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An Approach to the Development of Isohyetal Maps for Mountainous Areas

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Abstract. A technique was developed in which anomalies from precipitation-elevation relationships were used in preparing isohyetal maps of Utah. October-April and May-September precipitation normals (averages for the 1921 to 1950 period) were computed for all available Utah precipitation records. The double-mass analysis technique was used in the derivation of the October-April normals, and for this purpose the state was separated into eight climatic divisions. Relationships between precipitation and water equivalent of snow cover at a network of 29 stations were used in estimating normal October-April precipitation for snow courses located above 8000 feet. The May-September precipitation values for short-term stations were adjusted to the 1921–1950 period by the ratio method. The state was divided into 20 geographic zones, and for these zones it was found that good correlations existed between precipitation and station elevation for both the October-April and May-September periods. The precipitation-elevation relationships showed marked differences for some adjacent areas separated by high mountain ranges. From combined data for several zones, general precipitation-elevation curves for larger areas were obtained and departures of individual station normals from these curves were plotted on a contour base map. Analysis of these anomalies showed that the departures were related to physiographic features. Normal May-September and October-April values were determined for a grid of points over the state by using the anomaly pattern and general precipitation-elevation relationships. These values, together with the observed and adjusted normals, were used to locate the October-April and May-September isohyetals. The large variations in normal precipitation due to topography were taken into account, yet the general precipitation-elevation relationships for small zones were retained. The accuracy of the isohyetal maps is considered comparable to that obtained by presently known methods, and the technique is less time consuming.

INTRODUCTION

Isohyetal maps of good quality are not available for most of the intermountain area of western United States, and the lack of such maps is one of the problems confronting those who are interested in mountain hydrometeorology. The purpose of this paper is to show how precipitation-elevation relationships and precipitation anomalies may be used in the development of isohyetal maps of Utah. This technique is especially useful in mountainous areas where precipitation is related to physiographic features. Since the isohyetal maps discussed in this paper were prepared, some of the concepts used have been described in a brief paper by *Dawdy and Langbein* [1960].

In the preparation of isohyetal maps for western Colorado, *Russler and Spreen* [1947] demonstrated the use of coaxial-graphical procedures in correlating precipitation averages with physiographic features, and the same general technique was used by *Hiatt* [1953] in the development of similar maps for northern Arizona. These maps are considered to be quite accurate, but they cover only a small portion of the mountainous western United States.

The coaxial-graphical procedures which are frequently used in preparation of isohyetal maps require considerable time and experience for best results. Often used as a parameter in these studies are 'zones of environment' such as major river basins. Use of such large areas may cause difficulty in estimating precipitation along the borders of adjacent zones because of the abrupt change in relationship from one zone to another.

Previous investigators found that consideration should be given to seasonal precipitation patterns. In Utah, as in western Colorado, October through April is generally the snow-accumulation period and the season when the movement of storms is principally from the west or northwest [*Russler and Spreen*, 1947]. During the late spring, summer, and early fall (May through September), Utah receives most of its moisture from the south or the southwest. During the October–April period, at the same elevation, precipitation is greater on the western slopes of the Wasatch Mountains than on the eastern slopes. In the May–September period, the distribution of precipitation is more uniform. Isohyetal maps were prepared for each seasonal period, October–April and May–September, and were combined to produce an annual map.

Source of Data

Precipitation records from approximately 300 stations, published primarily by the U. S. Weather Bureau, were used in this study. Included were records from a large number of precipitation stations at high elevations which have been established in Utah since 1952 by the Soil Conservation Service and the Weather Bureau. The snow surveys made by the Soil Conservation Service are another source of data. Collectively, these records provide what is considered one of the best networks of basic precipitation data for any mountainous area in the western United States.

Methods of Determining Normals

Base period. In developing an isohyetal map it is necessary to reduce, or adjust, all precipitation data to a common period. The World Meteorological Organization has defined normals as 'period averages computed for a uniform and relatively long period comprising at least three consecutive ten-year periods.' In this study all data were reduced, or adjusted, to the 30-year period 1921–1950. This corresponds to the 1921–1950 normal period used by the U. S. Weather Bureau from 1951 through 1960.

Precipitation normals. The double-mass analysis procedure as described by *Linsley, Kohler, and Paulhus* [1949] was employed in deriving October–April normals for precipitation stations. The state was separated into eight climatic divisions for determining the precipitation bases for the double-mass analyses. October–April normals were determined for stations having records for less than 30 years (usually 5 years or more of consistent data) by double-mass slope ratios. In a few cases, normals were derived for stations having records for less than 5 years in areas of sparse data.

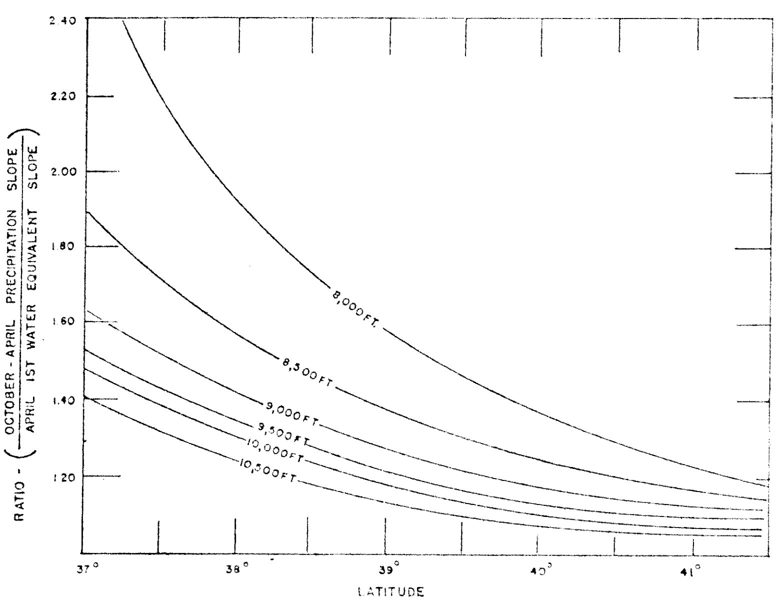

Fig. 1. Graph for use in estimating normal October-April precipitation for Utah snow survey stations above 8000 feet.

