Proceedings of the Indiana Academy of Science
(1991) Volume 99, p. 161-176

SPATIAL VARIATION OF SUMMER PRECIPITATION IN THE TERRE HAUTE AREA DURING THE 1988 DROUGHT

Sean M. Model and John E. Oliver
Department of Geography and Geology
Indiana State University
Terre Haute, Indiana 47809

ABSTRACT: During the summer of 1988 (June, July, and August) the high variability of precipitation and paucity of reporting stations in Vigo and surrounding counties in west-central Indiana and east-central Illinois, led to problems in estimating intrastation precipitation amounts. To solve this problem, areal estimation methodologies normally used in watershed precipitation analysis were applied to the study area. Areal variation was analyzed visually through the use of three-dimensional graphs and mathematically through the use of weighted-means. Monthly precipitation values acquired from local observers were subjected to computer analysis to produce isohyetal maps, and to manual analysis through the use of Thiessen Polygons. Intrastation precipitation estimates were produced and subsequently verified through additional observations. The Thiessen Polygon method proved to be most accurate although the results were not significantly different than were those of the computer-aided method.

The Indiana State University (ISU) Climatic Station uses automated instruments to monitor daily weather. Although unofficial, the station is a data source for local media, industry and educational institutes. Apart from supplying routine data, the station also provides information to the general public upon request. During 1988, requests concerning precipitation data reached unprecedented proportions, a reflection of the drought that prevailed in that year over much of the Midwest (Changnon, 1989).

In providing weather information, data measured at the station were usually given; clearly, however, during the year in question, the precipitation measured at ISU was not really indicative of amounts that fell in the surrounding area. An effort thus was made to estimate the rainfall for a given location, based upon data from ISU and other nearby locations. Various methodologies were used to derive this estimation, and the analysis of resulting patterns provides the basic rationale for this discussion. Essentially, the purposes of this paper are:

1. to determine the spatial variation of precipitation throughout the study area during a period of drought, and

2. to determine the best way to estimate precipitation at locations between monitored stations, for the information of the general public.

Such a study obviously relates to the old problem of rain gauge density and distribution (Bruce and Clark, 1980), but in the present case the pervasive dryness has attached special meaning. It must be noted that, in all cases, persons requesting data were informed that the estimates were only a guide, and could not be used as other than general information.

To place the study in the perspective of the precipitation patterns of 1988, prior to outlining the ways in which precipitation was estimated, the monthly rainfall patterns at ISU are presented. Thereafter, summer rainfall amounts at several stations are used

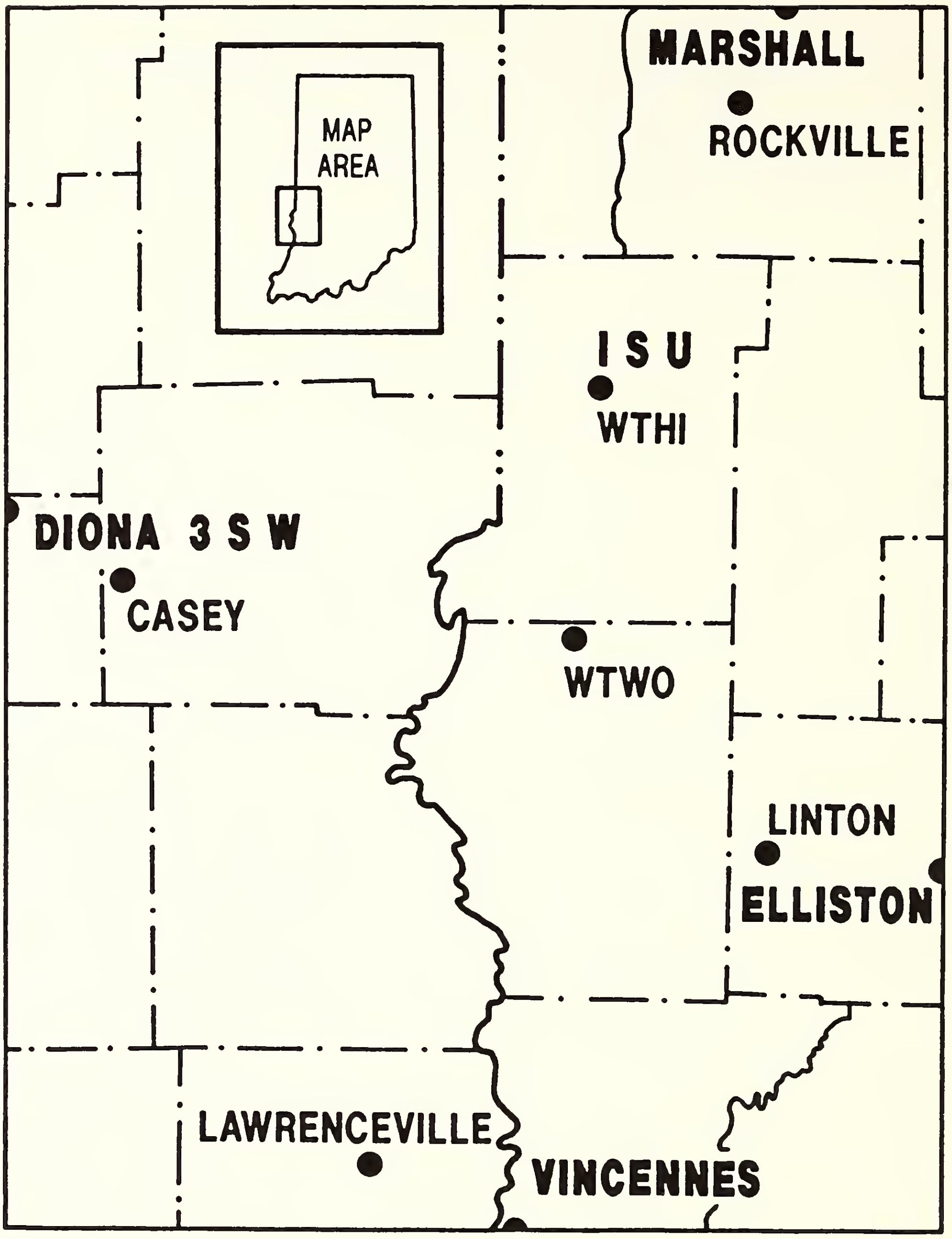

Figure 1. Study Area. Includes a Portion of Extreme West-Central IN and Extreme East-Central IL. Research Based on Data From Stations in Bold Letters.

in the analysis and data from these observers were used to estimate areal amounts. Figure 1 is a map of the study area, and locates stations used in making the original estimates.

MONTHLY PRECIPITATION PATTERN

Figure 2 shows 1988 monthly precipitation as measured at the ISU Climate Station. During 1988, precipitation remained above normal until April, when rainfall was about one-half the normal value. May and June were also below normal, with June being extremely dry.

