A Water Budget of the Carson Valley, Nevada

GEOLOGICAL SURVEY PROFESSIONAL PAPER 417-F

A Water Budget of the Carson Valley, Nevada

By ARTHUR M. PIPER

CONTRIBUTIONS TO STREAM-BASIN HYDROLOGY

GEOLOGICAL SURVEY PROFESSIONAL PAPER 417-F

An estimate of water yield in the "shadow" of the Sierra Nevada

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1969

UNITED STATES DEPARTMENT OF THE INTERIOR

WALTER J. HICKEL, *Secretary*

GEOLOGICAL SURVEY

William T. Pecora, *Director*

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402 - Price 60 cents (paper cover)

CONTENTS

ILLUSTRATIONS

TABLES

CONTRIBUTIONS TO STREAM-BASIN HYDROLOGY

A WATER BUDGET OF THE CARSON VALLEY, NEVADA

By Arthur M. Piper

LOCATION AND GENERAL FEATURES OF THE AREA

Carson Valley, Nev., is a plain that is about 100 square miles in extent, about 4,700–5,000 feet above sea level, and in the rain shadow of the Sierra Nevada (pl. 1). Its catchment area, measured at the rock-bound narrows which closes the valley plain to the north, is 887 square miles. Summit altitudes of that catchment area are as much as 11,462 feet above sea level in the Sierra Nevada to the west and south and 9,450 feet above sea level in the Pine Nut Mountains to the east. Drainage of the area is by the Carson River.

Climate ranges from semiarid over the valley plain and the Pine Nut Mountains to humid or superhumid over the highest parts of the Sierra Nevada. Precipitation occurs mostly from November through March in the form of rain or snow at the lower and intermediate altitudes and largely as snow at the highest altitudes. Runoff reaches its yearly peak commonly in May or June owing to melting of snow; less commonly, the yearly peak is generated by rain in November or December.

Yearly runoff varies notably, both according to altitude of the land surface and according to individual localities at a common altitude. In most years little or no runoff is generated below an altitude of about 5,000 feet. Most runoff that reaches the valley floor comes from the Sierra Nevada to the west and south; little comes from the Pine Nut Mountains to the east.

NATURE OF THE PROBLEM

Originally, much of the Carson Valley plain was native-grass meadow watered principally by overbank flow of the sinuous interbraided stream channels during the yearly snowmelt freshet. This natural regimen long has been modified by rudimentary irrigation—that is, by so-called wild flooding and by introduction in some places of more productive grasses and other forage plants.

As one aspect of current pressure for optimum management of land and water resources in arid parts of the United States, it has become desirable to know the water budget of the Carson Valley plain. For such a budget an estimate must be made of runoff from some 363 square miles of land between the margin of the plain and the gaging stations next upstream on the two forks and on the several tributaries of the Carson River. Because this intervening area is in the lee of, and in part immediately adjacent to, a major mountain range—the Sierra Neveda—the usual bases for such estimates are not appropriate. This paper presents a unique estimate, made from a standard vertical variation in runoff, according to land-surface altitude, combined with coefficients of horizontal variation.

STANDARD RUNOFF

MEAN YEARLY RUNOFF BY GAGED AREAS

Streamflow in the Carson River basin has been measured for 4 consecutive years or more at 13 gaging stations above the Carson Valley. Records from these stations, supplemented by those from two stations in the adjacent Truckee River basin to the west, afford the base for the estimate of ungaged runoff that will be derived. Plate 1 outlines the several gaged areas; tables 1 and 2 list the areas in conventional downstream sequence and summarize their relevant principal characteristics. Items 7, 10, and 13 in the two tables pertain to the intervening areas between a principal gaging station and the station or stations next upstream. As tabulated, each characteristic of one of these intervening areas is the difference between a measured value of the particular characteristic at the downstream station and the aggregate of corresponding measured values at all the upstream stations.

Among the records the longest two are those of the East Fork Carson River near Gardnerville, Nev., and the West Fork Carson River at Woodfords, Calif. (stations 11 and 14, respectively, on pl. 1 and in tables 1 and 2). Both these records start with 1890 but are discontinuous until late in the thirties. However, continuous records of monthly runoff have been synthesized for the two stations for water years 1901–65 through correlations and estimates by the U.S. Bureau of Reclamation and by the State Engineer of Nevada. (The writer has "spot" verified and accepts these correlations and estimates.)

