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A REEVALUATION OF THE GROUND WATER BUDGET FOR LAS VEGAS VALLEY, NEVADA, WITH EMPHASIS ON GROUND WATER DISCHARGE[1]

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ABSTRACT: An essential component to the ground water budget for the Las Vegas Valley (LVV) in southern Nevada is discharge from the ground water system. Discharge for the LVV has been based on estimates made more than 50 years ago of 35,524,224 m3 per year as evapotranspiration (ET) and 0 m^3 per year as subsurface outflow. Newly published values for recharge based on a more robust data set (70,308,360 m^3) indicate a large imbalance associated with the earlier discharge estimates, providing the basis for the reevaluation conducted in this study. ET estimates in this study, as opposed to previous studies, were assigned a range in values that included an approach that assigned higher weight to the unique soil, plant, water, and climatic conditions that existed in predevelopment (1905) LVV. The earlier discharge estimates also assumed that the basin was hydrologically closed; however, based on our evaluation, a range in yearly discharge by subsurface outflow from 1,480,176 m^3 to 19,735,680 m^3 could be assigned. Likewise, a range in yearly ET from 20,475,768 m^3 to 78,819,372 m^3 could be assigned. Based on newly published recharge values, closure can only occur if higher values are assigned to both the subsurface outflow and/or ET components of ground water discharge. We cannot provide a complete water balance closure with our ground water discharge estimate of 64,140,960 m^3. However our reevaluation gives support to the higher recharge estimates and provides the rationale for future studies to be conducted based on a more rigorous scientific assessment.

(KEY TERMS: evapotranspiration; subsurface discharge; phreatophytes.)

INTRODUCTION

Las Vegas Valley (LVV) (Figure 1) is an elongated slightly rectangular basin in southern Nevada that is typical of basin and range valleys in the region. Climatic conditions on the valley floor are classified as hot and arid, with a mean annual high temperature of 82°F (27°C) and an average annual precipitation of about 4 inches (10 cm) (NWS, 2002). Most of the natural ground water recharge occurs on the surrounding mountain blocks, and most of the discharge occurs on the valley floor. There are no perennial flows into the valley, and prior to urbanization (1905), no perennial outflow from the valley was thought to occur. Surface and ground water flow are tributary to Lake Mead on the Colorado River.

Population in the valley has almost tripled during the past 15 years (currently approximately 1.4 million, according to the Clark County Census), and this accelerated growth is expected to continue. Water managers, therefore, are examining all sources of water supply. Although the majority of water used in southern Nevada is drawn from the Colorado River, significant ground water use occurs during the summer months.

The earliest budgets for LVV were published 37 to 54 years ago by Maxey and Jameson (1948) and Malmberg (1965), and although more recent ground water models have been developed by Harrill (1976) and Morgan and Dettinger (1994), these later models have used essentially the same recharge estimates reported by Maxey and Jameson (1948). Even more recent investigations using geochemistry techniques (Dettinger, 1987; Thomas *et al.,* 1996) estimated natural recharge by using precipitation estimates by Harrill (1976). The natural recharge for LVV has been reevaluated recently by Donovan and Katzer (2000) and shows an increase ranging from about 1.5 to

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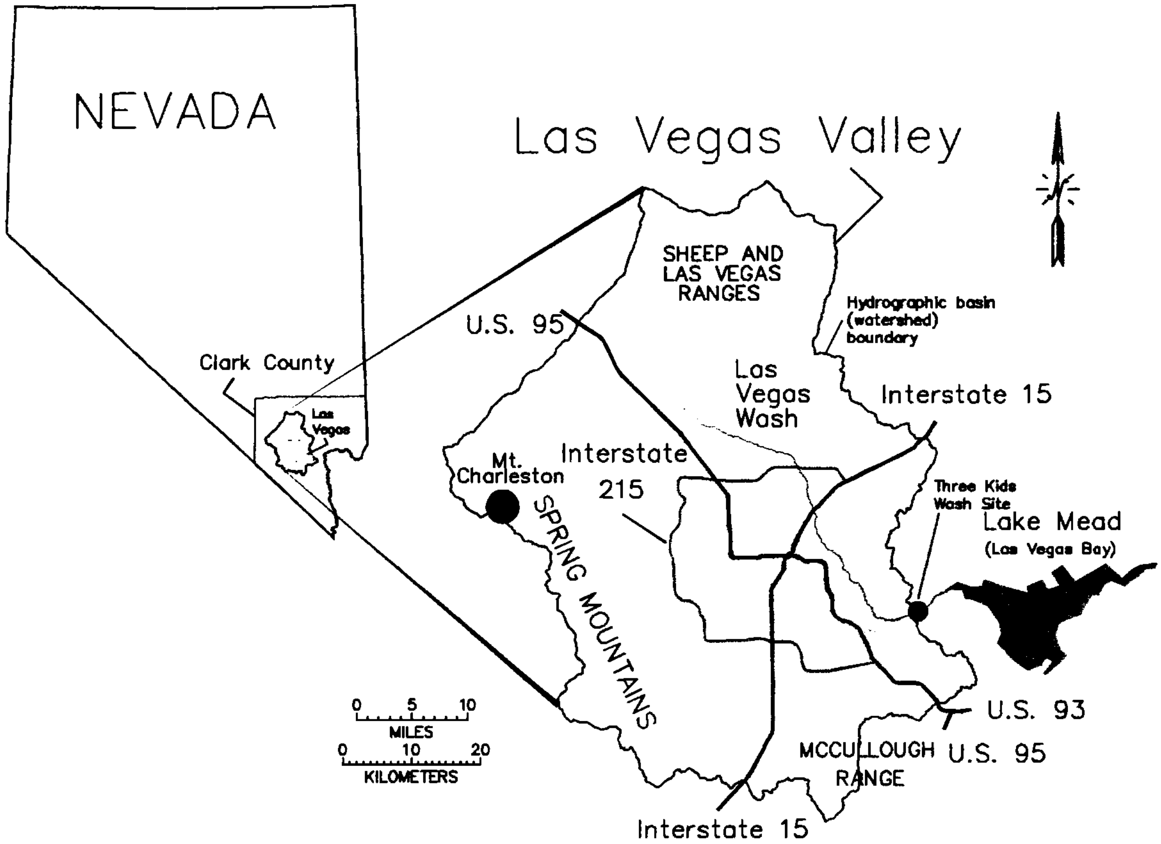