In July, several excessively heavy thunderstorms resulted in a total precipitation of 7.6 inches, well above average for the month. During July, measurable precipitation

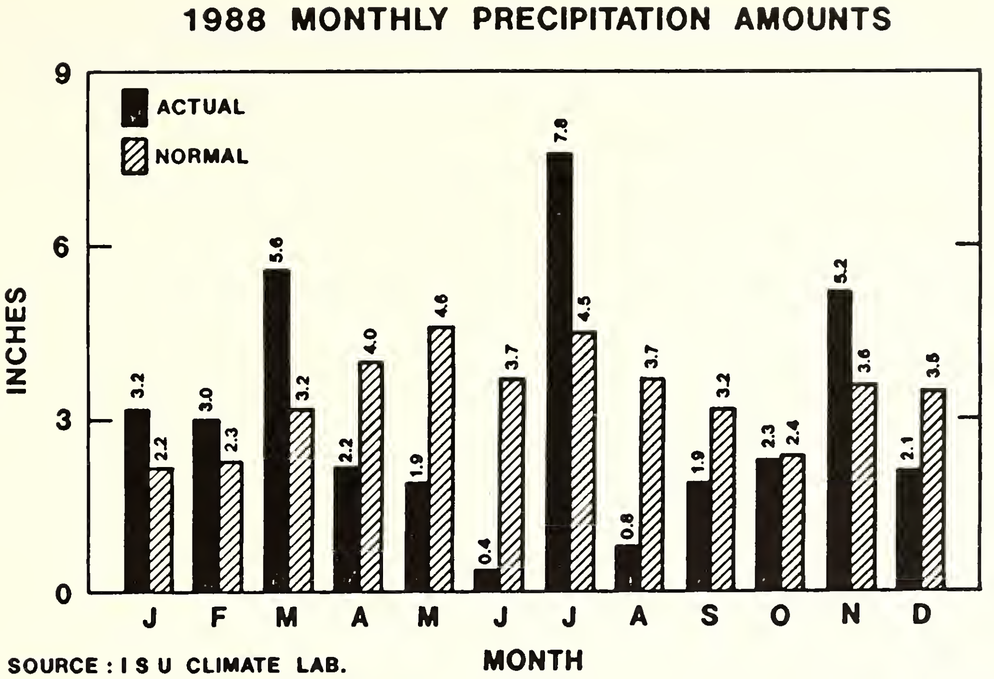

Figure 2. 1988 Monthly Precipitation Amounts. Measured at the ISU Climate Lab. Drought Severity Most Pronounced in June.

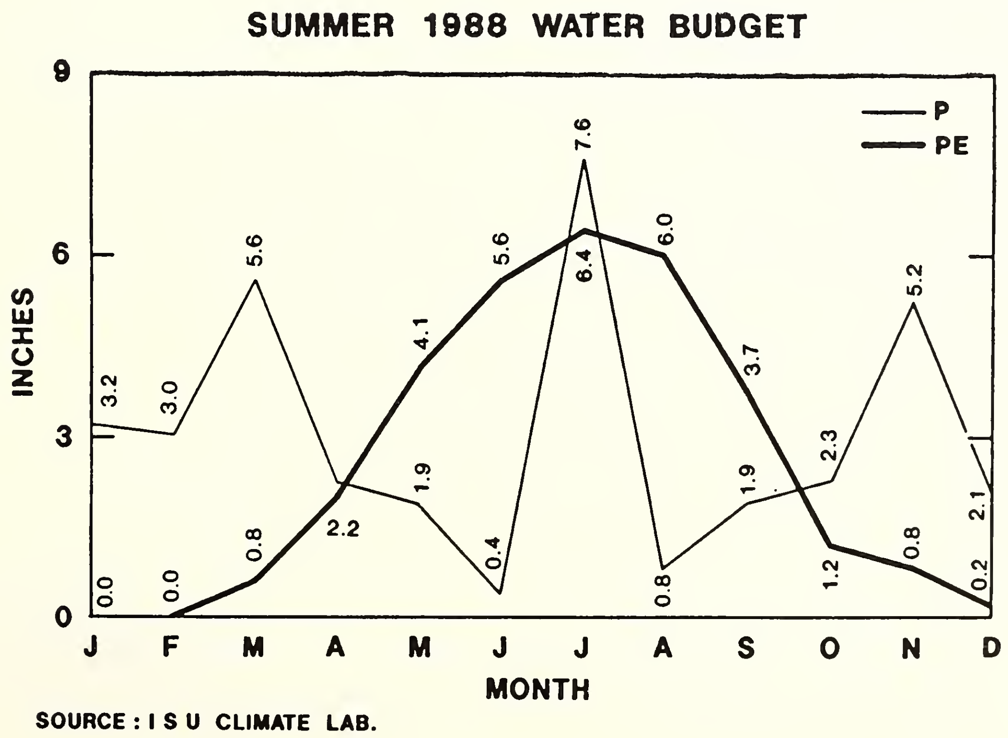

Figure 3a. Cursory Water Budget. Potential Evapotranspiration (PE) Exceeds Precipitation (P) From April to October With Brief Reversal in July.

fell on seven of the last twenty-two days. Rainfall on four days exceeded one inch, and most precipitation occurred in heavy thunderstorms that lasted less than one hour. The greatest daily precipitation occurred on the 14th of July, when 2.19 inches fell in about one hour. The severity of some storms is exemplified by the 1.7 inches that occurred on July 25th, when the first inch of rain accumulated in the first fifteen minutes of the storm.

The year remained dry in August and September; not until October did the monthly rainfall again attain a near normal value. November was moist, but December also had less than normal rainfall.

A water budget cursory analysis (Figure 3a), based upon the Thornthwaite method (Muller and Thompson, 1987), shows that the potential evapotranspiration exceeded precipitation in April, and except for July, was not reversed until October. In terms of surplus and deficit, Figure 3b shows that despite the excessively heavy July rainfall, the summer was mostly a period of deficit.

It is clear that the heavy rainfall of July had a significant bearing on the summer climatic characteristics recorded at the ISU station. However, and as noted, July rainfall was localized heavily, so the ISU data are not totally representative of the surrounding area. In order to provide a better guide to relative rainfall amounts during the three summer months, data were acquired from independent local observers in both Illinois (Diona 3SW) and Indiana (Vincennes, Elliston and Marshall), in addition to the rainfall recorded at ISU (see Figure 1).

LOCAL VARIABILITY

A good impression of the marked variability in rainfall across the study area can be attained by viewing three-dimensional graphs of total precipitation for June, July, August, and total summer precipitation; figures 4a through 4d provide such a perspective.

In June (Figure 4a) the heaviest rainfall occurred in the western part of the study area, with the tightest gradient between ISU and Diona 3SW, and a marked "valley" eastward from ISU. Total rainfall, however, was minimal throughout the region.

July, 1988, represents a totally different view, with the perspective again viewed from the northeast (Figure 4b). The major rainfall at the ISU station is shown as a peak, with a major gradient toward the northeast.

August rainfall is shown in Figure 4c. Viewed from the southeast, three peaks are seen in the northern and western areas, with the least amount occurring in the east-central area. Figure 4d, the sum of Figures 4a, b, and c, shows the total precipitation during the summer of 1988.

The computer-generated graphs show that rainfall, even across such a small study area, was highly variable, with marked gradients occurring between rainfall peaks and valleys. The problem faced by the ISU observers was to estimate the amount of rainfall that occurred in locations between the valleys and peaks. Although the three-dimensional graphs are used to estimate gradients, the more conventional methods, as described in the next section, were also tested.

