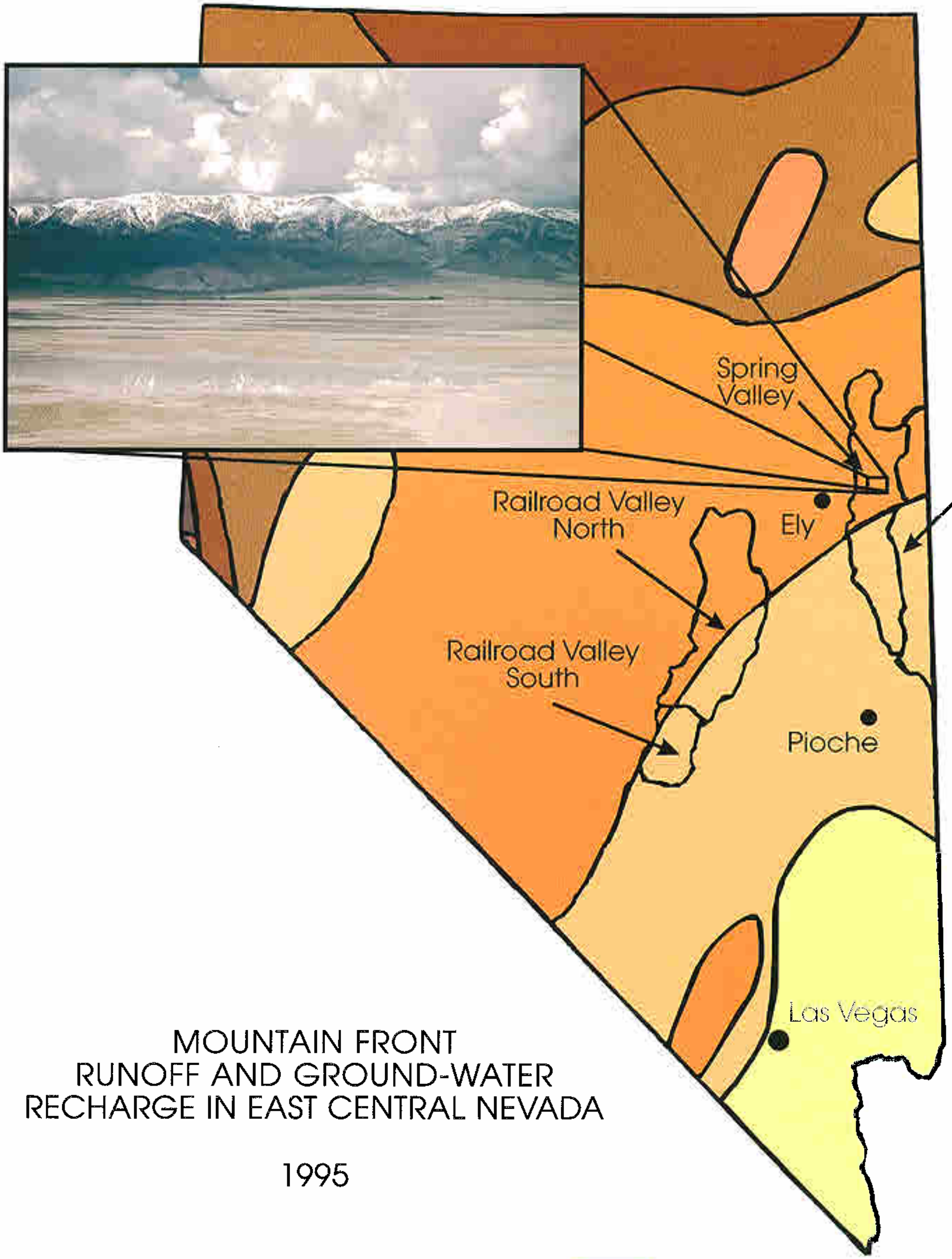

MOUNTAIN FRONT RUNOFF AND GROUND-WATER RECHARGE IN EAST CENTRAL NEVADA

1995

Las Vegas Valley Water District

COOPERATIVE WATER PROJECT
Water for Nevada's Future
Report No. 17

MOUNTAIN FRONT RUNOFF AND GROUND-WATER RECHARGE IN EAST CENTRAL NEVADA

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1995

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INTRODUCTION

In October 1989, the Las Vegas Valley Water District (District) filed for water rights in 28 hydrologic basins in eastern and southern Nevada. Consultants, retained by the District, were directed to evaluate all available hydrologic data for each basin and to develop computer models to represent the ground-water hydrology; one basin was evaluated primarily for surface water. Numerous reports were prepared which present the hydrology of the basins.

The U. S. Geological Survey (USGS) in conjunction with the Nevada Department of Conservation and Natural Resources conducted reconnaissance studies regarding the water resources for a number of hydrographic basins in Nevada during the 1960's and 1970's. These studies defined the basin's hydrologic budget, ground-water recharge and discharge, and estimated mountain front runoff for some basins.