Figure 1. Location of Las Vegas Valley Hydrographic Area Within Clark County, Nevada.

nearly three times any previous investigator's estimates.

The purpose of this study was to reevaluate the natural ground water discharge from LVV prior to urbanization, with the aim of making an assessment of closure to the ground water budget. This study emphasizes the hydrologic history and natural discharge from the LVV ground water basin, where the main discharge components evaluated were ET by phreatophytes (mainly mesquite and salt grass) and ground water outflow.

HISTORICAL BACKGROUND

When the first Spanish explorers entered LVV, they noted abundant flow from artesian springs and the presence of grassy meadows and a mesquite forest. Thus, it was appropriate they referred to the area as Las Vegas, which means "the meadows." When Mormon missionaries first settled the area in the 1850s, they mapped the general features of the valley. According to Paher (1971), a settler by the name of John Steele mapped "a tooley grass area along Las Vegas creek extending east of the Mormon fort two and a half miles long by about a half mile wide." He also noted an extensive mesquite forest from the Mormon fort down Las Vegas Wash along the base of Frenchman Mountain toward the Colorado River.

After the arrival of Mormon settlers, only minimal development occurred in the valley over the next 50 years. A few scattered ranches diverted artesian flow for irrigation purposes. However, in 1905, Las Vegas became a city, and to meet the growing need for water, deep and shallow wells were drilled into the valley floor. Deeper wells tapped a permeable and strongly artesian aquifer termed by investigators as the principal aquifer. The term "principal aquifer" is an informal designation, and Donovan (1996) proposed a formal aquifer name, the Las Vegas Springs Aquifer. According to Domenico *et al.* (1964), the first flowing well was completed in 1907 and by 1911, 75 deep wells had been drilled, all flowing under artesian pressure. Maxey and Jameson (1948) reported the extent of the area under artesian pressure, as an area of approximately 75 square miles (194 km^2) located in the central part of the valley. We know today, after more than 50 years of ground water development, that virtually the entire valley is under artesian pressure [unpublished aquifer test analysis, Las Vegas Valley Water District (LVVWD), 2001].

A comprehensive water table monitoring program was not initiated in LVV until the 1920s. However extensive stands of salt grass/sacaton suggest that the water table must have been relatively shallow in 1905. Robinson *et al.* (1947), describing water levels in LVV between 1913 and 1945, indicated that principal fluctuations in the water level were a direct consequence of seasonal withdrawal from the aquifer. They indicated that a marked drawdown (35 ft, or approximately ~10.7 m) occurred in the area two to four miles (1.6 to 6.4 km) west of Las Vegas during the period 1924 to 1944. They also noted that upward leakage from the deep artesian aquifer system to the near surface reservoir was occurring and that once the water entered this unit it moved laterally downgradient to the east.

Leeds *et al.* (1961) reported upward leakage from the artesian system as occurring in the general vicinity of Las Vegas, North Las Vegas, and an area west of McCarran Airport and Hidden Wells Ranch (not shown in Figure 1). These two areas totaled approximately 15,000 acres (6,071 ha), which led Leeds *et al.* (1961) to conclude that it would take a relatively small amount of consumptive use per acre to result in a loss of 20,000 or more acre feet per year (AFY) (24,669,600 m^3).

