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ESTIMATING MEAN RUNOFF IN UNGAGED SEMIARID AREAS

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FOREWORD

This report on Estimating Mean Runoff in Ungaged Semiarid Areas is a by-product of a cooperative program by the Nevada Department of Conservation and Natural Resources and the United States Geological Survey. Under this program, reconnaissance surveys of the water resources of the valleys in Nevada have been made by the United States Geological Survey and published by this department.

The techniques of estimating mean runoff described in this report were developed and applied during these reconnaissance surveys. Since their development in Nevada, these techniques have been used in other areas of the southwest with eminently good results.

I am pleased to have this report published as a Nevada Water Resources Bulletin to increase its availability to interested people in the southwest.

Elmo J. DeRicco

ELMO J. DERICCO, *Director*
Department of Conservation and Natural Resources

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ESTIMATING MEAN RUNOFF IN UNGAGED SEMIARID AREAS (1)

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ABSTRACT

Relations of runoff to altitude may be defined for a hydrologically homogeneous region by using a limited number of streamflow records. Mean runoff from ungaged basins in this same region can then be computed on the basis of this derived relation. When these relations of runoff to altitude are applied to small areas, the runoff may be different from that indicated by the relation, because of local differences in geology, precipitation, vegetation, land slopes, and land use. Two methods are described for adjusting the relations for the effects of these variations; one based on a streamflow measurement at miscellaneous sites which is applicable to perennial streams, the other on measurement of two channel parameters which is applicable to either perennial or ephemeral streams.

INTRODUCTION

The inventory of water resources is becoming more important in arid and semiarid regions as population increases and land use continues to change. In these regions it is difficult to inventory the mean runoff by obtaining streamflow records because the large number of small streams and the poorly-integrated drainage network makes it impractical to gage each stream separately. Mean runoff in these regions is difficult to estimate by conventional methods using a limited number of gaging stations because runoff may be poorly related to size of drainage area.

This report describes a method of estimating the mean runoff by use of regional runoff-altitude relations which are defined using limited streamflow data. These runoff-altitude relations are described by Riggs and Moore (1965). Data from a few streamflow stations within a region are used to derive a regional runoff-altitude relation which can be used to estimate the mean runoff from the ungaged basins within the region. Runoff, as used in this report, is considered synonymous with yield.

The region for which a runoff-altitude relation is to be derived must be one that can be represented by a single general precipitation-altitude relation and must have streamflow records from basins with a wide range of altitude and orientation. Delineation of the region based on a plot of precipitation versus altitude is desirable, but data suitable for such a plot are rarely available. Thus, it is usually necessary to first select a region on the basis of topography, then derive runoff values from the streamflow records, and finally eliminate those parts of the region that apparently have anomalous runoff.

The regions characterized by specific runoff-altitude relations are generally large and the relations may have to be adjusted for local effects when applied to small basins or areas. This adjustment may be made based on estimates of mean flow, at specific sites, derived from measurements of channel cross sections or streamflow measurements in areas having perennial streams, or by measurements of channel cross sections alone where only ephemeral streams exist.

DERIVATION OF REGIONAL RUNOFF-ALTITUDE RELATIONS

A region including much of northern Nevada and parts of southern Oregon and Idaho is used to demonstrate the procedure. Figure 1 is a map of the region, showing principal streams and gaging stations. Table 1 shows (1) the distribution of drainage area above the gaging station, by 1,000-foot altitude zones; (2) the total drainage areas; and (3) two values of mean runoff.

(1) Publication authorized by the Director, U.S. Geological Survey.
(2) U.S. Geological Survey, Carson City, Nevada.

TABLE 1

Distribution of drainage area above gaging stations by altitude, and mean runoff in the region shown in figure 1

Gaging station		Drainage area (sq mi)							Mean runoff (cfs)	
		Altitude zones (feet)								
Name	Period of record used (water year)	less than 5000	5000-6000	6000-7000	7000-8000	8000-9000	9000-10000	Basin total	Mean runoff from stream-flow records	Estimated from runoff values by zones
Trout Creek near Denio, Nevada	1923 1933-64	22	27	22	15	2	0	88	15	16
East Fork Quinn River near McDermitt, Nevada	1949-64	4	56	75	5	0	0	140	25	24
Martin Creek near Paradise Valley, Nevada	1922-64	2	78	68	22	2	0	172	30	34
East Fork Jarbidge River near Three Creek, Idaho	1929-32 1954-64	0	0	30	26	23	10	89	52	53
Marys River at Marys River Cabin near Deeth, Nevada	1914	0	0	51	25	17	7	100	*50	49

* Adjusted on basis of 50-year record of Salmon Falls Creek.

