PRECIPITATION PATTERNS OF THE COLORADO BASIN

Eugene L. Peck[1]

It is indeed a pleasure to have the opportunity of meeting with you today and to briefly discuss precipitation patterns of the Colorado River basin. I have always felt that there were many additional factors about precipitation, our basic source of water, that we should investigate more fully if we are to make maximum use of this most important natural resource. In addition to development of isohyetal maps, or maps showing long-term average precipitation, and related procedures which I plan to discuss today, we are also studying relationships of upper-air and topography parameters to distribution of precipitation for six- and twelve-hour intervals. In between these two extremes are many phases that still need study, including frequency and intensity relationships, especially for mountainous areas.

From our studies to date, we know that the distribution of precipitation over the Colorado Basin varies considerably from one type of storm to another and from season to season. In general, during the winter frontal type storms move into the Colorado Basin from the west and northwest bringing precipitation mainly to the northern portion of the basin. The heaviest precipitation over the basin often occurs during storms that do not have frontal systems associated with them. These storms are what we refer to as "closed low" or "cold low" types, which are due to closed

[1]Hydrologist in Charge, Water Supply Forecast Unit,
U. S. Weather Bureau, Salt Lake City, Utah

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circulation in the upper troposphere. These upper-air circulations may move into the Colorado Basin from any direction from south to north, but predominately from the west. They also quite frequently originate over the southern area of Nevada. These closed-low type storms are often associated with a general uplifting of the air mass that is not caused by the topography. Thus, they cause widespread precipitation with very heavy amounts over the lower elevations. In addition, these storms last longer (one to three days) than those that result from the frontal systems alone. In some cases the frontal systems may be associated with a closed low aloft and the precipitation distribution reflects both types of storms.

Over most of the Colorado Basin, the summer storms occur in moist flows from a southerly direction usually originating from the Gulf of Mexico. The predominate storm type is thunderstorm which may occur singly or over wide areas.

During the past few years, we have prepared maps showing average precipitation values (called isohyetal maps) for many areas of the Pacific Southwest. Those including portions of the Colorado Basin are listed below:

Area Covered	Publication
State of Utah	By State of Utah
Colorado River Basin above Lees Ferry	By USGS in technical report on Upper Colorado Study
Lower Colorado River below Davis Dam (west of 113°30" west longitude)	By USGS in technical report on Lower Colorado Study
State of Arizona	Nearly complete, no definite plans for publication

Maps for the first three areas mentioned are to be published as overprints on 1 to 500,000 contour bases, but none are in published form at the present time. Maps for three periods, October-April, May-September and annual have been prepared for each area.

As background for what I will show today, I would like to briefly explain the methods used in the development of these maps. The first step is to check on the consistency of the available records and to develop normals or average precipitation values for a selected period. Most maps are prepared using averages for the 30-year period ending with the last even decade. Averages for such 30-year periods have been designated as "normals" by the World Meteorological Organization.

The double-mass analysis technique, as developed by Linsley and Kohler (1949), is used for checking the consistency of precipitation records and for extrapolating normal values when the record is shorter than the period being used. There is not sufficient time to explain the entire technique today, but the general basis is the assumption that the October-April precipitation records in a homogeneous area are linearly related. By examining precipitation records in the Colorado Basin (excluding New Mexico), we find that approximately 19 homogeneous areas are apparent. Figure 1 shows these precipitation base areas as used for the double-mass analysis. The areas shown here are more or less climatological subdivisions which are mainly determined by the topography features of the basin. However, when average precipitation values are plotted against station elevation for each area, we find that further subdivision of the areas may greatly improve the correlation between average precipitation values and station elevations. In a recent paper describing the anomaly technique (Peck and Brown 1962), it was shown that twenty such small divisions were required for the State of Utah alone; however, the number of subdivisions is determined to some extent by the density of the precipitation network. Many earlier publications have indicated that elevation alone accounts for approximately 30 per cent of the variation in precipitation. The paper quoted shows that from 80 per cent to 96 per cent of the variation in average precipitation is accounted for by elevation when the small areas are considered separately, for the October-April period