GROUND WATER BUDGET

Ground water budgets in Nevada originally were derived by measuring and estimating the amount of natural discharge, as described by Maxey and Eakin (1949). The technique assumes that steady state conditions exist such that ground water recharge to the basin is equal to ground water discharge from the basin with any changes in ground water storage accounted for. Estimates of ground water discharge, however, often are fraught with potentially large errors. Estimating discharge by plant communities that use ground water has more certainty, and techniques and accuracy have improved significantly during the past half-century. Ground water discharge from springs usually can be measured very accurately, but ground water discharge to another basin through either the alluvial ground water system or rock aquifer systems, such as carbonate and volcanic rock, has great estimation uncertainty. This uncertainty is related directly to the inherent heterogeneity and anisotropy of aquifer systems. This paper reverses the natural order of the hydrologic cycle by discussing discharge first, followed by a brief explanation of the recharge estimate, and finally combining the two processes into a ground water budget assessment.

DISCHARGE

Previous natural discharge estimates for the LVV were based on the work of Malmberg (1965), who stated repeatedly that significant error could be attached to the various steps in the water use estimates, and thus he regarded them as approximations subject to error. Malmberg (1965) assumed ground water outflow to be insignificant. He also adjusted the acreage of native plant stands downward based on area densities (Figure 2) to achieve acreage estimates based on 100 percent densities. Estimates of ET were based on estimates from other states with little or no correction for differences in environmental demand, such as potential ET for Santa Ana, California, versus Las Vegas, Nevada. Malmberg selected two time periods to evaluate the water supply in LVV, 1905 under predevelopment conditions, and 1955.

Our natural discharge estimates were based on the 1905 information because (1) no assessment would need to be made regarding plant water use under falling water table conditions such as in 1955; and (2) Colorado River water was not available in 1905, so no distinction would need to be made between surface water imports and ground water contribution to the estimates of ET in the Las Vegas Wash, the only surface water drainage out of LVV. It should be noted, however, that not being able to make actual water use estimates and not possessing a complete scientific appraisal of the plant stands existing in 1905 places restrictions on any water use estimate made nearly 100 years later. Thus, certain assumptions must be clearly stated: (1) the general mapping of species composition and area density was accurate as defined by Malmberg (1965); (2) a long term steady state ground water condition existed in 1905; (3) potential ET (ET$_0$) as estimated in 2000 would be representative of the environmental demand in 1905; and (4) although no actual measurements of water use for native stands of salt grass and mesquite have ever been obtained for the LVV, information generated from nearby locations would be transferable if certain adjustments or caveats were attached.

The earliest field notes by scientists on plant communities in LVV were recorded by Meinzer (1927) and Carpenter (1915). However, it was Malmberg (1965) who first developed area density maps for these plant

