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Updated Estimates of the Distribution of Average Annual Precipitation in Carson Valley, 1971–2000, Douglas County, Nevada, and Alpine County, California

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ABSTRACT

Rapid growth and development in Carson Valley is causing concern over the continued availability of water resources to sustain such growth into the future. To address concerns over continued growth, the U.S. Geological Survey, in cooperation with Douglas County, began a study to refine estimates of water-budget components in Carson Valley. Precipitation data collected at 14 sites in and near Carson Valley were used to determine observed and adjusted average annual precipitation at the sites for the period 1971–2000. The averages for this period were used to estimate the distribution of annual precipitation in Carson Valley using two methods. The first method applied relations between precipitation and altitude for the western and eastern sides of Carson Valley to digital elevation models of the area. The second method adjusted a precipitation distribution developed using a climatological model called Precipitation-elevation Regressions on Independent Slopes Model (PRISM) to the 1971–2000 average at the 14 sites.

The distribution derived from the precipitation–altitude relations estimates as much as 40 inches per year near the southern part of the crest of the Carson Range and as much as 18 inches per year near the crest of the Pine Nut Mountains. The adjusted PRISM distribution also shows about 40 inches per year near the southern part of the Carson Range and about 15 inches per year near the crest of the Pine Nut Mountains. The total volume of precipitation from the two methods used for Carson Valley are in fairly close agreement; about 270,000 acre-feet per year from the precipitation–altitude relation, and about 250,000 acre-feet per year from the adjusted PRISM distribution. The overall uncertainty for both estimates is about 15 percent, or from 38,000 to 41,000 acre- ft/yr. Total precipitation from the unadjusted PRISM distribution is about 330,000 acre- feet per year; an apparent overestimation.

The volumes of precipitation for areas receiving more than 15 inches per year estimated by the precipitation-altitude relations are more than twice those estimated by the adjusted PRISM method. Similarly, the volumes estimated using the unadjusted PRISM distribution are 2 to almost 5 times those of the other two methods. Applying the Maxey-Eakin method to the unadjusted PRSIM distribution would greatly overestimate ground-water recharge.

Comparison of the total estimated precipitation with previous studies is difficult because of additional acreage included in the calculation of previous estimates. The updated estimates are somewhat less per acre than previous estimates. In contrast to previous estimates, they are based on recent data collected in and near Carson Valley.

INTRODUCTION

Rapid growth and development in Carson Valley is causing concern over the continued availability of water resources to sustain such growth into the future. As growth continues, ground-water pumping will increase, some land presently used for agriculture will be urbanized, and the effects of these changes on ground-water recharge and discharge are uncertain. These changes may affect discharge of the Carson River and, in turn, may affect water users downstream from Carson Valley (fig. 1).

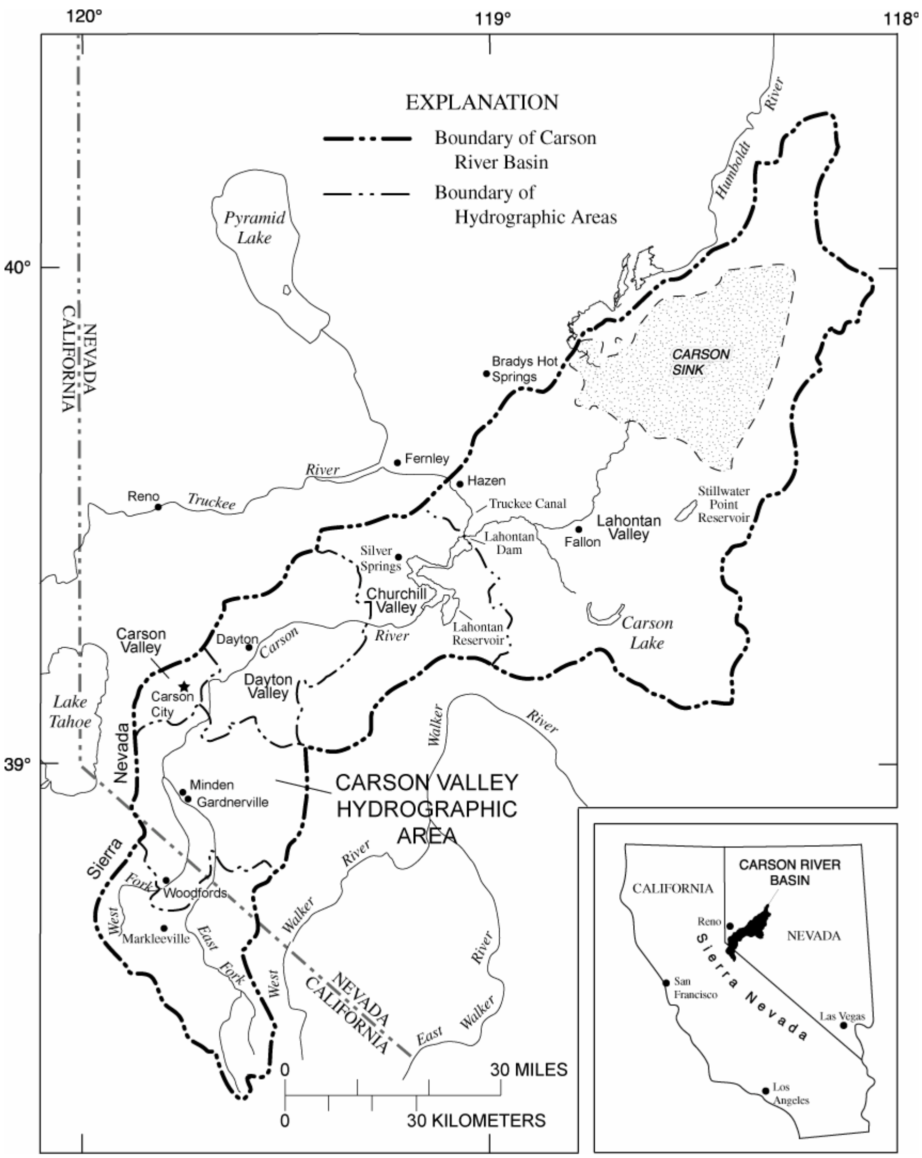

Figure 1. Location of Carson River Basin and Carson Valley subarea and study area.

This report presents updated estimates of the distribution of annual precipitation in Carson Valley. Data on precipitation has been collected at 14 sites in and near Carson Valley by Douglas County and the Natural Resources Conservation Service (NRCS), observers for the National Weather Service, and USGS personnel. Annual precipitation recorded at the 14 sites was used to obtain an average-annual value representative of the period 1971–2000. The averages for this period were used to estimate the distribution of annual precipitation in Carson Valley using two methods. The first method applied relations between precipitation and altitude for the western and eastern sides of Carson Valley to digital elevation models of the area. The second method adjusted a precipitation distribution developed using a climatological model called Precipitation-elevation Regressions on Independent Slopes Model (PRISM) to the 1971–2000 average at the 14 sites.

Geographic Setting

Carson Valley is in Douglas County, Nevada, about 4 mi south of Carson City, Nevada's capital (fig. 2). The southern end of the valley extends about 3 mi into Alpine County, California (fig. 2). The Carson Range of the Sierra Nevada rises abruptly from the valley floor on its western side with mountain peaks ranging from 9,000 to 11,000 ft, whereas on the eastern side, the Pine Nut Mountains rise more gradually to peaks ranging from 8,000 to 9,000 ft.