The writer concludes from the synthesized record for the East Fork near Gardnerville that the average for the 52 water years, 1909–60, affords the most credible value of mean yearly runoff over the long term. The 20-year average, 1941–60, is substantially the same. Then, from double-mass plots and other correlations with the East Fork record, a most credible value of long-term mean yearly runoff can be derived, whatever the periods of record, for each of the gaged areas. Such values are given in table 1, as both aggregate runoff from each area and average runoff (yield) per square mile.

Thus, yearly mean yield per square mile ranges about 16-fold among the gaged areas—from a minimum of 125 acre-feet from the 48.8 square miles between the stations on Bryant Creek and on the East Fork near Gardnerville to a maximum of 1,960 acre-feet from the 14.9 square miles above the station on Pleasant Valley Creek (areas 10 and 6, respectively, table 1 and pl. 1). The larger yields are from high areas, and the smaller yields are from low areas but not in close proportion to mean land-surface altitudes of the several areas. This seemingly discordant relationship corresponds to a generalization already stated—that yield varies both vertically and horizontally within the study area.

TABLE 1.—*Runoff from areas adjacent to the Carson Valley, Calif.-Nev.*

Number shown on pl. 1	Station or area	Drainage area (sq mi)	Altitude (feet above sea level)		Measured runoff		Most credible long-term runoff		
			Range	Area-weighted mean	Years of record	Mean of record (acre-ft per yr)	Acre-feet per year	Acre-feet per year per square mile	Cubic feet per second per square mile
1	East Fork Carson River above Soda Springs ranger station, near Markleeville, Calif	29.4	11,462–6,820	9,030	1946–51	44,630	48,100	1,640	2.26
2	Silver King Creek near Coleville, Calif	31.6	10,973–7,650	9,000	1946–51	27,000	27,900	884	1.22
3	Wolf Creek near Markleeville, Calif	11.3	10,934–7,350	8,690	1946–51	21,000	21,900	1,940	2.68
4	Silver Creek below Pennsylvania Creek, near Markleeville, Calif	19.7	10,934–6,500	8,340	1946–	30,480	31,700	1,610	2.22
5	Hot Springs Creek near Markleeville, Calif	14.6	9,417–5,880	8,070	1946–57	20,750	20,100	1,380	1.91
6	Pleasant Valley Creek above Raymond Canyon Creek, near Markleeville, Calif	14.9	10,011–5,950	8,010	1946–50	22,770	29,100	1,960	2.71
7*	Intervening	155.0	10,934–5,400	7,320	---	---	70,600	455	.63
8	East Fork Carson River below Markleeville Creek, near Markleeville, Calif	276.5	11,462–5,400	7,900	1960–	235,300	299,400	902	1.25
9	Bryant Creek near Gardnerville, Nev	31.8	8,963–5,450	7,340	1961–	4,480	4,300	135	.19
10*	Intervening	48.8	9,108–4,985	6,240	---	---	6,100	125	.17
11	East Fork Carson River near Gardnerville, Nev	357.0	11,462–4,985	7,620	1890–93 1900–05 1908–10 1917 1925–28 1929 1935–37 1939–	280,200	259,800	728	1.00
12	West Fork Carson River above Woodfords, Calif	52.6	10,881–6,860	8,090	1946–51	59,280	65,500	1,240	1.71
13*	Intervening	13.0	10,023–5,760	7,910	---	---	9,330	718	.99
14	West Fork Carson River at Woodfords, Calif	65.6	10,881–5,760	8,050	1890–92 1900–20 1938–	83,260	74,800	1,140	1.57
15	Clear Creek near Carson City, Nev	15.3	9,214–4,900	6,835	1948–62	3,920	4,130	270	.37
16*	Intervening	448.6	10,823–4,620	5,910	---	---	---	---	---
17	Carson River near Carson City, Nev	886.6	11,462–4,620	6,770	1939–	280,200	286,300	327	.45
18	Upper Trucklee River near Meyers, Calif	33.3	10,061–6,325	8,040	1960–	45,830	48,300	1,450	2.00
19	Trout Creek near Tahoe Valley, Calif	36.2	10,881–6,250	7,960	1960–	22,810	24,000	664	.92

*Not shown on plate.