The first step in the analysis is the selection of values of mean runoff per unit area for successive altitude zones. These runoff values should increase smoothly with altitude and produce reliable estimates of runoff for the basins. It was concluded from field observation that no appreciable runoff-producing precipitation occurs in areas whose altitude is less than 5,000 feet. Mean

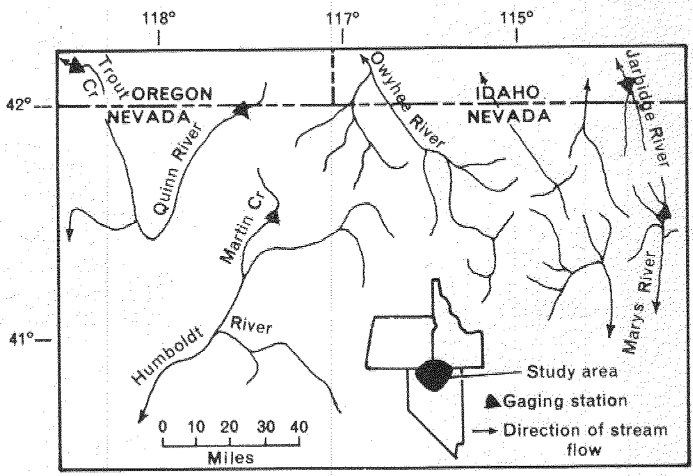


Fig. 1 — Map of parts of Nevada, Idaho, and Oregon, showing principal streams and gaging-station sites used in demonstrating the procedure for deriving a relation of runoff to altitude.

annual precipitation at the highest altitude in the region is estimated from snow-course data to be about 45 inches; the mean annual runoff from that altitude probably would not exceed 25 inches. Therefore, mean annual runoff values within the 0- to 25-inch range were arbitrarily selected for the 1,000-foot altitude zones and used to compute estimated mean runoff at the gaging stations. Final mean runoff values are defined by the streamflow data; they are not limited to the 0- to 25-inch range. That range only provides a reasonable basis for selection of the first trial values. The mean runoff from each zone is the product of the assumed value of mean runoff per unit area for that zone and the drainage area within the zone. (See table 2.)

TABLE 2

Computation of estimated mean runoff for Trout Creek near Denio, Nevada

Range in altitude of zone (feet)	Assumed mean runoff values: Inches/yr.	Assumed mean runoff values: Cfs/sq.mi.	Drainage area (sq. mi.)	Mean runoff (cfs)
5,000-6,000	0.5	.037	27	1.0
6,000-7,000	3.5	.259	22	5.7
7,000-8,000	7	.518	15	7.8
8,000-9,000	11.5	.851	2	1.7
Total	—	—	—	16.2

Similar computations were made for each of the stations shown in table 1, using the same assumed zonal estimates of mean runoff per square mile. The zonal estimates of mean annual runoff listed in column 2 of table 2 are considered to be the best of several sets tried because they produced the estimates of mean runoff which were closest to the values computed from the records of all of the control streams. Estimated values of mean runoff for the basins, computed as described above, are shown in the last column of table 1. Mean runoff computed from the streamflow records is shown in the next-to-last column. Agreement between the two is considered close enough to indicate the homogeneity of the region with respect to this type of analysis.

Application of relations to ungaged basins

Mean annual runoff fiom an ungaged basin in the region shown in figure 1, can be computed by (*a*) determining the area of the basin that lies within each of the altitude zones; and (*b*) multiplying the area of each zone by the appropriate zonal runoff value shown in table 2. For another region, different runoff values for the altitude zones may have to be derived. For example, the six sets of zonal runoff values shown in table 3 were derived for six different regions in Nevada.