The major incorporated towns in the valley are Minden and Gardnerville with populations of 2,800 and 3,400, respectively (fig. 2; U.S. Census Bureau, 2003). Subdivisions near the northern and southern ends of the valley are growing rapidly, with populations totaling over 2,000 in 2000 (U.S. Census Bureau, 2003). In addition, development is increasing along the eastern and western sides of the valley, and on the valley floor on land that has historically been agricultural. The population of Douglas County has grown from about 28,000 in 1990 to 41,000 in 2000, an increase of 49 percent (Economic Research Service, 2004).

For purposes of this study, the boundary of Carson Valley was delineated as a subarea of the entire Carson Valley Hydrographic Area[1] (figs. 2 and 3). The subarea boundary was selected to include only those parts of the hydrographic area connected by permeable aquifer materials capable of transmitting ground water to aquifers beneath the floor of Carson Valley. The greatest difference between the hydrographic area and the subarea is along the southern boundary, where the headwaters of the East and West Forks of the Carson River have been excluded. Bedrock underlies the points where the East and West Forks of the Carson River enter the valley, restricting ground-water inflow. Also excluded are areas downstream from the gages on the East and West Forks of the Carson River, near Gardnerville and at Woodfords, respectively (fig. 3). The subarea and study area for this report are shown in figures 2 and 3, which covers about 253,570 acres or 396 mi^2.

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[1]The U.S. Geological Survey and Nevada Division of Water Resources delineated formal hydrographic areas in Nevada systematically in the late 1960's for scientific and administrative purposes (Cardinalli and others, 1968; Rush, 1968).

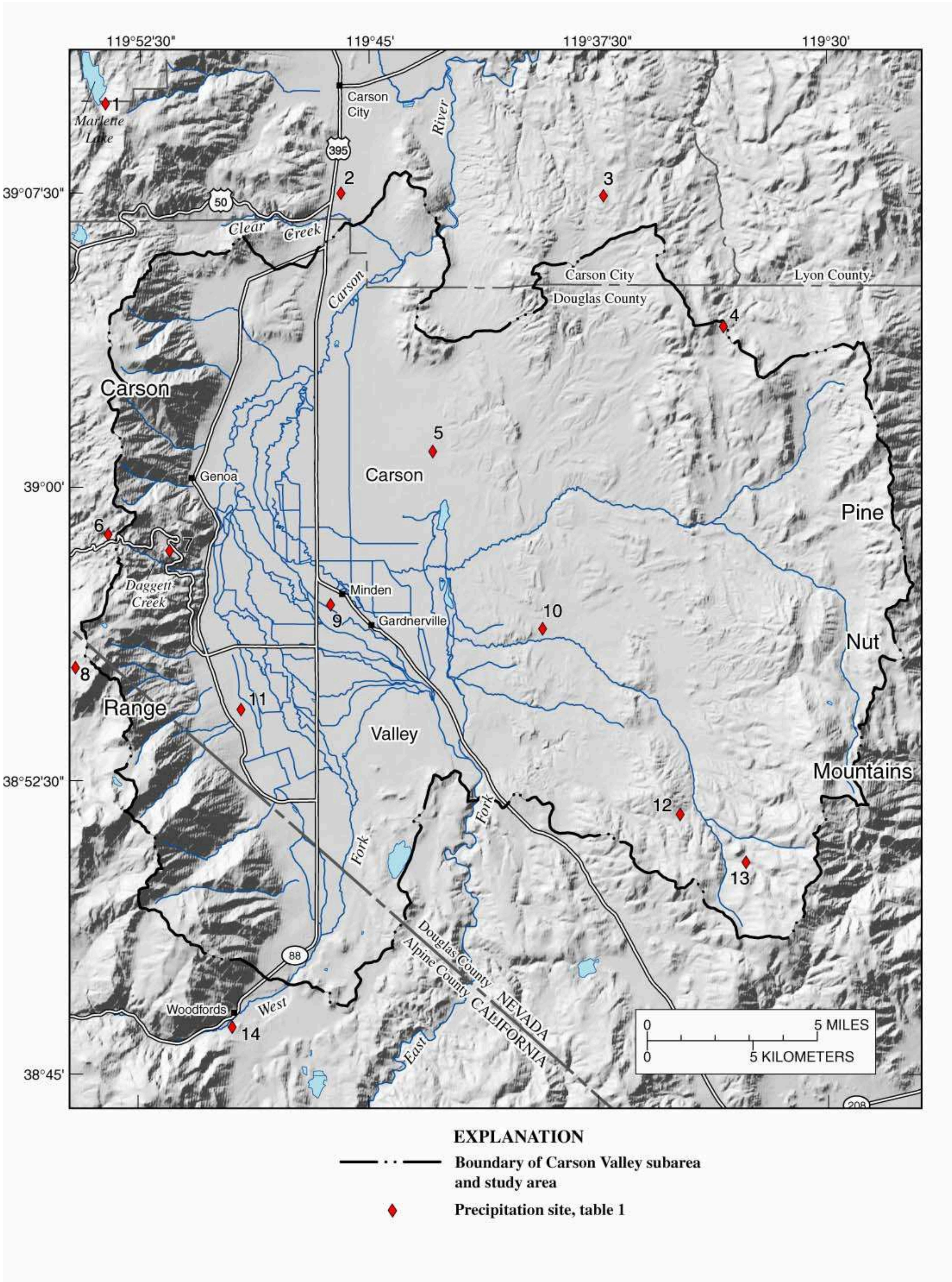

Figure 2. Location of Carson Valley subarea and study area, and location of precipitation sites used for this study.