When areas which had similar relationships between precipitation and elevation were grouped together, plotted values of the departures (or anomalies) from a mean curve for the group were found to be related to the topography of the area. Separate curves were used for the October-April and May-September periods. In the Colorado Basin covered by development of isohyetal maps (all but the New Mexico and old Mexico areas), one of these large groupings was used for the drainage area in Wyoming, three for Colorado, three for Utah, but only one was required for the entire state of Arizona. Precipitation-elevation relationships for the small areas in Arizona were found to be approximately linear and parallel in contrast to the curves for other areas of the basin. Separate analyses were made for the winter (October-April) and summer (May-September) periods since the storm types and paths are different for the two seasons and therefore the relationship with topography may be different. Figure 2 shows the anomaly analysis from a mean October-April precipitation-elevation curve for the Green River Basin in Wyoming. The solid lines are departures or anomalies in inches from the mean curve. A line labeled as "plus 6" indicates that the precipitation as measured at the stations along the line is six inches higher than the mean curve would indicate for their elevation above sea level. The dotted lines are the location of the 8,000 foot contour to indicate the general topography of the area. A study of the analysis provides some insight into the climatology of the region and into the relationship of precipitation distribution to topography. Winter storms generally move into the area from the west or northwest and the large plus values along the Wyoming Range on the western side of the Green River basin show the carryover effects. Values for stations at the same elevation on the western or windward side of the Wyoming Range would be even higher. As you move northward along the Wyoming Range towards the northern tip of the basin, the values steadily decrease and become negative along the Wind River Range on the eastern side of the basin. This reflects the blocking effect of the larger mountains to the west. For approximately the same elevation, the actual precipitation would be from 15 to 18 inches greater on the western side of the basin as compared to the eastern side. However, total October-April precipitation over the Wind River Range is greater than over the Wyoming Range since the elevation of the range is much greater. Even if one did not have a knowledge of the general storm paths in the basin, it would be fairly evident from the anomaly patterns.

Since it would be difficult to see plotted values on maps of this scale, the values were not entered. However, it has been found that the analyses may be drawn with what appears to be very good consistency and accuracy. In some cases where it is known that a station does not provide a good index of the actual precipitation, such as a mountain top station subject to strong wind effect, the data, if used, will depart from the general pattern. It should be mentioned that the basic data used in the analyses included October-April normal values as computed or extrapolated from precipitation records and as estimated from snow survey data about 8,000 feet using a procedure described in the paper by Peck and Brown (1962).

As a second example to illustrate precipitation patterns, I have selected the zone covering the northwest section of Colorado State. (Figure 3) Again, the solid lines are equal lines of departure values, the dotted line in this case shows the 9,000 foot contour and the dashed line the extent of the Colorado River Basin. The winter storms in this area also move into the area primarily from the west and northwest and the blocking effect of the more westerly mountain ranges (Park Range in the north, White River Plateau in the central portion of the area and the northern edge of the Grand Mesa to the south) are clearly demonstrated by the change from large positive values in the west to negative values along the main continental divide over the higher drainages of the Colorado Basin. For approximately the same elevation, precipitation is nearly eight inches higher over the western mountain ranges. When the mountain range is large and massive as for the White River plateau, the anomaly lines are more tightly packed downwind, while the decrease in values to the east at lower elevations is much more gradual.

The anomalies for the October-April period for Southeast Arizona are shown in Figure 4 (4,000 foot contour is shown by the dotted lines). In Arizona a large portion of the precipitation occurs with the "closed low" type of storm, but, in general, the direction of movement is from the west. This example was included to demonstrate that even small mountain ranges play an important part in determining the variation in precipitation. The small, generally north-south ranges along the Mexican border are reflected in the rapid changes from positive to negative anomaly values as you move from west to east. The height and mass of the mountain range determine the effect on the downwind ranges while the magnitude of the departure lines depends upon these and general meteorological factors such as the direction of movement of average storms, distance from moisture source, relation to larger mountain ranges, etc. As an example of the latter cause, precipitation is relatively light over western Nevada because it is in the lee of the Sierra and probably has general downward movement aloft over the area. In Eastern Nevada, precipitation amounts are relatively greater even though you are farther from the moisture source of the Pacific Ocean, but probably are in an area of more general lifting. On the map we may again see the gradual decrease in values as you move eastward from Tucson behind the mountain ranges. Figure 5 shows the major effect of the Mogollon Rim on the precipitation distribution in Arizona. High positive values are evident along the rim, while quite large negative values are shown over the Little Colorado River basin. The valley area of the Little Colorado Basin has negative values ranging from minus four to minus seven which is the result of the area being generally surrounded by higher terrain.