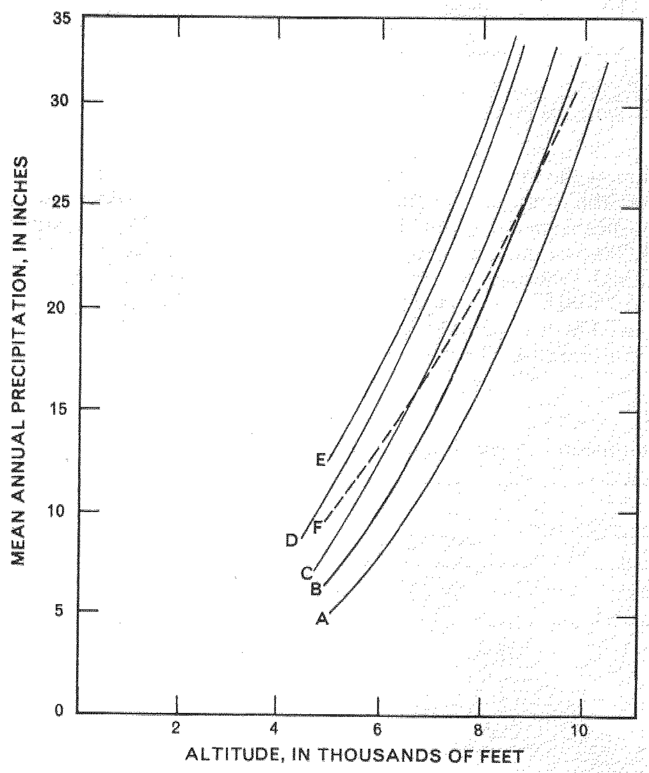


Fig. 2 — Relations of precipitation to altitude for six regions in Nevada.

In some areas, streamflow records are not adequate to establish the basic set of runoff values. If the area is considered to be similar in runoff characteristics to one of the several regions for which values are determined, it may be possible to assign a set of zonal runoff values to the area by using precipitation-altitude relations. In the Nevada study, precipitation-altitude curves were developed from available data for the principal regions (fig. 2).

For a basin widely separated from the regions of table 3, and in which a precipitation record is available, the mean annual precipitation is plotted against altitude in figure 2. The curve nearest which the plotted points fall identifies the region of similarity and the appropriate set of zonal runoff values.

TABLE 3

Runoff values by altitude zones for different regions in Nevada

Range of altitude of zone (feet)	Runoff (inches per year) in region indicated below					
	A	*B*	*C*	*D*	*E*	*F*
5,000-6,000	0	0	0.5	0.5	1.6	0.3
6,000-7,000	0	0	1.2	3.5	5.5	0.7
7,000-8,000	.4	.5	3.0	7.0	10	1.5
8,000-9,000	2.5	3.2	5.5	11.5	15.5	2.8
9,000-10,000	5.6	7.0	9.5	16.2	21	4.5
10,000-11,000	9.4	12	14	21	26	—
11,000-12,000	16	18	—	—	—	—

Adjustment of relations for local variations

The relations of runoff to altitude that are developed represent large areas or regions. When these regional relations are applied to small areas or individual valleys, the runoff may be different from that indicated by the relation, because of local differences in geology, precipitation, vegetation, land slopes, and land use. A method of adjusting the regional relation for the effects of these local variations is needed. It is intended that this adjustment be used only in short-term studies, such as reconnaissance or preliminary investigations. Longer-period studies would permit collection of more data during which a more detailed analysis would be possible. The method is especially advantageous in areas such as Nevada, where the many streams in each valley makes it impracticable to study each stream separately.

Adjustments to the regional runoff-altitude relation are based on determinations of the mean flow of a few selected streams which then are compared with the runoff determined by the runoff-altitude relation. Two procedures are described for determining this mean flow; one based on streamflow measurements at miscellaneous sites, which is applicable to perennial streams; and the other on measurement of two channel parameters which is applicable to either perennial or ephemeral streams.

Adjustment using streamflow measurements

The mean flow of ungaged streams is estimated by comparing streamflow measurements at iscellaneous sites on the ungaged stream to the appropriate daily flow record of a nearby