The estimation of ground-water recharge, occurring in the mountain block, is based on an empirical technique first described by Maxey and Eakin (1949). This technique now referred to as the Maxey-Eakin method was further described by Eakin (1951) and has been reviewed by numerous investigators, most recently Avon and Durbin (1992). Avon and Durbin (1992) performed a statistical analyses of the Maxey-Eakin method and compared Maxey-Eakin estimates with other independent estimates of recharge. They found the Maxey-Eakin method to be a fairly reliable predictor of recharge. Briefly, the Maxey-Eakin method estimates the percentage of precipitation which will reach the ground-water system for various precipitation zones within the mountain block which are defined by altitude. These percentages were arrived at by estimating the discharge of a basin from evapotranspiration and then balancing the amount entering the basin (recharge) with the amount leaving the basin (discharge).

The reconnaissance studies also included an estimation of the amount of runoff occurring at the bedrock-alluvial contact, referred to as mountain front runoff, for basins surrounded by high mountain ranges receiving significant snowpack. While the studies estimated the overall volume of mountain front runoff for these basins, the role of the mountain front runoff in the overall water budget was not specifically addressed. In many basins this mountain front runoff provides water for agriculture and phreatophytes in the spring and summer months when it is available. The reconnaissance report for Spring Valley (Rush and Kazmi, 1965) termed this runoff rejected recharge and implied that some was probably entering the ground-water system past the bedrock-alluvial contact. Brothers et al. (1994) concluded that in water rich valleys, such as Spring Valley, the shallow depths to water and extensive surface water regime suggest the application of the Maxey-Eakin method may underestimate the percentage of ground-water recharge.

The Maxey-Eakin method was developed about fifty years ago, and has provided estimates of annual ground-water recharge for basins in Nevada that the Nevada State Engineer has used to evaluate and allocate ground-water resources. Recent studies (Nichols, 1992) regarding evapotranspiration rates of various phreatophytes indicate that some rates might be as much as 3.5 times higher than rates used in the USGS reconnaissance studies. This could also indicate that the Maxey-Eakin method is low in estimating the amount of ground-water recharge occurring in basins where the discharge estimates are based on phreatophyte usage.

This report investigates the mountain front runoff component in Spring, Snake, and Railroad Valleys, and compares the volume of mountain front runoff from primarily carbonate mountains with runoff from other types of mountain blocks. It appears that the actual amount of water infiltrating into the ground-water system from the mountain block may be higher in carbonate systems producing lower mountain front runoff volumes and higher ground-water recharge than the Maxey-Eakin method estimates.

It must be emphasized that the Maxey-Eakin method is at best an empirical technique to estimate the amount of water entering a ground-water basin on an annual average. The method was applied to the majority of these basins in the 1960's and 1970's using annual average precipitation data available at that time from a limited amount of stations. Actual ground-water recharge is dependent on precipitation, type of vegetative cover, and most likely geologic type of the recharge area. However, ground-water recharge estimates made by the Maxey-Eakin method, as an overall average estimate, are the best estimates currently available.

Purpose and Scope

The purpose of this investigation is to evaluate the anomalous mountain front runoff estimates and how it is accounted for in the basin water budgets. Published reports which address mountain front runoff and water budget analysis were reviewed.

FATE OF PRECIPITATION

Part of the precipitation that falls in Nevada infiltrates through soil and rock and recharges the state's ground-water aquifer systems. The rest of the precipitation either directly evaporates, is transpired by plants, or becomes surface runoff (Watson et al., 1976). Surface runoff in the Great Basin will ultimately evaporate, be transpired by riparian plants or crops, or infiltrate and recharge the ground-water system. Surface runoff from those basins that are part of the Colorado River drainage have essentially the same fate, except some flows ultimately reach the Colorado River. Precipitation in Nevada is generally altitude dependent, with increased precipitation in high altitude mountains and decreased precipitation in valleys (Hardman, 1936). Independent methods have been developed to estimate mountain front runoff and potential ground-water recharge resulting from precipitation and these are discussed below.

Mountain Front Runoff

Mountain front runoff is the surface-water component of precipitation that flows from the mountains to adjacent alluvial basins. Its volume is estimated at the contact between the consolidated rock of the mountains and the unconsolidated sediments of the alluvial basins. Runoff from the mountain block occurs when infiltration capacities of soil and rock in the mountain block are exceeded. This condition exists during intense precipitation, rapid snow melt, and sustained spring flow. Spring flow has two components. The first are obvious springs of varying discharge that contribute directly to stream flow and the second are the extremely diffuse springs or seeps that add unperceptively to base flow. Spring flow within the mountain block can be considered rejected recharge; or recharge that is intercepted and diverted to land surface by fractures and dissolution channels on its way to the ground-water basin.

Mountain front runoff was calculated by the USGS in Railroad Valley, Spring Valley, Lake Valley, and other valleys using methods described in Moore (1968). Moore (1968) developed the runoff-altitude relationship shown in Table 1 for altitude zones in six runoff regions in Nevada. Figure 1 shows the locations of the runoff regions and the three valleys. Railroad, Spring, and Snake Valleys, are located in regions A and B.

Mountain front runoff was calculated for Railroad Valley, Spring Valley and Snake Valley from the adjoining mountains with elevations greater than 7,000 feet (Van Denburgh and Rush, 1974; Hood and Rush 1965; Rush and Kazmi, 1965). This elevation was selected because as shown in Table 1, significant runoff is only generated above 7,000 feet in Regions A and B. The average bedrock-alluvial contact in these valleys is also near 7,000 feet.

