WATER RESOURCES AND GROUND-WATER MODELING IN THE WHITE RIVER AND MEADOW VALLEY FLOW SYSTEMS

CLARK, LINCOLN, NYE AND WHITE PINE COUNTIES, NEVADA

by

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Front cover picture insets from top left: Iverson Spring at Muddy Springs near Moapa (May 2001), discharge from MX-5 well after pump start-up (February 1998), spring flow below Pederson Spring at Muddy Springs near Moapa (May, 2001). Background picture of Coyote Spring Valley near MX-4 and MX-5 with pump rig in background.

lower permeabilities of the Mesozoic clastic rocks. However, ground-water flow across and through this thrust does take place along zones of structural weakness and in the fractured carbonate rocks of Paleozoic age and probably to a lessor extent in some of the Mesozoic rocks.

Ground-water outflow from both flow systems is toward the southeast. Some of the outflow surfaces in the Muddy River in Lower Moapa Valley, but most of the flow discharges probably into several fault structures that define the present trace of the Colorado River or to undefined areas to the south.

4.4 GROUND-WATER RECHARGE

Ground-water recharge to the various aquifer systems within the CRBP in the study area starts as precipitation on the recharge areas. Precipitation in the form of snow is probably the most important source of recharge, but winter rain and summer convection storms also add appreciable volumes of water to the general area. Ground-water recharge processes have not been fully defined and there are significant differences in the amount of recharge in the various geologic terrain dependent on rock types and the degree of permeability. Rocks with greater permeability, such as carbonates, have greater amounts of recharge than other types of rocks within the study area. Although we recognize the actual recharge rate is strongly affected by rock type and other factors, the method used to estimate natural recharge in this study, Maxey-Eakin, has been used for over half a century, all over Nevada, in a wide variety of geologic terrains and climatic settings.

4.4.1 Development of Natural Recharge Estimates from Altitude-Precipitation Relationships

Natural recharge for the basins in this study were estimated from precipitation by a technique pioneered in Las Vegas Valley (Donovan and Katzer, 2000). It is conceptually similar to, and borrows heavily from, the Maxey-Eakin technique (Maxey and Eakin, 1949) and is characterized in the report as a "modified Maxey-Eakin". The primary variation between the two techniques is the relationship between altitude and precipitation. Nichols (2000) has also pioneered a new technique for estimating natural recharge but his technique varies significantly from the Maxey-Eakin technique in both the manner in which precipitation and the assumed recharge efficiency (recharge coefficients) are estimated. Nichols' (2000) technique is specifically for use with a modified version of the May 1997 Parameter-elevation Regressions on Independent Slopes Model (PRISM) map by Daly and others (1994) of the Oregon Climatic Service.

The "standard" Maxey-Eakin technique as summarized by Eakin (1966, p. 260-262) has been in use for over a half century and has probably been applied to every valley in Nevada although the estimate may not have been published. When the U.S. Geological Survey (USGS) and the Nevada Division of Water Resources (NDWR) estimated most of the basin budgets, either the standard or variants of the Maxey-Eakin technique were used. Avon and Durbin (1994, p.102) reported investigators deviated from the standard form of the method about 37 percent of the time.

In the "standard" Maxey-Eakin technique the acreage of an individual valley was divided into five altitude intervals listed below in **Table 4-4** (Eakin, 1966, Table 2):

Table 4-4. "Standard" Maxey-Eakin assumptions.

Precipitation Zone (in.)	Altitude Zone (ft.)	Average Annual Precipitation (ft.)	Recharge Efficiency (%)
< 8	< 6,000	Variable	Negligible
8 to 12	6,000 to 7,000	0.83	3
12 to 15	7,000 to 8,000	1.12	7
15 to 20	8,000 to 9,000	1.46	15
> 20	> 9,000	1.75	25

The acreage of the altitude intervals was multiplied by the average precipitation in feet, then multiplied by the recharge efficiency (the percentage of precipitation that becomes natural recharge), then summed to estimate the natural recharge as shown in **Table 4-5**. Typical variation of the technique was modification of the altitude intervals. Implicit in the technique, is that the recharge efficiency is a function of precipitation rather than altitude and at least two precipitation maps Hardman (1936 and 1965) were used in the USGS and NDWR basin reports.

The acreage of the valleys as reported in this study are within 3 percent of the acreage as reported in the various basin reports with exception of Coyote Spring and Muddy Springs Valleys. These small differences are mostly related to round-off, digitizing errors, and map scales. The major increase (~ 25 percent) in Muddy Springs Valley is due to the inclusion of Wildcat Wash which was historically included in Coyote Spring Valley on USGS hydrographic basin maps.

In the modified Maxey-Eakin technique (Donovan and Katzer, 2000), the available precipitation data is selected based on quality (length of record, percentage of record completeness). The data are separated into geographic regions, and processed through regression analysis to determine the local altitude-precipitation relationships. The development of the four local altitude-precipitation relationships, ("general", "dry", "wet", and "WRV") used in this study was described and presented in the Precipitation (4.2) section.

Donovan and Katzer (2000) introduced a slight variation in calculating the Maxey-Eakin natural recharge efficiency coefficients. The coefficients are calculated directly from the precipitation rate using the equation $r_e = 0.05\ (P)^{2.75}$ where r_e is the natural recharge efficiency coefficient and P is equal to precipitation rate in feet per year. The only purpose of this equation was to minimize calculation errors and the time required to calculate the estimate of natural recharge. The assumptions of mathematical approximation used by Donovan and Katzer (2000) were the same as Maxey-Eakin; Precipitation falling on areas that receive less than 8 inches is considered ineffective for producing ground-water recharge, the maximum recharge efficiency (25 percent) occurs at 20 inches and the recharge efficiency of the intervening intervals are the same. Donovan and Katzer (2000, p. 1142) reported that the mathematical approximation of the Maxey-Eakin efficiency coefficients reduced the natural recharge estimate by 3 percent when compared to the traditional methodology.

Table 4-5. Comparison of this study to previous Maxey-Eakin (1949) natural recharge estimates.