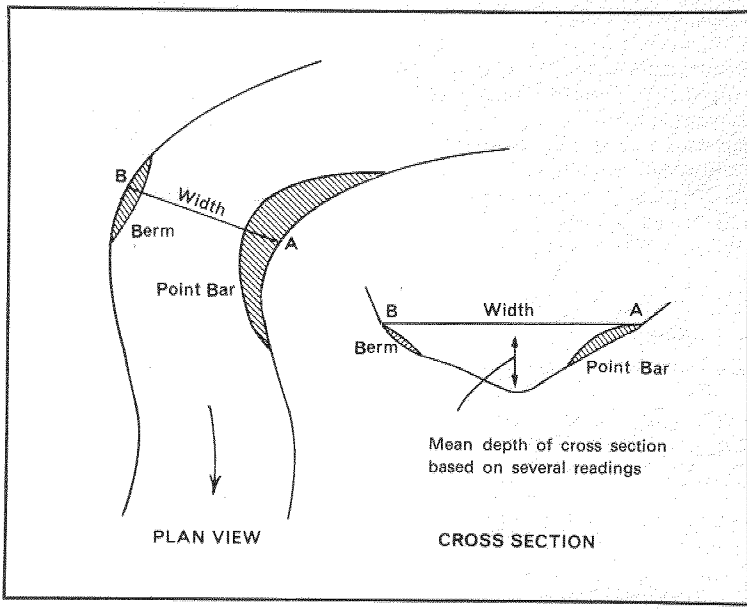


Fig. 3 — Sketch of stream channel showing parameters (mean depth and width) measured for determining mean discharge in figure 6 and 7.

Fig. 4 — Point bars on an ephemeral stream, Brunswick Canyon near Carson City, Nevada.

gaged stream. The mean flow is determined at the miscellaneous measurement site using the equation:

$$Qm = QM \frac{Qa}{Qb}$$

where Qm is the unknown long-term annual mean flow at the ungaged stream, QM is the long-term annual mean flow at the gaged stream, Qa is the measured streamflow at the ungaged station, and Qb is the daily streamflow at the gaged stream on the same day as Qa.

The above equation implies that the ratio of long-term mean annual discharges at the two gaging stations is equal to the ratio of their concurrent discharges at any given time. Obviously, this is not so. The surface-runoff characteristics of two basins in close proximity to each other will usually differ. It is therefore necessary that the concurrent discharges used in the equation occur during a period of base flow, that is, a period of relatively steady flow after direct runoff has ceased. Furthermore, the recession characteristics of two nearby basins will generally differ to the extent that the ratio of concurrent discharges of the two streams will vary with time.

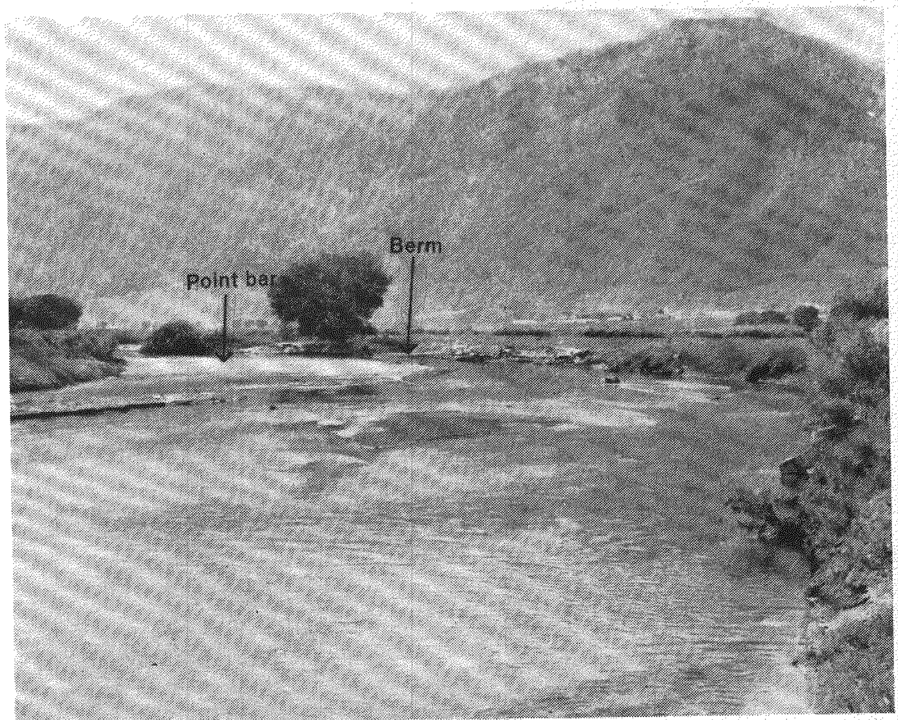


Fig. 5 — Point bars and berms on a perennial stream, Carson River near Carson City, Nevada.