As an example of the patterns found for the May-September departures, a map for Southeast Arizona is shown in Figure 6. Some values on this map have been drawn to the nearest half inch. It may seem strange, but the analyses for the May-September period are more consistent with the basic data than those for October-April. However, the relationship of May-September precipitation to elevation is generally not as good. This may be explained by the fact that the May-September storms are generated to a large degree by the lifting provided by the mountains with the storms moving out over the valley areas. It is certain that the paths which the storms follow are somewhat consistent since they are determined to a large extent by the wind direction and speed aloft and these are known to be fairly consistent. The patterns on the May-September analyses clearly show that the patterns do extend northward from the mountain masses even though we still retain some of the west-east variations observed on the October-April analyses. These patterns may be defined to a very fine degree when sufficient data are available. This may be seen in the small negative area east of Phoenix which has low elevation country to the south while values to the immediate west and southwest of Phoenix are slightly positive as a result of the small hills to the south and southwest. This is the reverse of the pattern found for the October-April period where the anomalies increased from west to east reflecting the lifting effect of the mountains to the east on incoming easterly moving storms.

Time has not permitted a detailed explanation of the use of the anomaly maps. There are several additional values for data that may be determined from the patterns. It is hoped that the effect of mountain barriers on precipitation distribution might be determined more objectively. Such information would be of value in determining what the precipitation should be in ungaged areas and also might have value in determining the physical aspects of mountain barriers on precipitation distribution. In preparing the analyses of the anomaly patterns, it is very evident where data are inadequate to define the precipitation pattern for the area. This provides a method for determining what additional precipitation measurements are needed to define the isohyetal maps.

References

Linsley, R.K., Kohler, M. A. and J. L. H. Paulhus, Applied Hydrology, McGraw-Hill Book Company, New York, 1949.

Peck, E.L. and M.J. Brown, An Approach to the Development of Isohyetal Maps for Mountainous Areas, Journal of Geophysical Research, Vol. 67, No. 2, February 1962.

