Estimating Precipitation in Mountainous Regions

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Introduction

Such conventional methods as the inverse-distance weighing technique have proved only partially successful in estimating annual and seasonal point precipitation in mountainous regions. Several investigators have suggested solutions to this problem, but in most cases, the solutions have been restricted to specific areas and conditions. Isopluvial maps of 6-hr and 24-hr precipitation have been prepared by the National Weather Service for each of the 11 western states (7), and these maps are helpful in many cases. However, problems of scale can lead to significant errors for specific stations or watersheds because of local differ-

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ences in aspect and elevation. There is a need for a coordinated effort to develop more generalized methods of estimating annual and seasonal precipitation in mountainous areas.

Related Studies

French (4) developed separate precipitation relationships for southern Nevada for excess stations, which were open to the flow of moist air from the south, and deficit stations, which were in the shadow of the Sierra Nevadas. Tung (8) optimized parameters in developing a linear program to estimate precipitation on the eastside of the Sierra Nevadas. Other researchers have reported on the correlation between precipitation and elevation, as well as the phenomena of "wet" and "dry" stations in the same region and at similar elevations. However, the excess and deficit stations are generally correlated with aspect, barriers between the station and the principal source of moisture, and distance from the principal source of moisture, as well as elevation. For example, Diskin (2) found that, in Israel, annual precipitation and elevation were correlated, but that precipitation and latitude were more highly correlated. Hanson et al. (6) reported that the precipitation-elevation relationship for a mountainous watershed in Idaho was strongly influenced by whether the gaging stations were on the "westside" (wet) or "eastside" (dry) of the watershed.

Evaluations

Data from Green (5) were used to analyze annual and seasonal precipitation-elevation relationships in Arizona. The study indicated a strong linear correlation between precipitation and elevation, and an equally

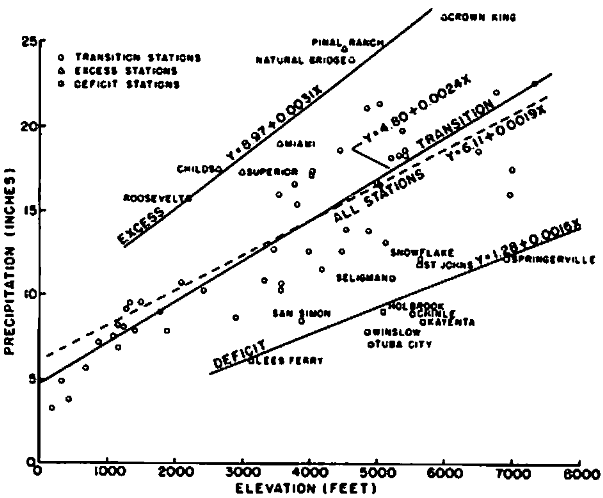

FIG. 1.—Correlation of Annual Precipitation with Elevation for Selected Arizona Stations

strong indication of excess and deficit stations at similar elevations (Fig. 1). The excess stations are all located in central Arizona, south of the Mogollon Rim, and are "open" to the southerly flow of moisture. The deficit stations are mostly north of the Mogollon Rim, in northeastern Arizona, although there are other deficit stations in the "shadows" of mountain ranges.

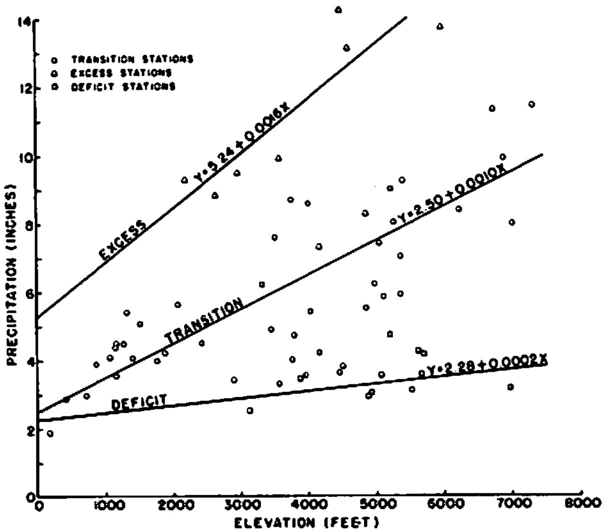

FIG. 2.—Correlation of Winter Precipitation with Elevation for Selected Arizona Stations