The relation in Table 1 was adjusted for local differences in geology, precipitation, vegetation, land slopes, and land use. These adjustments are based on determinations of the mean flow of selected streams, which are used to adjust the runoff-altitude relation for each mountain range or distinct areas of each range. Runoff is then determined by calculating the mountain area in each altitude zone.The resultant areas are multiplied by factors similar to those shown in Table 1, however the factors have been adjusted for local conditions.

Ground-Water Recharge

Ground-water recharge is the entry of water into the saturated zone. The primary source of ground-water recharge is the component of precipitation that is not evapotranspired and infiltrates through the unsaturated zone to the saturated zone. If rainfall is less than 5 to 10 inches per year, precipitation will generally not pass through the unsaturated zone to the saturated zone, except in cases where the unsaturated zone is very permeable. The exact amount of recharge depends on the permeability of the unsaturated zone, the specific retention of the unsaturated zone, and the distribution of precipitation in relation to temperature (Davis and DeWiest, 1966). In Nevada, both precipitation, and the percentage of precipitation that recharges the ground-water system, generally increases with land surface elevation. Therefore, the predominate source of ground-water recharge is precipitation falling in the mountain regions.

The ground-water recharge rate is the quantity of ground water that can offer a dependable long-term supply of water for use by both man and phreatophytes. The State Engineer of Nevada generally limits annual ground-water use in a region to the average annual ground-water recharge rate.

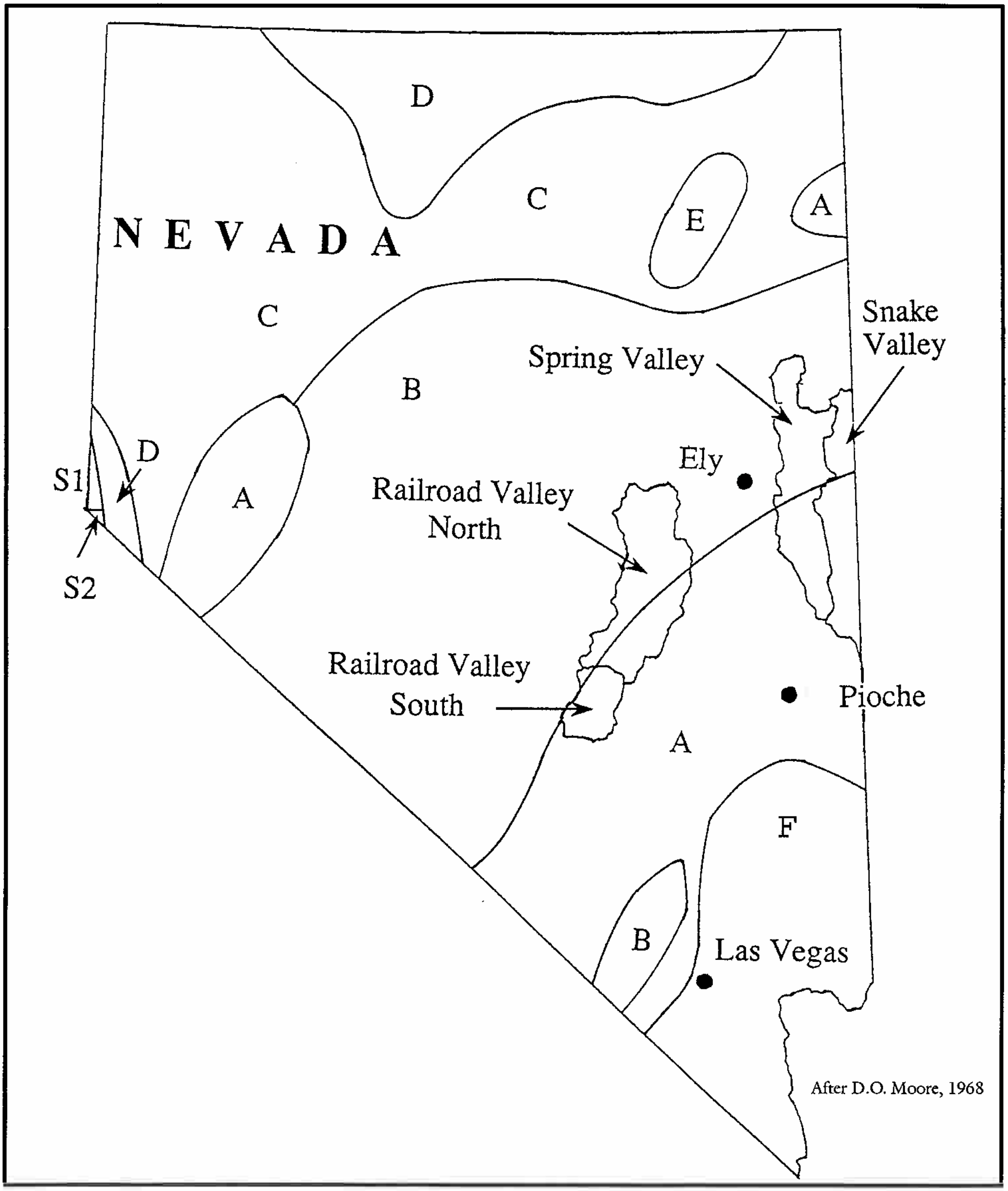

Figure 1.-- Runoff regions in Nevada

Table 1.--Runoff values by altitude zones for different regions in Nevada.