TABLE 1. Precipitation Normals in Utah, Based on April 1 Snow Survey Data

Station	Elevation	Latitude	Longitude	October-April	
				Normal*	Yrs. of Record
Barnard Creek	8000	40 57	111 50	31.4	24
Ben Lomond Peak	8000	41 22	111 56	41.3	9
Black Fork	9200	39 02	111 28	18.3	13
Blacksmith Fork	8400	41 36	111 28	15.3	8
Brown Duck Lake	10300	40 36	110 32	22.5	14
Chalk Creek #1	9100	40 52	111 03	27.6	9
Clear Creek Ridge #1	9200	39 51	111 17	20.6	5
Coop Flat	9500	37 35	113 01	25.1	19
Dills Camp	9200	39 03	111 28	17.0	11
Donkey Reservoir	9800	38 13	111 29	10.1	6
Duck Creek RS	8560	37 31	112 42	21.3	25
Ed Ward Flat	8300	37 46	112 47	14.2	16
Farmington Canyon (Upper)	8000	40 58	111 48	34.2	9
Fish Lake	8700	38 30	111 46	12.3	29
GBRC Meadows	9860	39 18	111 27	28.6	30
Hayden Fork	9300	40 46	110 52	19.6	8
Huntington Horseshoe	9800	39 37	111 19	24.3	30
Indian Canyon	9100	39 54	110 45	13.4	30
Jackson Park	11300	40 38	110 19	18.6	5
Johnson Valley	8850	38 37	111 39	9.7	5
Kimberly Mine (Lower)	8300	38 29	112 24	20.3	23
Kings Cabin (Lower)	8600	40 43	109 32	13.1	30
Lakefork Mountain #2	8900	40 34	110 22	11.4	7
Lakefork Mountain #3	8100	40 33	110 22	9.0	7
La Sal Mountain	8800	38 29	109 17	14.6	29
Merchants Valley	8200	38 19	112 26	17.9	29
Midway Valley	9700	37 33	112 51	31.7	6
Monte Cristo GS	8960	41 28	111 30	30.6	27
Mosby Mountain (Lower)	9500	40 36	109 54	14.2	29
Mount Baldy	9500	39 08	111 31	28.0	9
Mount Logan	9000	41 44	111 43	36.0	35
Mount Ogden	8600	41 12	111 53	30.2	12
Otter Lake	9300	38 19	112 22	21.7	24
Parrish Creek	8000	40 57	111 49	30.9	7
Redden Mine (Upper)	9000	40 41	111 13	23.3	26
Redden Mine (Lower)	8500	40 41	111 13	23.1	30
Rocky Basin Settlement Canyon	8900	40 27	112 13	29.4	6
Seeley RS #2	10000	39 19	111 26	19.4	29
Spring Hollow (Upper)	8000	41 44	111 41	29.8	35
Squaw Springs	9300	38 30	112 00	12.5	5
Strawberry Divide	8000	40 10	111 14	27.4	26
Switchback	8600	39 36	111 14	23.2	5
Tony Grove Lake	8200	41 54	111 39	44.2	32
Wrigley Creek	9000	39 08	111 21	14.6	5
Yankee Reservoir	8700	37 45	112 47	13.9	16

* Adjusted to 30-year period (1921–1950).

May–September normals for stations having complete records from 1921–1950 were obtained by averaging the precipitation for that period, if the record was believed to be consistent. For stations that did not have a complete record, the normals were computed by the 'ratio method'; i.e., a ratio factor for each incomplete station record was determined by comparison with a nearby station for which May–September normals were available. This factor, when multiplied by the May–September normal for the nearby station, gives a normal value for the station with the incomplete record. It is known that precipitation ratios between high- and low-

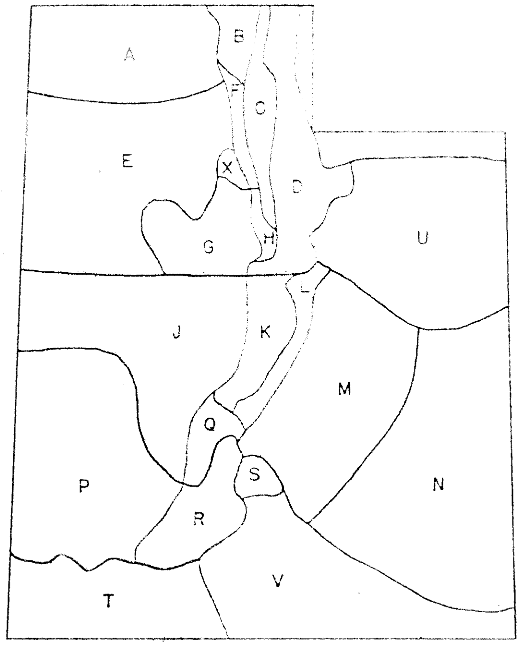

Fig. 2. Precipitation zones of Utah.

elevation stations may not be the same for different periods. For this reason, the May–September normals were derived from records of stations at comparable elevations and similar exposures whenever possible. Stations having at least 10 years' May–September data provided fairly consistent values; those having less than 10 years' data appeared to be less reliable. The October–April and May–September adjusted normals for all precipitation stations have been tabulated.[1]

Snow-survey station normals. Records from 29 stations measuring both winter precipitation and water equivalent of the snow on the ground as of April 1 were used to develop a procedure for estimating October–April normals for snow-survey stations above 8000 feet. The 8000-foot elevation was selected to avoid the high winter melting that occurs below this level. The April 1 water equivalent values at the snow courses were accumulated and plotted against the precipitation bases used in the double-mass analysis for precipitation records. The ratios of the double-mass slopes for the October–April precipitation to those for the snow-survey data, as measured at the same location, were related to latitude and elevation (Fig. 1). The orientation or direction of slope of the snow course is also significant in determining the ratios between precipitation catch and water equivalent of the snow course. The relationship was improved when courses having a southerly slope were assigned a positive correction of 0.12 to the computed ratio. On the other hand, courses having north and northwest exposures required a negative correction of approximately 0.12, limited by the condition that the corrected ratio would not be less than the ratio at 10,500 feet for the same latitude. The average error for the procedure was less than 10 per cent of the average October–April precipitation. This method was used to determine October–April normals for the remaining snow-survey stations above 8000 feet when a consistent slope was indicated on the double-mass curves (Table 1).