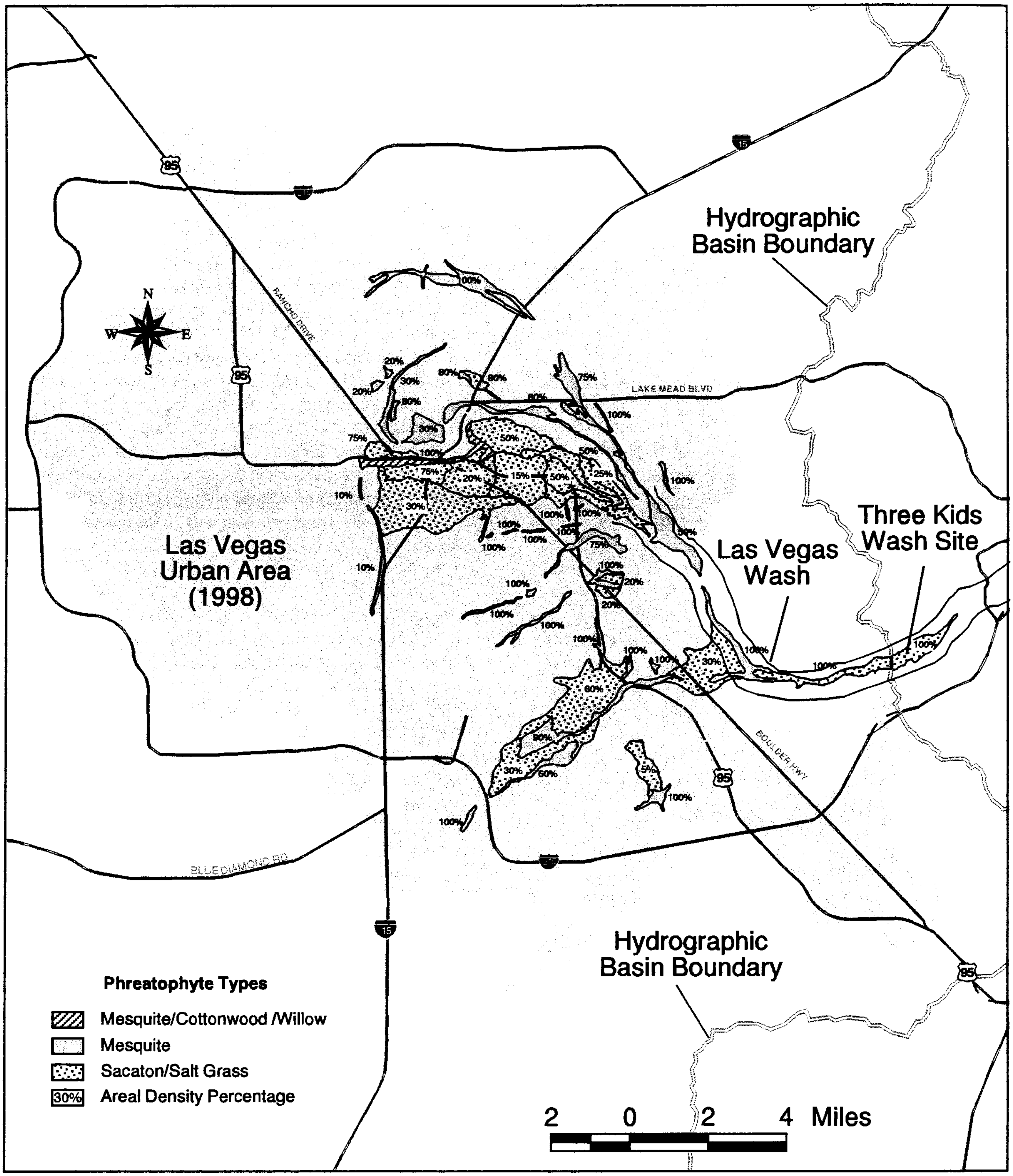

Figure 2. Las Vegas Valley's Approximate Areal Density of Pheatophytes Before Ground Water Development in 1905 (Malmberg, 1965).

communities (Figure 2), based on aerial photographs taken in 1943 and the early work of Meinzer (1927) and Carpenter (1915). Malmberg assumed the plant stands were virtually unchanged since predevelopment conditions, and he determined there were about 17,650 acres (7,143 ha) of mesquite, saltgrass, alkali sacaton (*Sporobolus airoides*), arroweed (*Pluchea sericea*), seep willow (*Baccharis glutinosa*), willows (*Salix gooddingii*), cottonwood (*Populus Fremontii*), tule (*Scirpus robustus*), and an unidentified marsh grass. The only species included in the maps, however, were mesquite, saltgrass, alkali sacaton, cottonwood, and tule, with mesquite and saltgrass being the dominant species.

All of the species included on the Malmberg map are considered to be either facultative or obligate phreatophytes. The term "phreatophyte" was 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." In 1891, a botanical survey of the Mojave Desert was completed by Coville (as reported by Meinzer, 1927), who indicated that mesquite could be used as a good indicator of ground water existing at depths of a few yards and alkali sacaton as an indicator of ground water existing at depths of only a few feet. Meinzer (1927) concluded that the presence of saltgrass was one of the most widespread and trustworthy of all plant indicators of ground water at or near the surface. Robinson (1952) indicated that saltgrass does not thrive where the depth of water exceeds 6 to 8 feet (1.8 to 2.4 m), which continues to be the case for LVV. Malmberg (1965) utilized this early survey work with a technique described by Gatewood *et al.* (1950) to convert acreage of each species to an equivalent area of 100 percent density, yielding a density adjusted acreage estimate of about 8,000 acres (3,238 ha).

PLANT RESPONSE TO WATER AVAILABILITY

Warm desert plants respond opportunistically to increased water availability (Ehleringer and Björkman, 1978). Higher growth rates of both grasses and trees in response to increased water availability can result in continuous cover, which allows phreatophytes to out compete more stress tolerant but slower growing species (Smith *et al.,* 1997). Continuous water availability also allows such phreatophytes to avoid partial dormancy during the hot dry summer months (Smith *et al.,* 1997). Thus, phreatophytes are in the best position to capitalize on a shallow, reliable ground water source and high solar radiation in a desert environment to achieve maximum growth. Mesquite, a woody legume, often provides an exception to the general ecological paradigm that primary production is very low in desert ecosystems (Rundel and Nobel, 1991).

Rundel and Nobel (1991) found that desert phreatophytes such as mesquite possess deep root systems that can tap ground water sources while possessing the ability to obtain nitrogen through symbiotic fixation, thus establishing high levels of net primary production by largely decoupling from these normal limiting factors. These authors also concluded that successful establishment of a phreatophytic population of mesquite is a very rare event. Thus, the existence of more than 4,400 acres (1,781 ha) of mesquite in LVV in 1905 (Malmberg, 1965) suggests that optimum growing conditions existed for this phreatophyte. Turner (1974), in an investigation along the Upper Gila River in Arizona, indicated when mesquite becomes established on sites with a shallow water table, the plant assumes a tree form with a nearly continuous forest canopy. Studies of riparian mesquite in Arizona by Stromberg *et al.* (1992) have shown that mesquite will grow farther from the channel than will more hydrophytic species such as willow, and they are only infrequently directly influenced by surface flow via overbank flooding. Mesquite stands in LVV were referred to as "forests" by the early settlers who cut them down for fence posts. Remnant stands assessed by Harrill (1976) indicated that dead branches protruded above newer, shorter canopy to heights of 10 feet (3.0 m). Healthy mesquite stands present in 2002 in the southern part of the valley are approximately 12 feet (3.7 m) in height, obtaining water from a perched shallow water table measured at a depth of approximately 8 feet (2.4 m) (D. A. Devitt, unpublished data). The previously presented evidence documents the existence of very large stands of the tree form of mesquite in LVV. To produce these stands, the water table must have been both shallow and fairly stable.