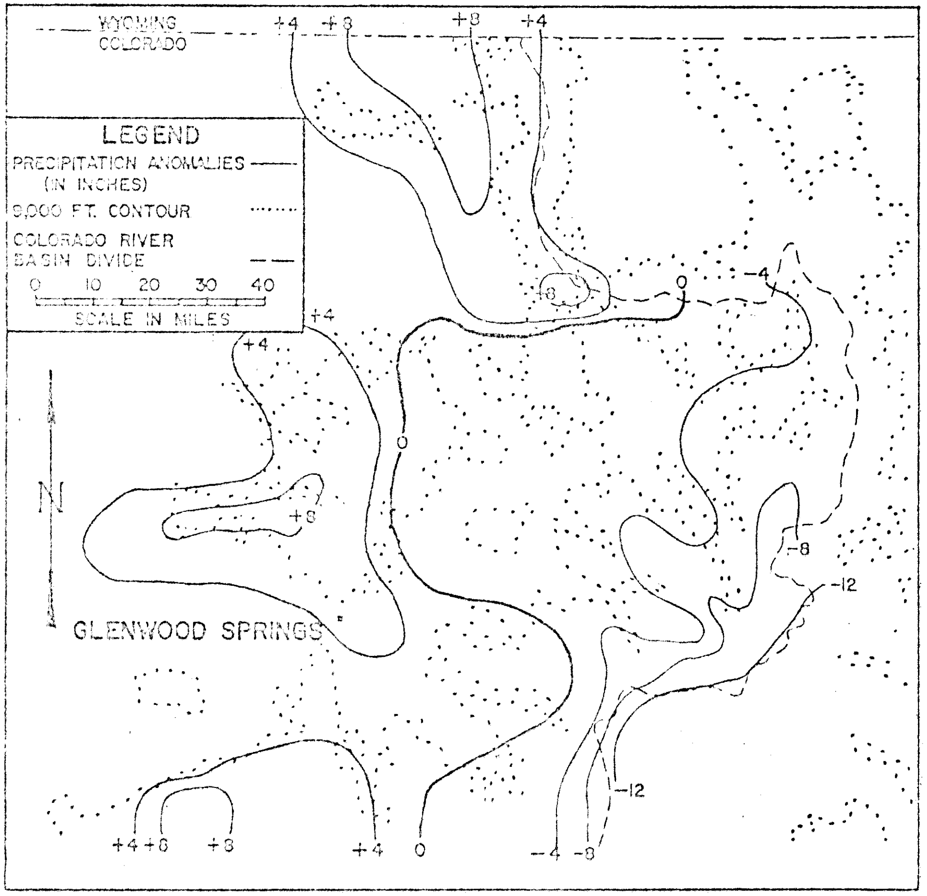


FIG. 3 ANALYSIS OF ANOMALIES FROM OCTOBER—APRIL PRECIPITATION-ELEVATION CURVE, COLORADO