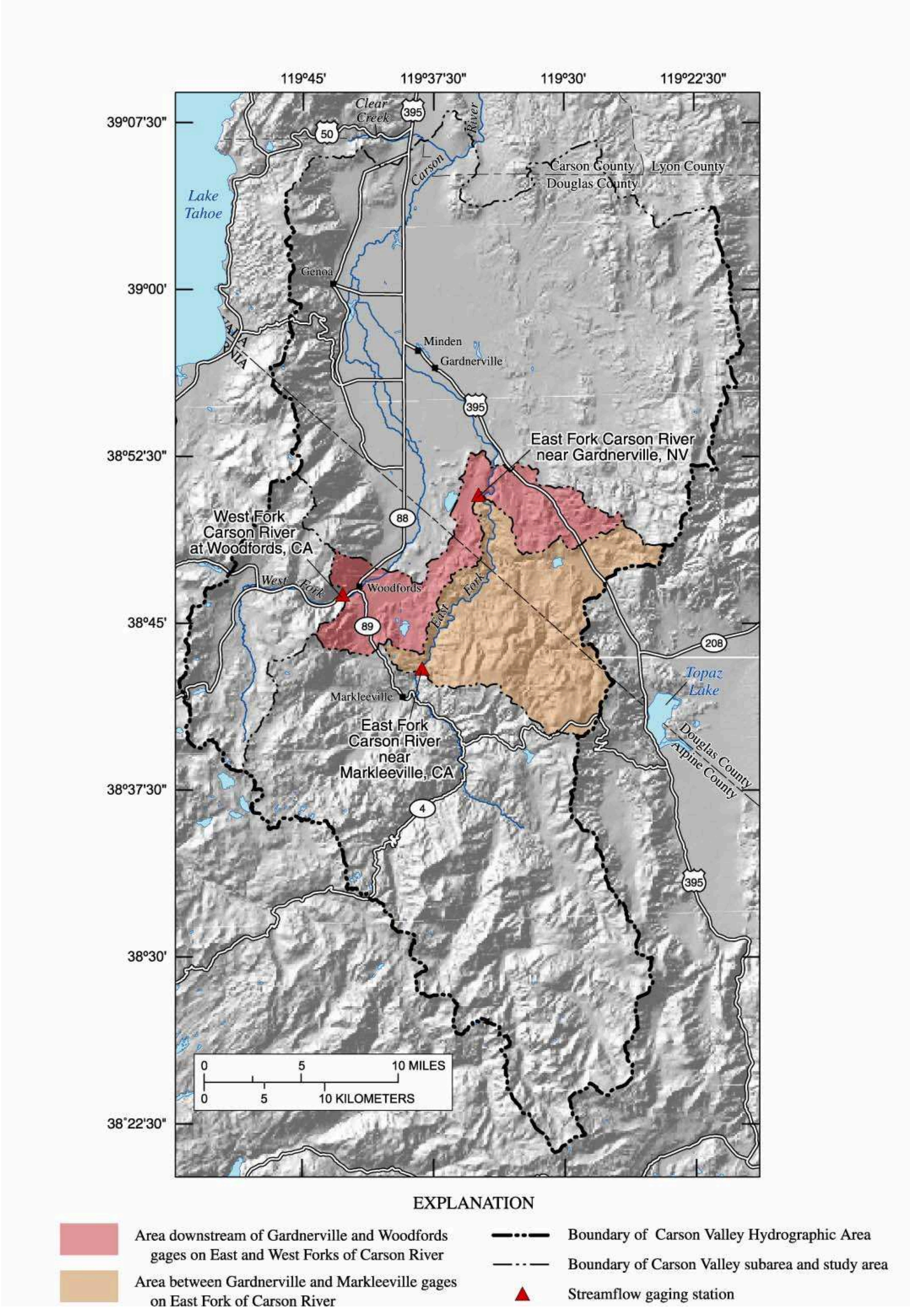

Figure 3. Location of the Carson Valley Hydrographic Area, Carson Valley subarea and study area, gages and drainage areas for the West Fork Carson River at Woodfords, California, and East Fork Carson River near Gardnerville, Nevada, and near Markleeville, California.

Carson Valley lies in the rain shadow of the Sierra Nevada, where average precipitation at the town of Minden is about 8.4 in/yr (period of record 1971–2000; National Oceanic and Atmospheric Administration, 2002, p. 12). In contrast, at the top of the Carson Range precipitation averages greater than 30 in/yr (period of record 1971– 2000; Western Regional Climate Center, 2003), and near the top of the Pine Nut Mountains precipitation averages greater than 15 in/yr (period of record 1984– 2002; Dan Greenlee, Natural Resources Conservation Service, written commun., 2003).

PREVIOUS INVESTIGATIONS

One of the first estimates of precipitation in Carson Valley was made by Vasey–Scott Engineering Co. (1974). They used estimates of annual precipitation for various altitude zones to derive an annual total of 280,000 acre-ft over a total area of 283,000 acres. The precipitation estimate listed 233,000 acre-ft for the Nevada portion of the valley and 46,300 acre-ft for the California portion of the valley. Their study did not include the Clear Creek drainage, but did include about 30,000 acres downstream from the Gardnerville and Woodfords gages on the East and West Forks of the Carson River, respectively, that are not included in the study area for this report (fig. 3; Vasey–Scott Engineering Co., 1974, p. 9–10). The 30,000 acres covers relatively low-altitude terrain (fig. 3).

Glancy and Katzer (1976) also used estimates of annual precipitation for various altitude zones to determine total precipitation in Carson Valley. The resulting estimate of average precipitation in Carson Valley was 270,000 acre-ft/yr for the Nevada portion of the valley, and 100,000 acre-ft/yr for the portion of the valley in California for a total of 370,000 acre-ft/yr (Glancy and Katzer, 1976, p. 48). Their total study area covered 342,000 acres downstream from the Woodfords gage on the West Fork Carson River and downstream from the Markleeville gage on the East Fork Carson River (fig. 3). This area covers 88,430 acres more than that included in the study area for this report, much at relatively high altitudes.

Spane (1977) estimated annual precipitation in Carson Valley using a correlation between precipitation and topographic features of elevation, slope, exposure, and orientation at 43 stations in eastern California and western Nevada. Five of the 43 stations were in or near Carson Valley. Spane applied the correlation to 329 locations in Carson Valley to obtain an estimate of annual precipitation totaling about 388,000 acre-ft for the Nevada and California portions of Carson Valley downstream of the Gardnerville and Woodfords gages on the East and West Forks of the Carson River, respectively (fig. 3; Spane, 1977, p. 56). In Spane's (1977) study, the Clear Creek drainage was included as part of the Carson Valley basin for a total area of 298,350 acres. The Clear Creek drainage covers an area of about 15,000 acres, the western part of which is at a relatively high altitude.

Maurer (1986, p. 36) used the distribution of annual precipitation derived by Spane (1977) to derive an estimate of 350,000 acre-ft for the Carson Valley basin for an area of 283,550 acres. The area used for the estimate did not include the Clear Creek drainage but included about 30,000 acres downstream from the Gardnerville and Woodfords gages on the East and West Forks of the Carson River, respectively (fig. 3).

In 1997, a new map of annual precipitation for the Western United States was developed by Daly and others (1994) using a climatological model called PRISM. The model generated a distribution of precipitation based on data from precipitation stations for the period 1961–90 and by using elevation and the orographic effect of mountain blocks (Daly and others, 1994, p. 141). The resulting map has not been applied to Carson Valley in a published report, but where applied in other parts of Nevada, resulting estimates of recharge have been 2 to 2.5 times greater than those using previous maps of precipitation (Nichols, 2000; Berger, 2000). The distribution of precipitation from the PRISM map was adjusted to average annual precipitation at 14 sites in and near Carson Valley to update precipitation estimates for the period 1971–2000.

METHODS USED

Average annual precipitation for the period 1971–2000 was estimated from precipitation measurements at 14 sites in and near Carson Valley (table 1). Accurate locations for the sites were obtained from site visits using Global Positioning Systems (GPS) operated by Dan Greenlee (Natural Resources Conservation Service, written commun., 2003), Warren Hibbard (NWS field observer, written commun., 2003), and the authors.

Table 1. Precipitation site locations, period of record, altitude, and average annual precipitation, 1971–2000

Site no. (see fig. 2)	Station name	Latitude [a],	Longitude [a],	Period of Record	Altitude [a], in feet above sea level	Average annual observed and adjusted precipitation 1971-2000, in inches
		in degrees, minutes, seconds				
1	Marlette Lake[b]	39°09 51″	119°53 45″	1970-2002	7,880	33.4[b]
2	Carson City[c]	39°07 31″	119°46 01″	1893-2002	4,750	10.5[c]
3	Brunswick Canyon[d]	39°07 20″	119°37 19″	1997-2002	6,370	9.8[e]
4	Lebo Springs[f]	39°03 59″	119°33 29″	1992-2002	7,000	12.5[e]
5	Johnson Lane[g]	39°01 10″	119°42 29″	1995-2002	4,850	7.9[e]
6	Daggett Pass[h]	38°58 37″	119°53 20″	1971-2002	7,330	25.5[h]
7	Kingsbury[i]	38°58 24″	119°51 30″	1988-2002	6,281	21.8[e]
8	Heavenly Valley[b]	38°55 28″	119°54 56″	1970-2002	8,582	32.9[b]
9	Minden[c]	38°57 12″	119°46 26″	1928-2002	4,709	8.4[c]
10	Fish Springs[h]	38°56 23″	119°38 56″	1991-2002	5,120	6.9[e]
11	Sheridan Acres[j]	38°54 19″	119°49 37″	1992-2002	4,774	15.0[e]
12	Lower Pine Nut Mountains[i]	38°51 40″	119°34 49″	1985-2002	6,440	13.6[e]
13	Upper Pine Nut Mountains[i]	38°50 27″	119°32 40″	1985-2002	7,201	15.2[e]
14	Woodfords[h]	38°46 16″	119°48 58″	1909-1990	5,650	21.0[h]

[a] North American Datum of 1927

[b] Location data from Dan Greenlee (Natural Resources Conservation Service, written commun., 2003), average for 1971–2000 from Natural Resources Conservation Service (2003).