Altitude Range (feet)	Runoff in each region (inches per year)					
	A	B	C	D	E	F
5,000 - 6,000	0.0	0.0	0.5	0.5	1.6	0.3
6,000 - 7,000	0.0	0.0	1.2	3.5	5.5	0.7
7,000 - 8,000	0.4	0.5	3.0	7.0	10.0	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	21.0	4.5
10,000 - 11,000	9.4	12.0	14.0	21.0	26.0	--
11,000 - 12,000	16.0	18.0	--	--	--	--

After Moore (1968)

The USGS has estimated ground-water recharge for most of the basins in Nevada, and published these values jointly with the State of Nevada in the "Ground-Water Resources Reconnaissance and Water Resource Bulletin" series. The method used to estimate ground-water recharge was developed by USGS Hydrogeologists G.B. Maxey and T.E. Eakin between 1947 and 1951 (Watson et al., 1975 p. 339). They applied the method based on Hardman's (1936) zones of assumed equal rainfall. Hardman (1936) showed that average annual precipitation in Nevada is related closely to altitude and that it can be reasonably estimated by relating precipitation rates to various altitude zones. In addition, it is assumed that for any given altitude zone, a particular percentage of total precipitation is available for recharge of the ground-water reservoir, with that percentage dependent upon the average amount of precipitation within that zone (Van Denburgh and Rush (1974). As described in Eakin et al. (1951, p. 79-81) information from thirteen valleys, where ground-water discharge estimates were available, were used to estimate the percent of rainfall in each zone of equal rainfall which recharges the ground-water system. It was assumed that the valleys were in hydrologic equilibrium, in that recharge to a basin equals discharge from the basin. Recharge percentages were balanced by trial and error to match the estimated discharge (Eakin et al., 1951, p.79-81). For convenience this method for estimating recharge is referred to as the Maxey-Eakin method in this and many other reports.

In some basins where ground water is close to land surface the Maxey-Eakin method overestimates recharge, since much of the calculated recharge is rejected by the ground-water system. For instance Rush and Everett (1966) did not use the Maxey-Eakin method in Huntington Valley because the alluvium near most streams is saturated and the method would have overestimated recharge because most potential recharge is rejected. Similarly the Maxey-Eakin method may underestimate recharge in basins with low mountain front runoff (Van Denburgh and Rush, 1974).

Table 2, 3, and 4 summarize the use of this method to estimate ground-water recharge in Railroad, Spring, and Snake Valleys. Comparing Table 1 to Table 2 it is apparent that the

Table 2.--Estimated average annual precipitation and ground-water recharge in Railroad (Northern Part), Nevada.

Precipitation Zone Altitude (feet)	Area (acres)	Estimated Annual Precipitation				Estimated Recharge from Precipitation	
		Range (inches)	Average (inches)	Average (feet)	Average (acre-feet)	Percent of Precipitation	Acre-Feet per Year
9,000 - 11,513	22,000	>20	21.6	1.8	40,000	25	10,000
8,000 - 9,000	58,800	15 - 20	18	1.5	88,000	15	13,200
7,000 - 8,000	183,000	12 - 15	13.2	1.1	201,000	7	14,000
6,000 - 7,000	368,000	8 - 12	10	0.8	294,000	3	8,800
5,000 - 6,000	421,000	5 - 8	6	0.5	210,000	0	0
4,706 - 5,000	324,000	<5	4.8	0.4	130,000	0	0
Total (Rounded)	1,380,000				960,000		46,000

After Van Denburgh and Rush (1974)
minor differences due to rounding

Table 3.--Estimated average annual precipitation and ground-water recharge in Spring Valley, Nevada.

Precipitation Zone Altitude (feet)	Area (acres)	Estimated Annual Precipitation				Estimated Recharge from Precipitation	
		Range (inches)	Average (inches)	Average (feet)	Average (acre-feet)	Percent of Precipitation	Acre-Feet per Year
Above 9,000	59,100	>20	21	1.75	103,000	25	26,000
8,000 - 9,000	107,300	15 - 20	17.5	1.46	156,000	15	23,000
7,000 - 8,000	183,500	12 - 15	13.5	1.12	206,000	7	14,000
6,000 - 7,000	393,000	8 - 12	10	0.83	326,000	3	10,000
Below 6,000	342,000	<8	-	0.5	171,000	0	0
Total (Rounded)	1,085,000				960,000		75,000

After Rush and Kazmi (1965)

Table 4.--Estimated average annual precipitation and ground-water recharge in Snake Valley, Nevada and Utah.

Precipitation Zone Altitude (feet)	Area (acres)	Estimated Annual Precipitation				Estimated Recharge from Precipitation	
		Range (inches)	Average (inches)	Average (feet)	Average (acre-feet)	Percent of Precipitation	Acre-Feet per Year
Above 9,000	83,900	>18	20	1.67	140,000	21	29,400
8,000 - 9,000	127,000	16 - 18	17	1.42	180,000	14	25,200
7,000 - 8,000	240,000	13 - 16	14.5	1.21	290,000	8	23,200
6,000 - 7,000	601,000	11 - 13	12	1	331,000	5	16,600
5,000 - 6,000	767,000	8 - 11	9.5	0.79	606,000	1	6,100
Below 5,000	412,000	<8	6	0.5	206,000	0	0
Total (Rounded)	2,230,000				2,000,000		100,000
Estimated ground-water underflow from southern Spring Valley to northern Hamlin Valley.							4,000
Estimated average annual recharge from all sources, in the Snake Valley area (rounded)							105,000
After Hood and Rush (1965)							

