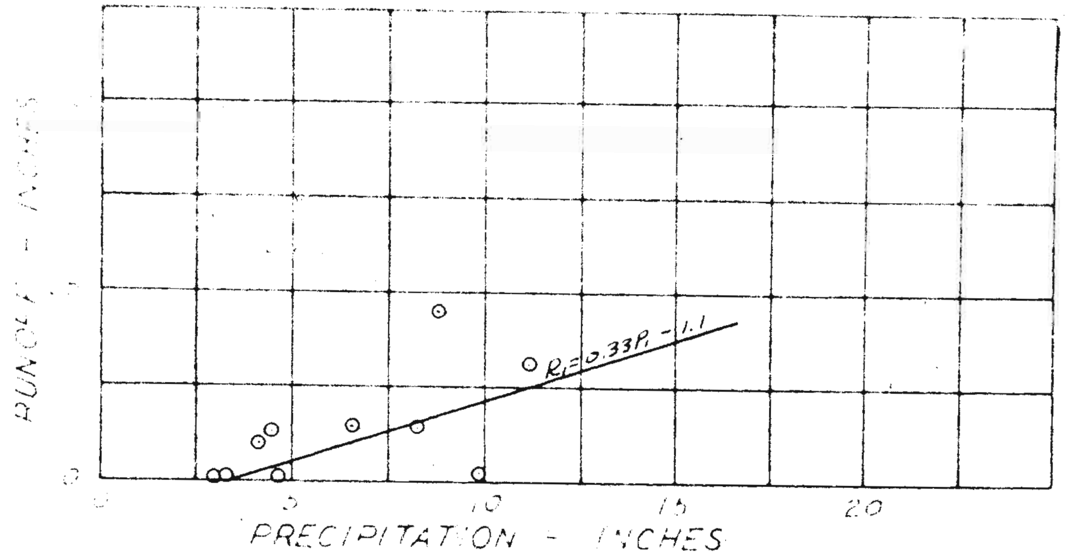

Fig. 9 PRECIPITATION - RUNOFF RELATIONSHIP
FIRST QUARTER, WELDON RIVER NEAR MERCER

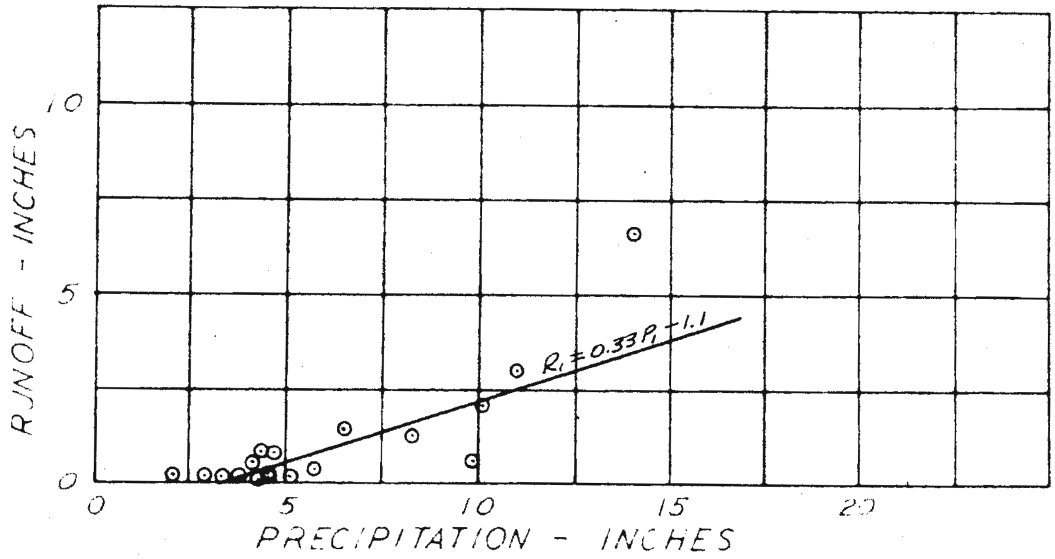

Fig. 10 PRECIPITATION - RUNOFF RELATIONSHIP
FIRST QUARTER, WELDON RIVER AT MILL GROVE

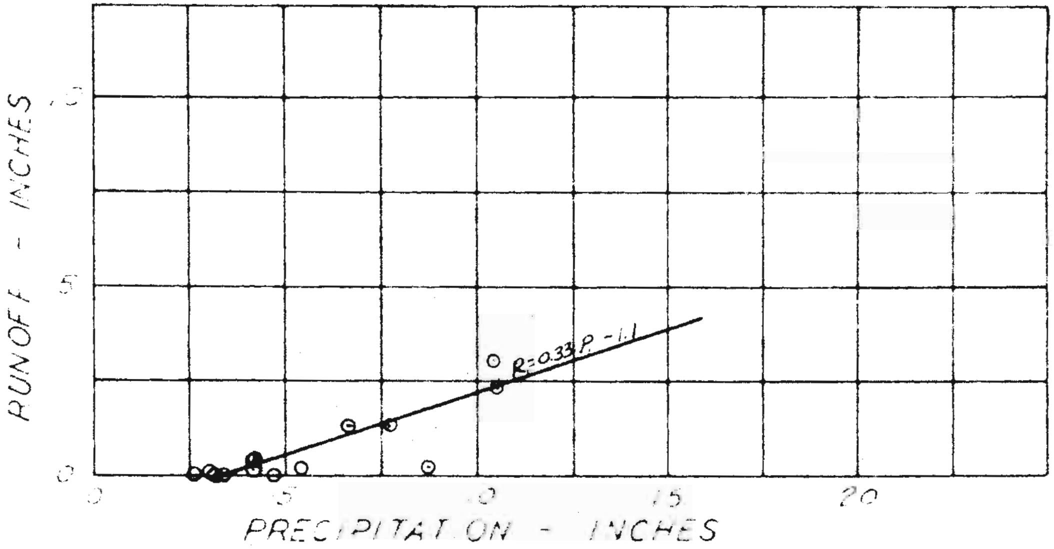

Fig. 11 PRECIPITATION - RUNOFF RELATIONSHIP
FIRST QUARTER, EAST FORK OF BIG CREEK
NEAR BETHANY

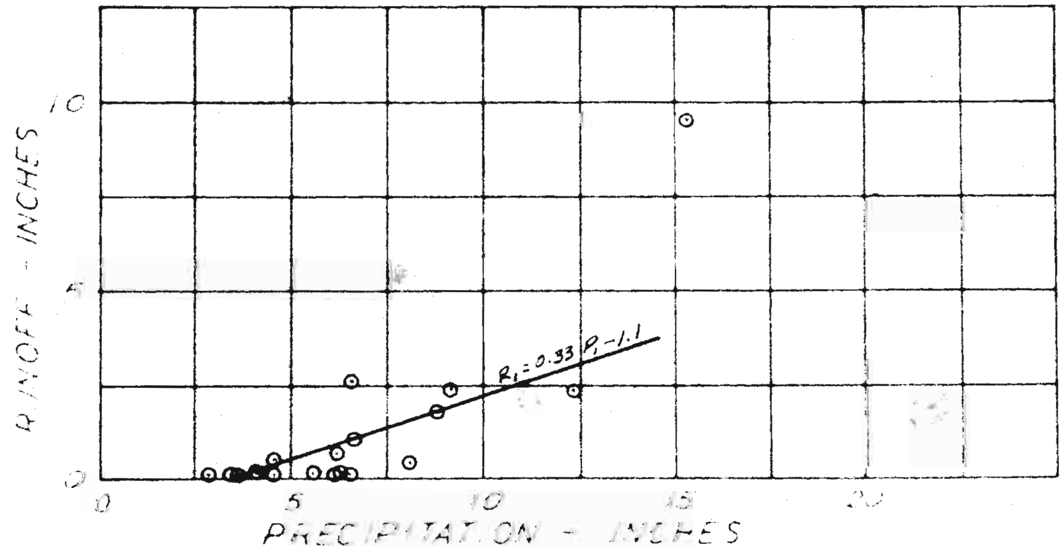

Fig. 12 PRECIPITATION - RUNOFF RELATIONSHIP
FIRST QUATER, MEDICINE CREEK NEAR GALT

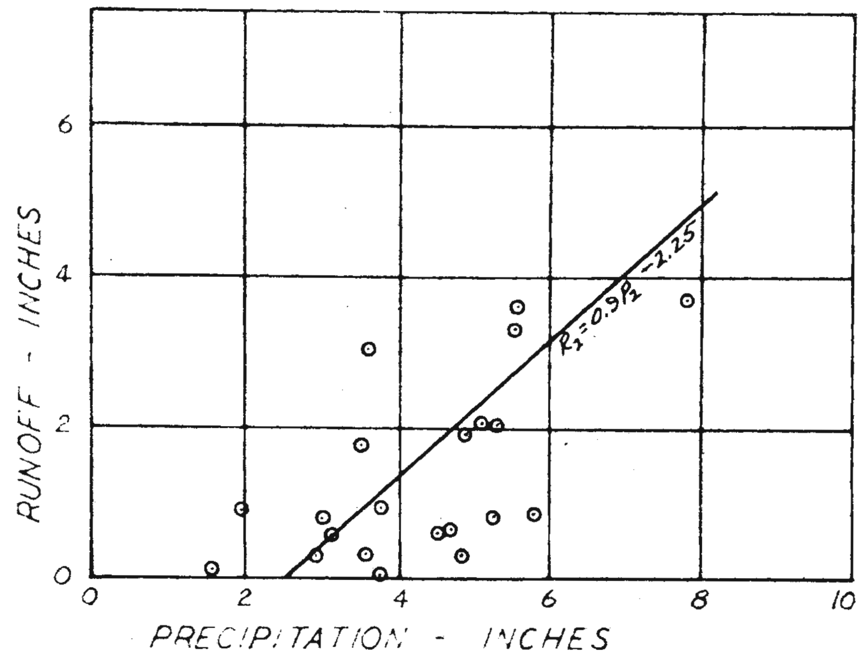

Fig. 13 PRECIPITATION - RUNOFF RELATIONSHIP
SECOND QUARTER, GRAND RIVER AT GALLATIN

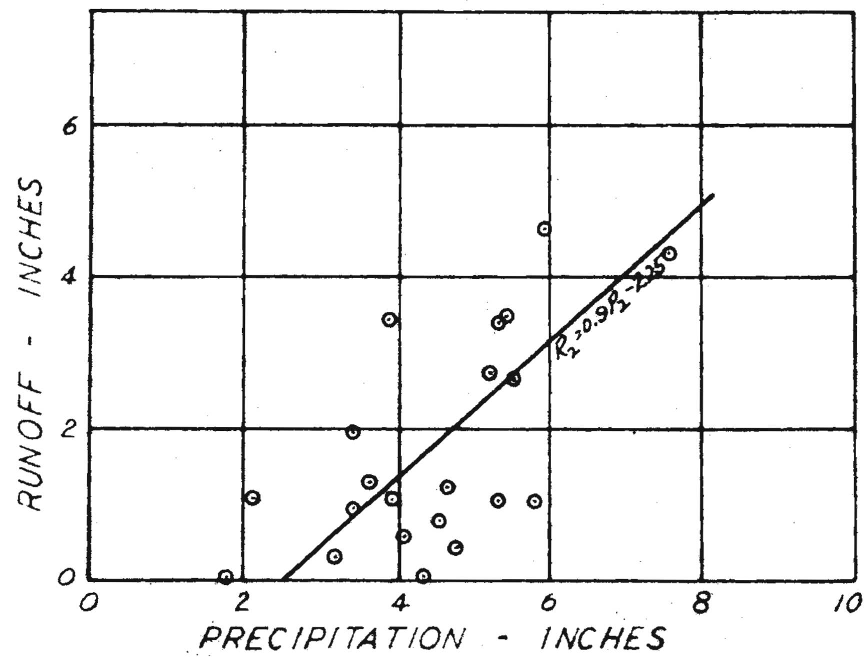

Fig. 14 PRECIPITATION - RUNOFF RELATIONSHIP
SECOND QUARTER, GRAND RIVER NEAR SUMNER

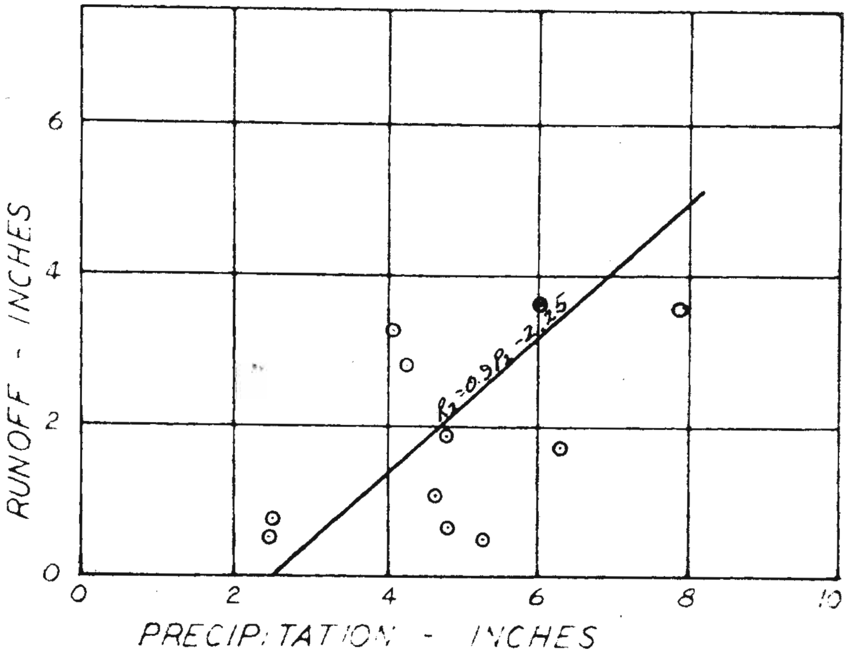

Fig. 15 PRECIPITATION - RUNOFF RELATIONSHIP SECOND QUARTER, THOMPSON RIVER AT DAVIS CITY

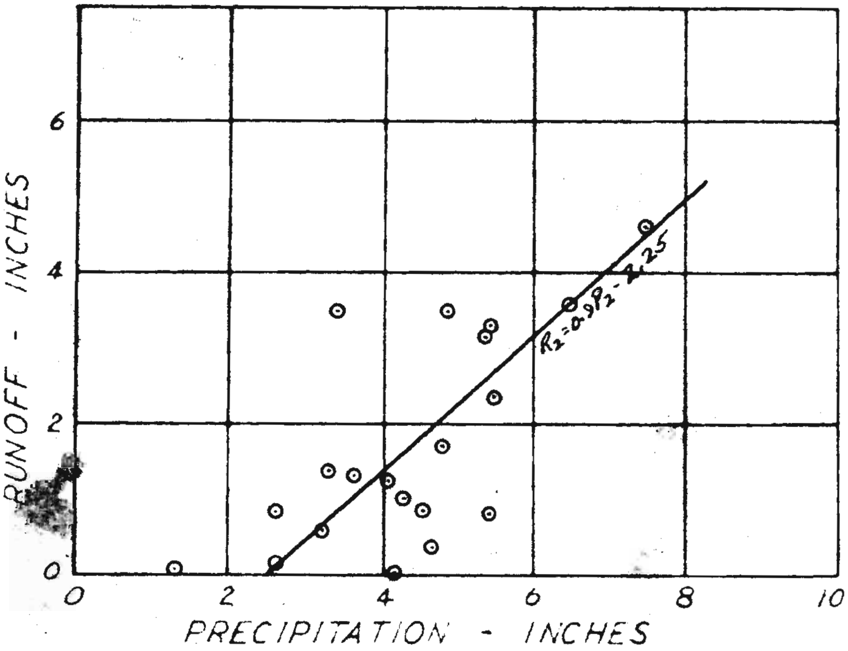

Fig. 16 PRECIPITATION - RUNOFF RELATIONSHIP SECOND QUARTER, THOMPSON RIVER AT TRENTON

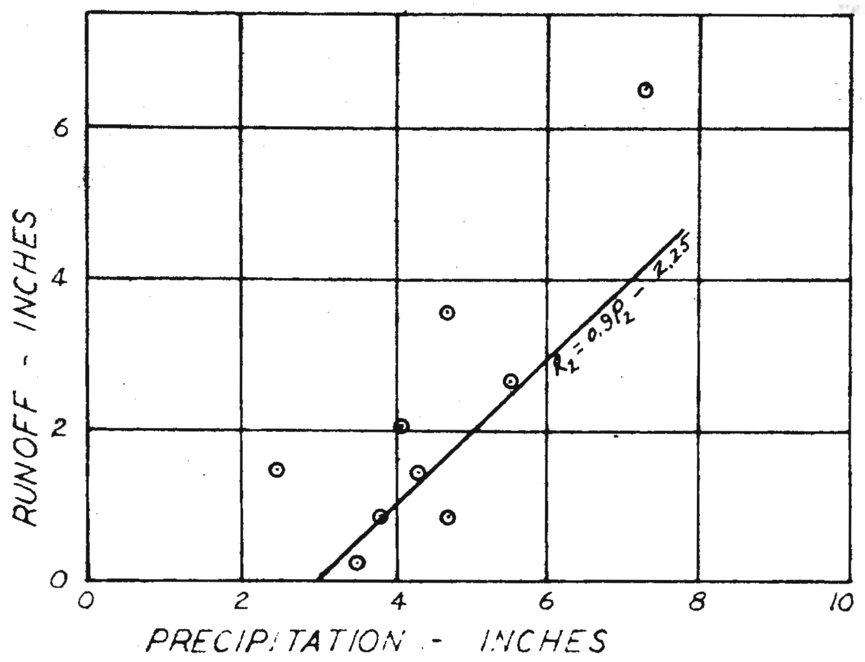

Fig. 17 PRECIPITATION - RUNOFF RELATIONSHIP SECOND QUARTER, WELDON RIVER NEAR MERCER

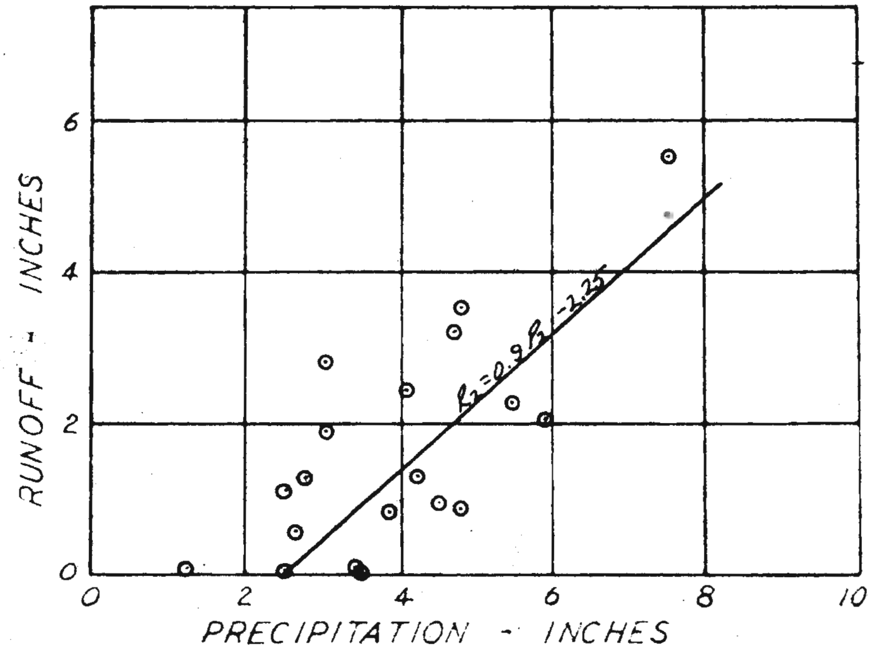

Fig. 18 PRECIPITATION - RUNOFF RELATIONSHIP SECOND QUARTER, WELDON RIVER AT MILL GROVE

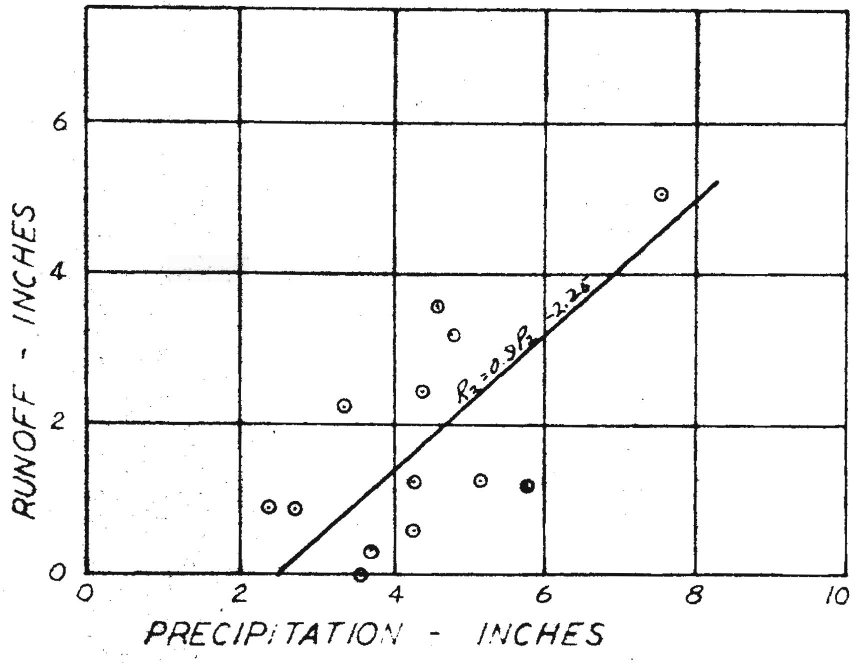

Fig. 19 PRECIPITATION - RUNOFF RELATIONSHIP SECOND QUARTER, EAST FORK OF BIG CREEK NEAR BETHANY

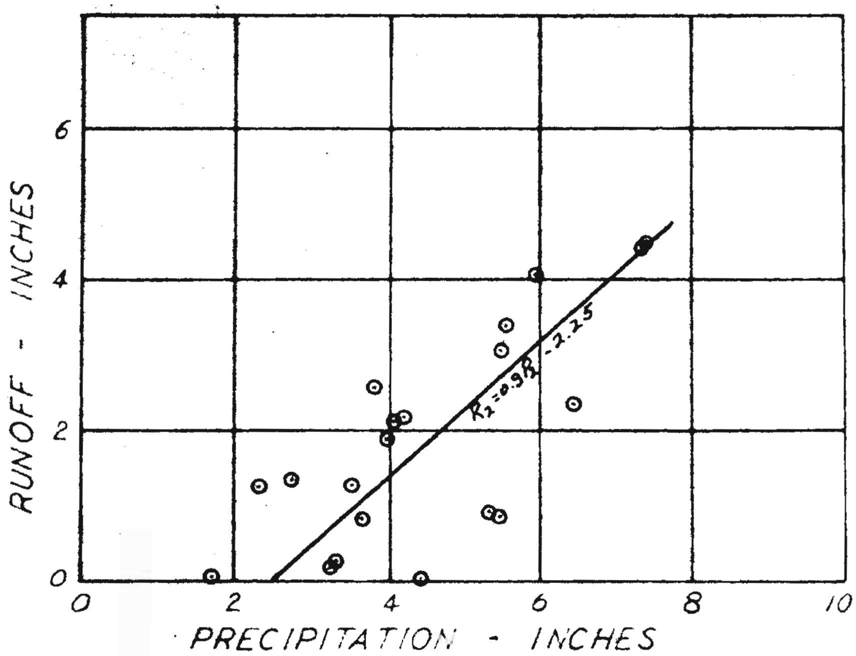

Fig. 20 PRECIPITATION - RUNOFF RELATIONSHIP SECOND QUARTER, MEDICINE CREEK NEAR GALT

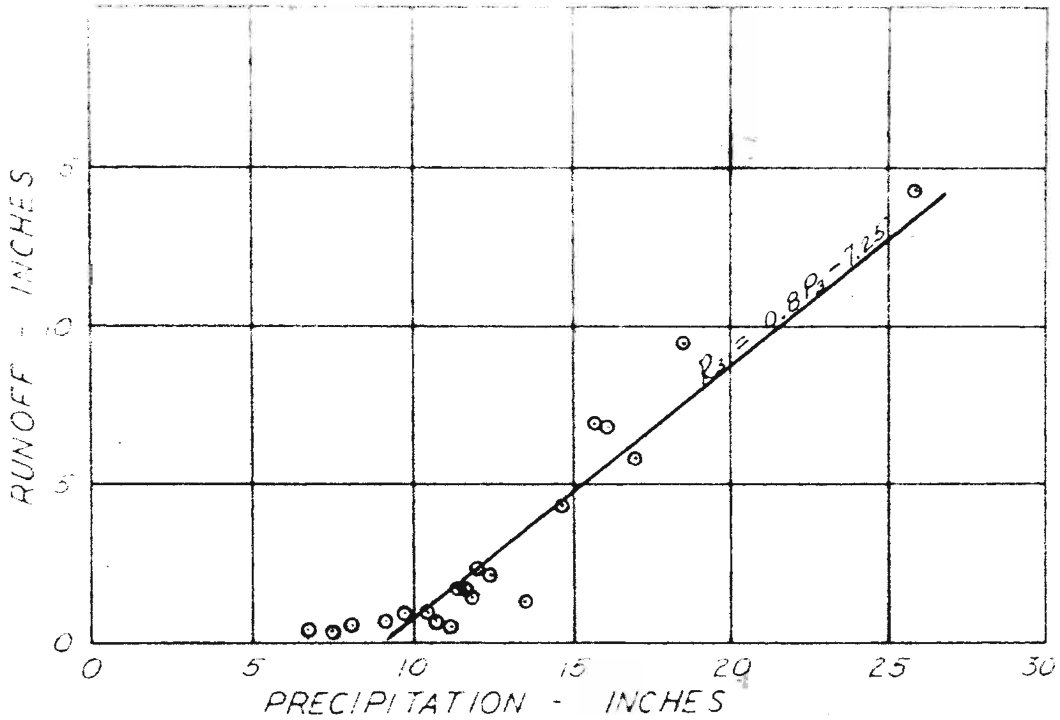

Fig. 21 PRECIPITATION - RUNOFF RELATIONSHIP