[c] Location data from USGS field visit, average for 1971–2000 from National Oceanic and Atmospheric Administration (2002, p. 12).

[d] Location and precipitation data from USGS database.

[e] Average calculated by muliplying average for period of record at site by ratio of 1971–2000 average at Minden, NV, divided by average precipitation at Minden for period of record at site

[f] Location and precipitation data from Kara Amestoy (Nevada State Climatologist Office, written commun., 2003).

[g] Location and precipitation data from Warren Hibbard (NWS field observer, written commun., 2003).

[h] Location from USGS site visit, 1971–2000 average from Western Regional Climate Center (2003).

[i] Location and precipitation data from Dan Greenlee (Natural Resources Conservation Service, written commun., 2003).

[j] Location from USGS site visit, precipitation data from George Uebele (NWS field observer, written commun., 2003).

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Average annual precipitation for the period 1971–2000 was available as published values for six of the sites. Published values were obtained from the National Oceanic and Atmospheric Administration (2002, p. 12) for sites 2 and 9 (table 1, fig. 2), from the NRCS (2003) for sites 1 and 8, and from the Western Regional Climate Center (2003) for sites 6 and 14. The eight remaining sites had partial precipitation records from 6 to 18 years (table 1). Average precipitation at these eight sites was adjusted from the partial records to the 1971–2000 period by correlation with an index site at Minden (site 9; fig. 2). The 1971–2000 adjusted average was calculated by multiplying average annual precipitation for the period of record at the sites by the ratio of the 1971–2000 average at Minden to the average precipitation at Minden for the period of record at each site.

To determine the effect of using an index station with greater amounts of annual precipitation, the same procedure was used to obtain adjusted annual precipitation for 1971–2000 using data from the Heavenly Valley site (site 8; fig. 2). The resulting values were from 4 to 10 percent greater at four sites, and less than or equal to 1 percent different at the remaining four sites (table 2).

Table 2. Adjusted average annual precipitation for partial record stations, 1971–2000, using Minden and Heavenly Valley as index stations, and percent difference

Site no. (see fig. 2)	Station name	Average annual adjusted precipitation 1971-2000 Minden index station, in inches	Average annual adjusted precipitation 1971-2000 Heavenly Valley index station, in inches	Percent difference between Heavenly and Minden, + greater, - lower
3	Brunswick Canyon	9.8	9.9	+1
4	Lebo Springs	12.5	13.7	+10
5	Johnson Lane	7.9	8.2	+4
7	Kingsbury	21.8	21.6	-1
10	Fish Springs	6.9	7.4	+7
11	Sheridan Acres	15.0	16.4	+9
12	Lower Pine Nut Mountains	13.6	13.5	-1
13	Upper Pine Nut Mountains	15.2	15.2	0

A precipitation distribution for the study area was estimated with two relations between the observed and adjusted average annual precipitation and altitude at the 14 sites (fig. 4). Separate relations were developed for the eastern and western sides of Carson Valley because the change in precipitation with altitude on the western side is twice as great as the relation on the eastern side of the valley. Previous reports have described significant differences in precipitation on the eastern and western sides of Carson and Eagle Valleys that result from the rain-shadow effect of the Sierra Nevada (Spane, 1977, p. 54; Arteaga and Durbin, 1979, p. 18). The relations developed for Carson Valley have R-squared values, or correlation coefficients, of 93 and 79 percent for the western and eastern sides, respectively. The coefficients indicate the amount of variation in the data that is explained by the regression equation. The percent errors associated with the regression equations are 11 and 15 percent for the western and eastern sides of the valley, respectively (fig. 4). The percent error is the standard error divided by the mean of the observed precipitation and multiplied by 100 (Tasker, 1978).

The percent error associated with the regression equations is applicable to the range in altitude represented by the data set (4,700 to 8,600 ft), as shown by plots of residual values. A test of regression equations is to plot the residual values, the difference between the observed values and the values estimated using the equation, against the predicted values (Helsel and Hirsch, 1992, p. 231). If the resulting plot shows an even scatter of points around the zero line, the data set is said to be homoscedastic and the variance explained by the equation is constant throughout the range of the data (Helsel and Hirsch, 1992, p. 12). Figure 5 shows residuals plots for stations on the western and eastern sides of Carson Valley, and an even scatter of points.

Adjusted values for partial-record stations using Heavenly Valley (site 8; fig. 2) as an index site result in a relation that predicts about 3 percent greater precipitation for a given altitude on the eastern side of the valley, and differences of 1 percent or less on the western side of the valley. However, using Heavenly Valley as an index site may overpredict precipitation on the eastern side of Carson Valley. The relation using Minden (site 9; fig. 2) as an index site is considered the better predictor because of its central location in relation to the distribution of the 14 precipitation sites.

An areal precipitation distribution was estimated by applying these relations to a digital-elevation model (DEM) of the study area (U.S. Geological Survey, 1999). The DEM used is a 30-meter digital-raster elevation data set based primarily on U.S. Geological Survey 7.5 minute digital elevation models. To provide a more manageable and somewhat smoothed data set, elevation values from the 30-meter DEM were interpolated using an inverse-distance weighted function (Isaaks and Srivastava, 1989, p. 257–261) to a 500-ft grid superimposed on the study-area boundary. Within about 5 mi of the study area boundary, gridded values of elevation from the 500-ft grid were substituted in the regression equations shown in figure 4, using Excel spreadsheet software.