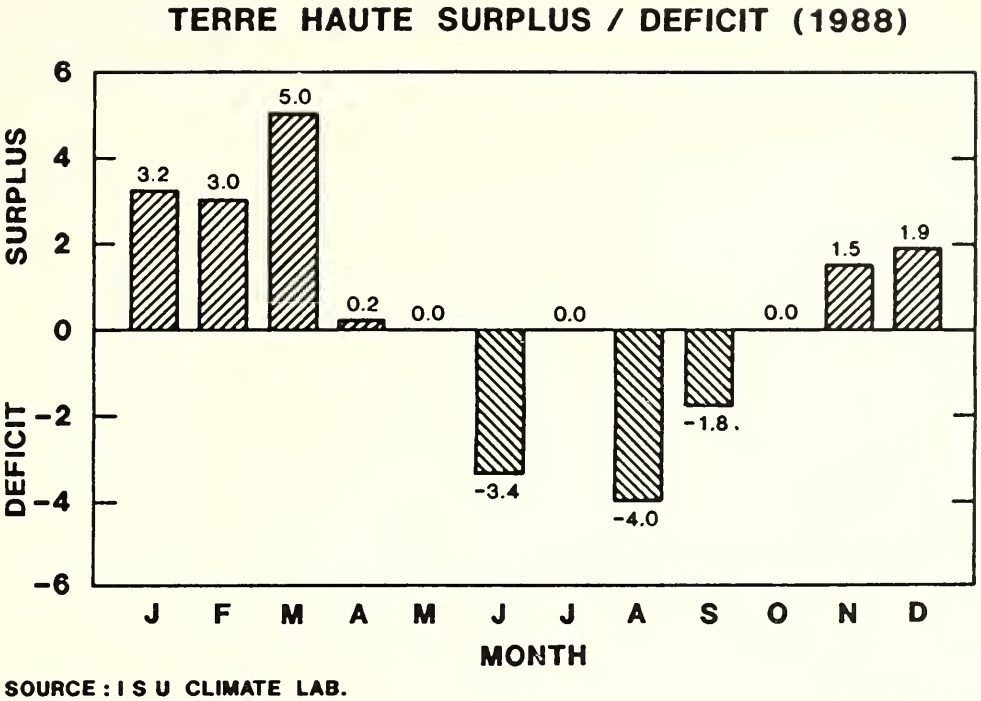

Figure 3b. Surplus/Deficit. Summer of 1988 — A Period of Deficit.

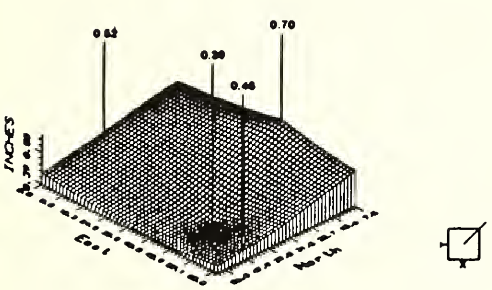

Figure 4a. June Precipitation.
Viewed From Northeast.

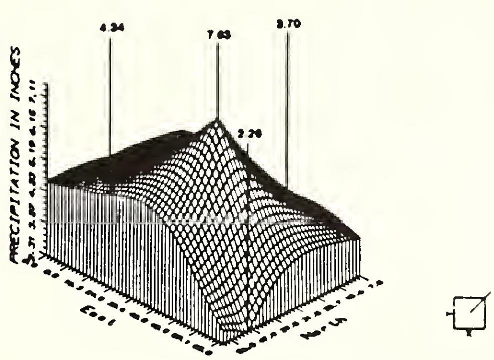

Figure 4b. July Precipitation.
Viewed From Northeast.

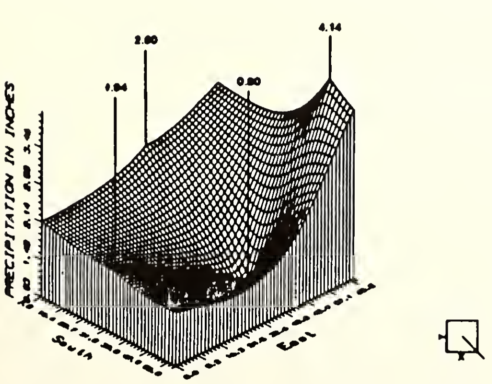

Figure 4c. August Precipitation.
Viewed From Southeast.

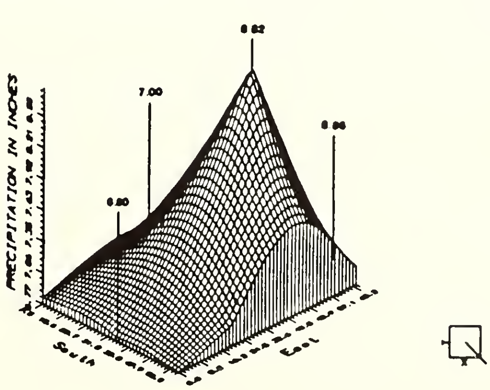

Figure 4d. Summer (Sum of June, July, and August) Precipitation. Viewed From Southeast.

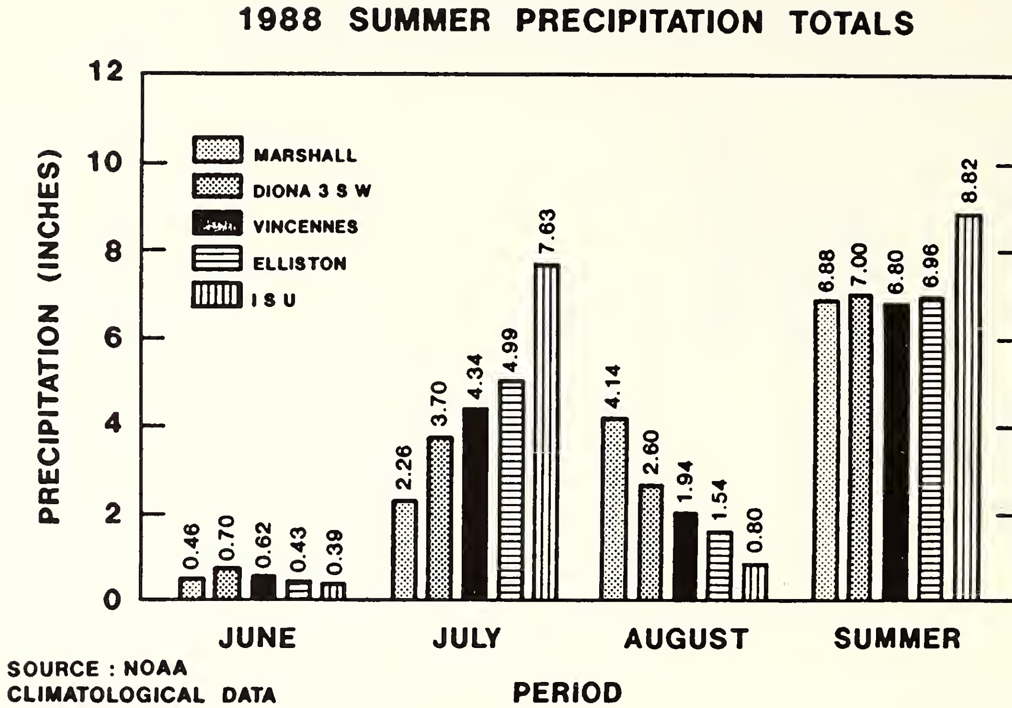

Figure 5. Summary of Summer Precipitation. No Consistent Pattern Recognizable.

ANALYSIS

Monthly rainfall for June, July, and August, for the five stations used in this study are shown in Figure 5. Again, the differing amounts recorded are evident. These monthly data are used to create patterns of precipitation over the study area, so that recipitation at locations intermediate between the recording stations can be estimated. Two methods are used:

1. Rainfall estimated by isohyetal maps (based upon the computer maps in Figures 4a through 4d) of varying intervals. In this presentation, the generic term isoline is used in discussing the distributions (Fairbridge and Oliver, 1987).
2. Rainfall estimated by areas within a Thiessen Polygon (Oliver, 1979). The initial use of the polygon method also identified nearest-neighbor characteristics.

These same methods are used to analyze the second component of the study, the derivation of the distribution of average areal precipitation.