THIRD QUARTER, GRAND RIVER NEAR GALLATIN

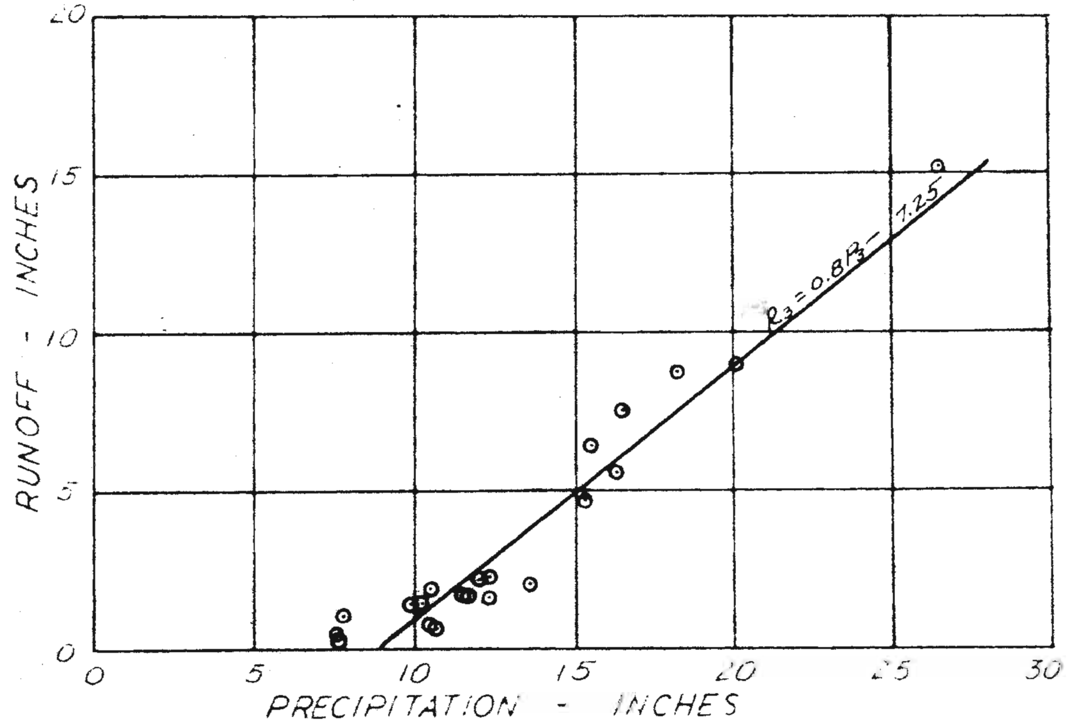

Fig. 22 PRECIPITATION - RUNOFF RELATIONSHIP
THIRD QUARTER, GRAND RIVER NEAR SUMNER

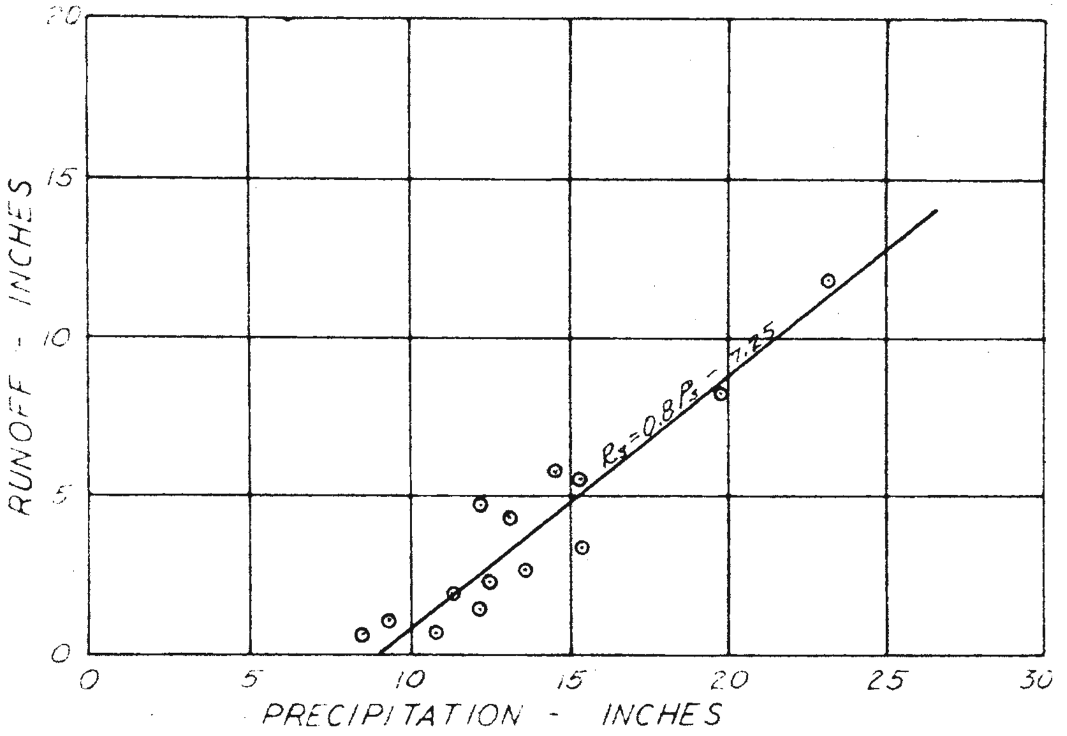

Fig. 23 PRECIPITATION - RUNOFF RELATIONSHIP
THIRD QUARTER, THOMPSON RIVER AT DAVIS CITY

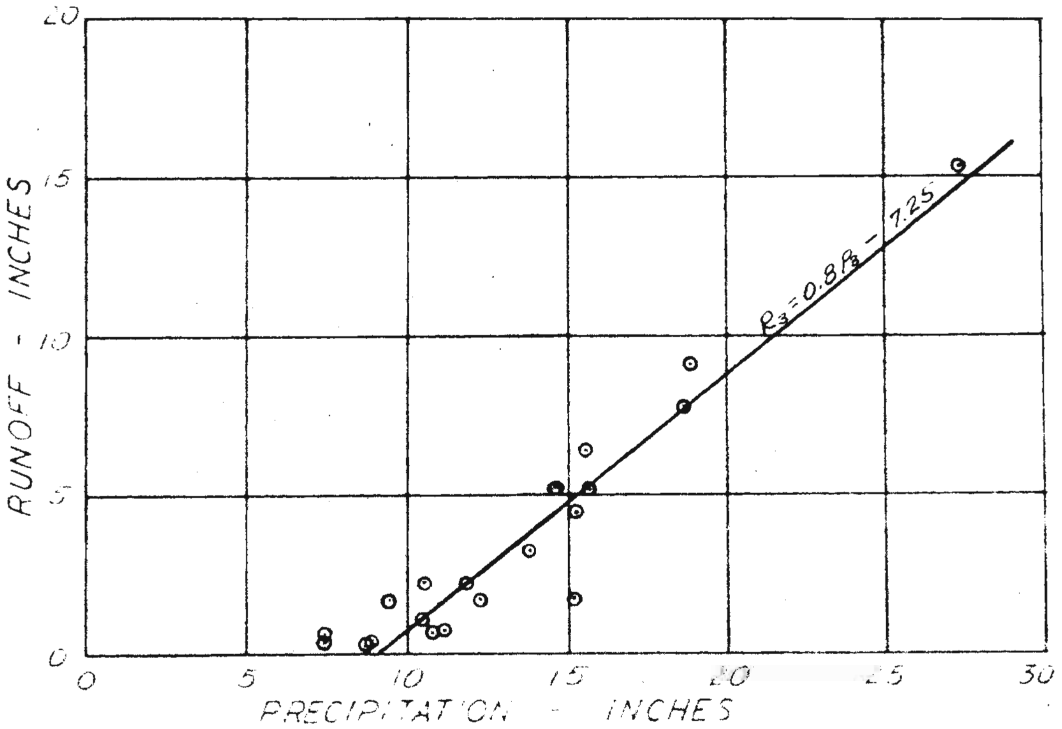

Fig. 24 PRECIPITATION - RUNOFF RELATIONSHIP
THIRD QUARTER, THOMPSON RIVER AT TRENTON

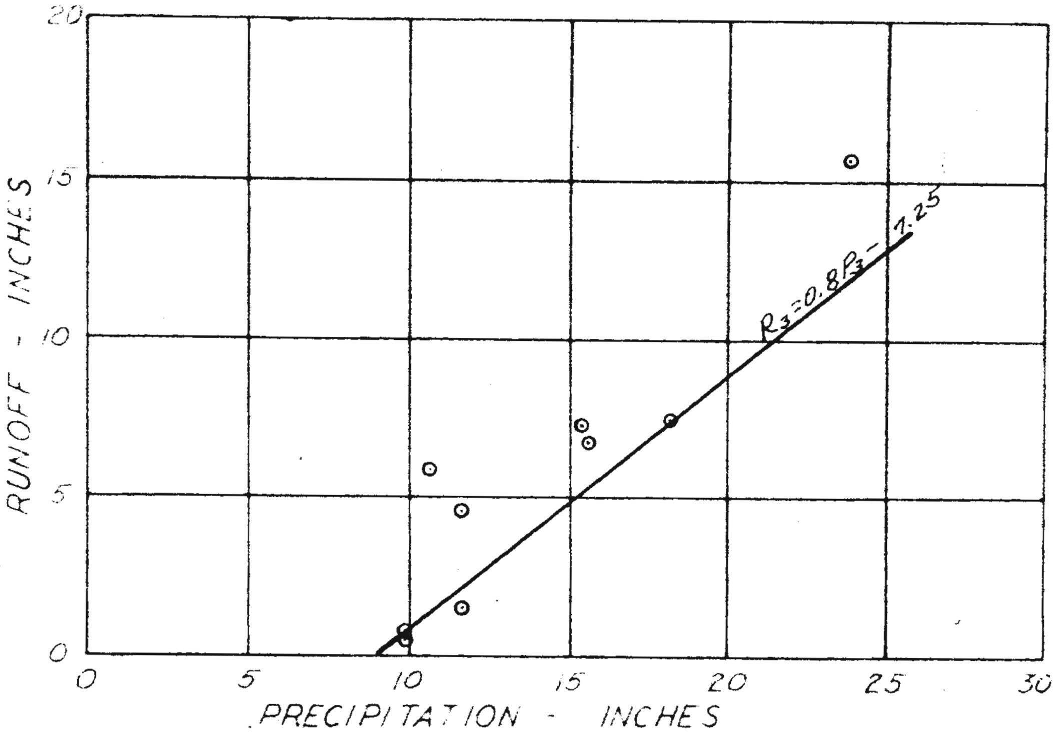

Fig. 25 PRECIPITATION - RUNOFF RELATIONSHIP THIRD QUARTER, WELDON RIVER NEAR MERCER

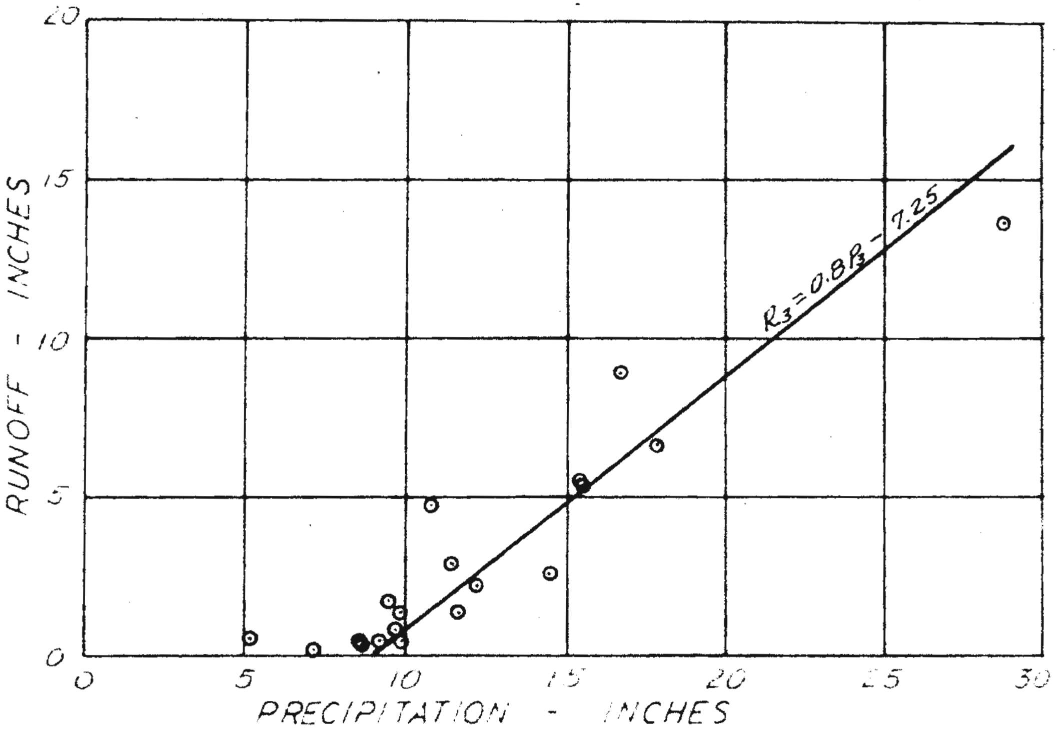

Fig. 26 PRECIPITATION - RUNOFF RELATIONSHIP WELDON RIVER AT MILL GROVE

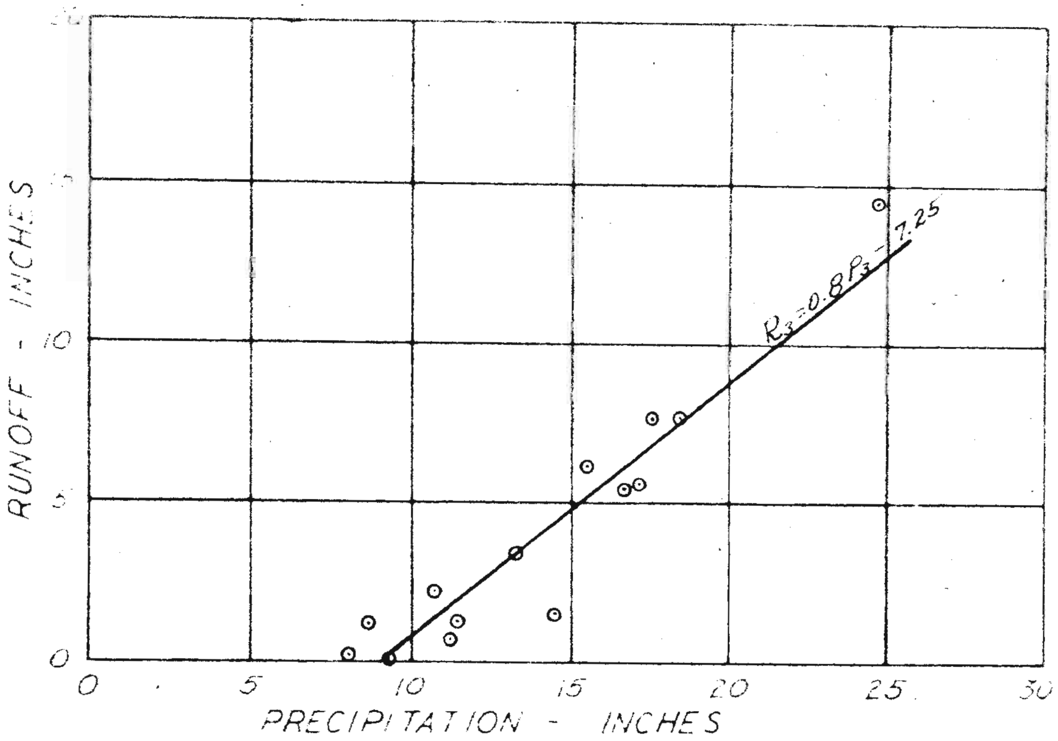

Fig. 27 PRECIPITATION - RUNOFF RELATIONSHIP
THIRD QUARTER, EAST FORK OF BIG CREEK NEAR BETHANY

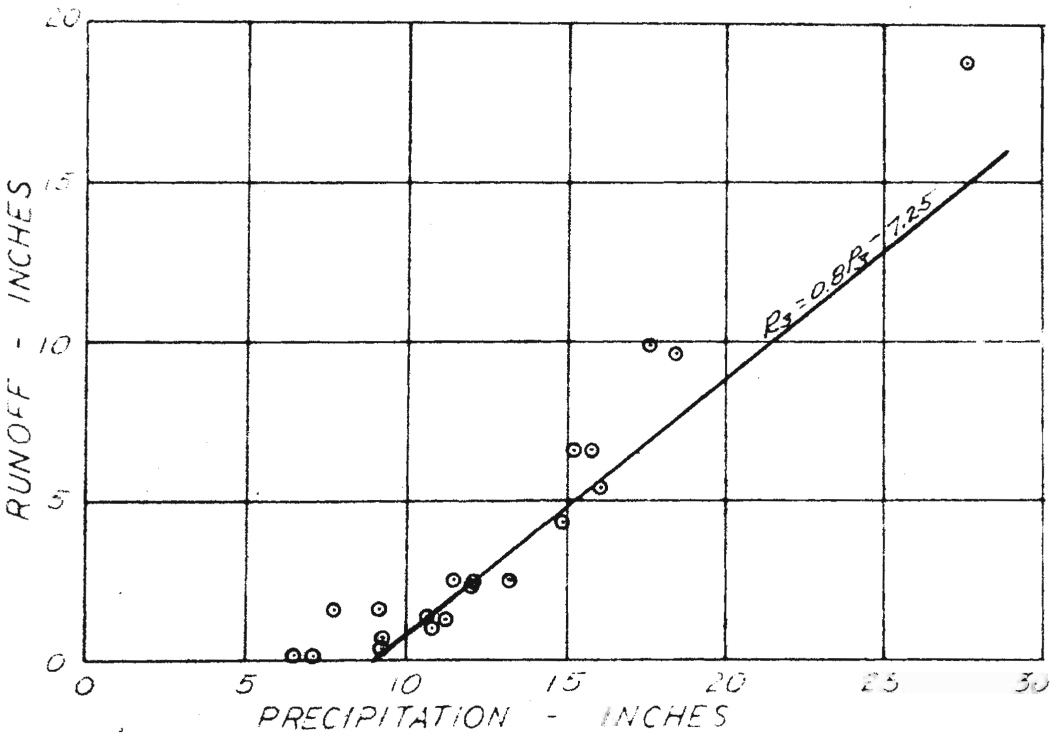

Fig. 28 PRECIPITATION - RUNOFF RELATIONSHIP
THIRD QUARTER, MEDICINE CREEK NEAR GALT

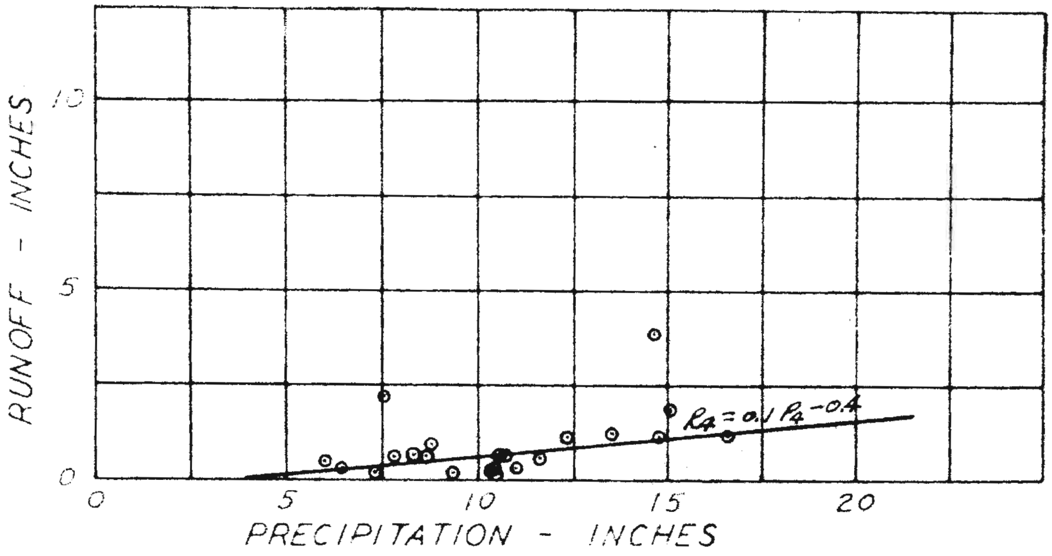

Fig. 29 PRECIPITATION - RUNOFF RELATIONSHIP
FOURTH QUARTER, GRAND RIVER NEAR GALLATIN

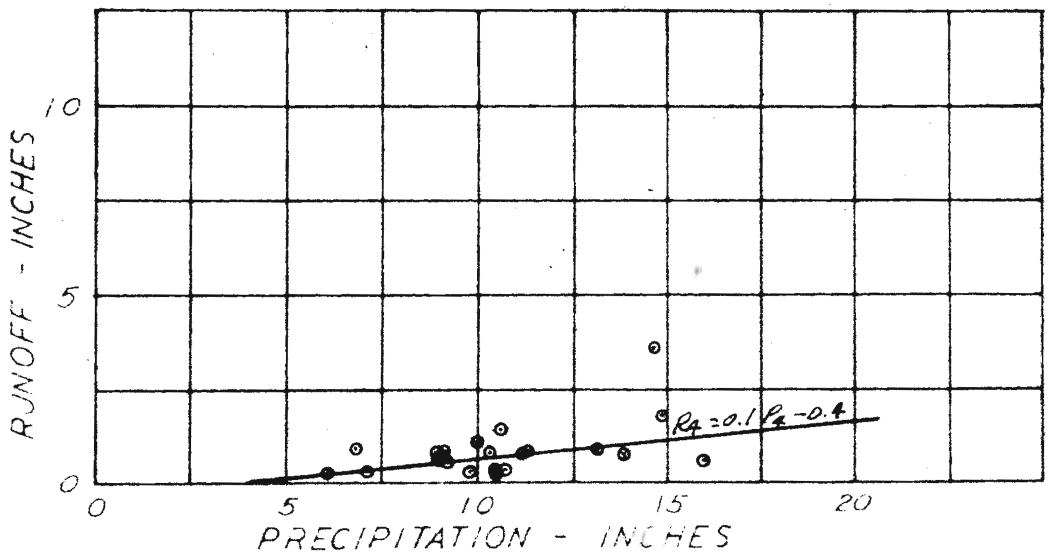

Fig. 30 PRECIPITATION - RUNOFF RELATIONSHIP
FOURTH QUARTER, GRAND RIVER NEAR SUMNER

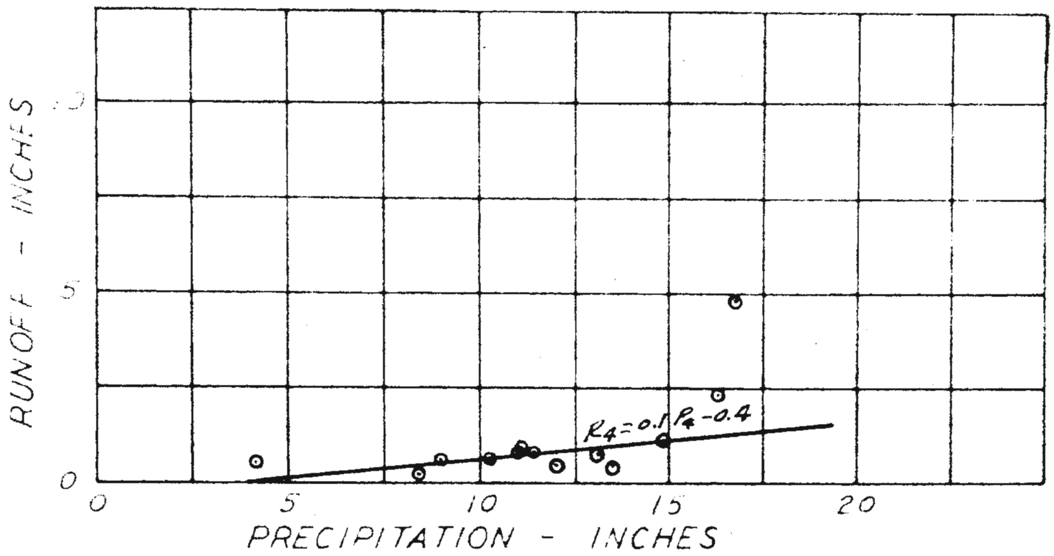

Fig. 31 PRECIPITATION - RUNOFF RELATIONSHIP
FOURTH QUARTER, THOMPSON RIVER AT DAVIS CITY

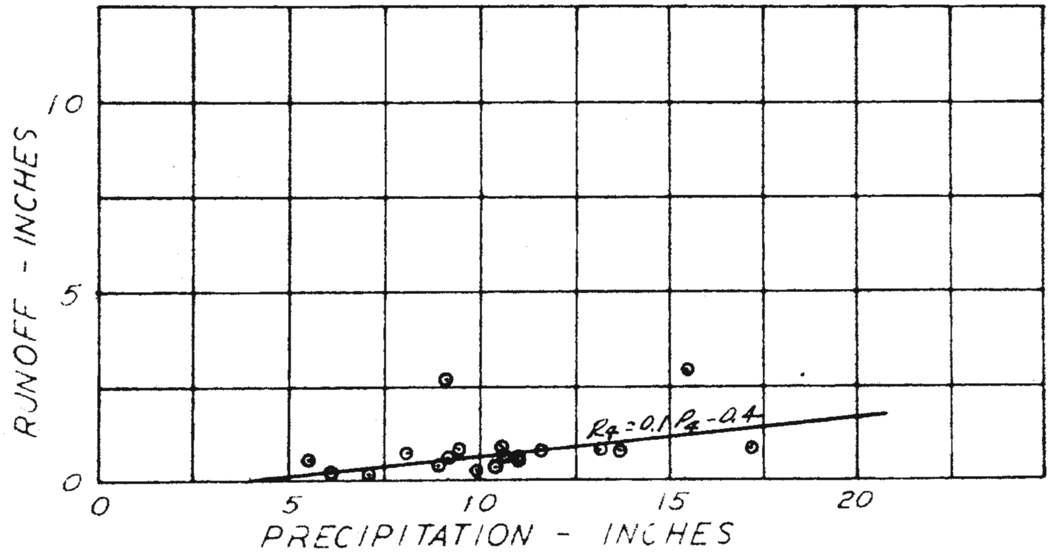

Fig. 32 PRECIPITATION - RUNOFF RELATIONSHIP
FOURTH QUARTER, THOMPSON RIVER AT TRENTON

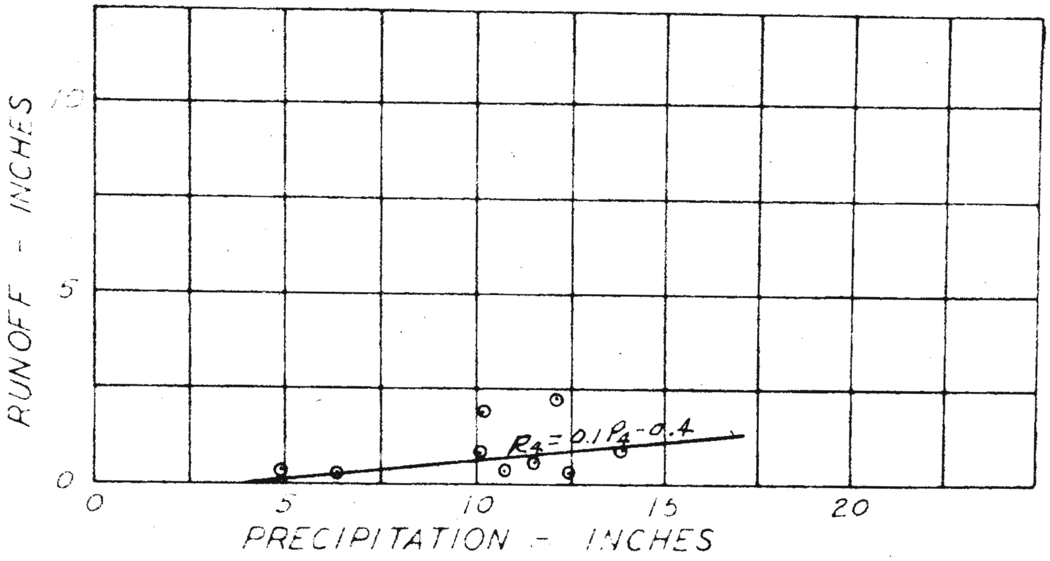

Fig. 33 PRECIPITATION - RUNOFF RELATIONSHIP
FOURTH QUARTER, WELDON RIVER NEAR MERCER

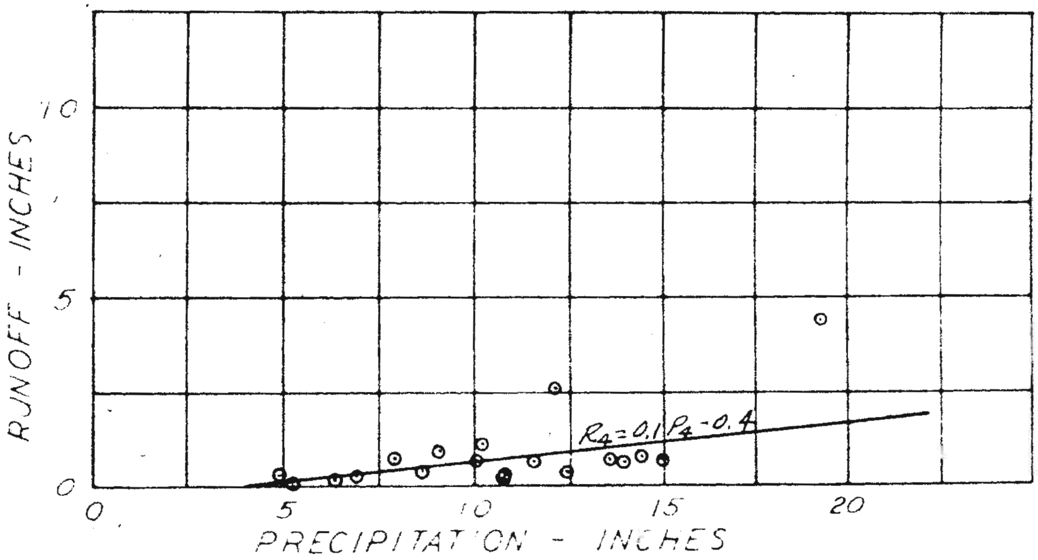

