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AS VEGAS VALLEY WATER DISTRICT and the
EVADA DIVISION OF WATER RESOURCES

Regional Ground-Water Evapotranspiration and Ground-Water Budgets, Great Basin, Nevada

Professional Paper 1628

S. Department of the Interior
S. Geological Survey

Table A1. General information for field sites, Great Basin study areas

[NR: Altitude not reported, but all sites are between 3,800 and 4,200 feet above sea level (Duell, 1990, p. E2).]

Site (fig. A1)	Location	Latitude (°N)	Longitude (°W)	Altitude (feet above sea level)	Dates of data collection	Source
1	Smoke Creek Desert, Nev.	40.534	119.818	3,907	June-Sept. 1991	Nichols, 1994
2	Smith Creek Valley, Nev.	39.330	117.512	6,046	May-Sept. 1989	Nichols, 1994
3	Owens Valley, Calif., site A	37.400	118.383	NR	Jan. 1984-Oct. 1985	Duell, 1990
4	Owens Valley, Calif., site C	37.317	118.367	NR	Jan. 1984-Oct. 1985	Duell, 1990
5	Owens Valley, Calif., site E	37.250	118.333	NR	Jan. 1984-Oct. 1985	Duell, 1990
6	Owens Valley, Calif., site F	37.108	118.250	NR	Jan. 1984-Oct. 1985	Duell, 1990
7	Owens Valley, Calif., site G	36.983	118.225	NR	Jan. 1984-Oct. 1985	Duell, 1990
8	Owens Valley, Calif., site J	36.842	118.183	NR	Jan. 1984-Oct. 1985	Duell, 1990
9	Owens Valley, Calif., site L	36.783	118.183	NR	Jan. 1984-Oct. 1985	Duell, 1990
10	Ash Meadows, Nev., site 1	36.482	116.332	2,255	March-Dec. 1994	Nichols and others, 1997
11	Ash Meadows, Nev., site 2	36.482	116.335	2,252	March-Dec. 1994	Nichols and others, 1997
12	Railroad Valley, Nev.	38.503	115.769	4,757	June 1992-Dec. 1994	Nichols, 1994

Table A2. Vegetation characteristics and depth to ground water at field sites, Great Basin study areas

[E, Estimated.]

Site (fig. A1, table A1)	Most common plant types	Plant density (d)	Maximum plant leaf area index ($LAIp$)	Minimum depth to ground water (feet below land surface)
1	Greasewood, saltbush, sagebrush [1]	0.17	2.7	8.9
2	Greasewood, rabbitbrush	.21	3.4	5.9
3	Alkali sacaton, russian thistle, bassia, saltgrass [2]	.42	2.0E	10.5
4	Saltgrass, rabbitbrush, alkali sacaton, saltbush, greasewood [2]	.35	1.0E	10.2
5	Rabbitbrush, alkali sacaton, mormon tea, sagebrush, saltgrass, greasewood [2]	.26	1.8E	10.2
6	Saltgrass, greasewood, alkali sacaton, saltbush [2]	.24	1.5E	7.9
7	Saltgrass, alkali sacaton, rabbitbrush, greasewood [2]	.33	1.9E	7.2
8	Saltbush, alkali sacaton, rabbitbrush, greasewood [2]	.50	1.8E	4.6
9	Saltgrass, alkali sacaton, wiregrass[2]	[3].73	2.6	.0
10	Saltgrass	.60	2.8	1.6
11	Saltgrass, wiregrass	.95	3.5	.0
12	Greasewood, saltbush	.13	1.4	5.9

[1] Perched ground water. Depth to water table is 20 feet.

[2] From Duell (1990).

[3] From Groeneveld and Warren (1992).

density and plant species reported by Duell (1990) and limited *LAIp* values given by Groeneveld and Warren (1992). The leaf area index, *LAI*, is given by

$$LAI = d\overline{(LAIp)}_{max} \quad (1)$$

where d is measured plant density, and
$\overline{(LAIp)}_{max}$ is the weighted-average maximum leaf area index of shrubs along the measured plant-density transect.