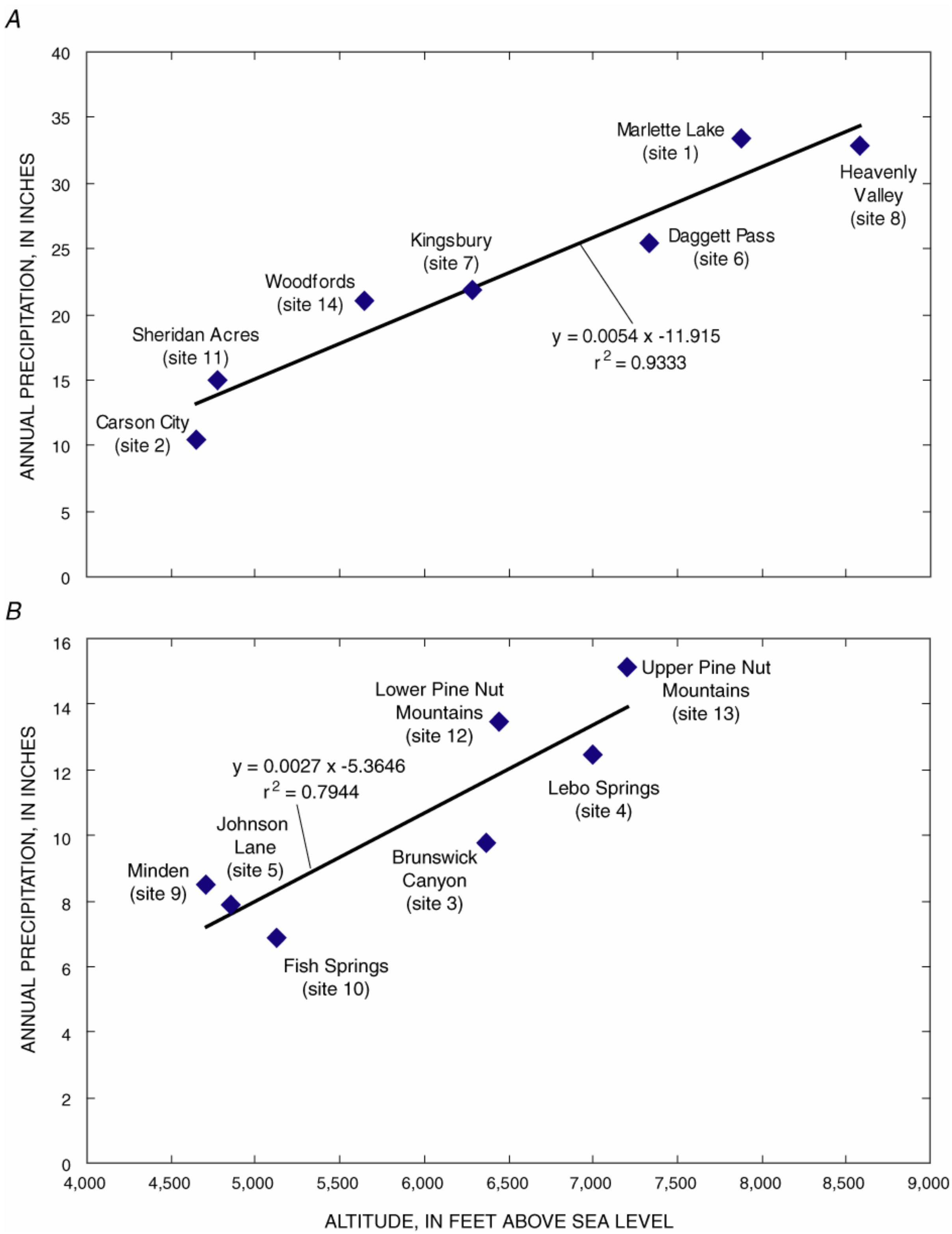

Figure 4. Relations between observed and adjusted average annual precipitation for 1971-2000 and altitude for: A – the western side of Carson Valley, and B – the eastern side of Carson Valley.

The relations in figure 4 were applied on the eastern and western sides of a line about 1 mi east of the base of the Carson Range (fig. 6). The line represents a dividing point between precipitation regimes on the eastern slope of the Carson Range and the central and eastern sides of Carson Valley. Although somewhat arbitrary, the line was chosen to include sites 2 and 11 on its western side, and is based on observations that precipitation during individual storms often decreases markedly within about 1 mi of the Carson Range. The gridded values were contoured using standard spreadsheet software within the study-area boundary to obtain the distribution shown in figure 6. Gridded values of precipitation estimated for both methods were summed within the Carson Valley subarea to obtain the total volumes estimated.

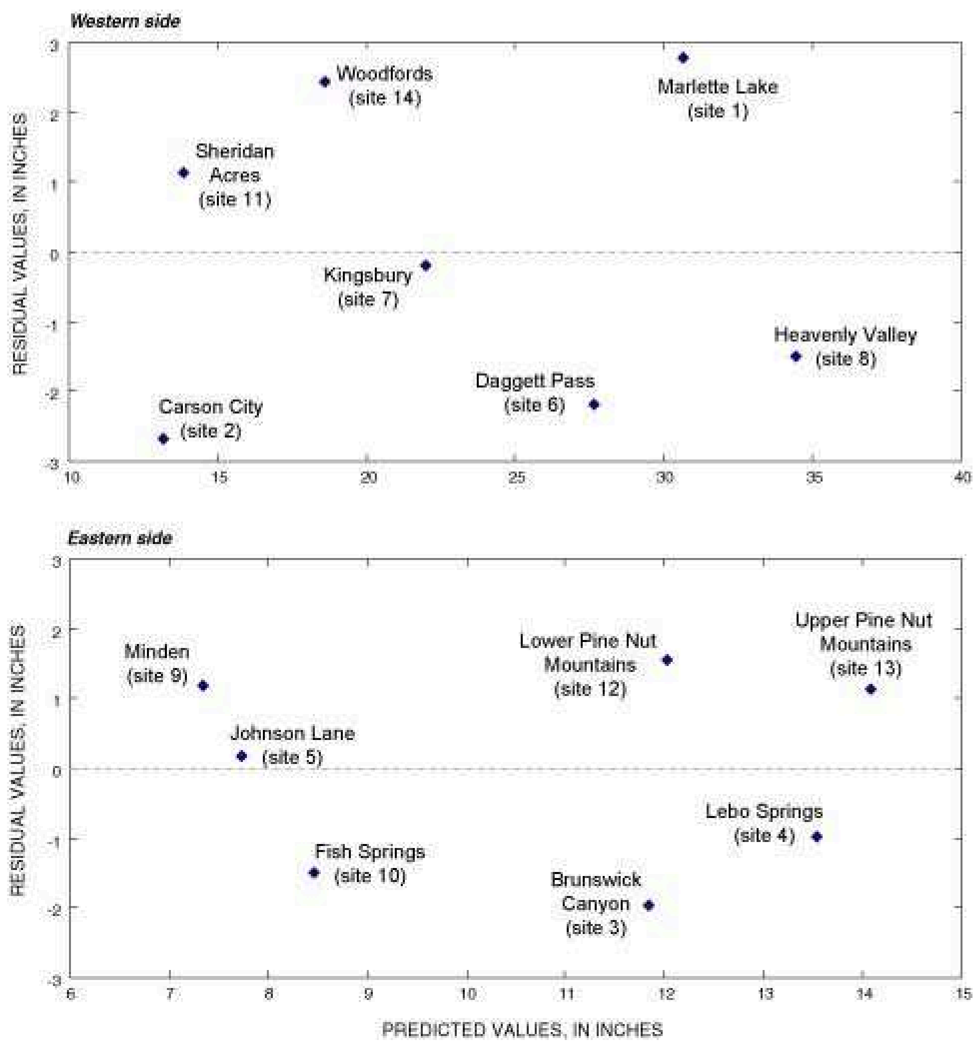

Figure 5. Scatter plots of residual values and predicted values for precipitation-altitude relations for the western and eastern sides of Carson Valley.