Valley	Acres	Volume of Precipitation (afy)		Ground-water Recharge (afy)	
		Maxey-Eakin[1]	This Study	Maxey-Eakin	This Study
Long Valley	416,966	296,940	459,937	10,300	31,112
Jakes Valley	271,493	NR	312,462	13,000	24,194
White River Valley	1,016,871	NR	1,032,143	40,000	62,133
Garden Valley	318,055	137,080	320,039	10,000	19,153
Coal Valley	289,998	62,038	234,361	2,000	7,002
Cave Valley	229,755	206,495	258,445	14,000	19,595
Pahroc Valley	325,289	56,764	260,197	2,200	7,545
Dry Lake Valley	574,417	117,562	454,998	5,000	13,254
Delamar Valley	231,582	33,530	176,189	1,000	4,597
Pahranagat Valley	497,312	42,640	344,195	1,800	7,407
Kane Springs Valley	150,429	48,878	140,218	2,600	6,757
Coyote Spring Valley	391,621		224,278		4,000
Muddy River Springs Area	92,541	NR	38,380	Minor	237
Lower Moapa Valley	175,656	1,160	101,358	50	1,354
Hidden Valley	52,435	11,400	27,512	400	339
Garnet Valley	101,981	10,600	45,268	400	393
California Wash	205,550	2,000	75,608	100	311
Lake Valley	354,246	228,930	437,170	13,000	41,320
Patterson Valley	267,430	136,860	275,015	6,000	15,761
Spring Valley	184,945	176,600	212,364	10,000	16,151
Eagle Valley	34,458	197,810	36,927	8,000	2,349
Rose Valley	7,647		7,349		352
Dry Valley	76,339		77,388		4,237
Panaca Valley	220,435		204,587		9,041
Clover Valley	231,964		223,852		10,557
Lower Meadow Valley Wash	605,723		523,247		22,823
Black Mountains Area	408,919	132,254	132,254	100	438
Total	7,734,059	1,899,541	6,635,742	147,950	332,413

[1] ***Only represents precipitation greater than 8 inches.***

In estimating the precipitation for this study, the standard assumption that precipitation less than 8 inches is "ineffective" had no impact on the estimation of natural recharge in valleys where the "general" and "WRV" local altitude-precipitation relationship was used. These are generally high northern valleys with minimal or no acreage below 5,000 feet. All of the local altitude-precipitation relationships predict, and the available gage suggests, that all of the acreage above 5,000 feet of altitude in the study area receive greater than 8 inches of precipitation. This assumption also had no effect on the only northern valley (Lake) where precipitation was estimated using the "wet" local altitude-precipitation relationship.

It was observed, however, (**Figure 4-9**) that, in valleys where the "wet" local altitude-precipitation equation was used to estimate precipitation the interval between 3,000 and 4,000 feet of elevation is about 7.6 inches. It was also noted that, in valleys where the "dry" local altitude-precipitation equation was used to estimate precipitation the interval between 4,000 and 5,000 feet of elevation is about 7.9 inches.

These transitional altitude intervals are a significant amount of acreage in the valleys in the central and southern parts of the study area. If the standard Maxey-Eakin assumptions are used, the precipitation in these intervals could either be considered "ineffective" (none of the precipitation in these areas becomes natural recharge), or partially effective (part of the precipitation could have been included in the recharge estimate). Another possibility exists however.

When Pohlmann and others (1998) analyzed the springs in the Lake Mead area, using stable and radio isotopes they concluded that the recharge sources of one-third of springs are "local" and low altitude. The area described in Pohlmann and others (1998) is the southernmost valley (Black Mountains Area) of this current study area **(Figure 4-1)**. Most of the area is at low altitude (< 3,000 feet) and the highest peak, Muddy Peak, is at an altitude of 5,363 feet. The use of the term "local" introduces the idea that precipitation below 8 inches may be "effective" although the recharge efficiency is very low (less than a percent). Eakin's (1966, p. 260-262) summary of the Maxey-Eakin method characterizes recharge in areas that receive less than 8 inches of precipitation as "negligible" rather than "none".

The Maxey-Eakin technique, as originally developed, is a step function designed for use with paper maps, planimeters, and adding machines. As long as the precipitation is reported by the same irregular intervals (8, 12, 15 and 20 inches of precipitation) of the traditional method no confusion exists as to the appropriate recharge efficiency coefficients. If an alternative precipitation map with either regular intervals (NDWR, 1971), other irregular intervals (some variations of the PRISM map), or in units other than feet and inches (meters, centimeters, millimeters) questions arise about the appropriate recharge efficiency coefficients to use near the break points. Because the Donovan and Katzer's (2000) mathematical approximation of the Maxey-Eakin efficiencies is a continuous function it can easily be used in conjunction with non-traditional precipitation maps and estimates.

Donovan and Katzer (2000) examined the potential use of the equation to estimate the natural recharge efficiency directly from the precipitation estimate of a given altitude interval ($r_e = 0.05 (P)^{2.75}$) for estimating the recharge efficiency coefficients for areas that receive less than 8 inches of precipitation. The increase in the Las Vegas Valley natural recharge estimate would have been about 5 percent.

Because of the large size of the transitional altitude areas in this current study, the same logic was applied. The increase in the natural recharge estimate in the whole area is about 3.5 percent from about 321,000 afy to 332,000 afy. As mentioned previously, modification of the assumption that precipitation of less than 8 inches is "ineffective" has no effect on the recharge estimate of the high altitude northern valleys and a minor increase (5 percent) in the Lower Meadow Valley natural recharge estimate. The largest percentage increases are in the 5 small valleys (including the Black Mountains Area) where recharge is estimated to be less than 500 afy and the one valley

(Lower Moapa) where the recharge is estimated to be about 1,400 afy. In the center of the study area where there are large areas of the transitional altitude zones, the natural recharge estimate for the valleys increased by about 20 percent. The 20 percent increase in the natural recharge estimate was assumed to be similar to the increase that would have occurred if the altitude intervals were adjusted, as was done on many Maxey-Eakin analysis, to include part of the acreage (the part of the area that receives greater than 8 inches) of the transitional altitude intervals.

Table 4-6 summarizes the natural recharge estimates used in this study. The complete analysis is included in Appendix A. Note: The recharge within the modeled area is reported as 37,000 afy because it is rounded off to the nearest 1,000 afy. The actual estimated natural recharge within the modeled area is 36,652 afy, which was rounded to 37,000 afy in the ground water model.