Fig. 34 PRECIPITATION - RUNOFF RELATIONSHIP
FOURTH QUARTER, WELDON RIVER AT MILL GROVE

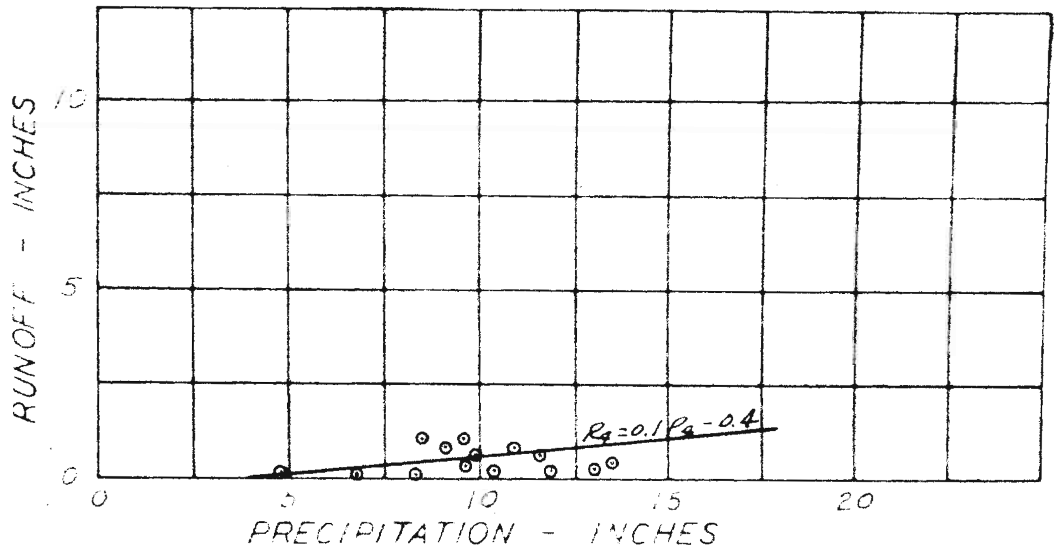

Fig. 35 PRECIPITATION - RUNOFF RELATIONSHIP
FOURTH QUARTER, EAST FORK OF BIG CREEK
NEAR BETHANY

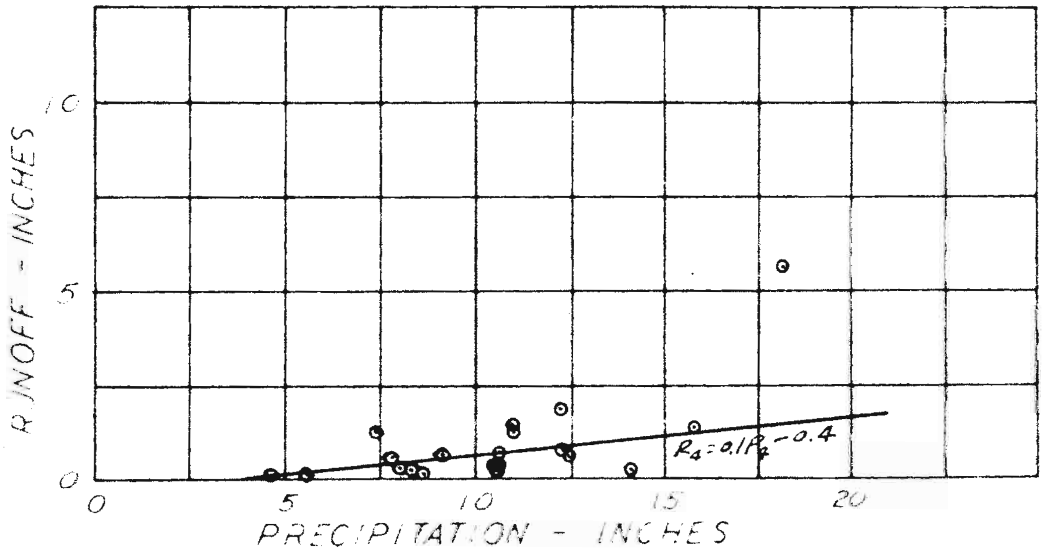

Fig. 36 PRECIPITATION - RUNOFF RELATIONSHIP
FOURTH QUARTER, MEDICINE CREEK NEAR GALT

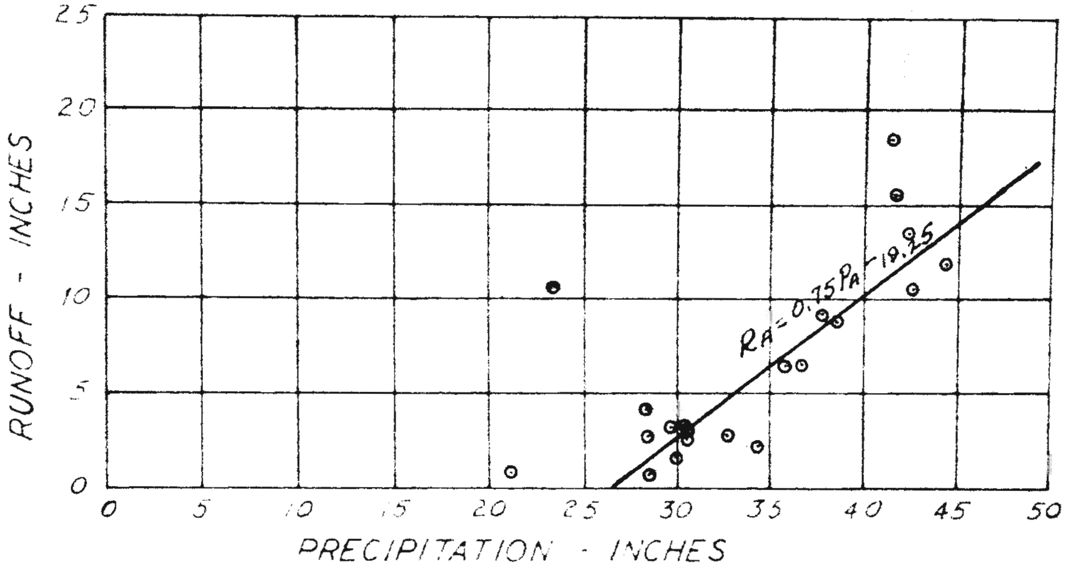

Fig. 37 PRECIPITATION - RUNOFF RELATIONSHIP
WATER YEAR, GRAND RIVER NEAR GALLATIN

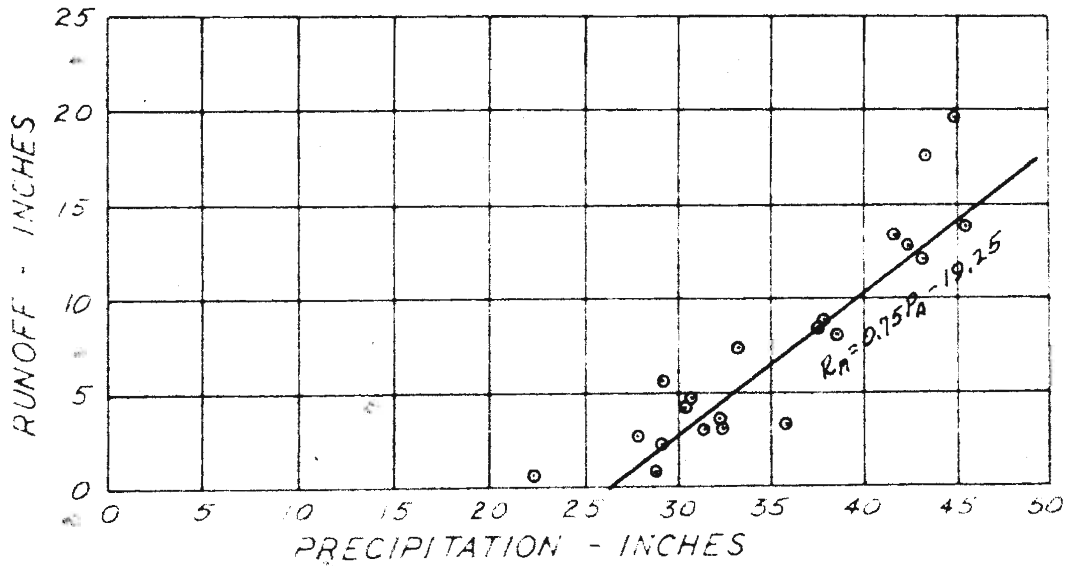

Fig. 38 PRECIPITATION - RUNOFF RELATIONSHIP
WATER YEAR, GRAND RIVER NEAR SUMNER

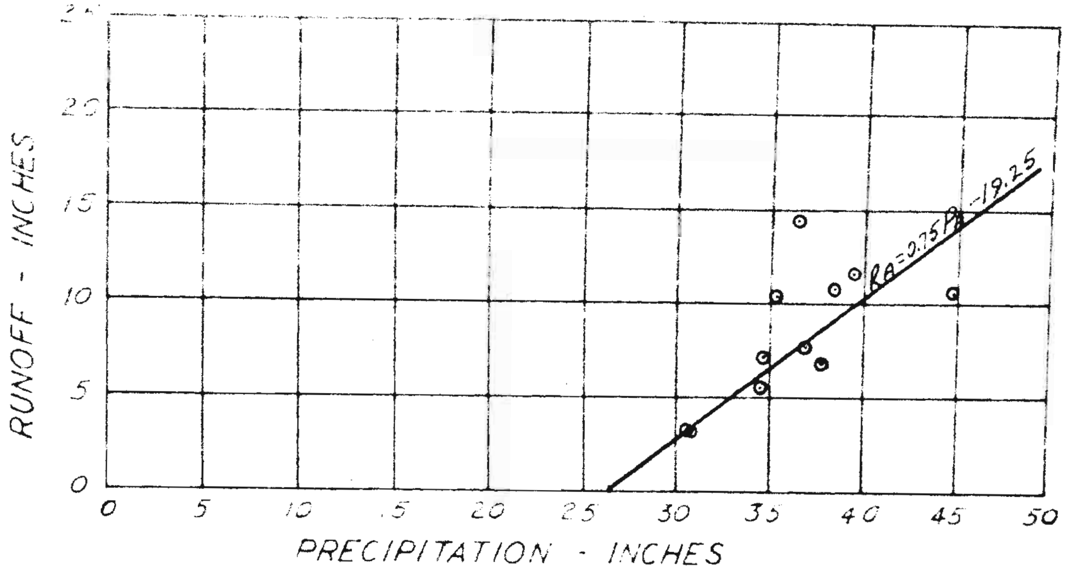

Fig. 39 PRECIPITATION - RUNOFF RELATIONSHIP
WATER YEAR, THOMPSON RIVER AT DAVIS CITY

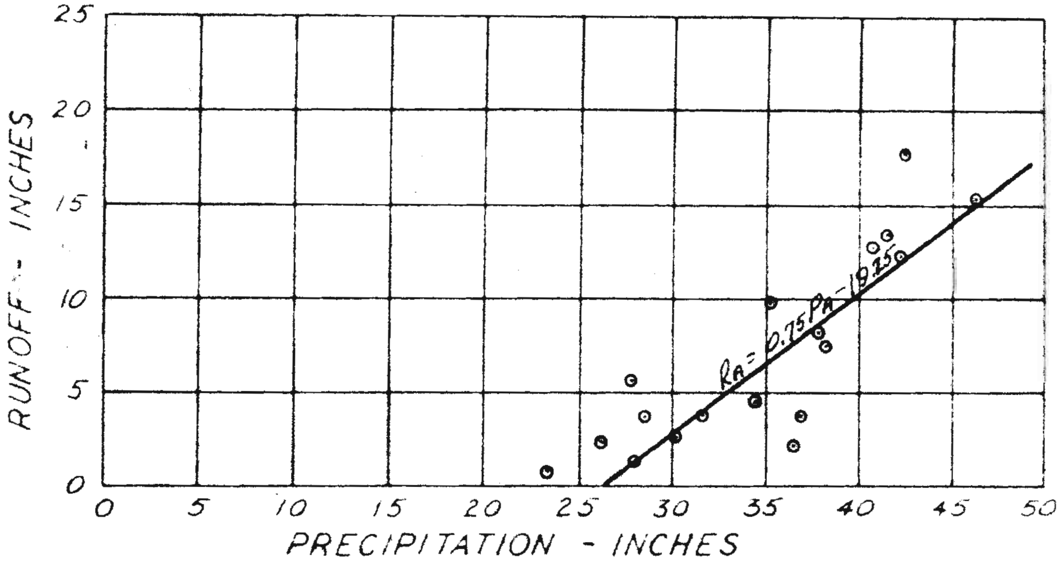

Fig. 40 PRECIPITATION - RUNOFF RELATIONSHIP
WATER YEAR, THOMPSON RIVER AT TRENTON

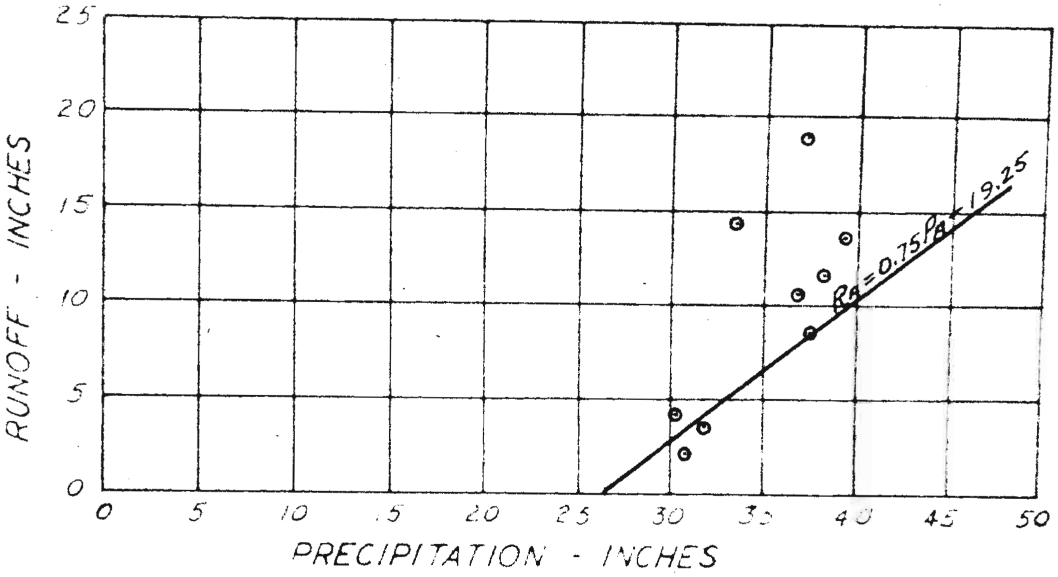

Fig. 41 PRECIPITATION - RUNOFF RELATIONSHIP WATER YEAR, WELDON RIVER NEAR MERCER

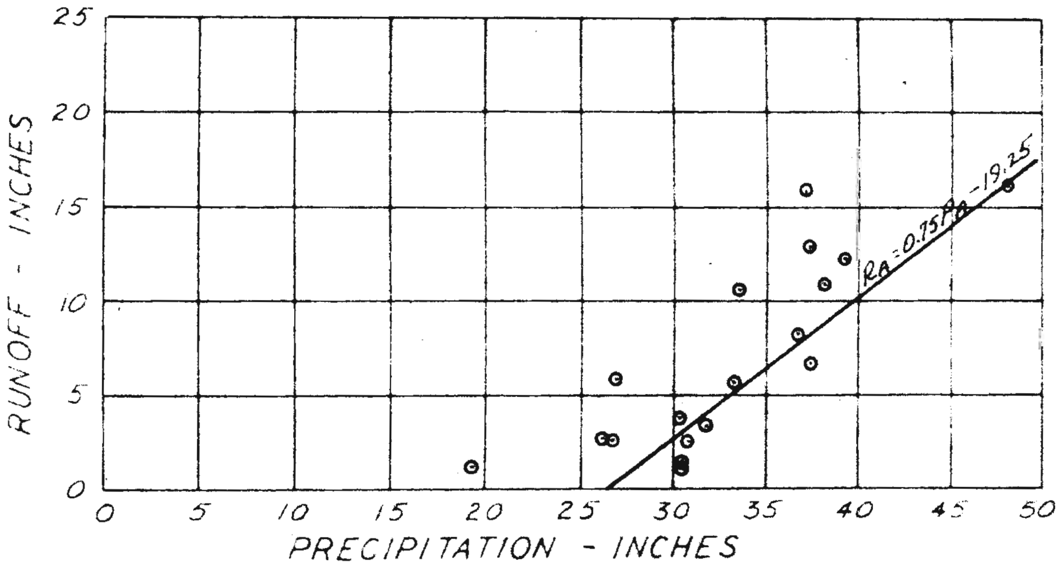

Fig. 42 PRECIPITATION - RUNOFF RELATIONSHIP WATER YEAR, WELDON RIVER AT MILL GROVE

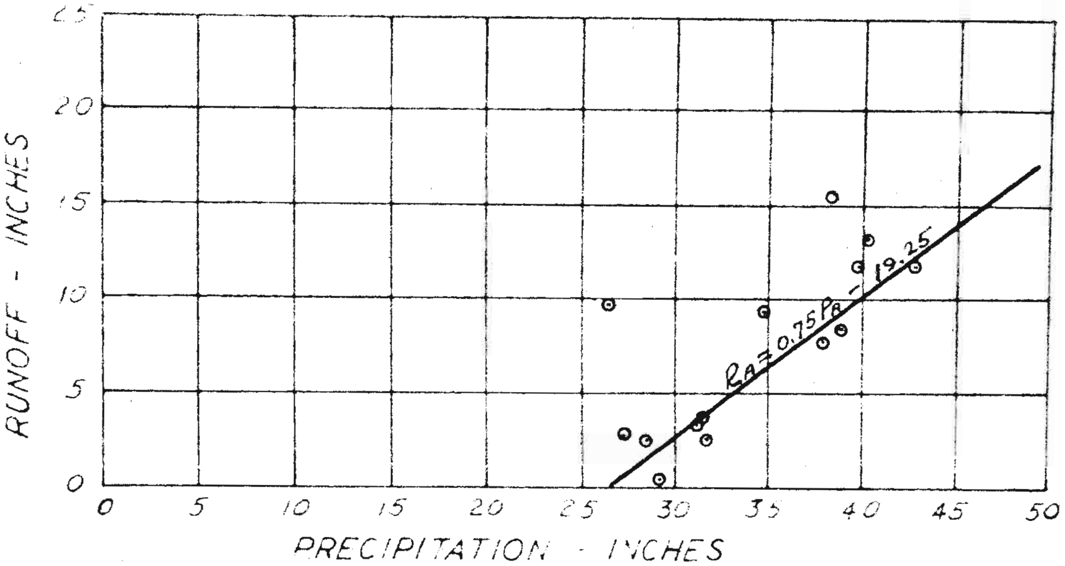

Fig. 43 PRECIPITATION - RUNOFF RELATIONSHIP WATER YEAR, EAST FORK OF BIG CREEK NEAR BETHANY

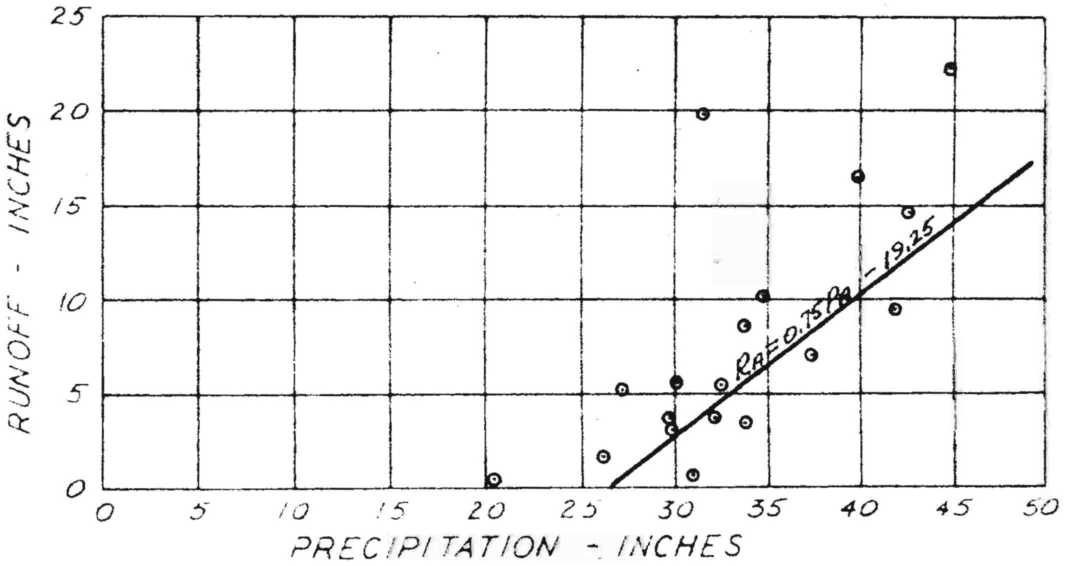

Fig. 44 PRECIPITATION - RUNOFF RELATIONSHIP WATER YEAR, MEDICINE CREEK NEAR GALT

Through the points plotted, a straight line was drawn, representing the precipitation-runoff relationship, and the equation of the line determined.

The equations thus found are:

First quarter: $R_1 = 0.33\, P_1 - 1.1$

Second quarter: $R_2 = 0.9\, P_2 - 2.25$