Usually, the closer the base-flow discharge is to the long-term mean annual discharge, the closer the ratio of the concurrent discharges will be to the ratio of the long-term mean discharges. Often, too, it will be found that the ratio of concurrent discharges during some particular month will tend to be constant in all years and approximately equal to the ratio of long-term mean annual discharges. The time of year when best results can be achieved with miscellaneous discharge measurements can be determined from inspection of gaging-station records in the area. For example, in the area shown in figure 1, miscellaneous discharge measurements made in November, when used in the above equation, gave estimates of the long-term mean annual discharge that were generally within 15 percent from the known value, but sometimes differed by as much as 30 percent. This method of estimating mean annual discharge is applicable only to perennial streams.

Adjustment using channel geometry

The other method of determining the mean streamflow is by use of channel parameters and is applicable to both perennial and ephemeral streams. This method is being developed by W.B. Langbein (personal communication). Langbein suggests that an empirical relation can be defined between known values of mean discharge and the width and mean depth of the stream channel at a cross section between the berms and point bars. These berms and point bars are

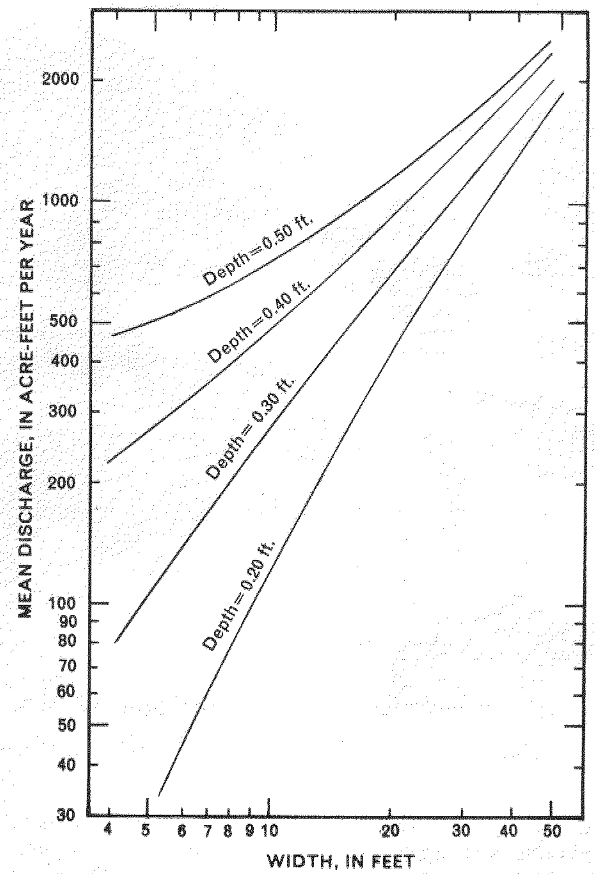
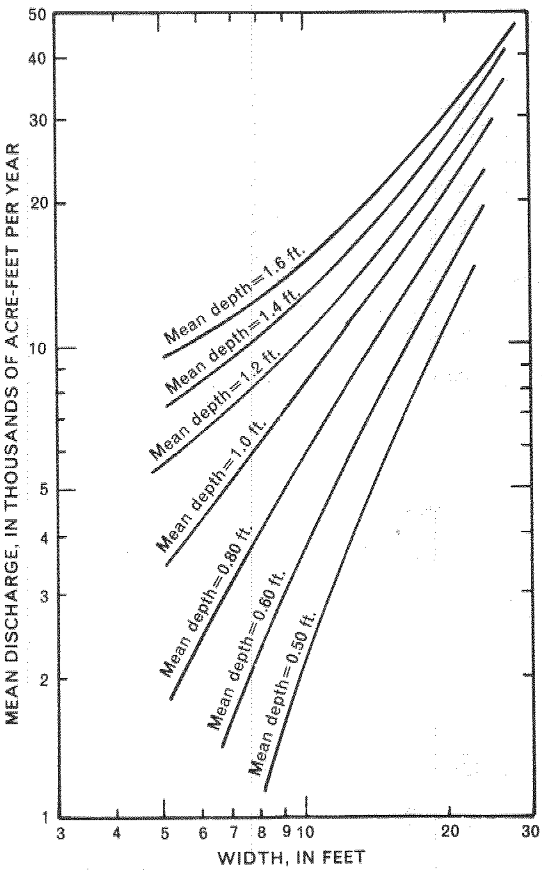


Fig. 6 — Relation of mean discharge to two parameters of a channel cross section (see figure 3) for ephemeral streams.