STATION AMOUNT ESTIMATES

Figure 6 uses the Thiessen Polygon Method for analysis of June, 1988, rainfall. The method geometrically divides the area into units which are based upon the location of stations. Patterns are derived so that any point within a polygon is closer to a control station than to any other station. The method, as used here, is for nearest-neighbor identification. In reporting rainfall amounts, it was assumed that the representative station in each identified polygon was the best estimate for other locations within the polygon. Thus, if a request was received for Brazil in Clay County, the estimate provided would be for the station at the center of the polygon (0.39 inch), in this case the ISU station. Estimations were made using this method for each station, during each summer month.

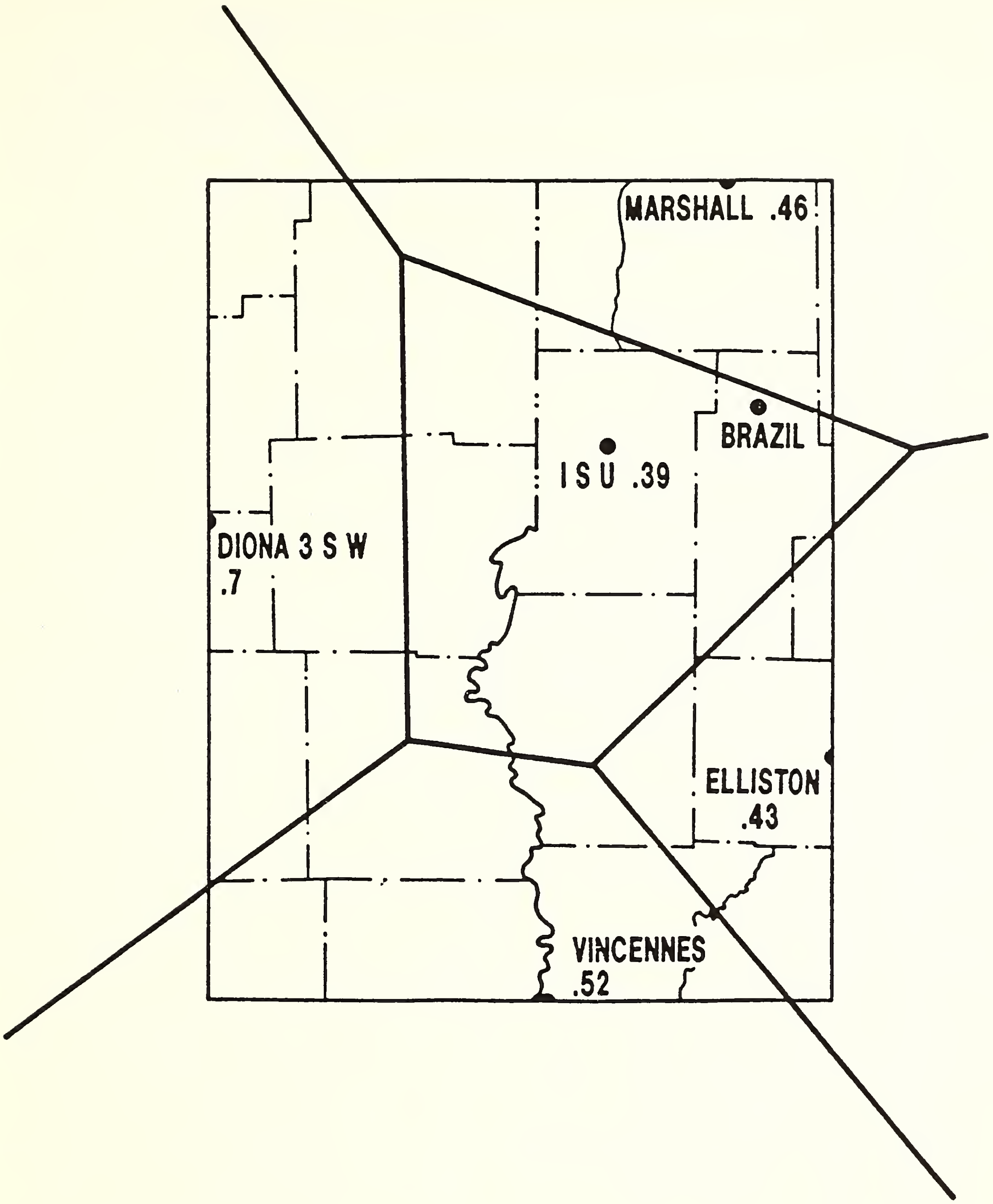

Figure 6. Thiessen Polygon Method. June Precipitation Data. Central Station Provides Estimate for any Location Within Polygon. Estimate for Brazil, IN — 0.39 inch.

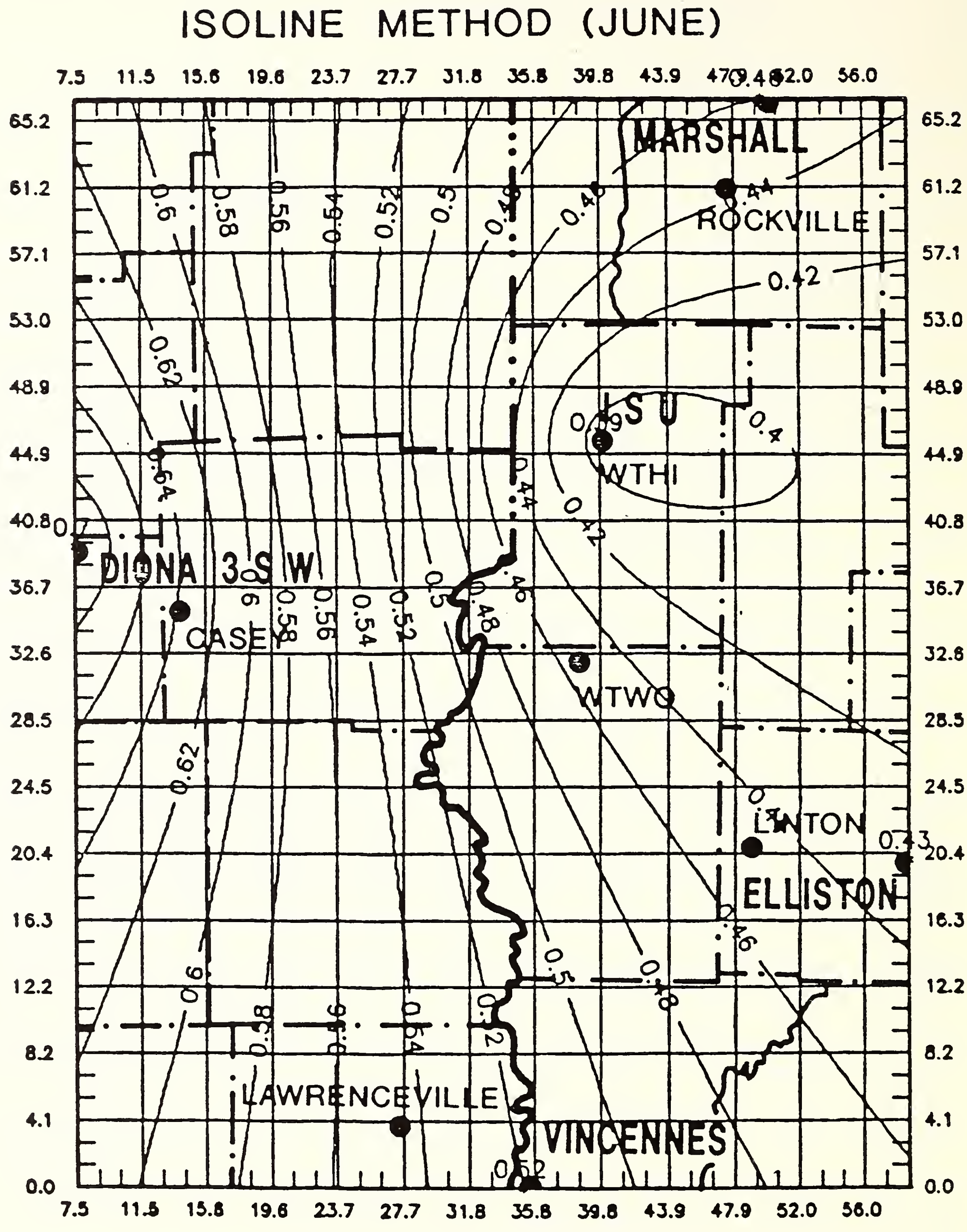

Figure 7a. Isoline Method. June Precipitation Estimates. Estimate for Brazil, IN — 0.41 inch.