Third Quarter: $R_3 = 0.8\, P_3 - 7.25$

Fourth Quarter: $R_4 = 0.1\, P_4 - 0.4$

Water Year: $R_A = 0.75\, P_A - 19.25$

in which R is the runoff, P is the precipitation, with the subscript denoting the quarters of the year and $_A$ denoting the annual.

As a check the author used the four quarterly formulas to compute the runoff of the drainage basin of Locust Creek near Linneus. The runoff thus obtained was used to construct the mass curve shown by broken lines in Figure 45. Ordinates for the curve were computed and plotted for each quarter. Runoff as determined by stream gaging at this point was used to construct the mass curve shown by the solid line in Figure 45. No reservoir corrections were taken into account.

It will be noted that the cumulative totals of the computed runoff for 18 years differ from the observed by a little less than 3 per cent, the computed being less than the observed. The two curves are approximately parallel throughout their entirety, getting closer together

Fig. 45
MASS CURVE
LOCUST CREEK NEAR LINNEUS

as time goes on. The one time in which they are not parallel is the second quarter of 1938. This was during a drought period of several years and the precipitation during the winter months was very evenly distributed. This resulted in practically no observed runoff, but did show some computed runoff.

A draft on the watershed of 4 inches per year was assumed and applied to the curves. The greatest depletion shown on the curve of observed runoff was 5.8 inches, and the mass curve of computed runoff showed a depletion of 4.5 inches, a difference of 22 per cent. This difference is on the