RIVER BASIN, NORTHWEST COLORADO

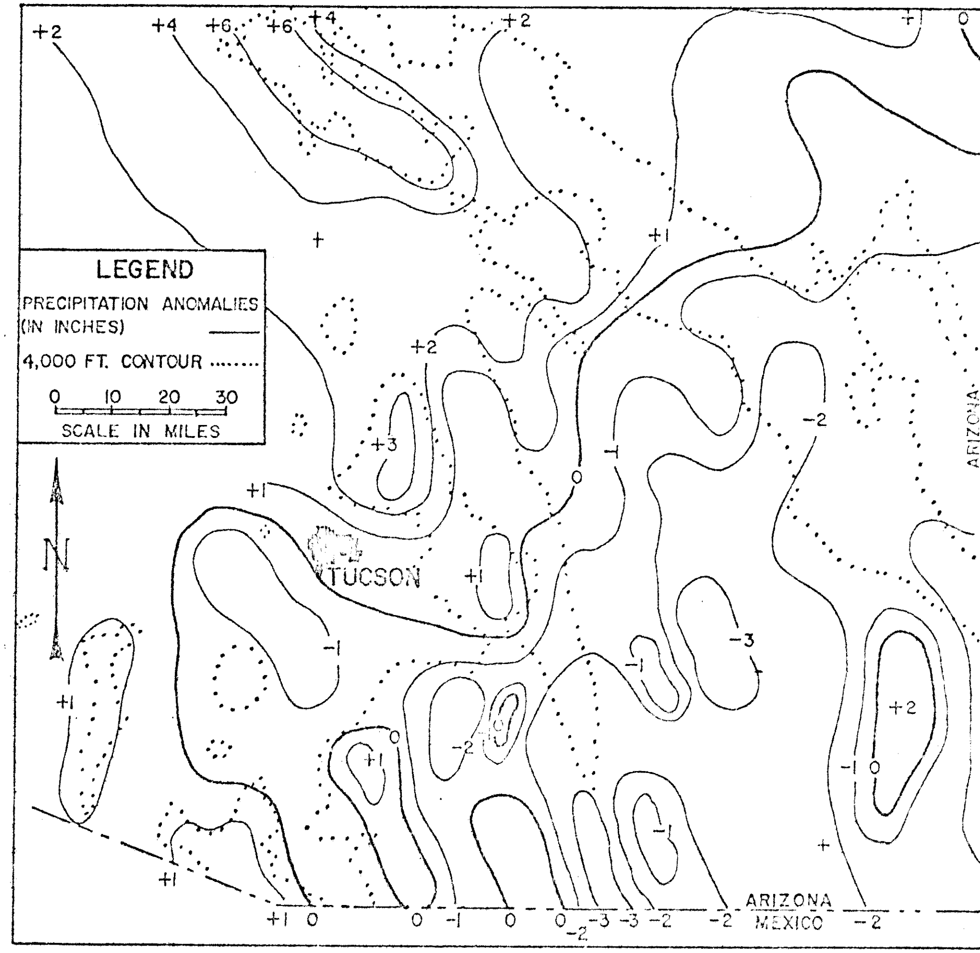
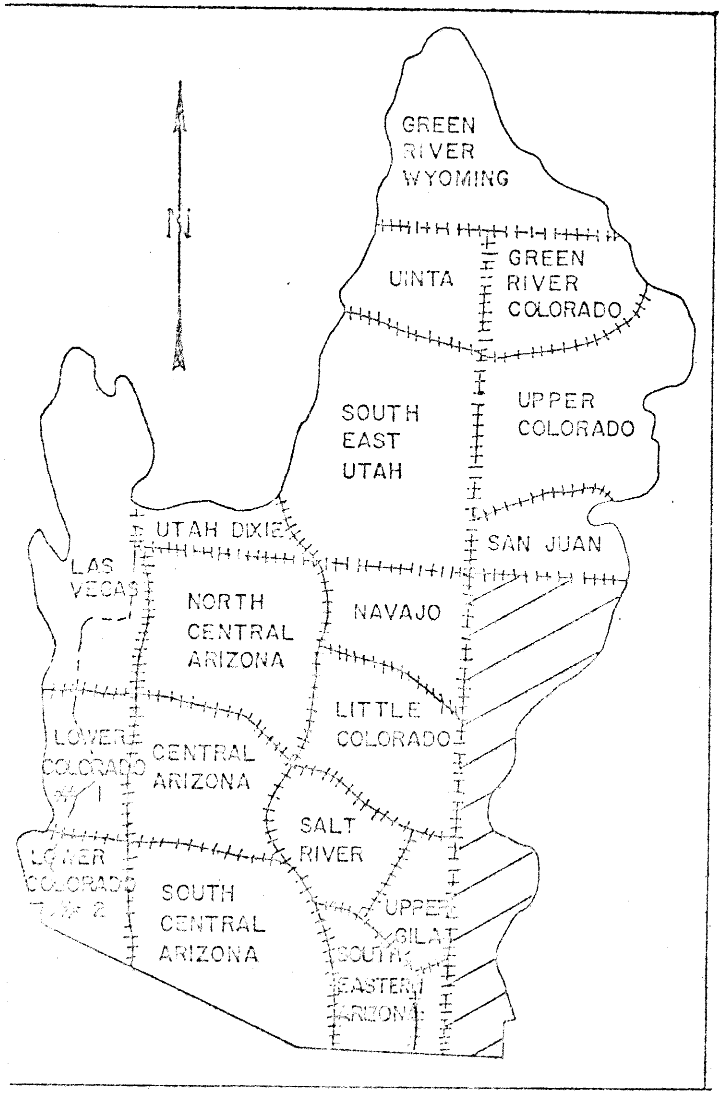