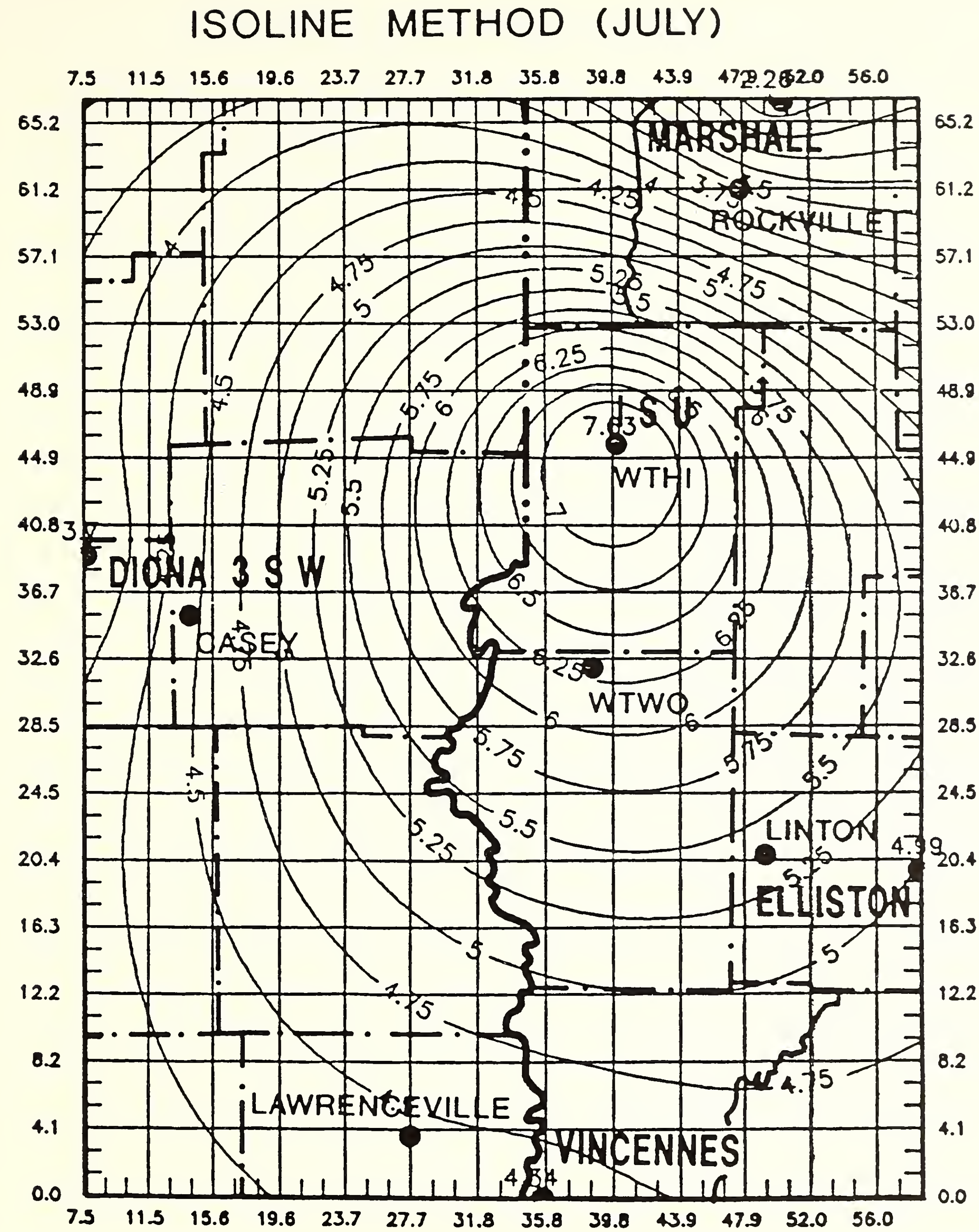

Figure 7b. Isoline Method. July Precipitation Estimates.