The leaf area index, *LAI*, then was normalized by dividing by 4, the assumed maximum value for *LAI*; the resulting index, which is referred to as plant cover, *Cp*, is given by

$$Cp = \frac{LAI}{4}. \quad (2)$$

Studies at field sites 1 and 2 in 1989 and 1991 followed several years of drought. Winter precipitation in western Nevada was sparse, and was evapotranspired by early to mid-May. The measured mean daily evapotranspiration from late May or early June to early September at each site was assumed therefore to represent mean daily ground-water evapotranspiration from phreatophyte shrubs for May through September. Field observations have shown that summer convective-storm precipitation is evapotranspired within 5 to 7 days. Consequently, evapotranspiration for periods of 5 to 7 days following convective storms was not included in the estimation of mean daily ground-water evapotranspiration.

Studies in 1994 at field sites 10 and 11 in the Ash Meadows area in southern Nevada also followed an extended dry period. Precipitation was not measured at the field sites; the nearest U.S. Weather Service stations are about 10 mi north and about 15 mi southeast of the study sites. On the basis of data from these stations, 0.65 inch of precipitation fell at locations near the study sites during the last 3 months of 1993 and as much as 1.44 inches fell during January and February 1994. No precipitation fell at field sites 10 and 11 during 1994 after February. Therefore, evapotranspiration from May 1 through September 30 at these sites was assumed to be derived entirely from ground water. The October through April evapotranspiration from the Ash Meadows sites was calculated using the January through April and October through December 1994 data; January and February precipitation was subtracted from the October to April total before calculating the mean daily evapotranspiration.

Duell (1990) measured precipitation only at field sites 4, 6, and 9 (Duell's sites C, F, and L; Duell, 1990). Evapotranspiration from Owens Valley field sites at which precipitation data were not collected have been corrected by subtracting precipitation recorded at the nearest field site. Evapotranspiration at field sites 3 and 5 (Duell's sites A and E) has been corrected by subtracting precipitation measured at field site 4. Evapotranspiration at field site 7 (Duell's site G) has been corrected by subtracting precipitation measured at field site 6, and evapotranspiration from field site 8 (Duell's site J) has been corrected by subtracting precipitation measured at field site 9.

Duell (1990, p. E25) presented data for January 1984 through October 1985. For the present study, May through September evapotranspiration (table A3) is the mean of May-September 1984 and May-September 1985 evapotranspiration reported by Duell (1990). October through April evapotranspiration (table A3) is for October through December 1984 and January through April 1985 (table A3).

GROUND-WATER EVAPOTRANSPIRATION FROM PHREATOPHYTE SHRUBS AND GRASSES AND FROM ASSOCIATED BARE SOIL

Evapotranspiration as a Function of Plant Cover

Measurements of May through September ground-water evapotranspiration from shrubs and saltgrass field sites in Nevada (sites 1, 2, 10, 11, and 12, fig. A2, tables A1 and A2) were the foundation for the analysis. However, because only two field sites (11 and 12) included data for October through April, data from the Owens Valley field sites were included so that the results of the analysis could extend to winter and annual estimates of ground-water evapotranspiration. May-September (153 days), October-April (212 days), and annual ground-water evapotranspiration (table A3) are plotted as a function of plant cover at each study site (figs. A2-A4). Least-squares analysis indicated the curve that best describes the data is an exponential equation of the form

$$ET = \exp\left[a + \frac{b}{Cp} + c\ \ln(Cp)\right] \quad (3)$$

where *ET* is mean daily May-September, mean daily October-April, annual mean daily, or annual total ground-water evapotranspiration.

Coefficients a, b, and c for estimating seasonal and annual ground-water evapotranspiration and the coefficient of determination, r^2, for each data set in table A3 are given in table A4.