FIG. 4 ANALYSIS OF ANOMALIES FROM OCTOBER—APRIL PRECIPITATION—ELEVATION CURVE, SOUTHEAST ARIZONA



G. I PRECIPITATION BASE AREAS, COLORADO

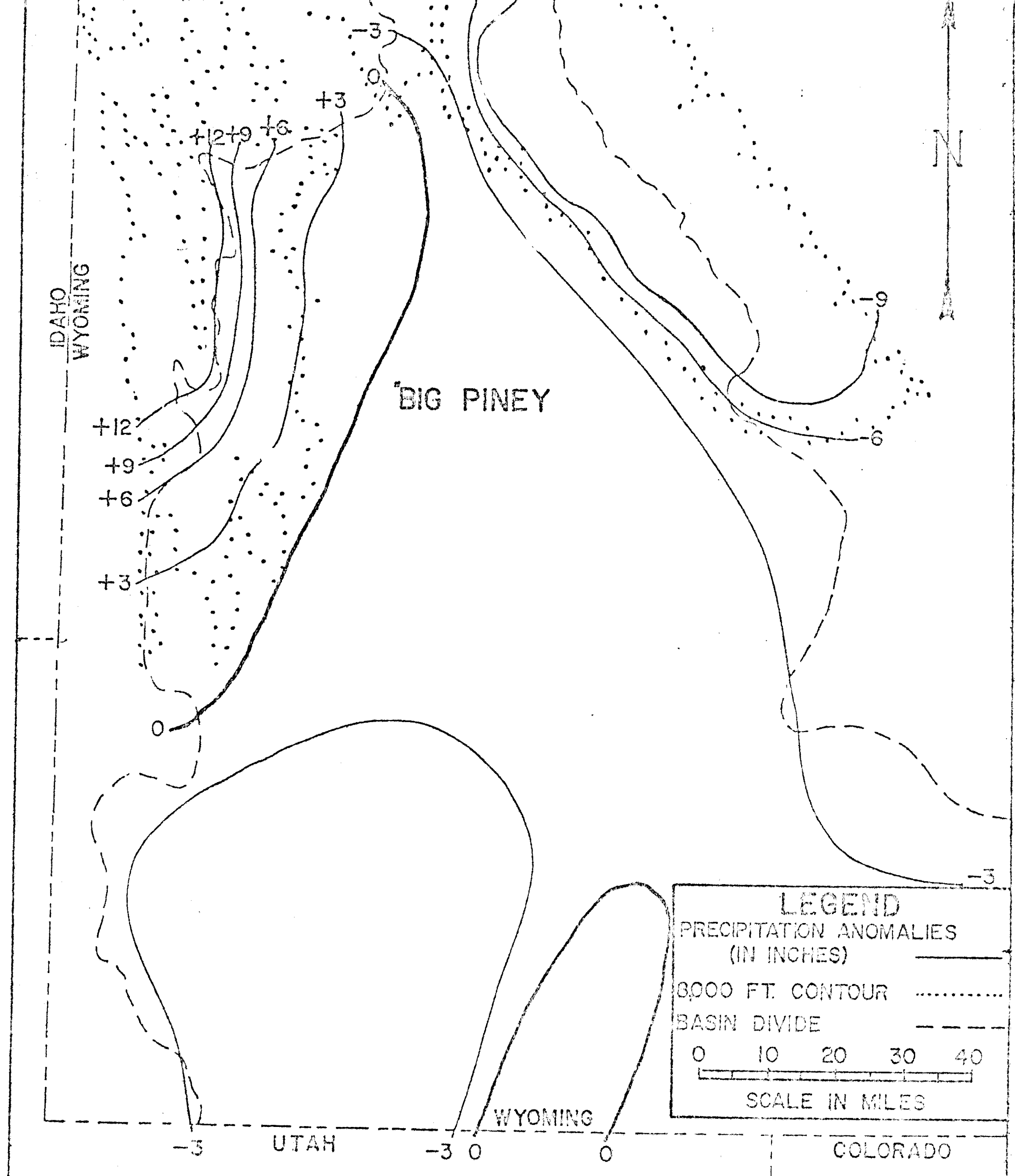


FIG. 2 ANALYSIS OF ANOMALIES FROM OCTOBER-APRIL PRECIPITATIO

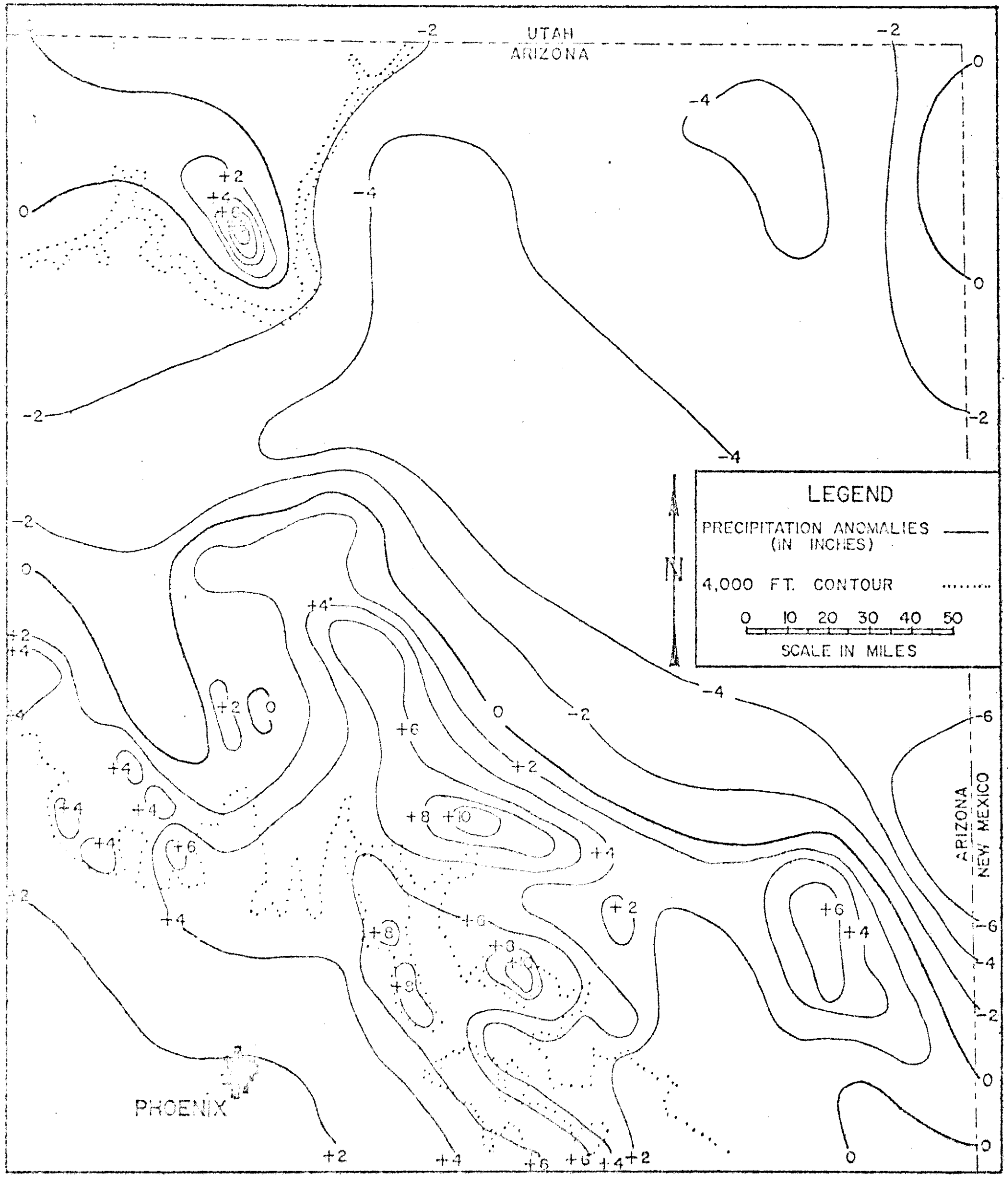