described by Leopold and Wolman (1957). The basic idea is that these channel dimensions adjust themselves to the streamflow. Large channels convey large flows and conversely small channels can convey only small flows. Thus, inspection and measurement of a channel can provide field evidence of its mean annual runoff. Figure 3 shows a sketch of a stream channel and the parameters measured. Figure 4 shows point bars in an ephemeral channel and figure 5 shows berms and point bars in a perennial channel. These in-channel features are believed to be diagnostic of the annual flow. The relations are then used to determine the mean discharge from those parameters. Langbein's basic procedure was used to develop two sets of preliminary curves for use in the State of Nevada, one set, shown in figure 6, for ephemeral streams based on 11 streams; the other set, shown in figure 7, for perennial streams based on 14 streams. Table 4 shows the mean discharges for 13 streams in Nevada and California, not used in the development of the relation, obtained independently both from streamflow records and by relating channel dimensions at cross sections to the curves on figure 7. The very close agreement probably is fortuitous in these examples.



7 — Relation of mean discharge to two parameters of a channel cross section (see figure 3), for perennial streams in Nevada.

The estimated mean streamflow of each basin determined by channel geometry for ephemeral streams and the average obtained by both channel geometry and miscellaneous measurements for perennial streams is then compared with the runoff computed by the relation of runoff to altitude developed for the region. That relation then may be adjusted for local conditions. If the runoff is less than that determined by the regional runoff-altitude relation, the runoff-altitude relation would be decreased to give less runoff at any given altitude. The basins having the same adjusted runoff-altitude relation should be grouped together. Each group of basins represents a homogeneous subregion within the region for which the runoff is to be estimated. From field observation it can usually be determined if the differences in the runoff-altitude relation are due to man-made or natural conditions which cause streamflow to differ from yield or due to the local variations in the other hydrologic elements that affect runoff.

TABLE 4

Comparison of measured and estimated mean discharge using channel geometry

Stream name	Actual discharge (acre-ft)	Years of record	Discharge estimated at individual sites (acre-ft)			Average estimated discharge (acre-ft)
E.F. Quinn River near McDermitt, Nev.	17,500	18	18,500	18,100	16,000	17,500
McDermitt Creek near McDermitt, Nev.	20,000	18	20,500	21,600	21,000	21,000
Truckee River near Truckee, Calif.	249,800	16	235,000	265,000	260,000	253,000
Sagehen Creek near Truckee, Calif.	7,800	13	8,200	7,300	—	7,800
Alder Creek near Truckee, Calif.	5,500	8	5,500	4,700	—	5,100
Little Truckee River above Boca Reservoir, Calif.	139,000	33	143,000	—	—	143,000
Cottonwood Creek nr Paradise Valley, Nev.	4,700	44*	4,800	4,400	—	4,600
Humboldt River at Battle Mountain, Nev.	208,500	52	220,000	202,000	180,000	201,000
Humboldt River at Argenta, Nev.	206,300	20	225,000	200,000	—	212,000
Humboldt River at Palisade, Nev.	256,300	59	265,000	290,000	—	278,000
Humboldt River near Comus, Nev.	175,200	41*	145,000	140,000	195,000	160,000
Humboldt River near Carlin, Nev.	228,800	23	265,000	225,000	230,000	240,000
Humboldt River above Rose Creek, Nev.	162,200	18	130,000	170,000	—	150,000

*Adjusted to long-term average.

Summary

The methods of estimating mean annual runoff in semiarid regions described in this report primarily are for preliminary or reconnaissance evaluations. Limited streamflow data are used to establish runoff-altitude relations by homogeneous regions. Where streamflow data are particularly limited, precipitation-altitude relationships can be used to support development of the regional runoff-altitude relations.

From the regional values, estimates of runoff can be made for ungaged basins within the region. Within generally homogeneous regions, effects of topography, geology, precipitation, and vegetation may result in local variations of the regional runoff-altitude relation. Adjustments for these can be made by measurements made during the course of the field study. Miscellaneous measurements of perennial streams in the basin can be used to adjust the regional values. Measurements of channel geometry can be used to adjust regional values for perennial and ephemeral streams.

After the runoff-altitude relations have been defined, the method of estimating runoff is easy to apply. The method can be applied to a small area consisting of all or a part of a drainage basin or to a valley or mountain block consisting of many drainage basins. Application to the larger areas probably will result in more reliable values as the areas of inordinately high and low runoff would tend to compensate.

This method has been used in reconnaissance studies in Nevada and adjacent States and produced very good results.

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