Base Map

For water resources and other hydrologic studies, isohyetal maps fitted to a large-scale contour map are desirable. Sectional aeronautical charts, as published by the Coast and Geodetic Survey, were used as a base map in this study. These charts have a scale 1 : 500,000, which is the same as the latest U. S. Geological Survey map for Utah.

Copies of the full-scale isohyetal maps are available, and the Utah Water and Power Board is planning to have the isohyetal maps printed as overlays on the U. S. Geological Survey base map for Utah. For maximum accuracy and most efficient utilization, isohyetal maps should be used in conjunction with the base map used in the development procedure.

Preliminary Investigations

Previous work (unpublished) on the development of an isohyetal map for the Wasatch Front area near Salt Lake City, Utah, completed by the Water Supply Forecast Unit of the Weather Bureau showed that, for limited geographic areas, elevation accounted for a major portion

[1] This table has been deposited as Document 6953 with the ADI Auxiliary Publications Project, Photoduplication Service, Library of Congress, Washington 25, D. C. A copy may be secured by citing the document number and by remitting $1.25 for photoprints, or $1.25 for 35-mm microfilm. Advance payment is required. Make checks or money orders payable to: Chief, Photoduplication Service, Library of Congress.

of the variation in normal October–April precipitation values. A similar study was made of elevation-precipitation relationships for all of Utah. This was accomplished by dividing the state into twenty zones, and it resulted in good precipitation-elevation relationships for the individual zones. The division into zones was primarily based on the October–April precipitation-elevation relationships, but the same divisions were later found to be applicable to the May–September period. Brief descriptions of each zone, including a discussion of the physiographic features that might account for the differences in the precipitation-elevation relationships, are listed below. A map of the zones is shown in Figure 2.

Description of Precipitation Zones

Zone A. A generally flat area in which there are several small north-south mountain ranges. Bordered on the northwest by the Raft River Mountains and on the east by the relatively low northern section of the Wasatch Front.

Zone B. Cache Valley area of northern Utah. Low mountain range on the western side with a major range running north-south to the east.

Zone C. Eastern slopes of the main Wasatch Range. To the leeward of the Wasatch Range during the winter period.

Zone D. The high valleys to the east of the Wasatch Range and the upper drainages of the Weber, Provo, and Duchesne river basins.

Zone E. The Great Salt Desert area (including southern portion of Great Salt Lake). Area lies west of the high Wasatch Front between Salt Lake City and Ogden and includes the area west of the north-south ranges southwest of Salt Lake City.

Zone F. Western slopes of sharp face of the Wasatch Range from Salt Lake City to north of Ogden, Utah.

Zone G. Utah Lake and other smaller valleys. Sheltered from the west by north-south ranges of 11,000-foot peaks and bordered on the east by the Wasatch Range near Provo, Utah.

Zone H. Western slopes of the Wasatch Front to the east of Utah valley. Sheltered from the west by the Oquirrh mountain range.

Zone J. Area includes the western slopes of the San Pitch and Pavant ranges and includes the western desert area.

Zone K. Interior valley of San Pitch River, in-

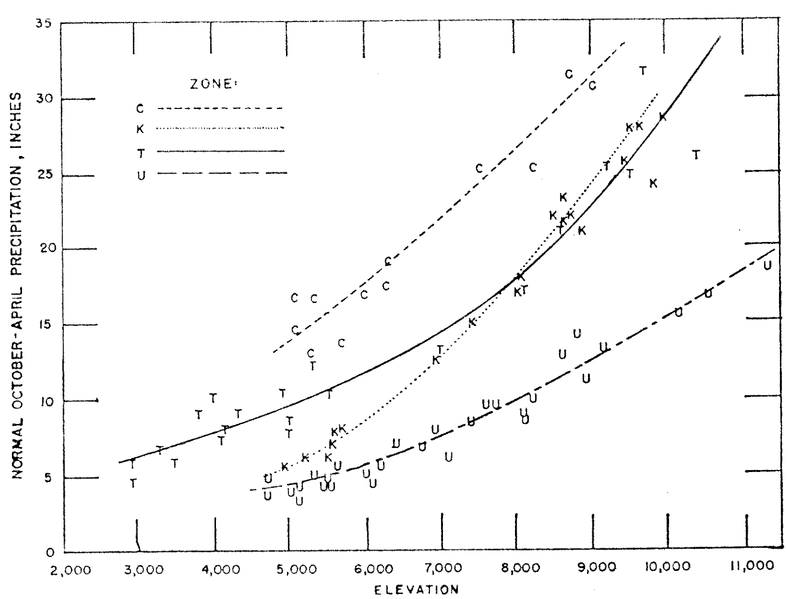

Fig. 3. October-April precipitation-elevation relationships, zones C, K, T, and U.

TABLE 2. Statistical Data for Precipitation Relationships for Twenty Zones in Utah

Zone	October-April						May-September					
	No. of Cases	Avg. Error	% Avg.	Est. Std. Error	% Avg.	$\bar{R}^2$	No. of Cases	Avg. Error	% Avg.	Est. Std. Error	% Avg.	$\bar{R}^2$
A	10	1.2	8.7	1.4	16.1	0.51*	9					
B	14	1.5	7.8	3.5	18.1	0.88	8					
C	12	1.4	7.0	1.6	8.0	0.92	9					
D	29	2.2	13.3	2.8	16.9	0.79	13	0.9	14.5	1.0	16.1	0.38
E	39	1.1	11.4	1.4	14.6	0.88*	31	0.5	11.1	0.6	13.3	0.77*
F	28	2.9	11.9	3.5	14.4	0.85	17	0.5	7.0	0.6	8.4	0.83
G	21	0.8	9.3	0.9	10.5	0.85*	17	0.3	6.5	0.4	8.7	0.63*
H	10	0.7	4.4	0.8	5.1	0.98	9					
J	22	1.6	14.9	2.0	18.7	0.89	18	0.6	13.3	0.8	17.8	0.79
K	19	0.8	4.4	1.4	7.7	0.96	12	0.6	9.4	0.9	14.1	0.80
L	20	1.1	15.3	1.3	18.1	0.91	13	0.7	15.0	0.9	19.1	0.57
M	11	1.1	6.2	1.4	7.9	0.73	3					
N	13	0.8	10.8	1.0	13.5	0.89	11	0.4	8.9	0.5	11.1	0.88
P	18	1.1	13.8	1.8	22.5	0.87	15	0.4	8.5	0.6	12.8	0.92
Q	9						7					
R	14	0.9	10.0	1.1	12.2	0.93	10	0.5	9.8	0.7	13.7	0.18
S	3						2					
T	21	1.4	10.5	2.0	15.0	0.93	18	0.5	9.6	0.7	13.5	0.93
U	32	0.7	8.3	0.9	10.7	0.95	20	0.6	9.1	0.7	10.6	0.95
V	5						4					