unsafe side. It is customary to apply a safety factor to the minimum reservoir capacity as determined by the mass curve to take care of any future deviations from past records. Also, most reservoirs have additional capacity for recreational facilities which could be utilized in case of an emergency. Had there been no runoff data on the Locust Creek watershed a reservoir of sufficient capacity could have been decided on from a study of the computed mass curve.

A further check is shown in Table II. In this table the end of water year ordinates for mass-curves constructed by three methods are shown. They are: ordinate from observed runoff, ordinate computed from the four quarterly formulas, ordinate computed from annual formula. The percent each of the two computed ordinate varies from the observed ordinate is also shown.

TABLE II

COMPARISON OF MASS-CURVE ORDINATES

LOCUST CREEK NEAR LINNEUS

Year	Ordinate from observed runoff inches	Computed from quarterly formulas		Computed from annual formula	
		Ordinate	percentage different from observed	Ordinate	percentage different from observed
1931	6.79	7.39	+9	9.04	+33
1932	24.00	17.15	-29	29.18	+22
1933	28.46	21.87	-23	33.19	+17
1934	28.99	22.73	-22	33.19	+14
1935	46.49	36.24	-22	48.35	+ 3.4
1936	49.04	38.74	-21	49.65	+ 1.2
1937	54.33	44.21	-19	52.16	- 4
1938	54.91	48.98	-11	56.81	+ 3.5
1939	61.39	57.72	- 6	64.02	+ 4
1940	63.77	61.02	- 4	66.37	+ 4
1941	67.97	66.94	- 1.5	72.15	+ 6
1942	78.72	79.23	+ 0.7	86.60	+10
1943	88.37	87.07	- 1.5	94.67	+ 7
1944	96.19	96.63	+ 0.5	103.80	+ 8
1945	109.90	108.56	- 1.2	115.75	+ 5
1946	117.50	116.15	- 1.1	122.84	+ 5