methods for estimating runoff and ground-water recharge are similar in that they are both based on a relationship to altitude. For example, in the altitude zone of 8,000 to 9,000 feet (Table 1. Region B) 3.2 inches of rainfall is estimated to runoff, whereas in the same elevation zone of Table 2, 15 percent of 18 inches of precipitation or 2.7 inches is estimated to recharge the ground-water system. An important difference between the methods is that Moore (1968) provides a method for calibrating the altitude-runoff relation using stream flow data and ephemeral channel characteristics to account for differences in geology and geography in each basin, whereas the altitude-recharge relation, which were developed by measuring and estimating ground-water discharge, may have a greater degree of uncertainty.

Watson et al. (1976) investigated the Maxey-Eakin method to determine whether a statistically rational basis exists for its use, and concluded the method could not be used to reliably predict recharge, however they further stated it is an appropriate reconnaissance technique and can be used as a first approximation of recharge. To improve the method, geologic and hydrologic characteristics of the consolidated rocks, antecedent moisture, and vegetation will need to be incorporated (Watson et al., 1976); additionally climatic parameters will also need better definition. Avon and Durbin (1992) with almost 20 more years of hydrologic data and the development of other estimating methods found that the Maxey-Eakin Method was quite reliable.

COMPARISON OF MOUNTAIN FRONT RUNOFF AND RECHARGE ESTIMATES

Mountain front runoff and ground-water recharge have been estimated and published in Reconnaissance Series reports for most basins in Nevada. The Nevada Division of Water Resources (1971, p.12) estimated the total annual mountain front runoff for Nevada of 3,200,000 acre-feet and a total ground-water recharge of 2,200,000 acre-feet. Based on these values the average ratio for Nevada basins of mountain front runoff to ground-water recharge is 1.5 : 1.

Carlton (1985) further evaluated these estimates for 160 of the 255 valleys in Nevada and for only five valleys in Utah. He determined that 54 of these valleys were in carbonate terrain and 111 were in non-carbonate terrain valleys. He calculated an average runoff: recharge ratio for the non-carbonate valleys of 1.55 : 1 and a ratio 0.78 : 1 for carbonate valleys. He proposed that one possible reason that carbonate valleys have less runoff than non-carbonate valleys is that precipitation more rapidly infiltrates in carbonate rocks along higher permeability faults, fractures, and joints enlarged by dissolution. Therefore, there is less stream flow at the mountain front. The Maxey-Eakin approach for estimating ground-water recharge is very simplistic. Most assuredly, parameters such as lithology distribution, structure, vegetal cover, soil moisture, surface elevation gradients, storm tracts, to name just a few are important factors in recharge processes. The approach for estimating mountain front runoff accounts for these factors empirically in the calibration process, however, the data base used to calibrate is generally limited.

Figure 2 summarizes the fate of precipitation in the mountains. A percentage of mountain precipitation is lost by evapotranspiration; a percentage infiltrates into the mountain block rocks; and a percentage flows on the ground-surface to the alluvial basins as mountain front runoff. Once it reaches the alluvial basin, mountain front runoff can potentially recharge the alluvial ground-water reservoir or be lost to evapotranspiration or a combination of both. Precipitation which infiltrates into the mountain aquifers may recharge either or both the deep carbonate aquifer system, if present, and the alluvial basin aquifer. Ultimately almost all precipitation falling in the Great Basin part of Nevada is eventually lost to evapotranspiration.

If mountain front runoff is lower than normal in carbonate rock mountains, either recharge to the mountain aquifer or evapotranspiration from the mountain region must be higher. It is doubtful that evapotranspiration from the mountains would be higher since the water probably infiltrates quickly through a thin soil mantel, if present, and fractured rock to depths below the root zone. Therefore, it seems likely that recharge into mountain aquifers would be higher than normal. Assuming this is the case, this could translate into a higher recharge to the alluvial basin and deep carbonate aquifer than would be calculated by the Maxey-Eakin method. Alternatively, recharge in an area with low mountain front runoff could be on the same order as regions with high mountain front runoff, because in a region with high mountain front runoff recharge on alluvial fans may be higher. However, it is likely that regions with low mountain front runoff, resulting from high infiltration rates in the mountain block will have a higher