* Not precipitation-elevation relationship.

cluding the western slopes of the high Wasatch plateau. Sheltered from the northwest by the San Pitch Mountains.

Zone L. Higher eastern slopes of the Wasatch plateau. On the leeward side during the general winter storms and parallel to the summer storm paths.

Zone M. Lower valleys on western drainage of the Green River. To the east of the high Wasatch plateau of central Utah.

Zone N. Area east of Colorado River, north of the San Juan River, and south of the Roan plateau. Dominated by two large mountain areas—the LaSal and Abajo mountains.

Zone P. Escalante valley of southeastern Utah, including the western slopes of the Markagunt plateau and the western slopes east of Beaver, Utah.

Zone Q. Interior valley of the central Sevier basin with major north-south mountain ranges to both the east and west.

Zone R. Valleys of the upper Sevier River basin. East-northeast of the Cedar Breaks area and north of Bryce Canyon National Park.

Zone S. Upper valley of the Fremont River, including the Fish Lake valley. Area sheltered by at least 9000-foot mountain ranges in all directions.

Zone T. Virgin River basin of Utah. Crest of west-east mountains through Cedar Breaks National Monument forms the northern boundary of the area.

Zone U. Uinta basin of eastern Utah, but not including higher western drainages. Bounded on the south by the comparatively low Roan plateau and on the north by the massive east-west oriented Uinta Mountains.

Zone X. Small area including most of Salt Lake County. During the winter, storms which move into the area from the west to northwest are apparently not affected by the blocking of the Oquirrh Mountains, and the October–April normals fit the relation for zone E. During the May–September period it appears that zone X is under the same general topographic influences as zone G.

Relationships of Precipitation to Topography

Figure 3 shows sample plottings of the October–April precipitation-elevation relationships which were developed for all except the northwest area of the state (zones A, E, F, G, and X). These plottings show that elevation accounts for most of the variation in normal precipitation. The average error and estimated standard error with percentage of average precipitation for each of the relationships are shown in Table 2. The estimated coefficient of correlation $\bar{R}$ for each relationship was computed. In these computations lost degrees of freedom were assumed to be 2 for linear relationships and 3 for curvilinear. The coefficients of determination $\bar{R}^2$ are listed in Table 2, indicating the proportion of the variance in precipitation accounted for by elevation. For the relationships of precipitation against elevation the proportions vary from 0.73 to 0.98, averaging 0.89 for the October–April period.

Wilson [1954] showed that measurements of precipitation in the form of snow are deficient when the gage is subject to strong wind action. A few precipitation records from stations at snow-survey sites had average October–April totals of less than the average April 1 water equivalent of the snow on the ground. In these cases the snow-survey data were used for computing the average October–April value for the location if the snow-course exposure indicated that the course was relatively free from snow accumulation by drifting. A few other high-level precipitation station records were discarded when it became known that the gage site was exceptionally windy.

Previous investigators, especially those working with precipitation-elevation relationships along the western coast of the United States, have shown that the rate of change of annual precipitation with elevation may decrease with continued increase in elevation. At higher elevations the actual amount of precipitation sometimes decreased with height. A review of the precipitation records indicates that this might have been partially the result of using data from gages subject to reduction in catch by strong wind action. In this study no evidence was found of a decrease in the winter precipitation (October–April) rate of change with height.

For zone F, 'effective' elevation rather than actual elevation of stations was used in the relationship. The previous unpublished study on the Wasatch Front showed that average precipitation was better correlated with 'effective elevation' than with station elevation. Because the major Wasatch Mountains lie on a line perpendicular to the normal storm tracks, the actual lifting effects on the air mass above a station in zone F may be related to the sur-

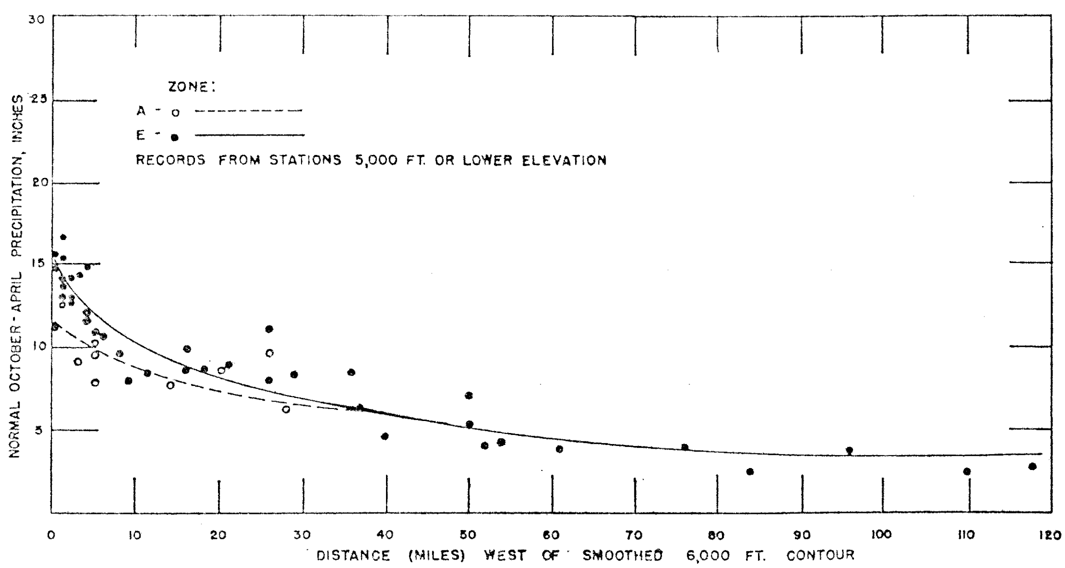

Fig. 4. Relationship of October-April precipitation and distance west from smoothed 6000-foot contour of Wasatch Front, zones A and E.