TABLE 2.—*Apportionment of drainage areas by altitude zones, Carson River basin above Carson City, and vicinity, California-Nevada*

Number shown on pl. 1	Station or area	Number of square miles for indicated altitude zones (ft above sea level)									Total area (sq mi)
		<4,800	4,800–5,600	5,600–6,400	6,400–7,200	7,200–8,000	8,000–8,800	8,800–9,600	9,600–10,400	>10,400	
1	East Fork Carson River above Soda Springs ranger station, near Markleeville, Calif				0.72	3.8	7.6	9.0	5.7	2.6	29.4
2	Silver King Creek near Coleville, Calif					2.2	12.2	10.2	5.9	1.1	31.6
3	Wolf Creek near Markleeville, Calif					1.8	5.1	3.2	1.1	.09	11.3
4	Silver Creek near Markleeville, Calif				1.2	4.4	9.8	3.4	.80	.08	19.7
5	Hot Springs Creek near Markleeville, Calif			0.44	.93	4.2	7.7	1.3			14.6
6	Pleasant Valley Creek above Raymond Canyon Creek, near Markleeville, Calif			.27	.69	5.9	7.2	.80	.04		14.9
*7	Intervening		1.6	25.1	48.0	43.2	27.5	8.0	1.5	.16	155.0
8	East Fork Carson River below Markleeville Creek, near Markleeville, Calif		1.6	25.8	51.5	65.5	77.2	36.0	15.0	4.0	276.5
9	Bryant Creek near Gardnerville, Nev		.20	3.4	8.9	13.7	5.7	.05			31.8
*10	Intervening		10.1	22.1	10.5	5.6	.43	.09			48.8
11	East Fork Carson River near Gardnerville, Nev		11.8	51.3	70.8	84.7	83.3	36.1	15.0	4.0	357.0
12	West Fork Carson River above Woodfords, Calif				4.1	23.1	16.8	7.0	1.5	.17	52.6
*13	Intervening			.78	1.9	3.4	5.7	1.3	.07		13.0
14	West Fork Carson River at Woodfords, Calif			.78	6.0	26.4	22.5	8.2	1.6	.17	65.6
15	Clear Creek near Carson City, Nev		1.5	4.6	3.6	3.4	2.1	.22			15.3
*16	Intervening, ungaged*	85.4	152.2	82.1	58.5	40.8	19.8	8.4	1.4	.04	448.6
17	Carson River near Carson City, Nev	85.4	165.5	138.8	138.9	155.3	127.6	52.9	18.0	4.2	886.6
18	Upper Truckee River near Meyers, Calif			.65	4.0	10.6	12.8	5.0	.21		33.3
19	Trout Creek near Tahoe Valley, Calif			2.7	8.2	7.1	9.5	7.0	1.5	.22	36.2
	***Subdivisions of intervening ungaged area (item 16)**										
20	Indian Creek and vicinity		21.2	11.9	1.3	0.82	0.65	0.41			36.2
21	Sierran Slope, southwestern		19.3	4.6	3.8	3.4	3.7	2.3	.55	0.02	37.6
22	Sierran Slope, south-central		4.6	2.8	2.2	1.8	2.1	2.6	.87	.02	16.8
23	Sierran Slope, north-central		2.4	3.0	3.2	2.5	1.3	.32			12.7
24	Sierran Slope, northeastern		14.4	3.8	2.8	3.0	3.5	.24			27.8
25	Buffalo Canyon and vicinity		21.5	14.2	5.8	.72					42.2
26	Pine Nut Creek and vicinity		16.7	16.3	11.1	8.1	4.5	1.7			58.4
27	Buckeye Creek and vicinity		25.8	10.1	21.1	19.5	4.1	.82			81.5
28	Hot Springs Mountain and vicinity		24.6	15.4	7.2	1.0	.04				48.2
29	Prison Hill		1.6	.03							1.7
------	Carson Valley (below 4,800-foot contour)	85.4									85.4

*Not shown on plate.