1947	137.13	133.54	- 2.6	138.02	+ 0.6
1948	143.75	139.80	- 2.7	142.26	- 1.0

The ordinates computed by the quarterly formulas differ from the observed ordinates by over 25 percent in only one year in 18; over 20 percent in only five years in 18, and over 10 percent in only seven years in 18. The difference is less than 5 percent in nine years out of the 18. It is interesting to note that the difference after the first eight years is never more than 4 inches.

The ordinates computed by the annual formula differ from the observed ordinates by over 25 percent in only one year in 18, by over 20 percent in only 2 years in 18, and over 10 percent in only 4 years in 18. The difference is 5 percent or less in 10 years out of the 18. The cumulative total of the runoff computed by the annual formula differs from the observed by just a little over 1 percent.

CONCLUSIONS

The author believes that the five formulas:

$$R_1 = 0.33P_1 - 1.1$$

$$R_2 = 0.9P_2 - 2.25$$

$$R_3 = 0.8P_3 - 7.25$$

$$R_4 = 0.1P_4 - 0.4$$

$$R_A = 0.75P_A - 19.25$$

will enable one to compute runoff values that will compare favorably with the actual runoff on any stream in the Grand River Basin.

Many of the drainage basin characteristics which are reasonably constant for one particular basin need not be taken into account in this type of study. Such characteristics as topography, geology, and vegetation will vary somewhat for different localities. For this reason the coefficients and constants in the five formulas stated above for the Grand River Basin should not be used for streams in other localities without caution.