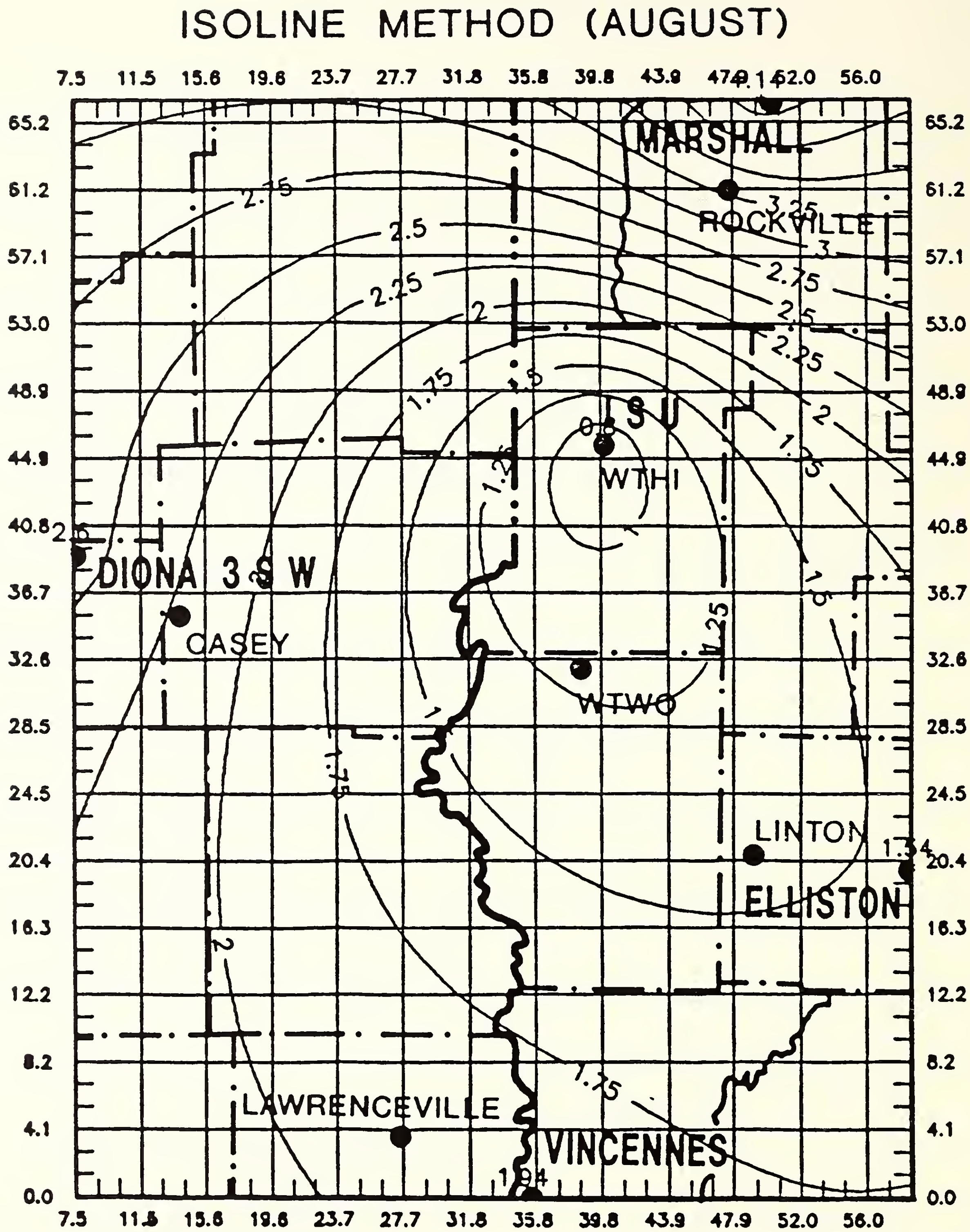

Figure 7c. Isoline Method. August Precipitation Estimates.

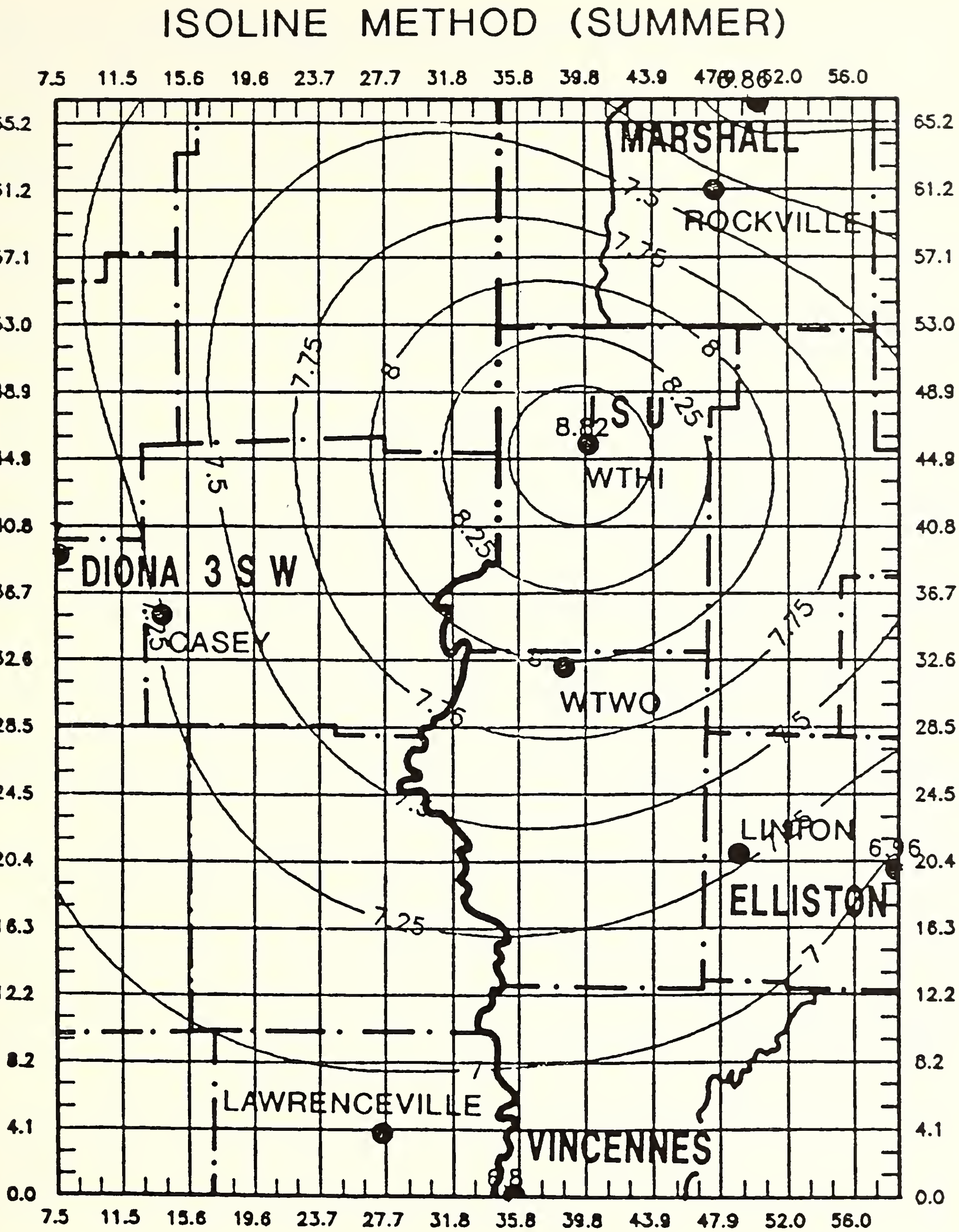

Figure 7d. Isoline Method. Summer (Sum of June, July, and August) Precipitation Estimates.

Figures 7a through 7d shows the isoline analysis. The extremely minor June precipitation (Figure 7a) resulted in a single isoline when using a 0.25 inch interval; as a result, for this month an interval of 0.02 inch was used to gain a more detailed delineation. To obtain an estimate for site rainfall, using this depiction, the place was located on the base map, and the rainfall amount derived by interpolation of the isolines. For Brazil, the estimate was 0.41 inch. Similar isolines were constructed for the other summer months, and for the total summer precipitation.

To test the efficacy of each estimate, other station data were compared with the summer estimates provided by each method used. The added stations were Casey and Lawrenceville in Illinois, and Linton, WTWO (TV station Channel 2, Terre Haute), and Rockville in Indiana (Figure 8). Results of the analysis are shown in Tables 1 and 2.

In each table, station pairs are identified as those that fall within the same Thiessen Polygon. For each station, the actual precipitation is given, and in Table 1 this amount is compared with the estimate derived from the Thiessen Polygon Method. For example, Marshall measured 0.46 inch in June, and the resulting estimate for Rockville would be 0.46 inch. The actual rainfall at Rockville was 0.38 inch, a difference between the observed and estimated of 0.08 inch; the positive value indicates the estimate was higher than the actual measured amount. This process is continued for each station, for each month and for the entire summer.

Table 2 is constructed similarly, but the values were derived by interpolation of isolines. Again, data are derived for the three summer months and the entire summer period. Both tables indicate differences between estimated and actual rainfall.

Although a variety of statistical methods are available to test the fit between the two rainfall amounts derived (Hammond and McCullagh, 1978), all that is required is a guide to their relative efficacy. To permit simple comparison, the ratio

$$\text{Estimated Amount} / \text{Actual Amount}$$

is used. Values less than 1 indicate an underestimation, and those greater than 1 an overestimation.

Table 3 provides a ratio, using the above formula, for each summer month and the summer total using both methods. With the exception of two cases (Diona/Casey in July and ISU/WTWO in August) both Thiessen and Isoline methods agreed in direction of estimate during the monthly periods.

The major problem is not, however, related to direction of the ratio, but to the estimate error of data for Rockville. Using the Thiessen Polygon Method, the estimate is more than three times, and the Isoline is two-and-one-half times the actual rainfall that occurred. An error of this magnitude needs more detailed examination, a project that currently is in progress.

Looking at the ratios derived for the three summer months, in three of five cases the Thiessen Polygon values provide the best estimate. This probably results from the relative proximity of the actual and forecast stations. If stations for which forecasts were made had been nearer the polygon boundaries, a different result may have been attained.