STANDARD VERTICAL VARIATION

The runoff considered here originates in precipitation from air masses which advance on the Sierra Nevada from the west or southwest, and spill over the mountain crest onto the Carson Valley and adjacent lowlands. The writer reasons that in such a fluid system precipitation on the land surface should tend to die away exponentially with diminishing altitude below, and leeward distance from, the crest—at least, near the crest. If runoff is presumed to diminish likewise, a "semilog" plot of runoff yield against land-surface altitude should approach a straight line. Figure 1 is such a plot of data in table 1—specifically, a plot of average yield per square mile against area-weighted mean altitude of the specified areas.

In figure 1, the upper and lower envelope curves (dotted lines) intersect the base of the diagram near the 5,000-foot abscissa. This feature is compatible with the general observation that in the study area nearly all runoff originates at altitudes greater than 5,000 feet above sea level (the base line of the diagram represents a runoff of 10 acre-feet per year, or 0.14 cfs, per square mile). Also, the several runoff stations would be intersected in the same general sequence (1) on the diagram by a parallel to the lower envelope, moved toward the upper left, and (2) on the land surface by a parallel to the Sierra Nevada front, moved westward—that is, across Carson Valley toward the mountain crest. This feature of the diagram is compatible with the preceding hypothesis that runoff yield would tend to die off exponentially with diminishing altitude below, and leeward distance from, the crest.