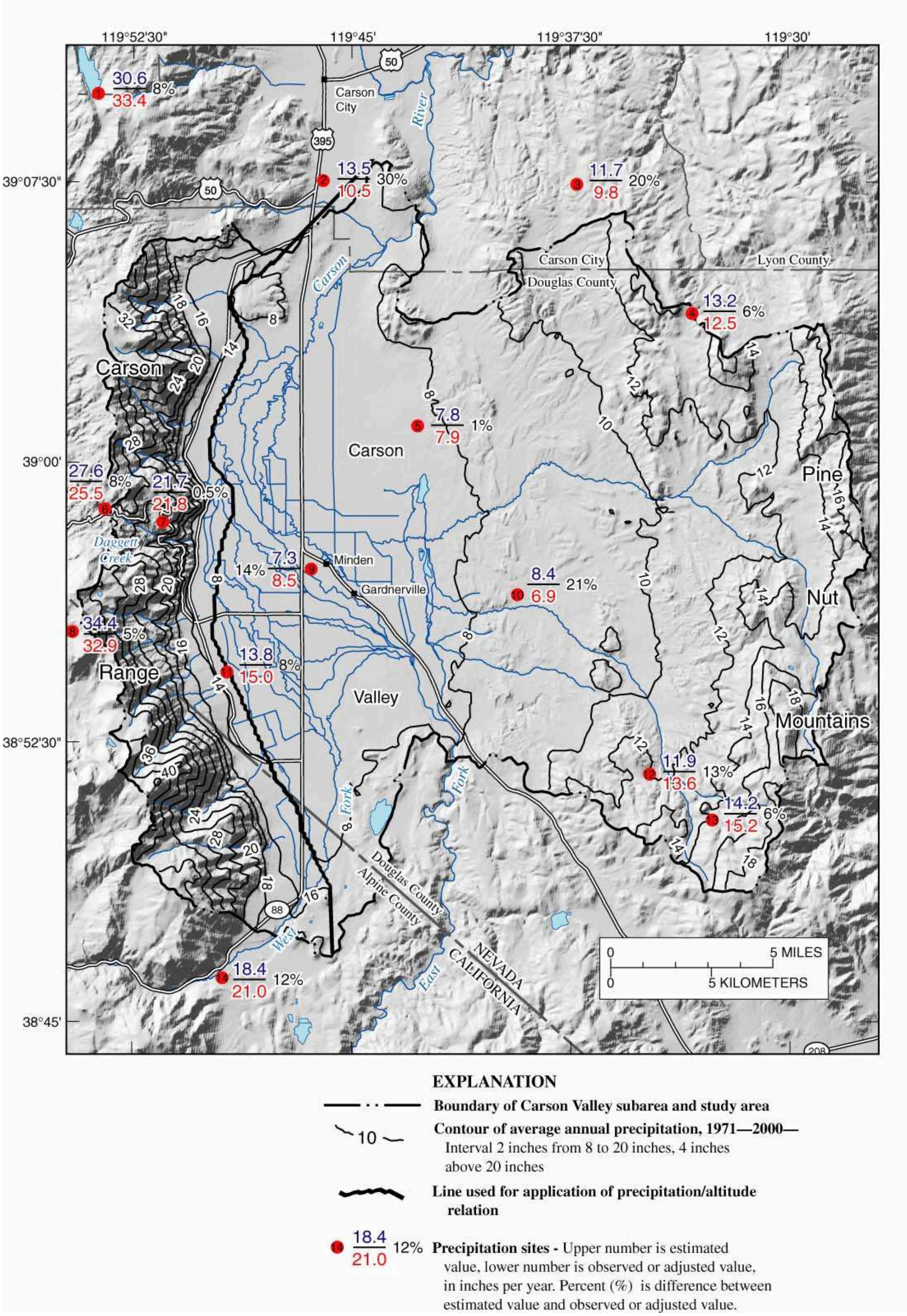

Figure 6. Distribution of average annual preciptation from linear relations for western and eastern sides of Carson Valley, location of a line used for application of the two relations, and observed and adjusted precipitation for 1971-2000 compared with estimated values at 14 sites.

The resulting precipitation distribution provides agreement with the observed and adjusted data points ranging from less than 1 to about 30 percent (fig. 6). Discrepancies are greatest for points that plot farthest from the best-fit lines shown in figure 4. The largest discrepancies were for sites 2–4 in the northeastern part of the study area, where gridded values are overestimated from 6 to 30 percent. Gridded values on the valley floor were underestimated from 8 to 14 percent, and overestimated at site 10 by 21 percent on the eastern side of the valley floor. In the southern part of the Pine Nut Mountains, gridded values were underestimated from 6 to 13 percent, and in the Carson Range, agreement ranged from 8 percent underestimated to 8 percent overestimated.

An alternative precipitation distribution is available from the PRISM map previously discussed (Daly and others, 1994; Oregon State University, 2003; data set downloaded from URL http://www.ocs.orst.edu/prism/products). PRISM estimates and observed and adjusted precipitation for 1971–2000 agree within about 3 percent for stations near the crest of the Carson Range (fig. 7A; sites 1, 6, and 8). PRISM estimates and precipitation measurements fail to agree on the eastern side of the valley. PRISM overestimates precipitation measurements from 80 to 90 percent in the Pine Nut Mountains (fig. 7A; sites 3, 4, 10, 12, and 13).

Gridded values of the PRISM precipitation distribution were adjusted to obtain a more reasonable agreement between the distribution of precipitation provided by the PRISM map and observed and adjusted precipitation for 1971–2000 at the 14 sites. The original PRISM grid has a cell size of 2 km. To apply adjustments, values from the 2-km cell were interpolated to a 500-ft grid equivalent to that used for the precipitation-altitude relations using an inverse-distance weighted function (Isaaks and Srivastava, 1989, p. 257–261). This process produced a grid of precipitation values that are smoothed relative to the original 2-km PRISM grid. Regionally, grid cells within about 5 mi of the study area boundary were used, and calculations were made using Excel spreadsheet software.

The new grid was then adjusted to annual precipitation at the 14 sites, again using an inverse-distance weighted function. The adjustment was made by calculating the ratio of observed and adjusted precipitation for 1971–2000 to PRISM values at corresponding cells for each of the 14 sites. Using Excel spreadsheet software, a corrector grid of the same 500-ft cell size was developed by multiplying the ratio at each station by the inverse of the distance between each station and the cell, summing these values, and dividing by sum of the inverse distances (Isaaks and Srivastava, 1989, p. 257–261). The PRISM grid was then multiplied by the corrector grid to obtain a grid of PRISM-adjusted values. Because the PRISM grid was adjusted to match observed and adjusted precipitation at the 14 sites, the PRISM-adjusted values are equal to the observed and adjusted values for 1971–2000 at those grid cells. The gridded values were contoured using Excel spreadsheet software to produce figure 7B. Gridded values of precipitation estimated for both methods and the unadjusted PRSIM data were summed within the Carson Valley subarea to obtain the total volumes within the study area boundary and the volumes of precipitation above selected amounts of annual precipitation.