Depth to shallow ground water, oscillations in ground water levels and ground water quality are critical factors in governing plant water use. Research on the Virgin River in southern Nevada (about 50 miles or 80.5 km northeast of Las Vegas) by Sala *et al.* (1996) and Devitt *et al.* (1998) indicated that growth and water use of salt cedar (*Tamarix ramosissima*), mesquite (*Prospis pubescens*) and narrow leaf willow (*Salix exigua*) were high if the depth to ground water was less than 10 feet (3 m). Research by Charles *et al.* (1987) in Colorado, also indicated that when the depth to the water table was less than 10 feet (3 m), stands of phreatophytic species were dense and growth was vigorous and that growth declined as the depth to water increased to about 30 feet (9 m).

The quality of the shallow ground water system in the valley now is poor due to salt loading via leaching associated primarily with overirrigation by homeowners with Colorado River water (approximately 1.0 deci-siemens per meter, dS/m). The water quality of the shallow system in 1905, however, would have been dominated by the quality of the artesian system (approximately 0.4 dS/m) (D. A. Devitt, unpublished data), becoming more saline in the near surface soil due to the process of ET. Thus, little if any growth reductions or reduced water use rates due to salinity would be suggested for these phreatophytic plants growing in the valley under the influence of the artesian system in 1905. This would be especially true for saltgrass, which has been observed to grow vigorously in soils with salinity levels in excess of 30 dS/m (saturation extracts) (D. A. Devitt, unpublished data).

Aerial photos of LVV in 1950 by the U.S. Department of Interior indicated all plant stands were within the two major artesian flow areas associated with major drainage channels draining in all cases toward the Las Vegas Wash. Plant association with drainage channels has been shown to be directly related to increased water availability via collection and storage of stormwater runoff (Balding and Cunningham, 1974). Most of these drainage areas also received lateral flow of artesian water in the near surface ground water system. Balding and Cunningham (1974) noted larger and more numerous perennial shrubs in ephemeral drainage systems (arroyos), in marked contrast to surrounding areas. As the length of an arroyo and area drained increased, the size and number of shrubs tended to increase. Based on the work of Malmberg (1965), we estimate that more than 4,400 acres (1,781 ha) of such plant stands existed in open areas in the LVV in 1905 where stand length exceeded stand width. As such, these stands also would be more susceptible to advection due to a narrow fetch. This additional energy into the system would have the potential to increase the rate of water use, if water availability were not limiting. Robinson (1958) noted water use of phreatophytes in more isolated stands of growth was greater than in larger thickets because the effect of sunlight, temperature, and wind movement was greater. Such a situation has been noted by Devitt *et al.* (1998) for salt cedar growing on the Virgin River in southern Nevada, where local advection was demonstrated to have a significant influence on ET estimates.

EVAPOTRANSPIRATION

In theoretically closed hydrologic basins, natural water loss occurs through the process of ET, where ET is defined as the sum total of water lost through evaporation from soil and wet plant surfaces and through transpiration from plants (i.e., water loss via stomata). Maxey and Jameson's (1948) ET estimate of approximately 8,000 AFY (9,867,840 m^3) was the first such estimate for LVV. This water use estimate was in addition to the predevelopment spring discharge of 6,400 AFY (7,894,272 m^3). They made no attempt, however, to balance their 35,000 AFY (43,171,800 m^3) natural recharge with this 14,400 AFY (17,762,112 m^3) natural discharge estimate.

Because most estimates of water use by plant communities include the evaporation component in the estimate, no bare soil evaporation estimate is included in this evaluation. We recognize, however, that in areas where plant life was not supported, evaporation would dominate water loss from such areas.

Malmberg (1965) assumed that precipitation that fell directly on plant stands on the valley floor contributed to plant water use, and thus he subtracted this amount from the ground water use component. Because mesquite and saltgrass are dormant during winter months, however, any precipitation that would fall during this time would be used at much lower rates, and it could be argued that what water use occurred would be from the ground water system. Even rainfall that occurs during summer months via convective storms probably would not be used extensively by the plants, as the active root system is located primarily in the capillary fringe. Roots near the soil surface typically are highly suberized and not active in water uptake (Devitt *et al.*, 1998; Nichols *et al.*, 1994). Ehleringer *et al.* (1991), investigating differential utilization of summer rains by desert plants, found that herbaceous perennial species utilized summer precipitation more than woody perennials did.