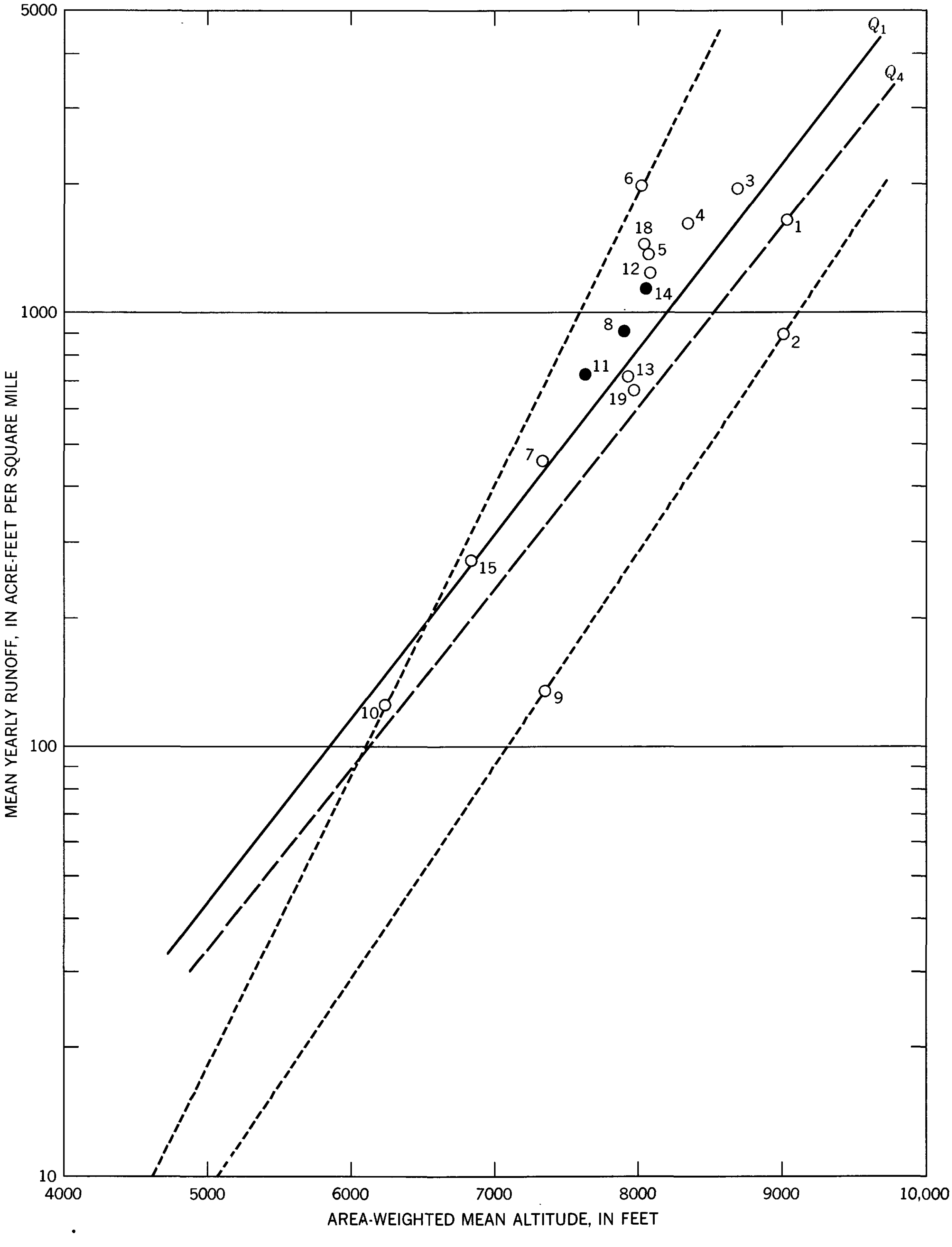

FIGURE 1.—Relation between runoff and altitude in the vicinity of Carson Valley, Calif.-Nev. (Numbered points identify drainage areas listed in table 1.)

Also, in figure 1 the straight line Q_1 represents a least-squares fit to the plotted station points (in the fit, items 7, 10, and 13 of table 1 are used in lieu of items 8, 11, and 14, respectively, for item 8 is a weighted mean of items 1–7; item 11 is a mean of items 1–7, 9, and 10; and item 14 is a mean of items 12 and 13). This line the writer accepts as a first approximation of the mean vertical variation in runoff yield within the aggregate gaged area above the Carson Valley. In principle this Q_1 line would be biased because points in the figure are plotted according to area-weighted mean altitude (from table 1); the points should be plotted to mean altitudes weighted both according to area of the successive altitude zones (table 2) and to rate of change in runoff yield among the zones. For a weight according to rate of yield, a first approximation can be derived from the slope of the Q_1 line in figure 1. Introducing such a weight leads to a second approximation of mean vertical variation in yield. Successive approximations should approach a true mean; actually, beyond the third approximation the change in slope of the least-squares line is inconsequentially small.

The third approximation of mean vertical variation, derived as just outlined and applied to the zonal areas of table 2, leads to a computed aggregate yearly yield from the two forks of the Carson River (stations 11 and 14, tables 1 and 2) which is 108.6 percent of the most credible long-term value from table 1. A discrepancy of such magnitude is not surprising in that the least-squares computations give equal weight to data from the several gaged areas, whereas those areas differ moderately both in aggregate extent and in relative extent of their several altitude zones (pl. 1; tables 1 and 2). To cancel the discrepancy, the third least-squares approximation of mean vertical variation is so diminished in arithmetic proportion among altitude zones, that computed aggregate yield from the two forks of the Carson River equals the most credible long-term value derived from measured flow (stations 11 and 14, respectively, tables 1 and 2). This diminished approximation is shown in figure 1 as the line Q_4, also in table 3 as a "standard" mean runoff from each of the several altitude zones. It can be expressed by the equation:

$$Q_s = 10 \times 2.61^{(H-3.70)}, \qquad (1)$$

in which

Q_s=standard runoff yield, in acre-feet per square mile per year, and

H=land-surface altitude, in thousands of feet.

The writer postulates that this so-called standard vertical variation in runoff yield applies to the Carson River basin above Carson City and probably to the immediate vicinity of that basin within the altitude range shown in the table. The yield from the 10,400- to 9,600-foot zone is presumed to apply also to the small areas whose altitudes are greater than 10,400 feet.

TABLE 3.—*Vertical variation of runoff by altitude zones, Carson River basin above Carson City, and vicinity, California-Nevada*

Feet above sea level		Standard runoff		
Range	Median	Acre-feet per year per square mile	Cubic feet per second per square mile	Inches per year
10,400–9,600	10, 000	4, 180	5. 77	78. 3
9,600–8,800	9, 200	1, 940	2. 68	36. 4
8,800–8,000	8, 400	902	1. 25	16. 9
8,000–7,200	7, 600	419	. 579	7. 85
7,200–6,400	6, 800	195	. 269	3. 65
6,400–5,600	6, 000	90	. 125	1. 70
5,600–4,800	5, 200	42. 0	. 0580	. 79
4,800–4,000	4, 400	19. 5	. 0270	. 37