Although this approach is a partial modification of the Maxey-Eakin assumptions, there are several advantages. One advantage is that the distribution of the Maxey-Eakin natural recharge efficiency coefficients for precipitation greater than 8 inches is preserved within Donovan and Katzer (2000) mathematical approximation. The Maxey-Eakin technique and the USGS and NDWR basin reports have well served the citizens of Nevada, for over half a century by consistent use of a simple, easy to understand, natural recharge estimation technique with a reasonable distribution of the relationship between precipitation and natural recharge coefficients. Another advantage of the approach used in this study is consistency, because a uniform methodology is applied to all of the precipitation that is estimated to fall on any valley. Two natural recharge analyses using two radically different precipitation maps can be compared directly on the influence of the precipitation estimate alone rather than on a combination of the precipitation distribution and the technique used to estimate natural recharge. The Hardman precipitation maps (1936, 1965) are no longer the only estimates of precipitation distributions available. Since the early 1990s, PRISM through it's widespread availability on the Internet, support by, and linked to, websites of important sources of climatic information like Desert Research Institute's Western Regional Climate Center (WRCC) (http://www.wrcc.dri.edu/precip.html), and The U.S. Department of Agriculture's Natural Resources Conservation Service (NRCS, formerly Soil Conservation Service, SCS) (http://www.ftw.nrcs.usda.gov/prism/prism.htmldistribution), is the most commonly used precipitation distribution map.

There are also disadvantages to the approach used to estimate natural recharge in this study. The approached used is a modified Maxey-Eakin therefore the advantages of the method are the advantages of the Maxey-Eakin (consistency, ease of use) and the disadvantages are the same as those of the Maxey-Eakin. Although the relationship between precipitation and natural recharge is reasonable, it is an assumption (non-unique), since the natural recharge estimate is strongly dependent on the precipitation estimate. The relationship between natural recharge and mountain front runoff is not intuitive. No factor that actually determines what portion of precipitation becomes natural recharge is actually included in the estimation technique. A short list of these factors includes: rock type, vegetation, average temperature, soil type, form (snow or rain) of the precipitation, typical storm size and duration, and the time of year when the precipitation occurs.

Table 4-6. Summary of annual natural recharge estimated for this study.

Valley No.	Valley Name	Area (ac.)	Total Estimated Precipitation (af.)	Natural Recharge Estimate (af)		Within Model Area
				A	B	
175	Long Valley	417,000	460,000[4]	31,000	31,000[a]	Tributary
174	Jakes Valley	271,000	312,000[4]	24,000	24,000	Tributary
207	White River Valley	1,017,000	1,032,000[4]	62,000	62,000	Tributary
172	Garden Valley	318,000	320,000[4]	19,000	19,000	Tributary
171	Coal Valley	290,000	234,000[2]	6,000	7,000	Tributary
180	Cave Valley	230,000	258,000[4]	20,000	20,000	Tributary
208	Pahroc Valley	325,000	260,000[2]	7,000	8,000	Tributary
181	Dry Lake Valley	574,000	455,000[2]	11,000	13,000	Tributary
182	Delamar Valley	232,000	176,000[2]	4,000	5,000	Tributary
209	Pahranagat Valley	497,000	344,000[2]	5,000	7,000	Tributary
206	Kane Springs Valley	150,000	140,000[3]	7,000	7,000	Modeled
210	Coyote Spring Valley	392,000	224,000[2]	3,000	4,000	Modeled
219	Muddy River Springs Area	93,000	38,000[2]	5	200	Modeled
220	Lower Moapa Valley	176,000	101,000[3]	400	1,400	Modeled
217	Hidden Valley	52,000	28,000[2]	150	300	Modeled
216	Garnet Valley	102,000	45,000[2]	150	400	Modeled
218	California Wash	206,000	76,000[2]	0	300	Modeled
183	Lake Valley	354,000	437,000[3]	41,000	41,000	Tributary
202	Patterson Valley	267,000	275,000[1]	16,000	16,000	Tributary
201	Spring Valley	185,000	212,000[1]	16,000	16,000	Tributary
200	Eagle Valley	34,000	37,000[1]	2,000	2,000	Tributary
199	Rose Valley	8,000	7,000[1]	400	400	Tributary
198	Dry Valley	76,000	77,000[1]	4,000	4,000	Tributary
203	Clover Valley	220,000	205,000[1]	11,000	11,000	Tributary
204	Panaca Valley	232,000	224,000[1]	9,000	9,000	Tributary
205	L. Meadow Valley Wash	606,000	523,000[3]	22,000	23,000	Modeled
215	Black Mountains Area	409,000	132,000[2]	5	400	Modeled
	Totals	**7,734,000**	**6,636,000**	**321,000**	**332,000**	**37,000[5]**

Recharge estimate "B" is the estimate used in this study, Estimate "A" is provided only for comparison.

[1] Precipitation was estimated using the "general" local altitude-precipitation relationship (Section 4.2)

[2] Precipitation was estimated using the "dry" local altitude-precipitation relationship (Section 4.2)

[3] Precipitation was estimated using the "wet" local altitude-precipitation relationship (Section 4.2)

[4] Precipitation was estimated using the "WRV" local altitude-precipitation relationship (Section 4.2)

[5] Total natural recharge of modeled area, Actual estimate = 36,652 acre-feet per year, Area = 2,186,000 acres, Total estimated precipitation = 1,307,000 acre-feet per year

[a] Only 23,000 afy is used in total because of ground-water outflow to non-White River Flow System Valleys based on proportionality of outflow defined by Nichols (2000).

Maxey-Eakin is one of numerous natural recharge estimation techniques, although it is the oldest and most commonly used in Nevada. In addition to numerous geochemical techniques, which include: conservative ion (usually Chloride), stable isotopes (Hydrogen and Oxygen), radiogenic isotopes (Chloride, Carbon, Uranium, etc..), tracers (chemical and isotopic) and combinations of the various technique appropriate at the "local" or regional scale. There are other empirical precipitation "budget" types techniques conceptually similar and dissimilar to Maxey-Eakin. There are also manual and computerized (models) techniques related to the Darcy equation. There are other runoff estimation techniques that may or may not include an estimate of the natural recharge. At least one natural recharge technique is strongly tied to soil types. All of these grow out of standard assumptions from Civil Engineering, Chemistry, Hydrology, Climatology and Soil Physics, and Biological Sciences.