Evaporation from soil surface is maximized after rainfall events during summer months in southern Nevada, as evaporative demand may exceed 0.4 inches (10 mm) per day. Studies by Lines and Bilhorn (1996) suggested that almost all precipitation along the Mojave River (10 to 15 cm) evaporates fairly quickly from the soil or is consumed by grasses, herbs, and shrubs. Katzer *et al.* (1976) documented the July 4, 1975, flood in LVV and calculated that about 20,000 to 25,000 AF (24,669,600 to 30,837,000 m^3) of precipitation fell on the valley floor with only about 15 percent of that amount discharging from the valley. With July daytime temperatures well over 100°F (38°C), he concluded that the remaining water was evaporated back to the atmosphere within a few days.

Based on the previous findings, we concluded that any rain that would have fallen on the valley floor would have been used only to a minimal extent by the plants, as the plants would have continued to rely upon the ground water system. Because most of the rain would have remained in the near surface soil, evaporation would have been determined by external conditions (Hillel, 1972), which would not have been rate limiting (constant rate stage). Thus the 4 inches (10 cm) of rain falling on the valley floor would not have a significant impact on the ground water budget and should be ignored.

Plant Water Use

Water use estimates for phreatophytes in the southwestern United States (U.S.) have been reported since 1912, when Lee (1912) quantified the ET of saltgrass in Owens Valley, California. Unfortunately, no ET studies in LVV were conducted during the time period in which large phreatophytic stands existed. Table 1 summarizes ET estimates from various locations in the southwest for species reported by Malmberg (1965). From such water use estimates, researchers have developed crop coefficients (Kc = actual ET divided by potential ET) to use in predicting water use rates for plant communities. Malmberg (1965) utilized Kc values in his water use estimates. It should be noted, however, that these Kc values were generated with the Blaney-Criddle potential ET model, which requires mean monthly temperature, monthly percent of daytime hours, and an empirical consumptive use coefficient. The model is very simplistic in nature and is best suited for regional first approximations of ET. Because all empirical ET models assume that water supply is not limiting, Kc values would only have real meaning if stands were large enough that border effects were minimal, stands were uniform in size, and water was nonlimiting at all locations within the stand. Such conditions may have existed in the large saltgrass/sacaton stands and mesquite stands in the LVV in 1905. Such conditions, however, would not hold true for the valley today.

Estimates of ET for the species reported in Table 1 show considerable variation. Such variation is to be expected, as the soil, plant, and climatic conditions varied from site to site. Lines and Bilhorn (1996) using water use data from a select group of studies in the Southwestern U.S., concluded that their estimates of water use by riparian vegetation along the Mojave River could vary by as much as 50 percent because of extreme hydrologic conditions. They compared their estimates of ET for riparian vegetation (17,000 AF or 20,969,160 m^3) along the Mojave River with those made in 1929 (40,000 AF or 49,339,200 m^3) and 1952 (35,000 AF or 43,171,800 m^3). Differences in these estimates were attributed to more accurate mapping and for the allowance of different plant communities, area densities, and extent of stressed vegetation in the 1996 study.

Robinson (1958) emphasized that conditions for growth must be specified for water use estimates of phreatophytes. In particular, he indicated that depth to ground water is a major factor in controlling water use rates of phreatophytes. If phreatophytes have a permanent water supply, they are able to tolerate drought periods and maintain high leaf area during dry seasons (Smith *et al.,* 1997). Increasing leaf area has been demonstrated to be a controlling factor in increased whole plant transpiration rates. Scientists have used various adjustments in their attempts at estimating whole stand transpiration. Adjusting the stands based on area density was proposed by Robinson (1958) and Gatewood *et al.* (1950). Hughes (1972) and van Hylckama (1974), however, found that reducing the density of a salt cedar stand from 100 to 50 percent reduced water use by only about 10 percent. Research by Devitt *et al.* (1998) on the Virgin River in southern Nevada also does not support the approach of using an area density adjustment.

Water Use Estimates for Plant Communities in LVV in 1905

Conditions for growth of phreatophytic stands of mesquite and saltgrass/sacaton were unique in LVV in 1905. Minimal disturbance, shallow water tables, high evaporative demand, high area densities, and good water quality all contributed to optimum water use rates for these plant stands. Similar conditions are extremely difficult to find in the southwestern United States. Only one study based on somewhat similar water table and climatic conditions is found in the literature (Sala *et al.,* 1996). Therefore, ET estimates reported from other sites must be used with great caution. Results reported by Robinson (1958), Ball *et al.* (1994), and Raymond and Rezin (1989) suggest that water use rates for mesquite would be in the 1.4 to 2.7 ft (43 cm to 82 cm) per year range. The conditions in which these estimates were made, however, included greater depth to water and greater plant water stress leading to plant stands that were significantly smaller in size when compared to that reported for LVV in 1905.