Certain corollaries of this postulate warrant emphasis. First, atmospheric transport of water into the region above the general crest level of the Sierra Nevada is determined by climatologic and meteorologic factors largely independent of local landforms. Thus, any die-away relationship of runoff yield to land-surface altitude, such as that expressed by equation 1, is intended to apply only in the lee of the crest and below the crest. Second, the numerical factors and the numerical exponent of equation 1 apply only to that part of the Carson River basin above Carson City and vicinity. Another area would have different numerical values for the factors and for the exponent of its die-away formula according to its landforms and their orientation to local storm tracks. Thus, it is of little consequence that equation 1 would indicate absurdly large values of water yield at altitudes above the general crest level of the Sierra Nevada.

S. E. Rantz (written commun., 1967) felt that on rectangular paper the graph of runoff plotted against altitude would tend to be linear in the humid (higher) range and curvilinear in the subhumid (lower) range. However, so plotted, the data of figure 1 would not closely define a linear trend for the higher altitudes, and a mean linear trend would not differ grossly from the relation shown by the figure. The seeming argument for rectangular versus semilogarithmic plotting cannot be resolved by the data of this paper.

HORIZONTAL VARIATION

The writer hypothecates that the variability of runoff yield in the Carson River basin above Carson City, as indicated by data in table 1, can be defined adequately in terms of the standard, or Q_4, vertical variation (just derived) and a coefficient of horizontal variation at any common altitude. In other words, runoff yield at any point in the basin can be expressed by the general equations:

$$Q = C_h \cdot Q_s, \text{ or} \quad (2)$$

$$Q = 10C_h \times 2.61\ (H - 3.70) \quad (3)$$

in which

Q=actual runoff yield, in acre-feet per square mile per year,

C_h=coefficient of horizontal variability.

Table 4 gives the coefficient of horizontal variability for each gaged area.

To disclose the pattern, if any, of horizontal variation over all the basin, (1) as controls, the mean coefficients from table 4 were plotted on a map at the centers of gravity of the respective gaged areas, and (2) isopleths of horizontal variation were interpolated between these controls, according to a logarithmic spacing (which would follow from the earlier presumption that runoff yield tends to die off exponentially). The interpolated isopleths covering the gaged areas are shown on plate 1 as continuous lines. Their very simple pattern and "smooth" spacing, as shown in the plate, tend to verify the model of vertical and horizontal variabilities that have been implicit so far in this paper.

The isopleths on plate 1 do not of themselves alone indicate relative quantities of runoff. Rather, they indicate dimensionless coefficients of horizontal variability, by which the standard vertical variation (by altitude zones, table 3) must be multiplied to derive the actual mean runoff from one plate to another within the study area.

D. O. Moore has derived a general relation between runoff and altitude over extensive parts of Nevada. He stated (written commun., 1967) that, on the basis of his derivations, logarithmic spacing of the isopleths on plate 1 appears reasonable.

Of all the data items in table 4, only item 10 is discordant with the interpolated isopleths—specifically, the coefficient of horizontal variability for the increment of drainage area between gaging stations on Byrant Creek and on East Fork Carson River, both near Gardnerville, Nev. However, in that one discordant item the net of all errors in measurements of flow at all stations upstream on the East Fork is ascribed to a very small incremental area. The writer feels that this one discordance does not vitiate the pattern delineated.

Over the northern half of the study area, the pattern of horizontal variation must be extrapolated, except that the record of flow from the Clear Creek basin (table 4, item 15) affords one tie at the northwest extreme. The extrapolated pattern, shown by dashed lines on plate 1, involves three assumptions:

1. Logarithmic spacing of isopleths projects without interruption, from the area of interpolation to the area of extrapolation.
2. Along the west margin of the basin, the "gradient" of isopleths passes through a minimum between drainage areas 15 and 19; from the minimum, gradients northward and southward are mirror images, one of the other.
3. At all latitudes isopleths have a simple largarithmic spacing from east to west across the basin.