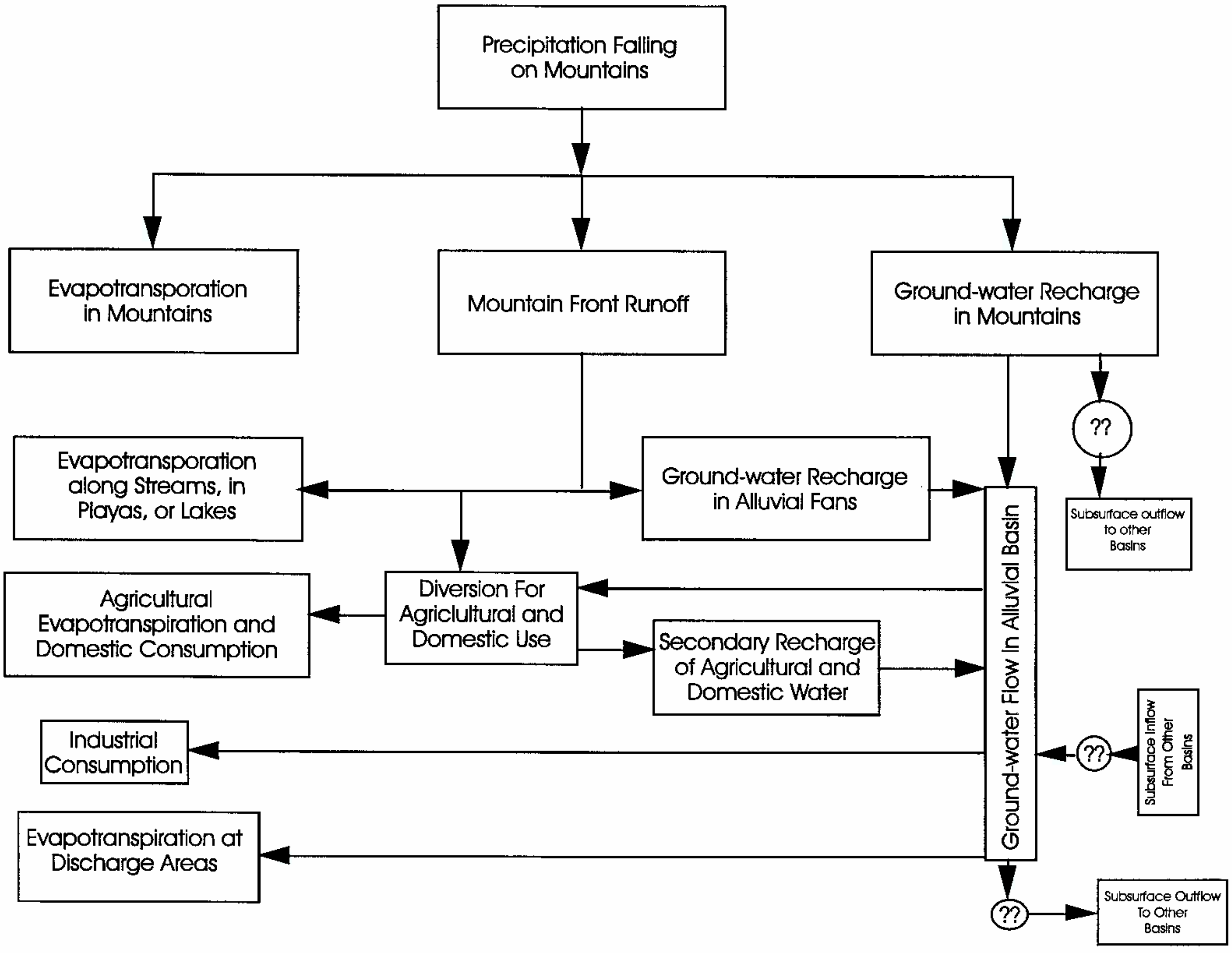

Figure 2.-- Flow chart showing the potential fate of precipitation in Mountains within the Great Basin.

recharge to the ground-water system because the water recharged in the mountain block will not be available for evapotranspiration as it would if it was flowing on the land surface.

Glancy and Katzer (1975, p. 49) offer this explanation of anomalous runoff-recharge ratios: " ... 1) estimates of recharge, runoff, or both may be in error because of inaccuracies inherent in the presently used estimation techniques, 2) the lack of high-altitude precipitation data may have caused overestimates of precipitation, and hence excessive recharge estimates ... , or 3) the geologic character of the consolidated-rock uplands may induce above-average recharge in the consolidated rocks, accompanied by reduced runoff quantities at the mountain fronts, thereby reducing the runoff-recharge ratio. Thus, users of these estimates should be aware of their limitations." Glancy and Katzer's work (1975) was in igneous rocks of the Carson River Basin in Western Nevada. There is little question that carbonate rocks have a greater degree of permeability than non-carbonate rocks and certainly higher than igneous rocks.

Recharge is probably higher in carbonate rocks than that predicted by the Maxey-Eakin method. Thus, additional investigations are necessary to evaluate the low mountain front runoff-recharge ratio. With additional data it may be possible to use mountain front runoff estimates to calibrate the Maxey-Eakin method.

Railroad Valley

Van Denburgh and Rush (1974) estimated recharge from precipitation, discharge, and mountain front runoff to Railroad Valley. The total value of recharge to the northern and southern parts of the valley was estimated to be 51,000 acre-feet per year by the Maxey-Eakin method. Discharge from Railroad Valley is primarily by evapotranspiration and was estimated to be about 81,000 acre-feet per year. The estimated total average annual mountain front runoff for Railroad Valley is 26,000 acre-feet per year. The fact that recharge plus mountain front runoff nearly equals discharge is extraordinarily coincidental. Other investigators (Burbey and Prudic, 1991; Roth and Campana, 1989) have modeled the ground-water flow system and defined ground-water underflow from adjacent basins to provide the additional recharge which balances discharge. The mountain front runoff : recharge ratio for Railroad Valley is about 0.5 : 1, which is a factor of 3 lower than the state wide average of 1.5 : 1 (Nevada Division of Water Resources, 1971, p.12). Van Denburgh and Rush (1974) stated that "This contrast and the presence of carbonate rocks throughout much of the recharge area in each valley suggest that a significant part of total recharge occurs in the carbonate rocks upstream from the mountain front. In fact, these conditions also suggest that the estimates of recharge may be low."