Water use in LVV by mesquite in controlled lysimeter studies under varying leaching fractions was studied by Devitt *et al.* (1994). Although the trees in that study were small in comparison to mature trees growing in the field and scaling up water use estimates would pose a challenge, mesquite clearly increased water use in response to increased water availability. Leakey and Last (1980) regarded mesquite as an extravagant user of water under arid conditions, as Tomble (1977) reported ET losses from stands of another species of mesquite (*Prosopis velutina*) during

TABLE 1. Historical Annual Evapotranspiration (ET) Estimates for Cottonwood, Mesquite, Sacaton, Saltgrass, and Tules Growing in the Western U.S., Relative to Water Table Depth.

Location	Date	ET Estimate (ft)	Water Table Depth (ft)	Investigator
		COTTONWOOD		
Carlsbad, New Mexico	1940	3.2	2	Blaney *et al.*[a]
		2.7	4	
San Luis Rey, California	1942	3.0	4	Blaney *et al.*[a]
Carlsbad, New Mexico	1944	7.6	7	Blaney *et al.*[a]
San Luis Rey, California	1945	5.2	4	Muckel and Blaney[a]
Carlsbad, New Mexico	1950	7.6	7	Gatewood *et al.,* 1950
Colorado Rive Basin	1952	6.0	–	USBR, 1952
Palo Verde, California	1987	3.5[b]	–	Raymond and Owen-Joyce, 1987
Palo Verde, California	1989	3.9[b]	–	Raymond and Rezin, 1989
		MESQUITE		
Carlsbad, New Mexico	1950	2.7	10	Robinson, 1958
Colorado River Basin	1952	3.3	–	USBR, 1952
Palo Verde, California	1989	1.9	–	Raymond and Rezin, 1989
Colorado River, Arizona	1994	1.4	–	Ball *et al.,* 1994
		SACATON		
Carlsbad, New Mexico	1940	3.2	2	Blaney *et al.*[a]
		2.7	4	
		SALTGRASS		
Owens Valley, California	1912	2.1	3.8	Lee[a]
Santa Ana, California	1929-1932	2.9	2	Blaney *et al.*[a]
		1.1	4	Blaney *et al.*[a]
Escalante Valley, Utah	1932	1.9	1.9	White[a]
New Mexico	1938	2.4	1.2	Blaney *et al.*[a]
Carlsbad, New Mexico	1950	5.5	2	Robinson, 1958
		4.7	4	Robinson, 1958
Ash Meadows, Nevada	1963	1.3	0 to 5	Walker and Eakin, 1963
Owens Valley, California	1988	2.1[c]	7.2 to 8.9	Duel, 1990
		3.2[d]	0 to 3.9	Duell, 1990
Ash Meadows, Nevada	1994	2.1	3 to 6	Nichols *et al.,* 1994
		1.3	6 to 10	Nichols *et al.,* 1994
Ash Meadows	1994	2.6	2.6 to 7.4	Nichols *et al.,* 1994
		2.7	4.6	Nichols *et al.,* 1994
		TULES (Marshland)		
Victorsville, California	1933	7.0	0	Blaney *et al.*[a]
		22.6 (oasis effect)[e]	0	Blaney *et al.*[a]
San Luis Valley, Colorado	1936	3.1	0	Blaney *et al.*[a]
King Island, California	1942	7.5	0	Stout, Young, and Blaney[a]
Gray Lake, Idaho	1944	3.5	0	Criddle and Marr[a]
Las Vegas, Nevada	1972	6.3	0	Westphal and Nork, 1972

[a] As reported by Blaney, 1952.

[b] Cottonwood/willow.

[c] Saltgrass, akali sacaton, and rubber rabbitbrush (*Chrysothamnus nauseosus*), 30, 13, and 9 percent plant cover, respectively.

[d] Saltgrass, akali sacaton, and baltic rush (*Juncus balticus*), 20, 17, and 15 percent plant cover, respectively.

[e] Oasis effect defined as effect of dry fallow surrounds on the microclimate of a relatively small acreage of land where an air mass moving into an irrigated (or wetland) will give up much sensible heat (Doorenbos and Pruitt, 1975).

the dry season at rates as high as 0.4 to 0.5 inches (10 to 12 mm) per day. Such rates rival even the highest values reported for salt cedar (Bowen Ratio estimates) along the Virgin River in southern Nevada (Devitt *et al.,* 1998). The only known transpiration estimates for mature mesquite in southern Nevada were made by Sala et al. (1996) along the Virgin River (leaf and branch level measurements). Sala *et al.* (1996) found that although water use estimated with sap flow gauges differed on a gram per hour basis for salt cedar, arrowweed, willow, and mesquite, if the data were normalized on a leaf area basis, no significant differences could be detected between these species. Sap flow per unit leaf area from five measurement days during the growing season revealed an average of 386 g m^{-2} h^{-1} [standard error (se) =53]; 0.0095 gallons ft^2/h for salt cedar, compared to 464 g m^{-2} h^{-1} (se = 64; and 0.0114 gallons ft^2/h for mesquite. Daily water use rates increased with leaf area, with no distinction made for the four species.