TABLE 4.—*Horizontal variation of runoff, Carson River basin above Carson City, and vicinity, California-Nevada*

Number shown on pl. 1	Station or area	Long-term mean runoff [1] (acre-ft per yr)	Standard runoff [2] (acre-ft per yr)	Coefficient of horizontal variability [3]
1	East Carson River above Soda Springs ranger station, near Markleeville, Calif.	48, 100	60, 400	0. 80
2	Silver King Creek near Coleville, Calif.	27, 900	60, 900	. 46
3	Wolf Creek near Markleeville, Calif.	21, 900	16, 500	1. 33
4	Silver Creek below Pennsylvania Creek, near Markleeville, Calif.	31, 700	21, 200	1. 50
5	Hot Springs Creek near Markleeville, Calif.	20, 100	11, 500	1. 75
6	Pleasant Valley Creek above Raymond Canyon Creek, near Markleeville, Calif.	29, 100	10, 800	2. 69
7	Intervening	70, 600	77, 000	. 92
8	East Fork Carson River below Markleeville Creek, near Markleeville, Calif.	249, 400	258, 300	. 97
9	Bryant Creek near Gardnerville, Nev.	4, 300	13, 000	. 33
10	Intervening	6, 100	7, 400	. 83
11	East Fork Carson River near Gardnerville, Nev.	259, 800	278, 600	. 93
12	West Fork Carson River above Woodfords, Calif.	65, 500	46, 200	1. 42
13	Intervening	9, 330	9, 700	. 96
14	West Fork Carson River at Woodfords, Calif.	74, 800	55, 900	1. 34
15	Clear Creek near Carson City, Nev.	4, 130	4, 880	. 85
18	Upper Truckee River near Meyers, Calif.	48, 300	27, 400	1. 76
19	Trout Creek near Tahoe Valley, Calif.	24, 000	34, 200	. 70

[1] From table 1.
[2] Vertical variation from table 3, times altitude-zone areas from table 2, accumulated.
[3] Long-term divided by standard.

The outstanding feature of the extrapolated pattern is a "valley" having a westward-trending axis about at midlatitude of the Carson Valley. In alinement with this valley the crest of the Sierra Nevada to the west is generally less than 9,000 feet above sea level. To the south and to the north the valley head is buttressed by the higher masses of Freel Peak and Mount Rose, respectively. Thus, the pattern of isopleths seems logically related to major topographic forms.

Admittedly, the pattern of extrapolated isopleths on plate 1 is arbitrary. D. O. Moore (written commun., 1967) derived, from recent short-term studies, somewhat greater runoff from subareas 22 and 23 (pl. 1). Also, in two small basins immediately north from the northwest corner of the area shown on the plate, runoff is probably less than would be implied by the writer's valley-and-buttress model. Accordingly, Moore suggested that the extrapolated isopleths possibly should trend nearly north—that is, about parallel to the long axis of Carson Valley. Data are not at hand to discriminate sharply between this interpretation by Moore and that by the writer. Moore's tentative interpretation seemingly would not greatly change the water budget of the Carson Valley, which is derived next.

WATER BUDGET OF THE CARSON VALLEY

Table 5 estimates the ungaged runoff from the 363 square miles of land between the margin of the Carson Valley and the gaging stations next upstream in the Carson River basin. The estimate derives from the standard vertical variation and the pattern of horizontal variation that have been developed in this paper. In magnitude, the estimate is compatible with all hydrologic features of the valley and its catchment basin, of which the writer is aware. General verification rests in the overall water budget next to be derived.

Table 6 is a budget of long-term mean yearly runoff for the 85.4 square miles (54,600 acres) that is enclosed by the 4,800-foot contour along or near the margin of the Carson Valley plain. Inflow items, as tabulated, represent virtually native terrain modified only nominally by acts of man outside the valley. Outflow, measured at the gaging station on the Carson River near Carson City, encompasses any effect of present and past irrigation practices on the valley plain. The irrigation practices have changed little during the 52 years (1909–60) that are presumed to measure the most credible long-term mean runoff.