Total Areal Distribution

The isoline and polygon maps can be used to derive a weighted, area-average value for precipitation distribution. By calculating areas representative of each polygon, the average value is determined by

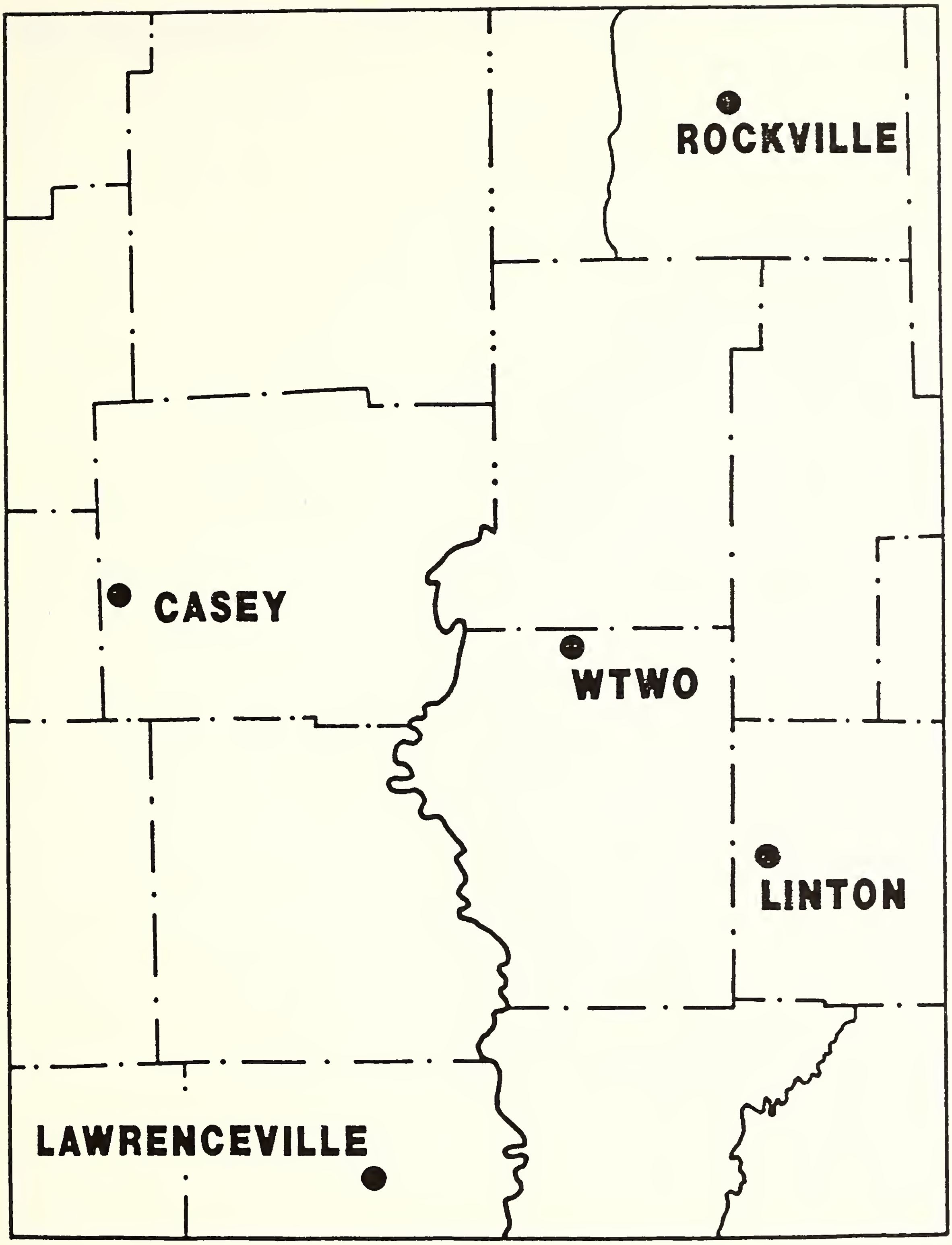

Figure 8. Locations for Which Precipitation Estimates Were Made.

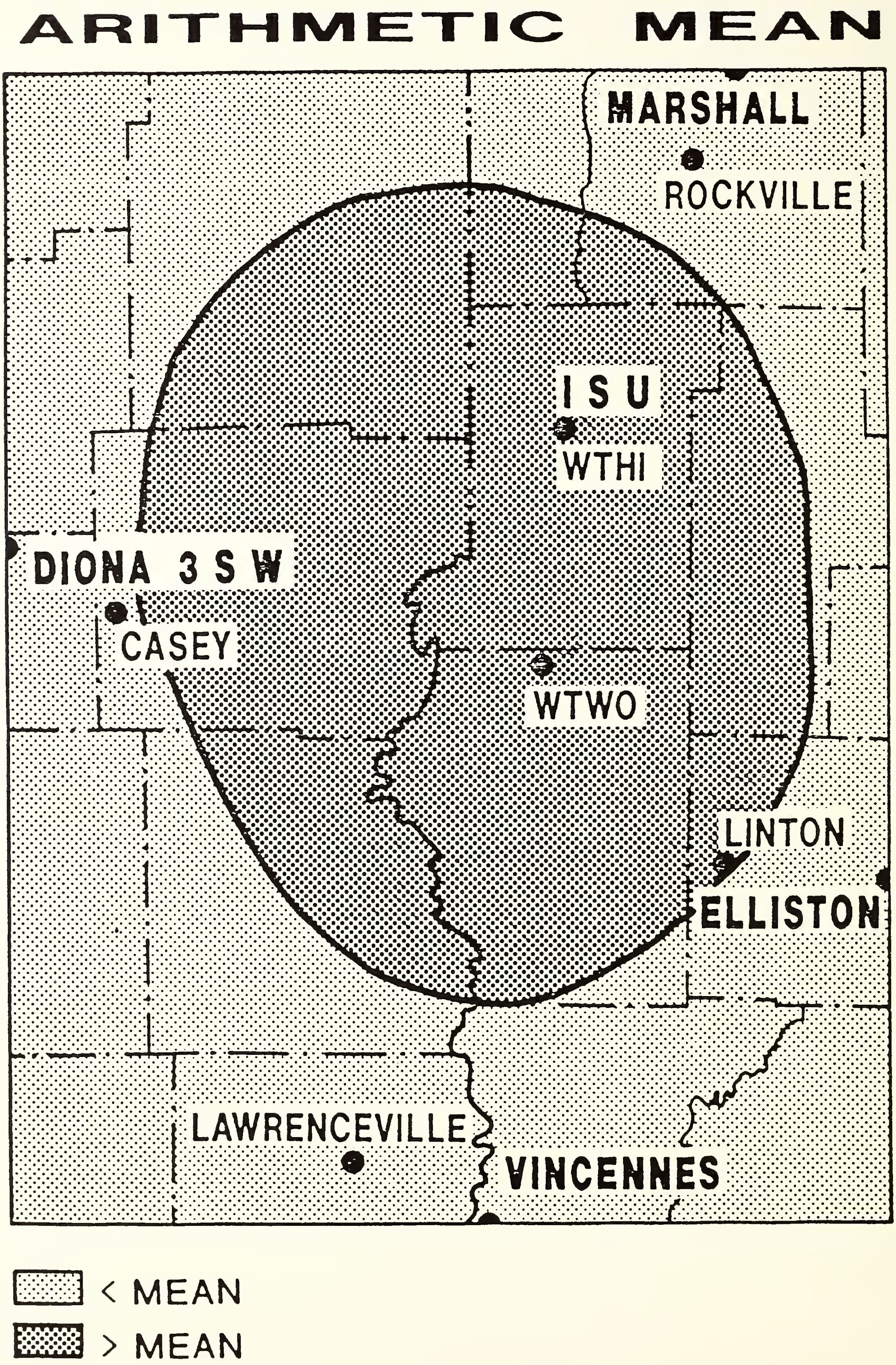

Figure 9. Distribution of Summer Precipitation Above and Below Mean. Mean = 7.3 inches. Dark Area in Center Above Mean. Area on Periphery Below Mean.