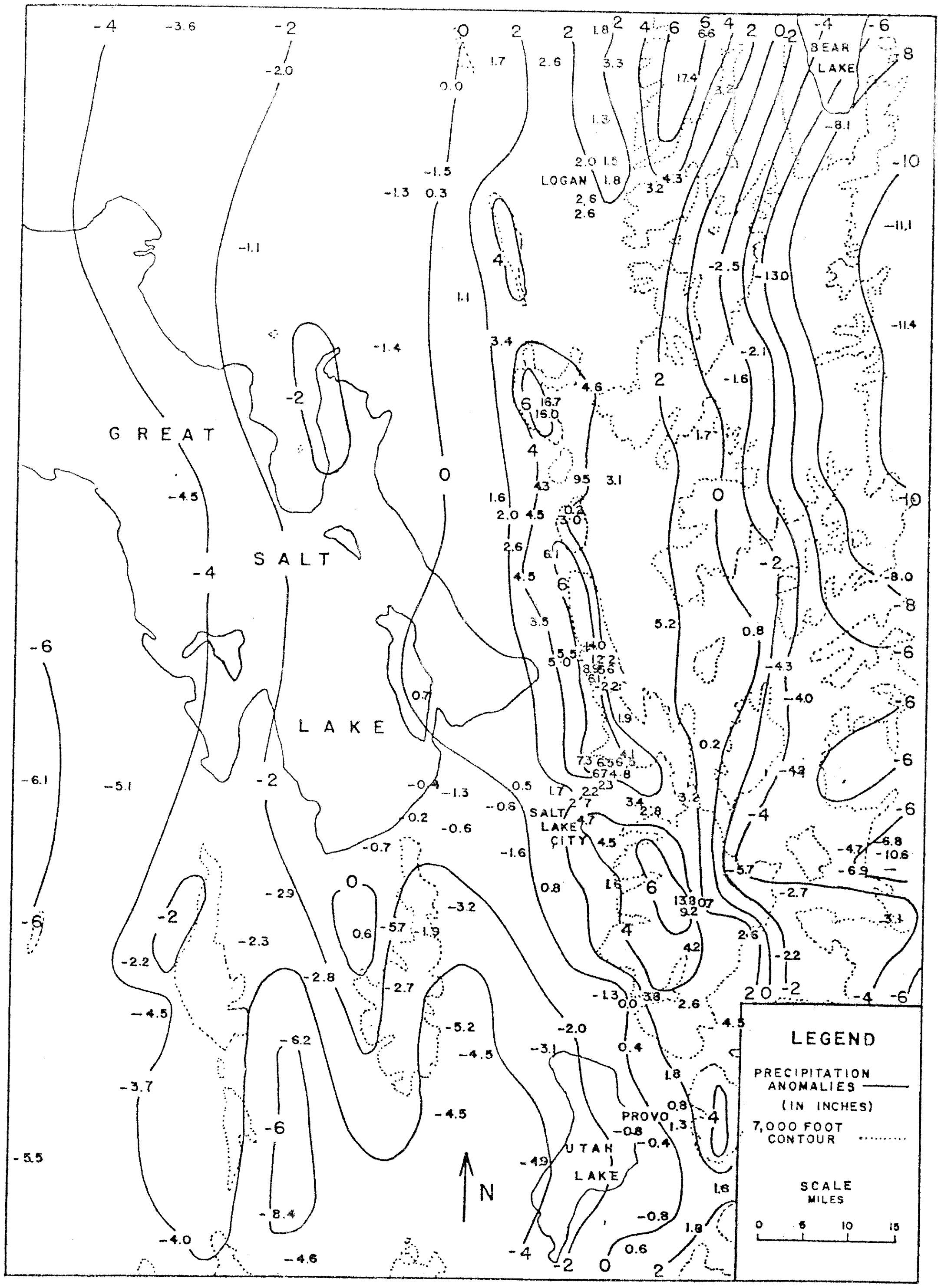

Fig. 5. Analysis of anomalies from mean October-April precipitation-elevation curve, Wasatch Front area of Utah.