An example of an empirical precipitation "budget" type of technique that are dissimilar to the Maxey-Eakin was discussed in Harrill and Prudic (1998, p A25). This technique is defined by the equation: $\log Q_r = -1.74 + 1.10 \log P_{p>8}$. Where Q_r is equal to the total natural recharge estimate in afy and $P_{p>8}$ is equal to the total volume of precipitation, where average annual precipitation is greater than 8 inches. This was developed following the example of Anderson (1985, p. 102-103) for the Southwest Alluvial Basins study area. Anderson's equation for southern Arizona is: $\log Q_r = -1.40 + 0.98 \log P_{p>8}$. Use of these equations implies that the total natural recharge estimate can be estimated directly from the total "effective" precipitation and all of the "effective" precipitation is equally "effective". This is very different conceptually from the Maxey-Eakin because the various recharge efficiency zones are distributed over the range of precipitation. The primary assumption in the Maxey-Eakin method is that higher precipitation rates yield a higher percentage of natural recharge, they further specify that the distribution of the percentages increase in a specific non-liner relationship with respect to increases in precipitation.

4.4.2 Mountain-Front Runoff

Mountain front runoff has its origin in precipitation that falls on mountain blocks. It is one component of precipitation that exits the mountain block in three ways. The other two are ground water recharge and evapotranspiration. Even though these are separate processes they are greatly interrelated. Mountain front runoff is defined as the volume of surface water that crosses the contact between the consolidated rocks of the mountain block and the unconsolidated sediments of the alluvial basin. How does it occur? It is caused when water from melting snow or rain literally runs off of the mountain block. This occurs when the infiltration capacity of the soil and rock and the evapotranspiration rate is exceeded by the volume of available water. Precipitation that infiltrates through the soil mantel and escapes evapotranspiration and moves down-gradient is often intersected by a drainage channel or is brought to the surface by springflow. Also fractures in the mountain block intercept ground water flow and provide a conduit to the surface where the water emerges from spring orifices. Thus ground water, which started as surface water, reappears through specific springflow orifices or as diffuse springflow and is considered once again to be surface water. This surface water is subject to evapotranspiration during its transient time to the valley and also, depending on other hydrogeologic parameters, may reinfiltrate to the ground water system. Springflow that does not reach a channel in sufficient volume to create runoff either evapotranspires or reinfiltrates to the ground water system once more becoming ground water recharge. Depending on the individual drainage, surface water runoff in perennial streams probably always has a component of ground water in it when it reaches the mountain front contact.

There is a significant amount of runoff into many of the valleys from ephemeral drainages, which do not have a ground-water component. The flow in these channels is generally sudden and last for perhaps just a few short days one or more times a year. In an effort to account for some of this runoff that potentially can become ground-water recharge we have extended the recharge efficiencies down to the lowest altitude in those basin that receive precipitation less than 8 inches as defined by the altitude precipitation relationships discussed previously. In an effort to collaborate this low-altitude recharge process we evaluated the ephemeral flow in Kane Springs and Coyote Spring Valleys using a technique described by Hedmen and Osterkamp (1982). This technique is based on certain channel characteristics that are formed by the discharge of water and sediment in a natural channel. The magnitude, duration, and frequency of flows dictate stream channel geometry, with additional control imposed by the distribution and size of sediment on the channel bed and banks. The channel characteristic measured in the ephemeral tributaries was the active channel width and the equations governing its use are found in Hedman and Osterkamp (1982, Table 2, p. 13, equations 12 -15). The standard error for these equations has not been determined, but is believed to be large, perhaps as much as 50 percent. The results of these measurements are listed in **Table 4-7** and the sites are shown on **Figure 4-10.** Measurements could not be made at some sites for a variety of reasons and the notation of ND (not determined) is indicated.

The results of this limited investigation show there may be a minimum of ~3,000 afy of runoff in Kane Springs Valley and nearly the same amount in Coyote Spring Valley that is lost from the respective channels. In reality there is probably much more, but because of tributary inflow and lack of reliable data, sites measurements could not be made. Some amount of this water that saturates the channel beds is lost to the atmosphere through ET and the remainder, probably a large percentage because of the coarse-grained nature of the channel sediments, infiltrates through the channel bed and moves down the soil column to the water table as ground-water recharge.

In this study all of Kane Springs Valley is in the precipitation zone that produces ground-water recharge, yet there is a significant amount of runoff from the mountain block that may be unaccounted for in the Maxey-Eakin method. If this is true then the amount of ground-water recharge estimated for this valley is conservative. Conversely this runoff may simply be rejected recharge from the mountain block because of the low permeabilities of the volcanic rock. In Coyote Spring Valley parts of the basin are below the effective precipitation threshold of 8 inches and by extending the Maxey-Eakin method to include this area results in an additional 1,000 afy (**Table 4-6**) of ground-water recharge. This value is within the estimated ground-water recharge that takes place as a result of mountain front runoff. This process of ground-water recharge from ephemeral channels has been discussed by other investigators such as Glancy and Van Denburgh (1969), Osterkamp et al (1994), Berger (2000a and b), and Savard (1998).

4.5 GROUND-WATER DISCHARGE

Discharge from the basins in pre-development times was by spring flow, evapotranspiration, and ground- and surface-water outflow. In some of the basins there has been no significant development and hydrologic conditions remain unchanged. In other basins there has been a high degree of water-resource development and pumpage for agriculture has replaced or is additive to spring flow use by phreatophytes. In some basins evapotranspiration increases yearly as

Table 4-7. Mountain Front Runoff at Selected Sites in Coyote Spring and Kane Springs Valley.