TABLE 5.—*Estimate of ungaged runoff crossing the 4,800-foot contour onto the Carson Valley plain, Nevada*

Number shown on pl. 1	Subdivision of ungaged area (table 2, item 16)	Standard runoff [1] (acre-ft per yr)	Mean coefficient of horizontal variability [2]	Long-term mean runoff [3] (acre-ft per yr)
20	Indian Creek and vicinity	4, 000	0. 54	2, 100
21	Sierran Slope, southwestern	13, 500	. 53	7, 200
22	Sierran Slope, south-central	12, 100	. 39	4, 700
23	Sierran Slope, north-central	3, 800	. 33	1, 300
24	Sierran Slope, northeastern	6, 300	. 51	3, 200
25	Buffalo Canyon and vicinity	3, 600	. 19	700
26	Pine Nut Creek and vicinity	15, 000	. 11	1, 700
27	Buckeye Creek and vicinity	19, 600	. 14	2, 700
28	Hot Springs Mountain and vicinity	4, 300	. 28	1, 200
29	Prison Hill	70	. 55	40
	Total	82, 200	0. 30	24, 800

[1] Vertical variation from table 3, multiplied by altitude-zone areas from table 2, accumulated.
[2] Interpolated from plate 1.
[3] Standard runoff multiplied by coefficient of horizontal variability.

TABLE 6.—*Budget of long-term mean runoff, Carson Valley, Nev.*

	Acre-feet per year
Inflow at gaging stations:	
East Fork Carson River near Gardnerville, Nev	259, 800
West Fork Carson River at Woodfords, Calif	74, 800
Clear Creek near Carson City, Nev	4, 130
Subtotal	338, 700
Ungaged inflow, along 4,800-foot contour	24, 800
Total inflow	363, 500
Outflow, Carson River near Carson City, Nev	286, 300
Depletion within the valley	[1] 77, 200

[1] Area of valley enclosed by the 4,800-ft contour is about 54,600 acres; depletion exclusive of rainfall is 1.41 ft. As determined above, inflow is substantially the natural amount, whereas outflow is that under irrigation as of 1909–60. Thus, the depletion derived above is likewise that under irrigation.

From the budget, depletion of runoff within the Carson Valley below an altitude of 4,800 feet averages about 77,000 acre-feet yearly. This volume would be equivalent to a mean depth over the valley of 1.4 feet. On the basis of the record for Minden, yearly precipitation on the valley plain averages about 9 inches, or 0.75 foot, in depth, or 41,000 acre-feet in volume. Thus, aggregate yearly consumptive use of water within the valley becomes about 2.2 feet in depth, or 118,000 acre-feet in volume. Both the depletion of runoff and the aggregate consumptive use, just cited, include the effects of irrigation as practiced in the valley during the past several decades.

The preceding estimate of aggregate yearly consumptive use is derived as the sum of runoff depletion within the valley plus precipitation on the valley plain. Table

7 derives a corresponding estimate from consumptive-use coefficients such as those given by Blaney and Criddle (1962),[1] adjusted approximately by the writer to apply to the somewhat-short growing season and the variable water supply of the Carson Valley. The two estimates being very nearly equal (118,000 and 114,000 acre-ft), the preceding estimate of mean yearly depletion of runoff within the valley (77,000 acre-ft) is strongly substantiated.

Incidentally, table 7 suggests that the increased consumptive use owing to irrigation in Carson Valley averages about 45,000 acre-feet yearly.

[1] Blaney, H. F., and Criddle, W. D., 1962, Determining consumptive use and irrigation water requirements: U.S. Dept. of Agriculture, Agr. Research Service Tech. Bull. 1275, 59 p.

TABLE 7.—*Estimated mean yearly consumptive use of water chargeable to the Carson Valley, Calif.-Nev., under current irrigation practice and under presumed natural conditions*

Land category	Acres	As irrigated		Naturally	
		Feet	Acre-feet	Feet	Acre-feet
"Bottom land" having an irrigation water right and a water table generally less than 3 ft below land surface (after U.S. Bur. Reclamation). Originally native meadow; currently irrigated for forage	18,400	1.75	32,200	1.60	29,400
"Bench land" having an irrigation water right and a water table generally 10 ft or more below land surface. Originally in native xerophytic vegetation; now generally in alfalfa and other forage plants	8,200	2.75	22,600	.75	6,200
Irrigated land between "bottom" and "bench," having a water table generally more than 3 ft below land surface	25,400	2.25	57,200	1.25	31,800
Not irrigated; xerophytic vegetation	2,600	.75	2,000	.75	2,000
Totals	54,600		114,000		69,400

U.S. GOVERNMENT PRINTING OFFICE : 1969 O—329-508