Table A3. Seasonal and annual rates of ground-water evapotranspiration at field sites, Great Basin study areas

Site (fig. A1, table A1)	Mean daily ground-water evapotranspiration (feet per day)			Mean annual ground-water evapotranspiration (feet)
	May-September	October-April	Annual	
1	0.0054	--	--	--
2	.0080	--	--	--
3	.010	0.0021	0.0054	1.97
4	.0043	.00078	.0023	.839
5	.0049	.0022	.0033	1.20
6	.0024	.00058	.0013	.474
7	.0070	.0020	.0041	1.46
8	.010	.0024	.0055	2.04
9	.014	.0028	.0075	2.73
10	.012	.0029	.0067	2.45
11	.013	.0025	.0069	2.52
12	.0013	--	--	--

Equation 3 was selected from several equations that equally well described the evapotranspiration-plant cover relation (all equations had an $r^2 \geq 0.96$). This equation was chosen because it is equivalent to the equation used to calculate saturation vapor pressure as a function of temperature (Arya, 1988, p. 52). Equation 3, therefore, may have a physical basis in the calculation of ET, compared to the strictly empirical relation described by the other candidate equations.

Evapotranspiration as a Function of Depth to Ground Water

The same ground-water evapotranspiration data (table A3) used in the above analysis are plotted against the depth to ground water (table A2) at each of the field sites in figures A5-A7. In all cases, the data are best described by a linear equation

$$ET = \alpha + \beta Z_w \quad \text{for } Z_w < 10\text{ft}, \qquad (1)$$

where ET is mean daily May-September, mean daily October-April, annual mean daily, or annual total ground-water evapotranspiration, and

Z_w is depth to ground water, in feet.

Coefficients α and β for estimating seasonal and annual ground-water evapotranspiration and the coefficient of determination, r^2, for each data set in table A3 are given in table A5.

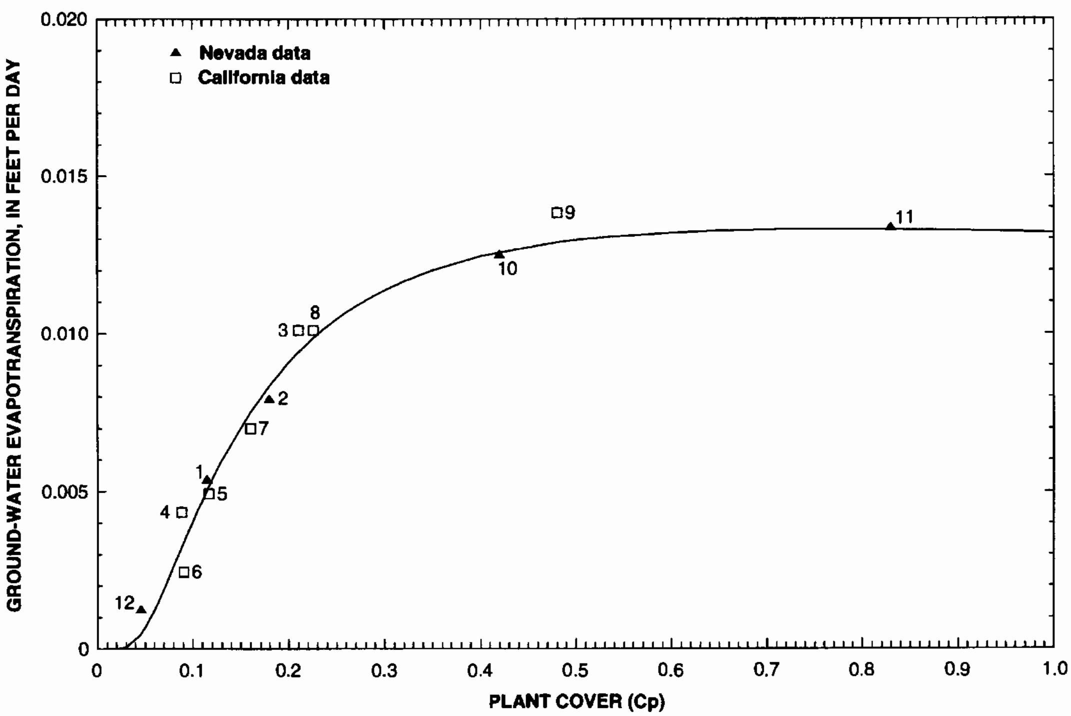

Figure A2. May through September ground-water evapotranspiration from phreatophyte shrubs and grasses and associated bare soil as related to plant cover. Numbers refer to field sites shown on figure A1 and described in table A1.