FIG. 5 ANALYSIS OF ANOMALIES FROM OCTOBER–APRIL PRECIPITATION–ELEVATION CURVE, COLORADO RIVER BASIN, NORTHEAST ARIZONA

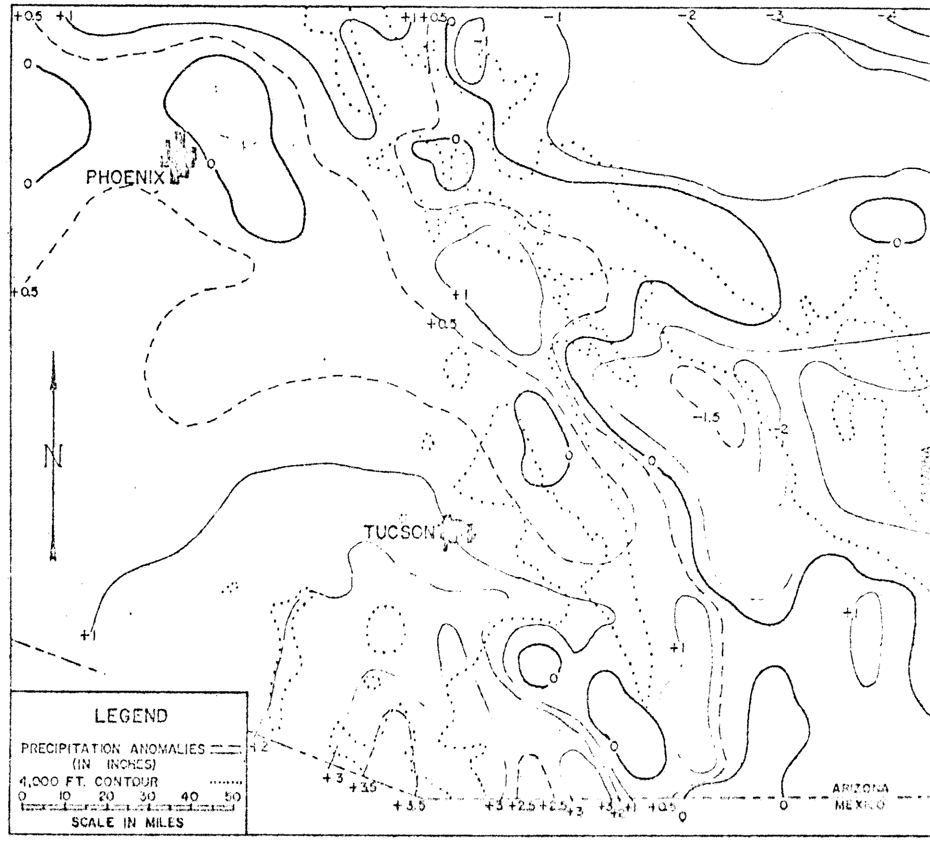


FIG. 6 ANALYSIS OF ANOMALIES FROM MAY–SEPTEMBER PRECIPITATION–ELEVATION CURV
SOUTHEAST ARIZONA