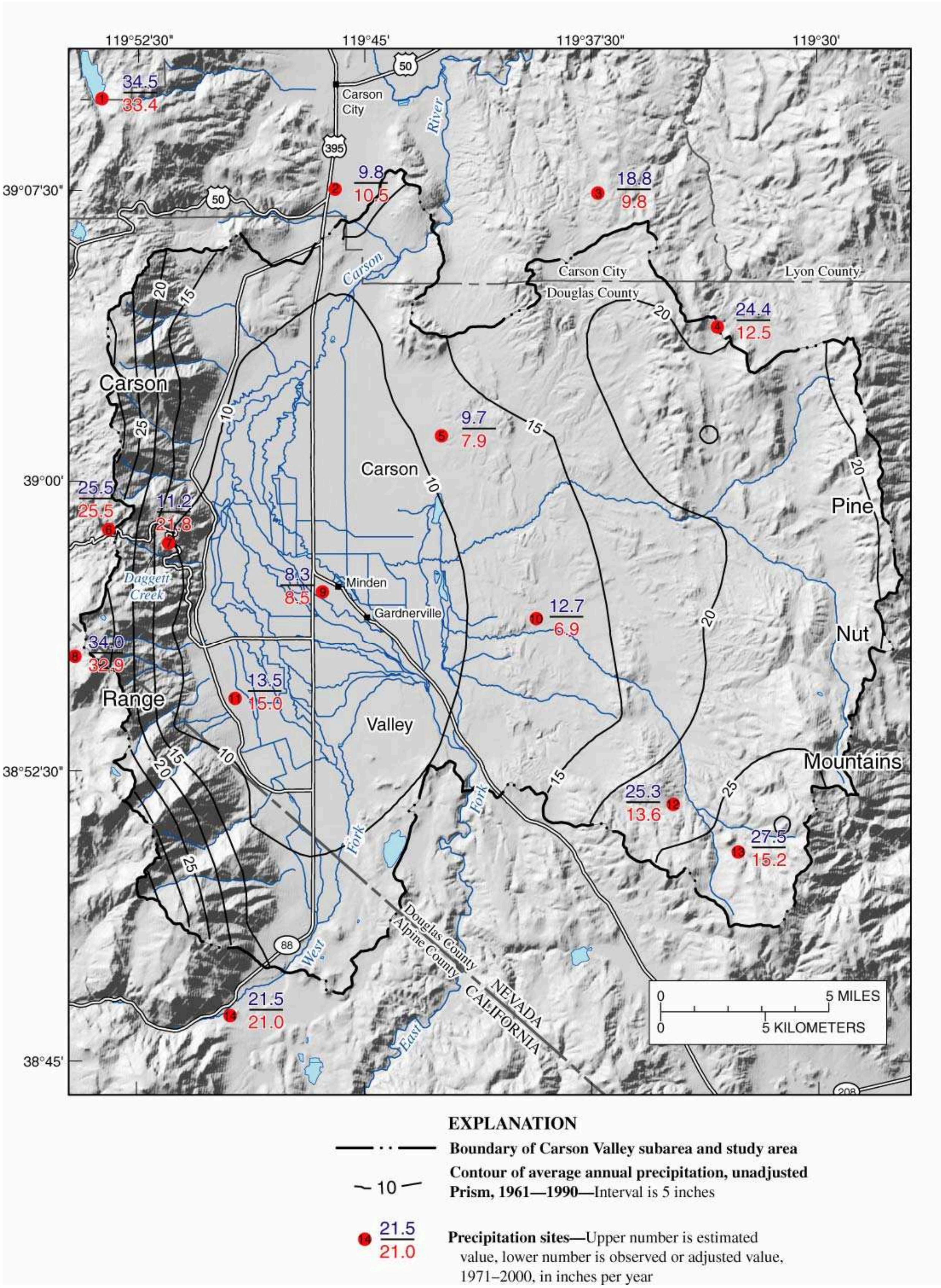

Figure 7A. Distribution of average annual precipitation from unadjusted PRISM data and observed and adjusted precipitation for 1971-2000 compared with unadjusted PRISM values at 14 sites.

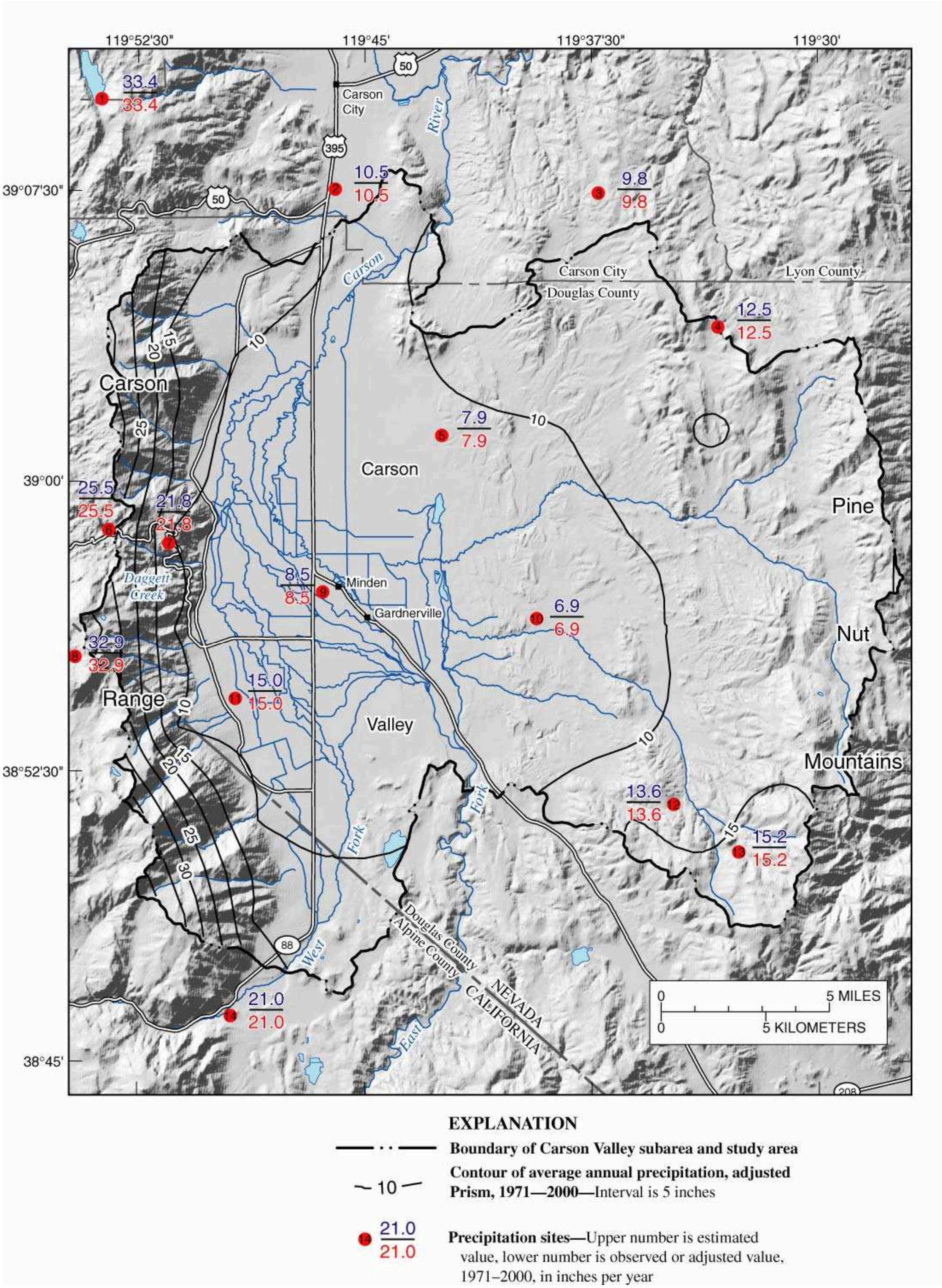

Figure 7B. Distribution of average annual precipitation from adjusted PRISM data, and observed and adjusted precipitation for 1971-2000 compared with adjusted PRSIM values at 14 sites.

UPDATED ESTIMATES OF THE DISTRIBUTION OF AVERAGE ANNUAL PRECIPITATION IN CARSON VALLEY, 1971–2000

Updated estimates of the distribution of annual precipitation in Carson Valley were derived using the 1971–2000 average annual precipitation at 14 sites (figs. 6 and 7B). The distribution derived from the precipitation–altitude relations estimates shows as much as 40 in/yr near southern part of the crest of the Carson Range, and as much as 18 in/yr near the crest of the Pine Nut Mountains (fig. 6). The adjusted PRISM distribution also shows a maximum of about 40 in/yr near the southern part of the Carson Range, and about 15 in/yr near the crest of the Pine Nut Mountains (fig. 7B).

Table 3 lists the volumes of estimated precipitation for the period 1971-2000 above selected amounts of precipitation within the Carson Valley study area. The total volume of estimated precipitation for the entire study area using the two methods developed for this study are in fairly close agreement. The precipitation–altitude relations estimate a total of 270,000 acre-ft/yr, and the adjusted PRISM distribution estimates a total of 250,000 acre-ft/yr. The difference, about 8 percent, likely is caused by the greater amount of precipitation estimated for the Pine Nut Mountains by the precipitation–altitude relations. Total precipitation from the unadjusted PRISM distribution is about 330,000 acre-ft/yr; a significant overestimation, largely caused by overestimation of precipitation on the eastern side of Carson Valley.