The Railroad Valley runoff : recharge ratio is also 33 percent lower than the average value of 0.78 : 1 calculated for 54 carbonate terrain valleys (Carlton, 1985). This further suggests the estimated recharge value for Railroad Valley may be low. Van Denburgh and Rush (1974) recognized that the estimate of recharge for Railroad Valley of 54,000 acre-feet per year was low (51,000 acre-feet per year from precipitation and 3,000 acre-feet per year of subsurface inflow) and selected a value of 75,000 acre-feet per year for the basin. They postulated two possible explanations for the higher recharge value. One is that the Maxey-Eakin method may underestimate recharge. This is probably due to the amount of increased recharge in the carbonate mountains based on the anomalously low mountain front runoff. The second possible explanation is that subsurface flow from adjacent valleys may be higher that previously estimated.

Spring Valley

Rush and Kazmi (1965) estimated recharge, discharge, and mountain front runoff for Spring Valley. The total recharge to the valley is estimated to be 75,000 acre-feet per year using the Maxey-Eakin method. Total discharge from the valley is estimated to be 74,000 acre-feet per year of which 70,000 acre-feet per year is evapotranspiration and 4,000 acre-feet per year is subsurface outflow. The estimated average annual runoff in Spring Valley is 90,000 acre feet per year. The runoff recharge ratio for Spring Valley is 0.78 : 1 which is lower than the state-wide average of 1.5 : 1 (Nevada Division of Water Resources, 1971, p.12) and equal to the average value calculated by Carlton (1985) for 54 carbonate terrain valleys in Nevada and western Utah. However, Rush and Kazmi (1965) noted that runoff is not evenly distributed throughout the mountains. It was estimated that about 81 percent or runoff occurs in the mountains on the western side of the valley and the remainder on the eastern side. The high mountains of the southern part of the Snake Range (east side of Spring Valley) had a lower than expected runoff (Rush and Kazmi, 1965). The ranges on the west side of the valley comprise 54 percent of the area contributing to mountain front runoff and have an estimated runoff of 74,000 acre-feet per year. The ranges on the east side of the valley comprise 46 percent of the runoff area but only contribute 16,000 acre feet per year of runoff. If both the east and western mountains contributed runoff equally as a function of area above 7,000 feet, the runoff from the eastern mountains would be higher by a value on the order of 60,000 acre-feet per year. Rush and Kazmi (1965) stated two factors that may be causing the lower than expected runoff. These factors are: (1) lower than expected precipitation and/or (2) the presence of east-dipping fault zones which may be highly permeable conduits that adsorb and transmit large quantities of water to the eastern side of the range, where it is discharged as spring fed mountain streams. Precipitation data for the Snake Range presented in Hood and Rush (1965) indicates that precipitation in the Snake Range is not appreciably lower than expected, suggesting lower runoff is probably caused by rapid infiltration in high permeability carbonate rocks. Therefore, based on this logic and Rush and Kazmi's (1965) second factor shown above, you would expect the east side of the Snake Range to have a higher than normal runoff : recharge ratio. However, as pointed out below, this is not the case. It is reasonable to speculate that precipitation in the mountains is readily infiltrating into carbonate rocks and recharging the ground-water system.

Snake Valley

Hood and Rush (1965) estimated recharge, discharge, and mountain front runoff for Snake Valley. The total recharge from precipitation to the valley was estimated to be 103,000 acre-feet per year using the Maxey -Eakin method. An additional 4,000 acre-feet of recharge is estimated to enter the valley as subsurface flow from Spring Valley. The total estimated average annual recharge is estimated at 107,000 acre-feet per year. Total natural discharge from the valley is estimated to be 105,000 acre-feet per year of which 80,000 acre-feet per year is evapotranspiration; 10,000 acre-feet per year is subsurface outflow to the Great Salt Lake Desert; and 15,000 acre-feet per year of leakage to the deep carbonate system. The estimated average annual runoff in Spring Valley is 58,000 acre-feet per year. The runoff : recharge ratio for Spring valley is 0.55 : 1 which is nearly three times lower than the state-wide average of 1.5 : 1 (Nevada Division of Water Resources, 1971, p.12) and significantly lower than the average value calculated by Carlton (1985) for 54 carbonate terrain valleys. Hood and Rush (1965) did not try to explain the cause or the effect on the water budget of this anomalously low mountain front runoff. Carlton (1985) studied Snake Valley and four adjacent valleys in Utah including Tule Valley, Fish Springs, Wah Wah Valley, and Pine Valley. He determined that the runoff : recharge ratio for the combined five valleys would be about 0.59 : 1. Furthermore he noted that the ratio is about 25% less than the ratio for 54 Great Basin carbonate valleys that he examined and 62 percent less than the 111 Great Basin noncarbonate valleys that he examined. To explain this anomaly he suggested, "One possible reason for carbonate valleys having less runoff than the non carbonate valleys is that recharge more rapidly infiltrates into carbonate rock along secondary faults, fractures, and joints due to dissolution of carbonate rocks."