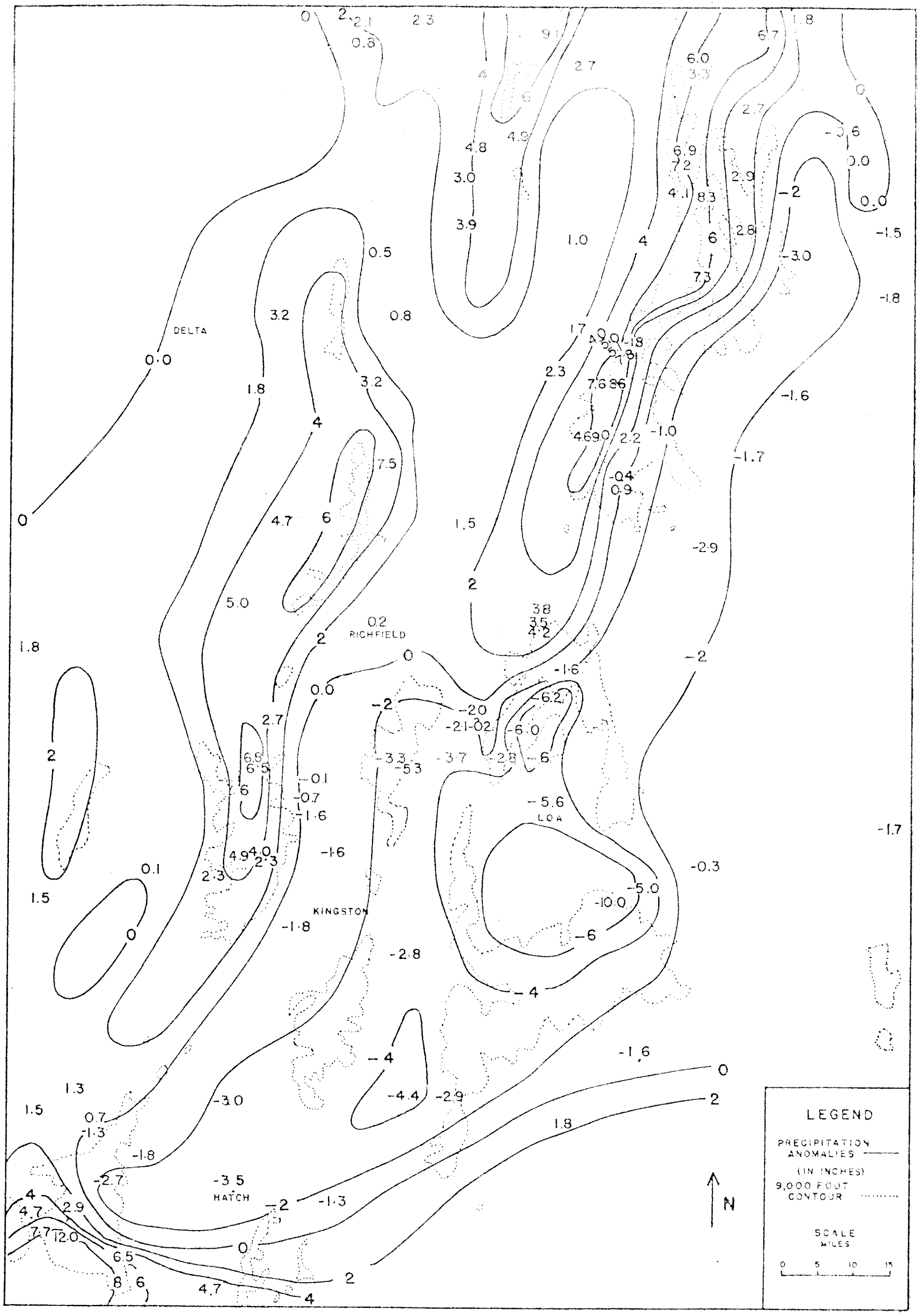

Fig. 6. Analysis of anomalies from mean October-April precipitation-elevation curve, central area of Utah.

rounding terrain. 'Effective' elevation was determined by averaging the elevations of 8 points of the compass at a distance of 1.5 miles from the station. The improvement in the use of 'effective' elevation in zone F was small for the average error, but it reduced the standard error by 25 per cent. Nowhere else in the area has 'effective' elevation been found to be so important.

Because of the generally flat terrain in the Great Salt Lake basin of northwest Utah, precipitation normals were not plotted against elevation for zones A, E, G, and X. Figure 4 shows the October–April precipitation plotted versus the distance west of the smoothed 6000-foot contour along the western base of the Wasatch Front for zones A and E. October–April precipitation for zone E has an average value of approximately 16 inches at the 6000-foot contour along the Wasatch Front; for zones A and G it is somewhat less. The higher values for zone E apparently are due to the large mountain range to the east in the area from Salt Lake City to Ogden. There is a possibility that a small part of the total precipitation is due to the location of the Great Salt Lake. The Oquirrh and Stansbury mountains to the west of zone G act as an effective block, thereby reducing precipitation in this zone. The general curve for zones A and E was drawn to fit data from stations apparently not affected by smaller mountain ranges. Several values for stations about 20 to 30 miles west of the Wasatch Front are located above the curve and are for locations near small ranges. In general, the effects of the Wasatch Mountains on increasing precipitation are observed for about 40 miles westward for zones A and E and only 20 miles for zone G. Detailed investigations of these relationships might provide some information for model studies of the effects of mountains on precipitation.

Anomalies

The precipitation-elevation and other relationships discussed above could be used for estimating precipitation within the various zones, but discontinuities would exist along the borders of the zones. Investigation of the precipitation-elevation curves showed that many of them had similar characteristics; that is, they were approximately parallel. It was possible to combine data for several zones into one relationship for a larger section of the state. Four of these large area relationships were used—Wasatch Front, Uinta, southwest Utah, and southeast Utah. Mean curves for these combined relationships were drawn, and anomalies (in inches) from the curves were computed for each station. Care had to be exercised in the construction of mean curves to insure that they were representative of the general slope of the curves of the individual zones. If the mean curve was not approximately proportional or parallel to each of the zone curves, inconsistencies in the anomaly pattern might result. After the relationships for the four large areas were determined, the original zones had no real function in this procedure. However, it is believed that they should have value as climatic indicators.

The anomalies from the mean curves were plotted on a base map. The values were found to be related to the general physiographic features, and a smooth pattern of isolines could be constructed as shown for the Wasatch Front area in Figure 5. A study of this map shows that the departure lines are generally parallel to the Wasatch Front. The isolines are more closely packed to the east of the summit of the Wasatch Range southeast of Salt Lake City, and have wider spacing behind the lower mountains south of Logan. The general decrease from +2 inches to −6 inches from the Wasatch Front to the western edge of the map reflects the general relationship shown for zones A and E in Figure 4. The effects of the Oquirrh Mountain Range (west-southwest of Salt Lake City) on precipitation is well demonstrated by the 5-inch decrease from west to east.