Site No. on Figure	Active Channel Width (ft.)	Annual Runoff (af.)	Estimated Channel Loss (afy)	Channel Sediment Characteristics
COYOTE SPRING VALLEY				
1	7	200		Some cobbles, gravel and sand
2	18	880	700	Cobbles, gravel and sand
3	7	200		Gravel
4	26	1,600		Course sand
5	43	3,400	2200	Minor gravel, coarse sand
6	22	1,200		Gravel, coarse sand, some silt
KANE SPRINGS VALLEY				
1	25	1,460	700 }200	Boulders ~ 4 ft., cobbles, gravel
2	17	800		Boulders, cobbles, gravel, coarse sand
3	14	600		Boulder, cobbles, gravel
4	29	1,840		Gravel, sand; cobbles/boulders
5	30	1,940	700	Gravel and coarse sand
6	22	1,200		Gravel and coarse sand, some cobbles, and silt
7	36	2,600	}400 }400	Gravel and coarse sand
8	33	2,250		Gravel and coarse sand
9	29	1,850		Gravel and coarse sand
Total			**5,300**	

4.5.1 Evapotranspiration

Evapotranspiration (ET) is the process whereby water is returned to the atmosphere through evaporation from soil, wet plant surfaces, open water bodies and transpiration from plants. The type of plants we are most concerned with are termed phreatophytes as first defined by Meinzer (1927) as "plants that habitually grow where they can send their roots down to the water table or the capillary fringe immediately overlying the water table and are then able to obtain a perennial and secure supply of water". The plant assemblage of interest is composed primarily of greasewood (*Sarcobatus vermiculatus*), saltgrass (*Distichlis spicata*), rabbitbrush (*Chrysothamnus nauseosus*), saltbush (*Atriplex canescens*), spiny hopsage (*Grayia spinosa*), shadscale (*Atriplex confertifolia*), and big sagebrush (Artemisia tridentata). There is also a riparian plant assemblage that is of interest and this includes cottonwood (*Populus fremontii*), willow (*Chilopsis linearis*), saltcedar (*Tamarix ramosissima*), mesquite (*Prosopis glandulosa*), and tules (*Typha sp.*).

Water-use rates for phreatophytes in the study area were first estimated starting nearly a half century ago. More recently, in the last ten years, research has shown that the early estimates of water use were low. This recent research in Nevada was conducted mainly by the University of Nevada, Department of Biological Sciences, and the USGS. Of particular importance is the work of Devitt et al., (1998) who conducted a three year study of ET from a stand of salt cedar on the floodplain of the lower Virgin River about 3 miles upstream from Lake Mead. The ET rate varied from a low of 2.8 af to a high of 4.8 af and these values may not represent the actual minimum and maximum caused by climatic differences. This particular ET rate is controlled by the availability of relatively shallow ground water provided by recharge from stream flow, canopy development, atmospheric demand, and the degree of advection (Devitt et al., 1998). Smith et al. (1998) have indicated that the leaf-level transpiration rates along the Virgin River are similar to native species, but in general have a higher transpiration rate than do other native plants. These interpretations probably apply in general to ET throughout the study area and in particular to Lower Meadow Valley Wash and the Muddy River area. In Las Vegas Valley Devitt et al. (in review, 2000) reevaluated ET first estimated by Malmberg (1965) for pre-development conditions in 1905. This reevaluation shows an increase in ET over the original USGS estimate by about 60 percent.

USGS research conducted by Nichols (2000) in 16 valleys in central and eastern Nevada also dramatically increases the ET compared to the original estimates made by earlier USGS investigators. Nichols (2000) increased the ET by an average factor of about 2.7. To match this discharge requires an increase in ground-water recharge of about 2.8 times the original estimates. Nichols (2000) showed that ET rates vary widely, and are similar to the variability defined by Devitt et al. (1998) along the Virgin River. This variability of ET with time and changing climatic conditions casts some uncertainty into ground-water budgets that rely on annual averages.

The two valleys that are common to this study and the study by Nichols (2000) are Long and Jakes Valleys. The ground-water recharge and discharge for these two valleys used in this study are based entirely on the techniques and data described in this study. We did use Nichols' (2000) estimate of ET for both valleys and his distribution of outflow by percent from Long Valley. In other valleys of this study (White River, Garden, Cave, Pahranagat, Lake, Patterson, Spring, Eagle, Rose, Panaca, and Clover) the ET rate for phreatophytes was estimated based on plant density, usually estimated between 10 and 20 percent and an average leaf area index of 2. These factors were substituted into Nichols equation No. 3 (2000, Chapter A, p. A6) to estimate the annual ET rate based on plant cover. The ET rate is very sensitive to densities under 35 percent and, for instance, a 5 percent increase from 15 to 20 percent nearly doubles the rate.

ET rates for Valleys in the model area are based on the work of Devitt et al. (1998, and in review 2001). The same ET rate of 5 af/acre/year is used throughout this area for agriculture and phreatophytes. This rate was used by the USGS and is in the range reported by the HRCS.

The land use and acreage were determined from LANDSAT scenes (July 1998) and virtually all areas were field checked. In the southern end of the flow systems aerial photographs for 1953 and 2000 were used in addition to LANDSAT scenes. Water-use rates used in this study are listed in **Table 4-8** and are compared to rates used by previous USGS investigators for phreatophytes and the Natural Resource Conservation Service (NRCS, formally the Soil Conservation Service) for agriculture. Additionally, and not referenced in **Table 4-8**, are the evaporation rates from open water; these values were taken from Shevenell (1996). The specifics of the valleys in the study area are discussed as follows:

Table 4-8. Water-use rates for valleys with significant ground-water discharge.