CONCLUSIONS

The annual estimated mountain front runoff is much lower than expected in Snake Valley and Railroad Valley and to a lesser extent in Spring Valley. Mountain front runoff estimates are based on an altitude-runoff relation which is calibrated using available stream flow information which accounts for local differences in geology, precipitation, vegetation, and land use. Workers in these three valleys all suggested that the mountain front runoff estimates for these valleys were low,when compared with many other valleys, due to the presence of high permeability carbonate rocks which cause a high percent of precipitation and runoff to infiltrate into the carbonate rocks before reaching the mountain front.

This anomaly leads to the question of where does this infiltrated water go and how does it fit in to the basin water budget? Van Denburgh and Rush (1974) suggested that the low value of mountain front runoff may indicate that recharge from precipitation in Railroad Valley is higher than the value calculated using the Maxey-Eakin method. The Maxey-Eakin method of calculating ground-water recharge is similar to the Moore (1968) method of calculating mountain front runoff in that both are based on a relation to altitude. However, the altitude-mountain front runoff relation is adjusted for local differences in geologic and geographic conditions, whereas the altitude-recharge relationship is not.

Therefore a basin with surrounding mountains comprised of high permeability carbonate rocks will probably have a low amount of runoff which is measured and reflected in a lower than expected estimated mountain front runoff. The estimated value of ground-water recharge does not take into account differences in geology or geography, therefore basins with mountains composed of high permeability carbonate rock will have a relatively low ratio of mountain front runoff to recharge. This could indicate that the Maxey-Eakin method of estimating recharge may underestimate recharge in these basins. Recharge could be entering the deep carbonate aquifer, the alluvial basin aquifer, or both. It is possible that in these basins the actual recharge of precipitation is near the value that would result if the recharge estimate were increased by the value that would be added to runoff to get a more normal runoff : recharge ratio. For example in Railroad Valley the estimated recharge of precipitation is 51,000 acre-feet per year and the estimated runoff is 26,000 acre-feet per year. A runoff value of 78,000 acre-feet per year would yield the average runoff : recharge ratio of 1.5 : 1. If the difference between the 78,000 value and the estimated value of 26,000 were assumed to be all an increase in recharge, the estimated recharge value of 51,000 acre feet per year would be adjusted to 104,000 acre-feet per year. Van Denburgh and Rush (1974) adjusted the recharge to Railroad Valley to 75,000 acre-feet per year to near the estimated basin discharge.

The assumption that the entire quantity of mountain front runoff below the average value of runoff, based on the runoff : recharge ratio, is accounted for by an equal increase in recharge is probably not correct. A percentage of mountain front runoff recharges the ground-water system via infiltration through alluvial fan deposits. Therefore some of the runoff lost to infiltration in the carbonate rocks in the mountains would probably have infiltered in the alluvial fans at below the mountain front had it not recharged the carbonate rocks. However, evaporation losses should be lower when precipitation runoff infiltrates rapidly below the zone effected by evapotranspiration. Therefore, it seems reasonable to assume that basins with lower than average mountain front runoff will have a higher than average recharge to the ground-water system when carbonate mountains are involved. The Maxey-Eakin method is based on an average altitude: recharge relation derived by trial and error in 13 valleys (Eakin et al. 1951, pg 78-80). Since it does not account for differences in geology or geography the method probably underestimates recharge in basins with carbonate rock mountains with low runoff : recharge ratios.

Van Denburgh and Rush (1974) recognized this possibility in Railroad Valley. Rush and Kazmi (1965) in their study of Spring Valley thought the anomalous quantity of runoff infiltrating on the western side of the Snake Range might be flowing eastward through the Snake Range and contributing to spring flow and runoff on the east side of the Snake Range. However since the runoff : recharge ratio on the east side of the Snake Range and Snake Valley is also very low, the infiltrated runoff could be recharging the deep carbonate aquifer, Spring Valley, or Snake Valley alluvial aquifer. Hood and Rush (1965) calculated Snake Valley mountain front runoff and recharge, but did not comment on the values or the runoff : recharge ratio. However they did comment that "Water from Snake and Hamlin Valleys may enter the carbonate rocks from precipitation and from the valley fill and be transmitted northeastward and northward to the Great Salt Lake Desert."(Hood & Rush, 1965, p. 21). Carlton (1985) calculated the runoff : recharge ratio for Snake Valley at 0.58 : 1 and noted that it was less than the average value for 54 Great Basin carbonate valleys and 111 Great Basin noncarbonate valleys that he examined. It is possible that the infiltrated runoff in the Snake Range is recharging the deep carbonate aquifer and flowing toward the great Salt Lake Desert.

The lower than expected mountain front runoff in Railroad Valley, Spring Valley, and Snake Valley suggests a significant percent of runoff is infiltrating into the carbonate rocks that comprise the mountains. This phenomena may be causing ground-water recharge of precipitation in excess to the amount predicted using the Maxey-Eakin methodology described in Eakin et al. (1951). This recharge may be contributing to the alluvial basin aquifers or the deep carbonate aquifer. There is little available data on the alluvial basin aquifers and almost no data available for the deep carbonate system, therefore it is not possible to state with certainty whether recharge is greater than the value predicted using the Maxey-Eakin method. However, the available information suggests that recharge of precipitation may be greater than previously predicted in these areas, but it will not be possible to evaluate with certainty until ground water in these areas is more fully developed and monitored.

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