Table 1. Summary of Actual and Estimated Precipitation at Station Pairs and Algebraic Differences Using Thiessen Polygon Method. See Test for a Discussion of Real Differences.

Station Pairs	Location		June Actual	June Fcst	June Diff	July Actual	July Fcst	July Diff	August Actual	August Fcst	August Diff	Summer Actual	Summer Fcst	Summer Diff
Marshall	49.6	66.6	.46			2.26			4.14			6.86		
Rockville	47.1	61.6	.38	.46	.08	1.96	2.26	.3	1.26	4.14	2.88	3.6	6.86	3.26
Diona 3SW	07.5	39.2	.7			3.7			2.6			7		
Casey	14.0	35.3	.37	.7	.33	4.12	3.7	-.42	3.72	2.6	-1.12	8.21	7	-1.21
Vincennes	35.1	00.0	.52			4.34			1.94			6.8		
Lawrenceville	27.6	03.7	.58	.52	-.06	5.19	4.34	-.85	1	1.94	.94	6.77	6.8	.03
Elliston	58.7	20.0	.43			4.99			1.54			6.96		
Linton	49.0	20.9	.48	.43	-.05	4.7	4.99	.29	1.99	1.54	-.45	7.17	6.96	-.21
ISU	39.9	45.6	.39			7.36			.8			8.82		
WTWO	38.6	32.5	.31	.39	.08	8.26	7.63	-.63	1.02	.8	-.22	9.59	8.82	-.77
Total Diff					.38			-1.31			2.03			1.1

PRECIPITATION FORECASTS USING THE THIESSEN POLYGON METHOD.

Table 2. Summary of Actual and Estimated Precipitation at Station Pairs and Algebraic Differences Using Isoline Method. See Test for a Discussion of Real Differences.

Station Pairs	Location		June Actual	June Fcst	June Diff	July Actual	July Fcst	July Diff	August Actual	August Fcst	August Diff	Summer Actual	Summer Fcst	Summer Diff
Marshall	49.6	66.6	.46			2.26			4.14			6.86		
Rockville	47.1	61.6	.38	.445	.065	1.96	3.5	1.54	1.26	3.3	2.04	3.6	7.3	3.7
Diona 3SW	07.5	39.2	.7			3.7			2.6			7		
Casey	14.0	35.3	.37	.635	.265	4.12	4.43	.31	3.72	2.2	-1.52	8.21	7.3	-.91
Vincennes	35.1	00.0	.52			4.34			1.94			6.8		
Lawrenceville	27.6	03.7	.58	.545	-.035	5.19	4.45	-.74	1	1.95	.95	6.77	6.9	.13
Elliston	58.7	20.0	.43			4.99			1.54			6.96		
Linton	49.0	20.9	.48	.45	-.08	4.7	5.4	1.3	1.99	1.45	-.74	7.17	7.3	.13
ISU	39.9	45.6	.39			7.63			.8			8.82		
WTWO	38.6	32.5	.31	.45	.14	8.26	6.4	-1.86	1.02	1.06	.04	9.59	8	-1.59
Total Diff					.365			.55			.77			1.46

PRECIPITATION FORECASTS USING THE ISOHYETE METHOD.

Table 3. Ratios. Values <1 are Underestimations. Values >1 are Overestimations.

	Thiessen Ploygons June	Thiessen Ploygons July	Thiessen Ploygons August	Thiessen Ploygons Summer	Isoline Method June	Isoline Method July	Isoline Method August	Isoline Method Summer
Marshall Rockville	1.21	1.15	3.29	1.91	1.17	1.79	2.62	2.03
Diona 3SW Casey	1.89	0.90	0.70	0.85	1.72	1.08	0.59	0.89
Vincennes Lawrenceville	0.90	0.84	1.94	1.004	0.94	0.86	1.95	1.02
Elliston Linton	0.90	1.06	0.77	0.97	0.94	1.15	0.73	1.02
ISU WTWO	1.26	0.92	0.78	0.92	1.45	0.78	1.04	0.83

$$\frac{(((A1)(P1)) + ((A2)(P2)) + \ldots ((An)(Pn)))}{\text{Total Area}}$$

where A is the area of a polygon, and P is the precipitation measured at the central station of the polygon.

A similar value may be derived by determining the areas contained between isolines, and using the mean of the boundary isolines as a multiplying factor. Accordingly

$$\frac{(((A1)((P1+P2)/2)) + ((A2)((P2+P3)/2)) + \ldots ((An)((Px+Py)/2)))}{\text{Total Area}}$$

where A is the area between a pair of isolines, and (Pa + Pb)/2 is the precipitation mean between two adjacent isolines.

These weighted area means, together with the derived arithmetic mean are:

Thiessen Polygon	7.41 inches
Isoline Method	7.38 inches
Arithmetic Mean	7.28 inches

for the three month summer period. The differences between the values are insignificant.

Using these values, it is possible to obtain a map (Figure 9) showing areas that received precipitation greater or less than the areal average. The map shows an interesting pattern, in which precipitation greater than the study area mean is centered upon the Terre Haute urban area.

SUMMARY AND CONCLUSIONS

Data accumulated at the ISU Climatic Laboratory show that during the 1988 drought year the three summer months experienced rainfall extremes. It became increasingly difficult to estimate the amount of rainfall for neighboring locations. Estimates were thus acquired by interpolation of Thiessen Polygons and constructed isolines.

The efficacy of each method was tested by a simple ratio. Similar results were obtained, although at one location both modes of estimation varied significantly from the actual rainfall. The polygon-derived values probably were biased due to the proximity of stations used in testing the forecast amount.

Using both methods, the average rainfall for each of three summer months was derived for the study area. The derived values are used to identify areas that recorded precipitation more or less than the aerially weighted mean.

LITERATURE CITED

Bruce, J.P. and R.H. Clark. 1980. Introduction to Hydrometeorology. Oxford: Pergamon Press. p. 106-111.

Changnon, S.A. September 1989. "The 1988 Drought, Barges, and Diversion." Bulletin of the American Meteorological Society 70 (9):1092-1104; Soule, P.T. and V. Meentemeyer, May 1989. "The Drought of 1988: Historical Rank and Recurrence Interval" Southeastern Geographer. 29 (1):17-25.

Fairbridge, R.W. and J.E. Oliver. 1987. "'Iso'Terms" The Encyclopedia of Climatology. Ed. Oliver, J.E. and R.W. Fairbridge. New York: Van Nostrand Reinhold Company. p. 520-521.

Hammond, R. and P.S. McCullagh. 1978. Quantitative Techniques in Geography: An Introduction. Oxford: Clarendon Press.

Muller, R.A. and R.C. Thompson. 1987. "Water Budget Analysis." The Encyclopedia of Climatology. Ed. Oliver, J.E. and R.W. Fairbridge. New York: Van Nostrand Reinhold Company. p. 914-920.

Oliver, J.E. 1979. Climate and Man's Environment. New York: John Wiley & Sons, Inc. p. 37-38.