Valley	Land use[1] and area (ac.)	Water-Use Rates				
		Acre-feet/acre/year[2]			Volume (afy)	Total Volume (afy/valley)
		This study	USGS[3]	NRCS[4]	This study	This study
Long[5]	P/21,882	--	Variable	--	--	11,000
Jakes[5]	P/416	--	Variable	--	--	600
White River[6]	P/147,211	0.3	6/	--	44,736	
	A/14,736	2.0	--	2 - 4.5	29,472	
	W/1,975	3.0	--	--	5,925	79,560
Garden[7]	P/6,144	0.75	--	--	4,608	4,608
Cave[8]	P/9,272	0.3	--	--	2,781	
	A/1,021	2.0	--	2 – 4.5	2,042	4,823
Pahranagat[6]	P/1,431	0.45	6/	--	644	
	A/6,256	5.0	--	3.5 - 6	31,280	
	W/1,289	5.0	--	--	6,445	38,369
Upper Muddy	P/1,016	5.0	5.0	--	5,080	5,080
California Wash	P/1152	5.0		--	5,760	5,760
Lake	P/6,654	0.45	0.1 – 1.5	--	2,994	
	A/6,883	3.0	--	2.5 -5	20,649	23,643
Patterson	A/1,607	3.0	--	2.5 - 5	4,821	4,821
Spring	P/1,548	0.45	0.1 – 1.5	--	697	
	W/45	3.0	--	--	135	832
Eagle	A/549	2.0	3.0	2.5 - 5	1,098	1,098
Rose	A/350	2.0	3.0	2.5 - 5	700	700
Dry	P/153	0.45	0.1-0.2	--	69	
	A/2,039	2.0	3.0	2.5 - 5	4,078	
	W/58	4.0	--	--	232	4,379
Panaca	P/145	0.45	0.1-0.2	--	65	
	A/8,649	3.0	3.0	2.5 - 5	25,947	26,012
Clover	P/101	0.45	0.2-0.5	--	45	
	A/1,066	2.0	3.0	2 - 4	2,132	2,177
L. Meadow Valley Wash	P/3,854	5.0	0.1-3	--	19,270	
	A/1,576	5.0	5.0	3 - 7	7,880	27,294
Lower Moapa	P/5,301	5.0	--	5 - 7	26,505	26,505

[1] *Abbreviations: P, Phreatophytes; A, Agriculture; and W, open water.*

[2] *If no value is listed then no estimate was made or the estimate was not available.*

[3] *Values referenced are from appropriate USGS Reconnaissance and Bulletin Series.*

[4] *Consumptive use values according to the Natural Resource Conservation Service (NRCS, formally the Soil Conservation Service,1981), taken from sites closest to indicated valley (rounded to nearest half foot) and represent the range for alfalfa and pasture.*

[5] *Nichols (2000, p. C42-43).*

[6] *Eakin (1966, Table 1) indicates that evapotranspiration is equal to regional spring discharge.*

[7] *Land use acreage includes several hundred acres of undifferentiated agriculture*

4.5.1.1 White River Valley

There are three types of ET that represent current conditions; ET from phreatophytes, agriculture, and open water. Clearly this was not the case in predevelopment times, because there was no agriculture. However, phreatophytes and open water under natural conditions most likely covered the land that is currently being irrigated. There are some irrigated lands on higher parts of the alluvial fans that undoubtedly did not support phreatophytes, but it was beyond the scope of this project to make this determination. Eakin (1966) did not map the phreatophytes, but simply indicated that ET probably took up the spring discharge of 37,000 acre-feet/year. We believe the valley, under natural conditions, had a very high water table near land surface over large areas with extensive marsh land and that the ET rate was much greater than estimated by Eakin. Ground-water levels remain high today along the central axis of the valley, in spite of the numerous wells used for irrigation. Thus ground-water discharge and associated land areas under natural conditions are replaced by pumping for agriculture. We assume the higher rate of ET for agriculture verses the ET rate for phreatophytes is justified to represent natural conditions. The total ET for this valley is estimated at 80,000 acre-feet/year and it falls within the range and magnitude for other large valleys where ET was estimated by Nichols (2000), such as Railroad Valley to the west and Steptoe and Spring Valleys to the east.

4.5.1.2 Garden Valley

There are agriculture lands that are adjacent to perennial drainages such as Cherry and Pine Creeks. These are prime areas for phreatophytes and we believe under natural conditions the lower reaches of these drainages and their relatively small flood plains were covered with phreatophytic vegetation. Many of the canyons draining the east slope of the Quinn Canyon Range and the southern end of the Grant Range have numerous springs of varying discharge. Most of this water is captured by local ET, but some undoubtedly infiltrates to the valley ground-water system. Eakin (1966, Table 1) estimated 2,000 acre-feet/year for ET and we have increased this estimate to 5,000 acre-feet/year.

4.5.1.3 Cave Valley

The single estimate of ET is reported by Eakin (1966, Table 1) to be a few hundred acre-feet/year, however there is a large playa with a healthy stand of greasewood in the south end of the valley. A monitoring well constructed on the southwest side of the playa within the greasewood assemblage showed the water table to be about 30 feet below land surface. The water is obviously perched because most of the other wells (Brothers et al., 1993, Table 1, p. 6) have reported depths over 100 feet to water. Even though part of the ground-water system is perched it is still part of the total water resource for the valley. If the water were not perched it would have infiltrated to the main valley aquifer. The playa altitude is about 6,000 feet, nearly 1,000 feet lower than the north end of the valley so ground water could have reached the playa from the north. However, because the valley floor is well within altitudes commonly accepted as recharge areas we believe there is a component of ground-water recharge that takes place directly from the valley floor and is the principal source of the perched water table. There are other numerous springs in the mountain blocks and there is some agriculture of mostly meadow grass. We estimate the ET for this valley at 5,000 acre-feet/year.

4.5.1.4 Pahranagat Valley

This long and narrow valley floor has been converted from phreatophytes to agriculture. Under natural conditions the floor was probably covered by a dense growth of phreatophytes that, according to Eakin (1966, Table 1) consumed only the estimated regional spring discharge of 25,000 acre-feet/year. Our rationale for increasing this amount to 38,000 acre-feet/year is the same as discussed previously for White River Valley. Water levels were probably shallow and resulted in large marshy areas in the southern and northern parts of the valley. The now breached and dry Maynard Lake at the extreme south end of the valley probably indicates the abundance of water during natural conditions and a redistribution of ET under current conditions.

4.5.1.5 Upper Muddy Springs

The hydrographic area for the Muddy Springs has about 5,000 afy of natural ET. The distribution of ET upstream and downstream of the USGS gage (Muddy River near Moapa) is about 3,000 and 2,000 acre-feet/year respectively. The estimated ET (this study) upstream from the river gage agrees closely with Eakin's (1966, Table 1) original estimate of 2,300 acre-feet/year. Unlike ET estimates in other valleys current conditions for ET were not estimated. The reason for this is natural ET conditions were needed to determine if there were any impacts to total spring discharge. Within error of all hydrologic measurements by many investigators, the volume of spring discharge today appears to be equal to predevelopment conditions.