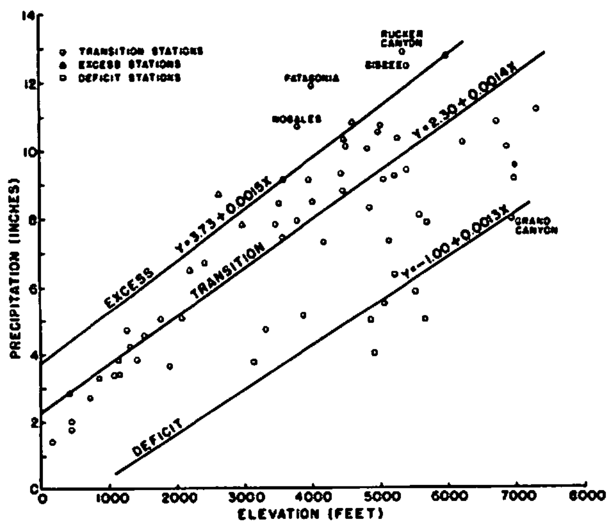

FIG. 3.—Correlation of Summer Precipitation with Elevation for Selected Arizona Stations

TABLE 1.—Effect of Elevation on Precipitation Based on Linear Regression

Location	Winter			Summer			Annual		
	a	*b*	*r*	*a*	*b*	*r*	*a*	*b*	*r*
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Nevada									
Excess stations							0.62	0.0020	0.89
Deficit stations							3.45	0.0004	0.62
Transition stations							1.97	0.0010	0.64
All stations							0.91	0.0013	0.67
Arizona									
Excess stations	5.24	0.0016	0.97	3.73	0.0015	0.97	8.97	0.0031	0.97
Deficit stations	2.28	0.0002	0.35	-1.00	0.0013	0.79	1.28	0.0016	0.75
Transition stations	2.50	0.0010	0.76	2.30	0.0014	0.88	4.80	0.0024	0.89
All stations	3.34	0.0007	0.44	2.78	0.0012	0.75	6.11	0.0019	0.65
Santa Catalina									
Duckstein et al.				2.2	0.0010	—			
Batten & Green				1.2	0.0011	—			
Walnut Gulch									
USDA-ARS	2.3	0.0003	0.40	5.0	0.0006	0.44	7.3	0.0009	0.46
Alamogordo Creek									
USDA-ARS	0.5	0.0005	0.60	2.8	0.0013	0.67	3.3	0.0018	0.71

Note: $y = a + bx$; y = precipitation in inches; and x = elevation in feet.

A breakdown between winter precipitation (Fig. 2) and summer rainfall (Fig. 3) indicates that the slopes of the linear regressions for summer rainfall are almost parallel, whereas the linear regressions for winter precipitation diverge. In the summer, strong surges of moist tropical air push into and across Arizona from the Southwest. Tropical moisture can move into Arizona in the winter as well, but most events in the drier northeastern part of the state are the result of frontal systems from the Northwest with relatively dry air. This may explain the parallel slopes in the summer and the divergent slopes in the winter. There is no significant correlation between precipitation and elevation for winter storms at deficit stations.

Simple linear regressions for seasonal and annual precipitation-elevation relationships are shown in Table 1. Southern Nevada data, from the publication by French (4), were transformed to compare with linear regressions developed from other data. Batten and Green (1) and Duckstein et al. (3) developed relationships from the same summer rainfall data for the Santa Catalina Mountains, in southeastern Arizona. The relationships were similar to those developed from the larger Arizona networks of gages.

Conclusions

Many investigators have looked at the relationship between precipitation and elevation, and other topographic factors that influence precipitation. However, in most cases, these studies have been restricted to a particular state, area, or watershed. The writer feels that the time has come to generalize the precipitation-elevation relationships for various regions, and to determine whether the regional variabilities are significant. The data presented in this paper are a step in such a regional evaluation. Such an effort could supplement the information provided in NOAA Atlas 2.

Appendix.—References

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