Table C6. Summary of area, percent plant cover, mean annual ground-water evapotranspiration (ET) rate, and annual ground-water evapotranspiration for indicated land cover for 1985 and 1989 for eastern Nevada study area [1]

[Symbols: <, less than; ≥, greater than or equal to]

Land cover	1985 Area (acres)	1985 Plant cover (percent)	1985 Annual ET rate (feet)	1985 Annual ET (acre-feet)	1989 Area (acres)	1989 Plant cover (percent)	1989 Annual ET rate (feet)	1989 Annual ET (acre-feet)
Water	82,431			650	1,487			650
Bare soil/playa	162,736		0.150	24,410	122,341		0.150	18,351
< 10 percent plant cover	728,988	6.0	.290	211,361	804,624	7.1	.410	322,891
10 – < 20 percent plant cover	171,415	13.7	1.346	230,777	227,276	13.1	1.276	290,003
20 – < 35 percent plant cover	67,745	25.3	2.144	145,252	58,178	25.6	2.154	125,291
35 – < 50 percent plant cover	23,980	41.2	2.506	60,103	20,902	40.6	2.504	52,346
≥ 50 percent plant cover	20,697	63.1	2.584	53,485	23,184	62.9	2.582	59,847
Total [2]	1,258,000			726,000	1,258,000			869,000
Weighted average		[3].105	.577			[3].110	.690	

[1] Calculated values are not rounded, to minimize rounding errors in subsequent calculations, except as indicated.

[2] Totals are rounded to the nearest 1,000 acres and acre-ft.

[3] Does not include areas of bare soil, playa, or areas covered by water.

over recharge, which may represent discharge greater than the long-term mean annual discharge or recharge less than the long-term mean annual recharge, or again a combination of both. Interannual changes in ground-water levels commonly are a foot or two and as such do not significantly increase or decrease water-level gradients, and consequently ground-water flow rates, in areas of interbasin ground-water flow. Annual ground-water evapotranspiration in combination with annual ground-water recharge is largely responsible for changes in ground-water storage and, therefore, changes in ground-water levels.

Appropriate ground-water level data are sparse in the valleys of the study area, and detailed estimates of changes in ground-water storage were not possible. Only Ruby, Clover, and Steptoe Valleys have water-level data that provide some insight into changes in ground-water storage in 1985 and 1989. Even in these valleys, however, data were insufficient to characterize the change in storage over the entire valley. While including the change in ground-water storage together with ground-water evapotranspiration is an objective method for estimating long-term mean annual discharge, this method cannot be applied in the present study because of the lack of appropriate water-level data. Consideration of this method should be given in future studies of this type.

Ground-water evapotranspiration estimated for 1985 was similar to that estimated for 1989 in Clover, Hot Creek, Jakes, Little Smoky, Long, Newark, and Railroad Valleys; the average of the 2 years was assumed to approximate mean annual ground-water evapotranspiration in these valleys. Ground-water evapotranspiration estimated for 1989 from Antelope and Tippett Valleys exceeded the estimates for 1985, but the totals for each year are relatively small; the average of the 2 years was assumed to approximate the mean annual value for these two valleys as well. Differences between ground-water evapotranspiration estimated for 1985 and 1989 for Ruby, Spring, and Steptoe Valleys are substantial, but in the absence of sufficient water-level data with which to estimate changes in ground-water storage to reconcile the difference, the average of the 2 years was assumed to approximate mean annual ground-water evapotranspiration. Ground-water evapotranspiration estimated for 1989 from Butte, Goshute, and Independence Valleys significantly exceeded that estimated for these valleys for 1985. Estimates of mean annual ground-water evapotranspiration for these valleys, and for Little Fish Lake Valley (table C5), were developed during determination of mean annual recharge estimates discussed below.

estimated by the present study, such as those described for Railroad and Newark Valleys; these are described more fully in the following section. Proposed values of predicted interbasin ground-water flow are not demonstrated by direct hydrologic measurement. They are, however, supported by geologic and hydrologic conditions that are described more fully in the following section. The model then was calibrated by increasing or decreasing estimated interbasin flow, where necessary, for predicted recharge to equal estimated discharge for each basin, while also meeting the two criteria given above.