4.5.1.6 California Wash

Phreatophytic vegetation along the Muddy River corridor during predevelopment conditions was probably dominated by Mesquite and salt grass. The relatively flat flood plain where these phreatophytes grew has been converted to agriculture. We estimate the predevelopment ET was about 6,000 afy.

4.5.1.7 Lake Valley

Spring discharge along the west side of the valley undoubtedly accounted for much of the predevelopment ET. The larger springs are in the northwest part of the valley and under natural conditions there would have been an even larger marshy area than there is today. There is a large amount of agriculture land currently under production that is irrigated by ground-water pumpage and water levels are within a few 10s of feet of land surface throughout much of the valley. We believe that most, if not all, of this land was type converted from natural areas of phreatophytes, mostly the greasewood assemblage, to agriculture. ET for this valley is estimated at 24, 000 afy and is assumed to represent predevelopment conditions.

ET from shrubs may be using soil moisture
whereas ag is pumping from GW

4.5.1.8 Patterson Valley

There are no remnants of natural ET left in this valley. The estimated ET today of about 5,000 afy is based on agriculture usage. Under natural conditions there was probably a much higher water table than currently exists and Patterson Wash would have had a significant amount of phreatophytes, mostly greasewood, particularly along its lower reach.

4.5.1.9 Panaca Valley

The predevelopment water table in this valley was undoubtedly very near land surface, and despite large scale agricultural development, large areas of standing water are common. Meadow Valley Wash is perennial today and even though there are significant still flows several thousand afy. So under natural conditions the flow was probably much larger. Additionally permeable carbonate rocks are at land surface and are in contact with less permeable volcanic rocks which tends to bring water closer to land surface. Phreatophytes and marsh land probably occupied much of the lands now under agriculture, and the predevelopment ET is estimated to be about 26,000 afy.

4.5.1.10 Remaining Valleys in the White River Flow System

Coal, Pahroc, Dry Lake, Delamar, Kane Springs, Coyote Spring, Hidden, and Garnet Valleys have only small amount of ET. The ET from Hidden and Garnet Valleys is virtually zero. The ET was estimated at a token 1,000 acre-feet/year for each of the other valleys to account for local spring discharge that is consumed including evaporation from bare soil. Most of the springs in these valleys are in the mountain blocks, some have been developed for stock watering. The hydrology of Black Mountain is dominated by surface flow in Las Vegas Wash and also the ET along the wash. These components are not part of this study

Estimates of ET and ground-water outflow are listed in **Table 4-9** and are compared to previous USGS estimates. In general the ET has been increased significantly in this study compared to previous estimates, although only minimally in some valleys. Ground-water outflow is also increased because the ground-water recharge is much higher than previously estimated.

4.5.2 Spring Flow in Model Area

Surface-water discharge in the model area occurs in Kane Springs Wash, Coyote Spring Valley, Lower Meadow Valley, California Wash, the Muddy Springs Area, and Black Mountains Area. The major springs in the model area are shown in **Figure 4-11.**

Several small springs discharge in Kane Springs Wash, Coyote Spring Valley, and California Wash at rates generally less than a few hundred acre-feet per year. The discharge from these springs is consumed locally through ET. In Kane Springs Valley the numerous small "local" springs are not part of the large regional carbonate aquifer system. These local springs are generally in volcanic rock and reflect local recharge and discharge. A single discharge point at the location of Kane Springs was used in the ground-water model to represent the diffuse local

6 WATER RESOURCE BUDGET

6.1 WATER RESOURCE BUDGET IN THE STUDY AREA

The water-resources budget for each valley in the study area is an accounting of ground-water inflow and outflow based on the local ground-water recharge, ground-water inflow if it occurs, and the local evapotranspiration. The ground-water outflow is the residual between inflow and evapotranspiration. These values are listed in **Table 6-1** and shown in **Figure 6-1**. Most of the valleys have ground-water inflow and all have ground-water outflow. The ground-water outflow from a valley becomes the inflow to the adjacent down gradient valley. There are some unknowns in this routing of ground water between valleys. We do not know, for instance, if Cave Valley is tributary to White River Valley or to Pahroc. Large structural features in the west-central part of the South Eagan Range may be an avenue for ground-water flow from Cave Valley to White River Valley. Sparse water-level data indicate the flow may be to Pahroc Valley out of the south end of Cave Valley. It makes little difference in the overall project goal, however, it does cause discontinuity between the interpretation in this routing and the geochemistry model by Thomas et al. (2001). The same is true for the ground-water flow from Coal Valley either into Pahroc Valley or Pahranagat Valley. In terms of the ground-water model this is not a problem because the model boundary has a ground-water flux across it that represents the residual ground-water outflow from all the up-gradient valleys.

In the model area for this section there is a lumping of ground- and surface-water flows together as inter-basin flow. As an example, ground-water discharge forms the surface water of the Muddy Springs and the springs become the Muddy River which is considered inter-basin flow from Upper Moapa Valley to California Wash and on into Lower Moapa Valley. Ground-water flow into the model area from Panaca Valley has a surface-water component that is not separated out. In the ground-water model the distinction is made between ground and surface water regardless of where it occurs. **Table 6-2** lists the sum of the budget components for the entire study area. The water-resources budget for the model area is listed in **Table 6-3**. These three budget variations are considered a water-resources budget which is dominated by ground water, based on the values listed in **Table 6-1**.

6.2 GROUND-WATER YIELD

Historically, in the ground-water basins of Nevada, the perennial yield for a ground-water system was based on the amount of discharge by ET that could be reasonably captured and the value varies per basin. The concept of perennial yield can also extend to the capture of ground-water outflow from major flow systems such as the White River and Meadow Valley through deep seated carbonate rocks underneath Lake Mead and the Colorado River. However, the complexity of the relationship between surface and ground-water, recharge and discharge, and geology and hydrology is such that generally the total discharge can never be captured, no matter if the discharge is from ET or ground-water outflow. This is further complicated by the vast amounts of water in storage in the carbonate aquifer and the overlying alluvial aquifers and the long transient time, measured in hundreds to thousands of years (Thomas et al., 1991), for ground water to move from recharge areas to discharge areas.