Another example of the October–April anomaly patterns is shown in Figure 6. This chart is for the central area of Utah, which is traversed by two generally large mountain ranges oriented NNE–SSW, with a west-east range along the southwest border. The anomaly lines are generally parallel to the mountain ranges and show the large effect of the mountains. The −6-inch anomaly line near Loa shows the effect of the almost complete encirclement of that area by high mountain ridges. The general pattern of tight spacing to the east of large mountain masses and wider spacing to the east of smaller mountain ranges is again observed. The large rate of change of the anomalies in the Cedar Breaks area in the southwest corner of the map is an indication of the higher precipitation with

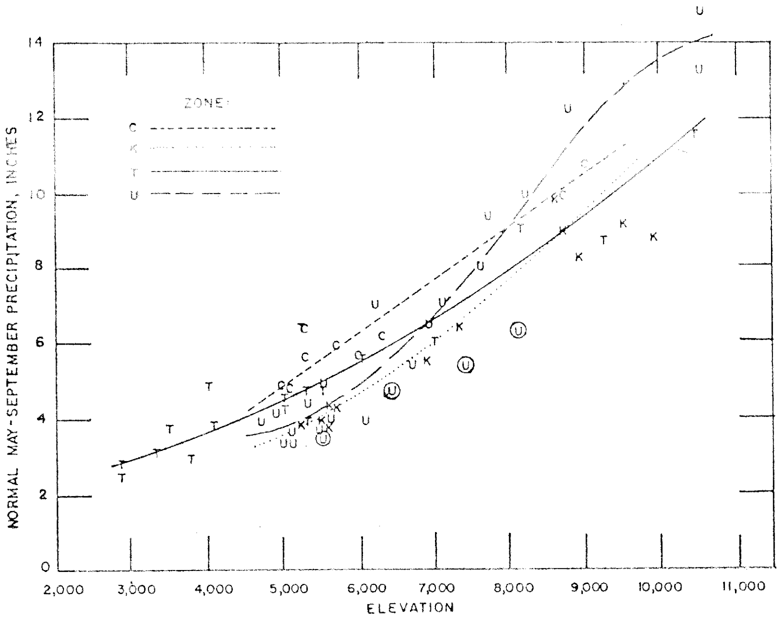

Fig. 7. May-September precipitation-elevation relationships, zones C, K, T, and U.

respect to elevation for the areas with southern exposure in the extreme southwest Utah. The higher precipitation to the south of Cedar Breaks National Monument is derived from storms, centered principally over Arizona, which do not extend north of the major mountain range. From the spacing of the anomaly lines, a 1000-foot rise to the south apparently changes the precipitation relationship substantially with respect to elevation. The map for central Utah covers several precipitation zones which can be detected by a study of the anomaly lines. It is evident that there are transition areas which would be difficult to define by precipitation zones alone. The analysis of the anomalies provides a means of estimating precipitation in both the well-defined zones and the transitional areas.

The principal reason for separating the state into the four large areas was that the precipitation-elevation curves for individual years tended to be grouped into four different areal patterns. To provide consistency in the analysis when changing from area to area, additional precipitation-elevation relationships were developed from data along the borders of adjacent areas. In the procedure outlined above large variation in normal precipitation values due to topography are allowed for, yet the general elevation-precipitation relationships found for the precipitation zones are retained, provided that care is used to insure that the mean curves are approximately proportional or parallel to the individual curves.

Preparation of Maps

All computed October-April normals were plotted on a base map. The anomalies of the large and overlapping areas were used with the mean curves to compute values for a grid of points on the base map. The analysis of the isohyetal lines was based on these data and on the use of the precipitation-elevation relationships. Because of the large variation in precipitation in the mountainous areas, a variable isohyetal spacing was selected.

The May-September precipitation-elevation relationships were developed for the same zones as in the October-April period. In general the relationships, samples of which are shown in Figure 7, were found to be nearly as good as those for October-April. Statistical computations for the May-September relationships are also given in Table 2.

The coefficients of determination for the May-September relationships of precipitation against elevation vary from a low of 0.18 for zone R to 0.95 for zone U. The average was 0.72. It is