Table 3. Volumes of precipitation for entire study area and above selected precipitation amounts for distributions derived from precipitation-altitude relations, adjusted PRISM, and unadjusted PRISM.

Inches of precipitation	Method					
	Precipitation-altitude relations		Adjusted PRISM		Unadjusted PRISM	
	Volume (acre-ft/yr)	Difference between zones	Volume (acre-ft/yr)	Difference between zones	Volume (acre-ft/yr)	Difference between zones
0 (Total for study area)	270,000	-- [a]	250,000	-- [a]	330,000	-- [a]
8	100,000	170,000	80,000	170,000	160,000	170,000
10	76,000	24,000	52,000	28,000	120,000	40,000
12	57,000	19,000	32,000	20,000	97,000	23,000
15	38,000	19,000	17,000	15,000	64,000	33,000
20	21,000	17,000	8,300	8,700	22,000	42,000
25	11,000	10,000	3,400	4,900	4,000	18,000
30	4,700	6,300	1,000	2,400	300	3,700
40	100	4,600	20	980	0	300

[a] – Difference between zones not applicable

The volumes of precipitation above selected precipitation amounts are the volumes totaled above horizontal “slices” across the entire study area. Areas receiving 8 in/yr or more cover the entire study area except for the lowest part of the valley floor. The difference in volume between the entire study area and that above 8 in/yr is similar for all three precipitation distributions, 170,000 acre-ft/yr (table 3). This is because differences between the three precipitation distributions are only slight for areas near the valley floor receiving less than 8 in/yr. The differences in volumes between precipitation zones also are similar for that estimated by the precipitation-altitude relations and the adjusted PRISM for precipitation of less than 15 in/yr. With increasing precipitation, the volume differences between zones estimated by the precipitation-altitude relations are more than twice those estimated by the adjusted PRISM method.

The difference between the volumes estimated for increasing amounts of precipitation becomes most important when applying methods to estimate ground-water recharge such as the Maxey-Eakin method used by Glancy and Katzer (1976, p. 48) and Maurer (1986, p. 35) in Carson Valley. Using this method, a greater percentage of precipitation potentially becomes recharge for precipitation amounts of 15 to 20 in/yr and above. Differences in volumes above 15 in/yr using the unadjusted PRISM distribution are 2 to almost 5 times those of the other two methods. For this reason, applying the Maxey-Eakin method to the unadjusted PRISM distribution would greatly overestimate ground-water recharge.

Comparison of the total estimated precipitation with previous studies is difficult because of additional acreage included in the calculation of previous estimates. Differences in area, estimated annual precipitation per acre, and relative altitude of additional areas between previous studies and this study are listed in table 4.

Table 4. Comparison of total precipitation, area, annual precipitation per acre, and relative altitude estimated in previous studies with this study.

Previous study	Total estimated precipitation, in acre-feet per year	Area of study, in acres	Estimated annual precipitation, in acre-feet per acre [1]	Relative altitude of additional area
Vasey-Scott Engineering Co. (1974)	280,000	283,000	0.99	Low
Glancy and Katzer (1976)	370,000	342,000	1.08	High
Spane (1977)	388,000	298,350	1.30	High [2]
Maurer (1986)	350,000	283,550	1.23	Low
This study –adjusted PRISM	250,000	253,570	0.99	-- [3]
This study – precipitation-altitude relations	270,000	253,570	1.06	-- [3]

[1] – Total estimated precipitation divided by area of study.

[2] – A portion (about 10,000 acres) is at relatively high altitude.

[3] – No additional acres.

Estimates of annual precipitation per acre in this study are somewhat less than previous studies. The estimates are most similar to that of Vasey–Scott Engineering Co. (1974) and similar to that of Glancy and Katzer (1976). However, the estimate of Glancy and Katzer included an additional area of about 88,000 acres at relatively high altitude (table 3). The estimates of Spane (1977) and Maurer (1986) are greater than this study and include additional areas of relatively high and low altitude, respectively. In contrast to previous estimates, estimates for this study are based on recent data collected in and near Carson Valley.

The uncertainty of the estimate of precipitation using the precipitation–altitude relations is assumed to be about 15 percent of the total, or about 38,000 acre-ft/yr. The relations between precipitation and altitude for the western and eastern sides of Carson Valley provided estimates of precipitation that were as great as 30 percent different than the observed or adjusted values at the locations of the precipitation stations. However, precipitation estimated by the relations both overestimated and underestimated observed or adjusted precipitation at the 12 stations. Thus, errors at individual stations may tend to compensate each other, reducing the overall bias (Taylor, 1982, p. 71). The maximum percent error associated with the two regression equations is 15, which strictly applies only to the estimated precipitation at each of the 12 stations. However, the plots of residual values indicate the error is constant throughout the range of the data. For purposes of estimating the overall uncertainty, it is assumed that the estimated precipitation varies similarly to that of the 12 stations. Thus, the uncertainty of the total estimated precipitation may be about 15 percent of the total 250,000 acre-ft/yr, or about 38,000 acre-ft/yr. The uncertainty of precipitation estimated for grid cells at higher altitudes than the precipitation stations, about 8,600 ft in the Carson Range and about 7,200 ft in the Pine Nut Mountains, is unknown.

The uncertainty involved with estimates of precipitation made by adjusting the PRISM distribution is difficult to quantify. However, given that total precipitation estimated by the adjusted PRISM distribution agrees within about 8 percent of that obtained from the precipitation–altitude relations, it is assumed that the overall uncertainty for the PRISM distribution also is about 15 percent of the 270,000 acre-ft/yr, or about 41,000 acre-ft/yr.

CONCLUSIONS

Annual precipitation data from 14 stations in and near Carson Valley, when adjusted to a common period of record, 1971-2000, show different linear relations between altitude and annual precipitation on the western and eastern sides of Carson Valley. The relation on the western side of the valley shows an increase of precipitation with alitude twice as great as that on the eastern side. Applying the relations to a digital elevation model results in a total volume of about 270,000 acre-ft/yr.

A precipitation distribution developed for the western United States using a climatological model called PRISM, compared with precipitation measured at the 14 stations, agrees within about 3 percent for stations near the crest of the Carson Range. However, PRISM overestimates precipitation by 80-90 percent for stations in the Pine Nut Mountains and on the eastern side of the valley. The PRISM distribution of precipitation appears to inadequately represent the full effect of the Sierra Nevada rain-shadow on the eastern side of Carson Valley. Adjusting the PRISM distribution to match measured precipitation at the 14 stations results in a total volume of about 250,000 acre-ft/yr; about 8 percent less that that estimated by the precipitation-altitude relations.

For the precipitation distributions estimated using the precipitation-altitude relations and the adjusted PRISM, the volumes of precipitation for selected precipitation zones are similar for amounts less than 15 in/yr. With increasing precipitation, the volumes estimated by the precipitation-altitude relations are more than twice those estimated by the adjusted PRISM method. Differences in volumes above 15 in/yr using the unadjusted PRISM distribution are two to almost 5 times those of the other two methods. Applying the Maxey-Eakin method to the unadjusted PRSIM distribution would greatly overestimate ground-water recharge.

The overal uncertainty for both estimates is about 15 percent, or 38,000 to 41,000 acre-ft/yr. The estimates are somewhat less per acres than previous estimates. In contrast to previous estimates, they are based on recent data collected in and near Carson Valley.

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