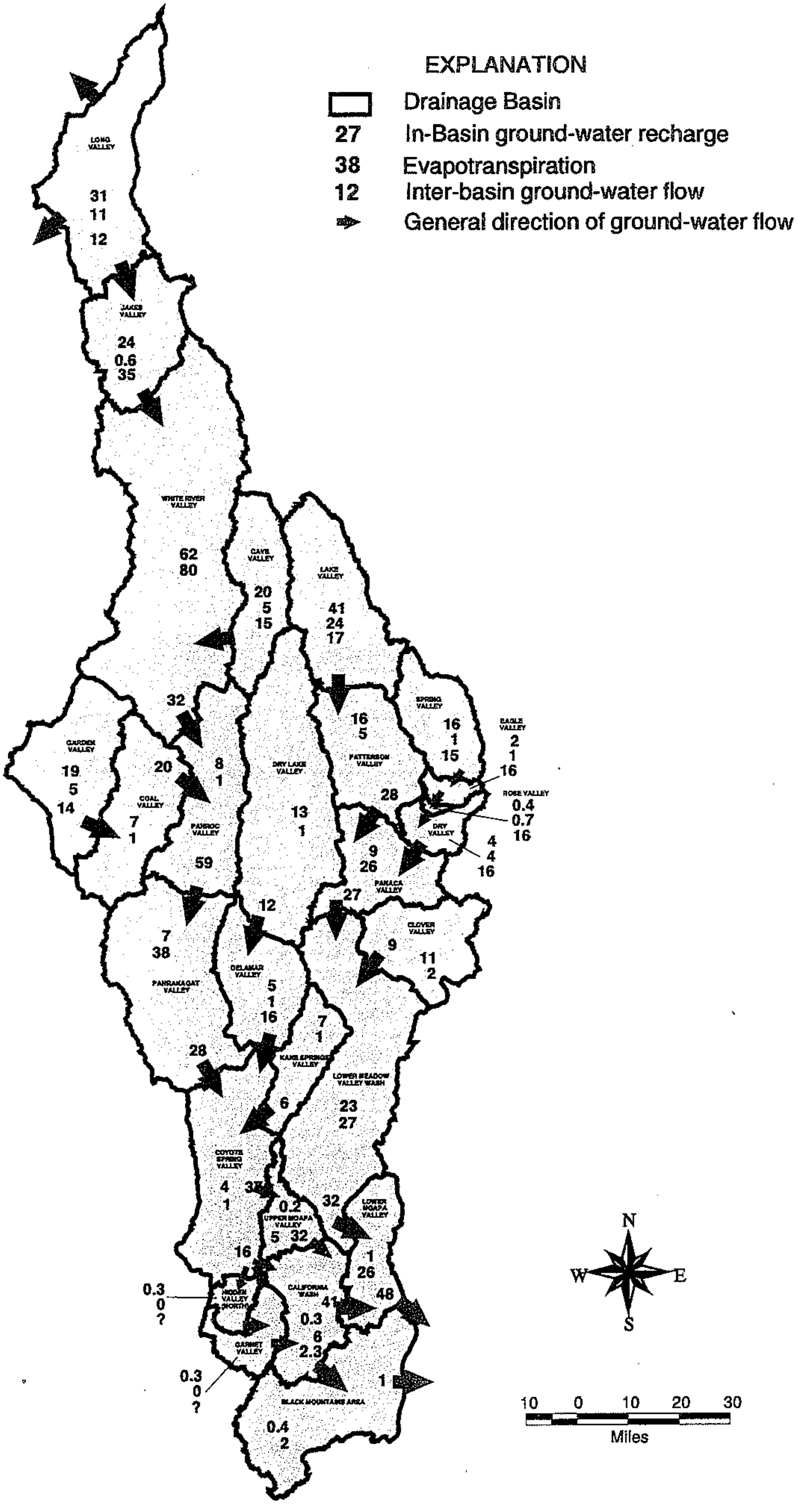

Figure 6-1. Generalized ground-water recharge, evapotranspiration, and inter-basin flow of the White River and Meadow Valley Flow Systems, units in thousands of acre-feet per year.

Table 6-1. Ground-water recharge, discharge, and inter-basin flow for selected Colorado River Basins in Nevada, in thousands of acre-feet/year (rounded).

Valley	Recharge from precipitation	Ground-water inflow	ET	Ground-water outflow	
				To	Volume
WHITE RIVER GROUND-WATER FLOW SYSTEM					
Long	31[a]	0	11	Jakes	12
Jakes	24	12	.6	WRV	35
Cave	20	0	5	WRV	15
WRV	62	50	80	Pahroc	32
Garden	19	0	5	Coal	14
Coal	7	14	1	Pahroc	20
Pahroc	8	52	1	Pahranagat	59
Pahranagat	7	59	38	Coyote	28
Dry Lake	13	0	1	Delamar	12
Delamar	5	12	1	Coyote	16
Kane	7	0	1	Coyote	6
Coyote	4	50	1	U. Muddy	37
				Hidden	16
				Garnet	
Hidden	0.3	16	0	California Wash	17
Garnet	0.3		0		
U. Moapa	0.2	37	5	California Wash	32
California Wash	0.3	49	6	L. Moapa	41
				Black Mtn.	2.3
Black Mountain	0.4	2.3	2	Carbonate outflow	1
Subtotals	200.5		158.6		
MEADOW VALLEY WASH GROUND-WATER FLOW SYSTEM					
Lake	41	0	24	Patterson	17
Patterson	16	17	5	Panaca	28
Spring	16	0	1	Eagle	15
Eagle	2	15	1	Rose	16
Rose	0.4	16	0.7	Dry	16
Dry	4	16	4	Panaca	16
Panaca	9	44	26	LMVW	27
Clover	11	0	2	LMVW	9
LMVW	23	36	27	L. Moapa	32
L. Moapa	1	73	26	Carbonate outflow	48
Subtotals	123		116.7		
Totals	**324**		**275**		

a. Only 23,000 acre-feet included in totals, remainder to non-White River flow system valleys (Nichols, 2000).