In the event that runoff values are desired on other streams the method of correlating rainfall to runoff presented here should give results of equal accuracy. The United States Weather Bureau has precipitation stations conveniently located all over the country, and the Water Resources Branch of the United States Geological Survey operates stream gaging stations at well distributed points so that one is never without the basic data to compile the precipitation-runoff relationship on any particular drainage basin.

If the five formulas presented here are applied to any particular season or year, they may not give true runoff. It has been shown, however, that these formulas may be used for obtaining quarterly runoff values that when plotted in a mass-curve will indicate a necessary reservoir capacity which is within the limit of adequate design.

The author is of the opinion that the many variables of the hydrologic cycle need not be taken into account in a correlation of the precipitation-runoff relationship if the results of that correlation are to be used in a limited area having the same topographic, geological, geographic and cultural characteristics.

The author feels that the formula $R = qP - C$ constitutes a simple and adequate method of correlating the precipitation-runoff relationship when the coefficient and constant C have been evaluated for the particular basin under consideration.

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VITA

Jasper Kent Roberts was born on January 15, 1922 at Ryan, Oklahoma, the son of Jasper L. and Fern Roberts.

He received his grade school and high school education in the public schools of Comanche, Oklahoma, graduating in 1939.

In September, 1939, he entered the University of Oklahoma at Norman. In September, 1940, he transferred to Cameron State College at Lawton, Oklahoma, where he continued his studies. In September, 1941, he re-entered the University of Oklahoma and remained until April, 1943.

The summer of 1942 was spent with the V.V. Long Engineering Co. as a draftsman and party chief doing engineering work on the U.S. Naval Technical Training Station at Norman, Oklahoma.

He was inducted into the Army of the United States on April 19, 1943. After receiving basic training at Jefferson Barracks, St. Louis, Mo., he was assigned to the Army Specialized Training Program at South Dakota State College, Brookings, S.D. until March, 1944. With the dissolution of the ASTP he was assigned to Battery C, 220th Field Artillery Battalion, 44th Infantry Division. With this unit he saw combat in France, Germany, and Austria. He was discharged at Camp Chaffee, Arkansas on October 6, 1945.

In January, 1946, he returned to the University of Oklahoma where he received the degree of Bachelor of

Science in Civil Engineering in June, 1947.

Upon graduation he accepted the position of Instructor in Civil Engineering at the Missouri School of Mines and Metallurgy and has served in that capacity to date.

During the summer of 1948 he served as Engineer Inspector II with the Missouri Highway Commission. The summer of 1949 was spent with the Water Resources Branch of the United States Geological Survey.

He was united in marriage to Winona Clark on December 5, 1943. A son, Patrick Kent, was born February 9, 1948.