Data for 14 of 16 basins were used to solve the multiple linear regression model (eq. 1); Jakes Valley was excluded from the analysis because essentially no ground water evapotranspired from the valley. Data for Goshute Valley were excluded during preliminary calibration of the model because of the large difference between the 1985 and 1989 estimated ground-water evapotranspiration. Initial solutions of the model suggested recharge to Goshute Valley of about 41,000 acre-ft/yr. An estimated ground-water evapotranspiration of 42,500 acre-ft/yr was selected to be consistent with a balanced ground-water budget that also accommodated previous estimates of interbasin flow (Harrill and others, 1988) and excess recharge to Steptoe Valley estimated by the present study. The data for Clover, Independence, and Butte Valleys were combined and treated as data for a single valley for initial model calibration. Data for each valley separately were used for final model calibration. Estimated mean annual ground-water evapotranspiration for Independence and Butte Valleys were determined so as to allow sufficient interbasin flow to satisfy ground-water evapotranspiration from Clover Valley. The predicted interbasin flows are consistent with hydrologic conditions as discussed below.

The coefficients, or percentages, by which to multiply precipitation in each precipitation zone are given in table C12. The y-axis intercept, b_0, for equation 1 was 8.7; setting b_0 to zero leads to no change in the coefficients. Statistics for the regression model are not valid because it was calibrated so that estimated recharge equaled total estimated discharge for each valley and the solution therefore has an $r^2 = 1.0$ (table C11). However, simple linear regression of estimated discharge (Column D, table C11) against predicted recharge (Column E, table C11) yields an r^2 of 0.975 and an adjusted r^2 of 0.909.

Table C12. Coefficients for estimating recharge from precipitation in eastern Nevada study area

Precipitation zone (inches)	Coefficient
8 to less than 12	0.008
12 to less than 16	.130
16 to less than 20	.144
20 to less than 34	.158
equal to or greater than 34	.626

Estimated Recharge

The coefficients (table C12) calculated with equation 1 were used to compute estimated ground-water recharge from each precipitation zone in each valley of the study area (table C19 at the end of this chapter). The results are summarized and compared with ground-water recharge estimated by the reconnaissance studies in table C13. The present study estimates a little more than twice as much recharge from precipitation as was estimated by these earlier studies. The largest percentage changes in estimated recharge were in Antelope, Butte, Goshute, Independence, and Long Valleys, all with present estimates more than 300 percent of the reconnaissance study estimates. Estimates of recharge increased between 200 and 300 percent in Clover, Jakes, Little Smoky, Newark, and Ruby Valleys. Increases in estimated recharge to Railroad, Spring, Steptoe, and Tippett Valleys were less than 200 percent greater than the reconnaissance estimates. Estimated recharge to Little Fish Lake Valley and Hot Creek Valley was about 10 to 20 percent less than that estimated by the reconnaissance study for these valleys.

ESTIMATED GROUND-WATER BUDGETS AND REGIONAL FLOW

Estimated ground-water evapotranspiration for each valley of the study area given in table C7 and the estimated recharge from precipitation given in table C13 were used to develop ground-water budgets for the eastern Nevada study area. The estimates of ground-water evapotranspiration apply specifically and completely to the valley for which the estimate was made. The estimated ground-water recharge applies to the topographic basin of a given valley which is not necessarily coincident with the hydrologic basin. Additionally, the estimated recharge is a bulk estimate that only indirectly implies where the recharge occurs

Table C19. Precipitation areas and volumes for selected precipitation zones and estimated recharge in valleys of eastern Nevada study area [1]