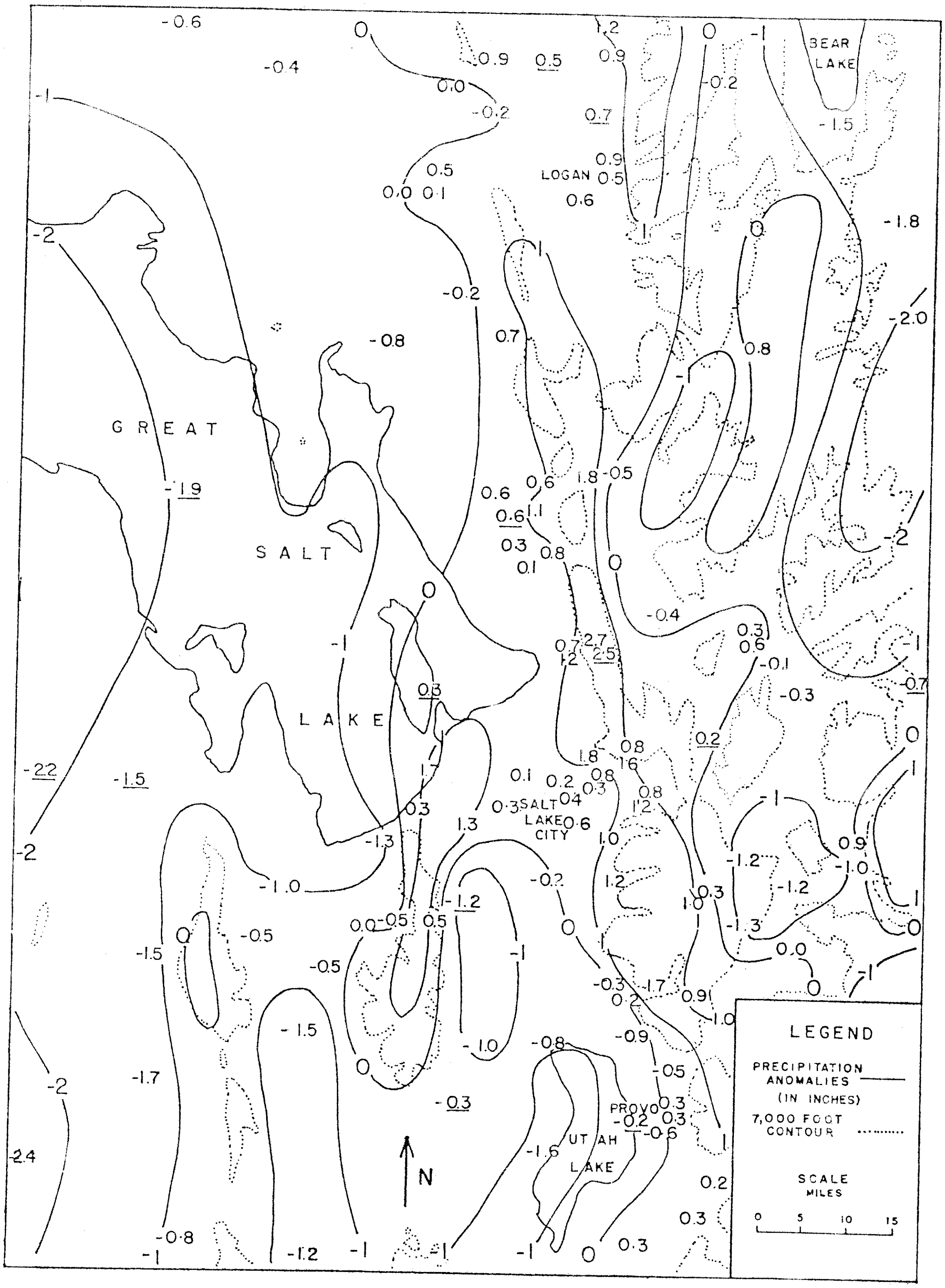

Fig. 8. Analysis of anomalies from mean May-September precipitation-elevation curve, Wasatch Front area of Utah.

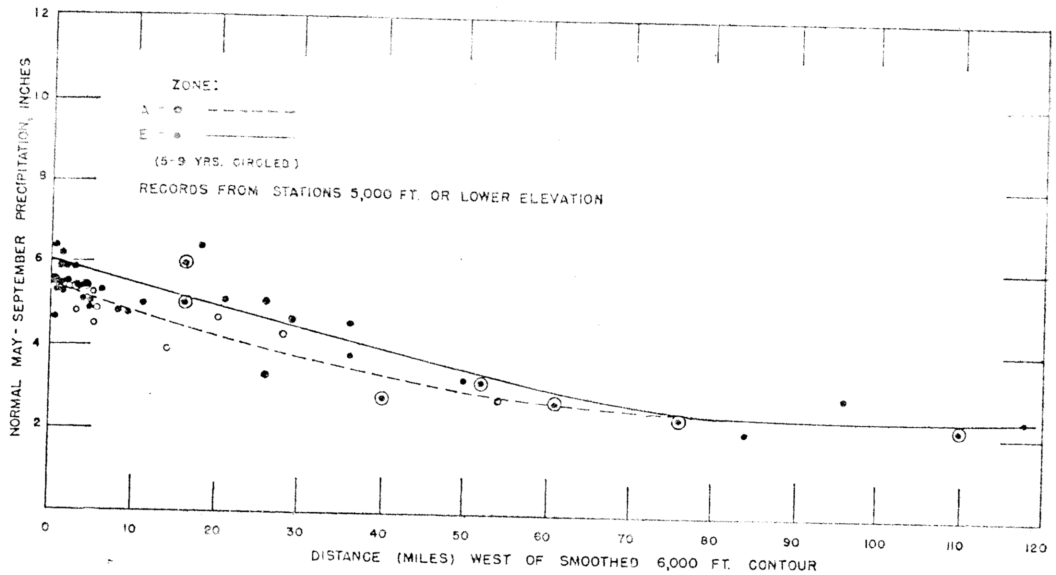

Fig. 9. Relationship of May-September precipitation and distance west from smoothed 6000-foot contour of Wasatch Front, zones A and E.

evident that the relationships are not as good as those found for the October–April period, but they indicate that a high amount of the variation in the May–September precipitation is accounted for by elevation.

The relationship for the Uinta basin area (Fig. 7) has two interesting points. The mean curve for this relationship has been drawn as an S curve. This is the only relationship which tends to indicate that the precipitation rate of increase with height shows a decrease with higher elevations. The four plotted points for the Hill Creek area (circled) show a much smaller rate of increase than for the remainder of the basin, even though this area tended to fit the general curve of the October–April relationship. One explanation would be the location of these stations on the general north slopes of the Roan plateau, and therefore they do not receive the same amount of convective precipitation as those at similar elevations on the southern slopes of the Uinta Mountains.

Analyses of May–September anomaly maps were made for the same areas as in the October–April period and, in general, these showed as consistent a pattern as those for the winter period. The anomaly patterns for both periods were similar except that the magnitude of changes was smaller for May–September. This would be expected, however, because the normals for May–September for most areas are less than those for October–April. An example of the May-September anomaly analysis for the Wasatch Front area is shown in Figure 8.

Figure 9 shows the May–September normals versus distance west from the Wasatch Front 6000-foot contour. A comparison of the relationships for areas A and E shows a much flatter curve for May–September than for October–April. The May-September normals for stations up to 40 miles west of the Wasatch Front are more dependent upon the effects of the mountains to the south than upon the distance west of the Front. The decrease in May–September normals for those stations more than 60 miles west of the Front may reflect the absence of major mountain ranges to the south.

The map for the May–September period was prepared in a manner similar to that followed in preparing the October–April map. A 2-inch precipitation interval was used for the isohyetal lines; however, in areas with less than 4 inches of precipitation, lines were drawn for each inch.

The annual map was prepared by graphical addition of the October–April and May–September maps. As a final check, the isolines of the annual map were compared with the combined normals for each station. Isohyetal intervals for the annual map are the same as those for the October-April map.

Conclusions

The precipitation-elevation relationships for the various zones indicate that elevation accounts for a large portion of the variation of normal precipitation if the zones are limited to relatively small areas having similar physiographic features. The use of the anomalies to estimate precipitation values helps to eliminate abrupt changes that might result from the use of 'zones of environment.' A principal advantage of the anomaly procedure is the reduced time required for the preparation of isohyetal maps as compared with the method used by *Russler and Spreen* [1947]. When many data are available, a combination of the techniques of the coaxial-graphical and anomaly analysis might produce the best results.

Experience in developing the map for Utah has shown that there is some danger in applying anomaly analysis without a fairly thorough knowledge of the precipitation-elevation relationships in the area being studied.

In analyzing the anomaly maps, areas with deficient data are readily recognized, and this knowledge may be used in determining the locations and spacing of stations for a network that would provide needed information for the development of future isohyetal maps.

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