Precipitation range (inches)	Weighted average precipitation (inches)	Area in zone (acres)	Precipitation in zone (acre-feet per year)	Recharge factor	Estimated recharge (acre-feet per year)
Antelope Valley					
10-11	0.872	144,863	126,355	.008	1,011
12-15	1.055	102,064	107,720	.130	14,004
16-19	1.410	8,233	11,609	.144	1,672
20	1.667	520	867	.158	137
Total		255,680	246,551		16,824
Butte Valley					
10-11	.869	240,477	208,887	.008	1,671
12-15	1.062	312,316	331,732	.130	43,125
16-19	1.420	56,963	80,872	.144	11,646
20-28	1.864	42,607	79,414	.158	12,547
Total		652,363	700,905		68,989
Clover Valley					
12-15	1.059	229,427	242,962	.130	31,585
16-19	1.433	24,140	34,601	.144	4,983
20-33	2.075	32,393	67,210	.158	10,619
34-40	3.015	6,155	18,554	.626	11,615
Total		292,115	363,327		58,802
Goshute Valley					
9-11	.855	356,277	304,657	.008	2,437
12-15	1.061	213,006	226,057	.130	29,387
16-19	1.407	37,302	52,486	.144	7,558
20-24	1.733	5,584	9,675	.158	1,529
Total		612,169	592,875		40,911
Hot Creek Valley					
6-7	.515	312,361	161,019	.000	0
8-11	.729	321,452	234,328	.008	1,875
12-15	1.055	18,176	19,175	.130	2,493
16-19	1.447	5,942	8,595	.144	1,238
20	1.667	570	950	.158	150
Total		658,501	424,067		5,756
Independence Valley					
10-11	.900	22,239	20,016	.008	160
12-15	1.044	289,556	302,256	.130	39,293
16-19	1.418	39,624	56,173	.144	8,089
20-24	1.726	9,251	15,970	.158	2,523
Total		360,670	394,415		50,065
Jakes Valley					
12-15	1.034	241,415	249,744	.130	32,467
16-19	1.360	28,476	38,722	.144	5,576
20	1.667	607	1,011	.158	160
Total		270,498	289,477		38,203

Table C19. Precipitation areas and volumes for selected precipitation zones and estimated recharge in valleys of eastern Nevada study area [1]—Continued

Precipitation range (inches)	Weighted average precipitation (inches)	Area in zone (acres)	Precipitation in zone (acre-feet per year)	Recharge factor	Estimated recharge (acre-feet per year)
Little Fish Lake Valley					
8-11	.792	220,218	174,385	.008	1,395
12-15	1.046	47,885	50,084	.130	6,511
16-18	1.428	8,379	11,961	.144	1,722
Total		276,482	236,430		9,628
Little Smoky Valley					
6-7	.518	280,030	145,134	.000	0
8-11	.761	398,698	303,574	.008	2,429
12-15	1.054	39,123	41,217	.130	5,358
16-19	1.437	19,317	27,756	.144	3,997
20	1.667	3,407	5,678	.158	897
Total		740,575	523,359		12,681
Long Valley					
10-11	.869	116,460	101,196	.008	810
12-15	1.095	246,665	269,979	.130	35,097
16-19	1.392	51,115	71,143	.144	10,245
20-24	1.793	5,604	10,050	.158	1,588
Total		419,844	452,368		47,740
Newark Valley					
6-7	.564	7,668	4,323	.000	0
8-11	.777	208,764	162,209	.008	1,298
12-15	1.053	219,748	231,357	.130	30,076
16-19	1.442	42,564	61,371	.144	8,837
20-28	1.841	30,538	56,210	.158	8,881
Total		509,282	515,470		49,092
Railroad Valley (northern part)					
6-7	.524	534,026	279,952	.000	0
8-11	.768	514,489	394,890	.008	3,159
12-15	1.100	195,057	214,587	.130	27,896
16-19	1.417	77,818	110,253	.144	15,876
20-28	1.855	48,281	89,567	.158	14,152
Total		1,369,671	1,089,249		61,083
Ruby Valley					
11	0.917	308	283	.008	2
12-15	1.096	401,677	440,282	.130	57,237
16-19	1.425	127,550	181,797	.144	26,179
20-33	2.086	93,302	194,587	.158	30,745
34-43	3.123	16,099	50,276	.626	31,473
Total		638,936	867,225		145,636
Spring Valley					
8-11	.806	536,370	432,094	.008	3,457
12-15	1.089	311,781	339,613	.130	44,150
16-19	1.429	122,768	175,490	.144	25,271
20-32	2.022	96,091	194,247	.158	30,691
Total		1,067,010	1,141,444		103,569