Uncertainty exists over the influence that stand densities have on ET rates of plant communities. Our approach separated data based on area densities greater than 50 percent and area densities less than 50 percent and assumed no reduction in water use if area densities were greater than 50 percent and assumed a 50 percent reduction in water use if area densities were less than 50 percent, recognizing that a certain level of error must be attached to such estimates. Malmberg (1965) estimated mesquite ET by using a crop coefficient (Kc) of 0.75 and a consumptive use factor of 4.3 ft/yr (1.3m). Because the Blaney Criddle potential ET estimate was 31 percent less than the Penman Combination prediction, however, we felt justified in not using the numbers generated by Malmberg (1965). Based on the work of Sala *et al.* (1996) and the 4.8 ft (145 cm) per year ET estimate for salt cedar by Devitt *et al.* (1998), an ET estimate for mesquite was made by correcting the salt cedar ET value with a leaf area index adjustment factor. This correction was based on the previously reported lack of a water use species separation on a leaf area basis (Sala *et al.* 1996) and numerous approaches in ET estimates that incorporate a leaf area index (LAI) factor (Jensen *et al.,* 1989). LAI for salt cedar associated with the 4.8 ft (145 cm) per year ET estimate reported by Devitt *et al.,* (1998) was approximately 2.5, while LAI for mature mesquite stands actively growing in the southern part of the valley was estimated at 2.25. Thus, we took 89 percent of the 4.8 ft (145 cm) per year ET estimate and predicted mesquite ET at 4.23 ft (129 cm) per year. The ET estimate for the LAI adjusted mesquite (4.23 ft) would generate a crop coefficient of 0.68, a value actually lower than that used by Malmberg (1965) and a value almost identical to that recommended by Rantz (1968) for mesquite growing in association with a water table at 4 ft (122 cm) using the Blaney-Criddle formula. The 0.68 crop coefficient would also be lower than the 0.79 value (Penman combination equation) recommended by the Food and Agriculture Organization of the United Nations (Doorenbos and Pruitt, 1975) for deciduous trees irrigated under dry, very windy conditions.

Only one ET study for alkali sacaton could be found in the literature. Estimates for saltgrass previously published vary significantly from site to site and with changing depth to ground water. Values ranged from a low of 1.1 ft (34 cm) to a high of 5.48 ft (167 cm) per year. Malmberg (1965) based his ET estimates for saltgrass on Blaney's work from 1929 to 1932, which estimated saltgrass ET in lysimeters in Santa Ana, California. Potential ET for Irvine, California (very near to Santa Ana, California), however, is estimated at 4.1 ft (126 cm) compared to 6.2 ft (190 cm) per year for Las Vegas (both based on Penman combination potential ET estimates). This represents a 51 percent increase in the environmental demand for Las Vegas over Santa Ana, yet Malmberg made no adjustments based on these differences. saltgrass ET estimated for Santa Ana, California, was 3.5 ft (107 cm) when the water table was between 0 to 2 feet (0 to 61 cm). Malmberg (1965) scaled his saltgrass ET estimate back to 3 ft (91 cm) to compensate for a possible deeper water table condition. Estimates for low fertility bermuda grass (*Cynodon dactylon*, with similar growth characteristics to those of saltgrass) under adequately watered conditions in Las Vegas have been estimated by Devitt *et al.* (1992) at 3.5 ft (107 cm). Because the true water table depths in 1905 are unknown, we believe a 3.5 ft (107 cm) value for saltgrass ET under high water table conditions is possible even if only as a high end estimate, considering the significantly higher ET_0 rate in Las Vegas.

Acreage associated with cottonwood and marshland (wet, low lying land generally under water) represented only 4 and less than 1 percent, respectively, of the total plant stand area existing in LVV in 1905. Based on the reported high water use rates for cottonwood in other localities (Table 1) and not knowing the exact compositional makeup of the 240 acres (97 ha) classified as cottonwood/mesquite, we did not adjust the ET estimate for LAI using the technique outlined for mesquite, but instead used the 4.8 ft (145 cm) value for salt cedar. This value represents a 13 percent decrease from the 1965 Malmberg estimate. The ET estimate made for marshland was based on a Kc adjusted ET_0. The Kc value was selected from Doorenbos and Pruit's FAO booklet (1975) titled "Crop Water Requirements." The ET_0 estimate for the active growing period was adjusted using a Kc value of 1.0, giving an ET estimate of 6.2 ft (190 cm) for marshland.

Based on results from a previous study in Las Vegas in which tree to grass water use ratios were estimated at 1.9 to 2.0 for mesquite and low fertility bermuda grass (Devitt *et al.,* 1995), we assumed a similar ratio for mesquite and saltgrass. It should be noted, however, that ET ratios as high as 2.9 have been reported by Horton *et al.* (1959) for salt cedar and bermuda grass growing in riparian corridors in Arizona, yet Malmberg used an ET ratio for mesquite and saltgrass of 1.1. Because we had a better indirect means of estimating mesquite than saltgrass, we applied the ratio to the mesquite ET estimate. The reverse approach also could have been taken in using an estimated saltgrass ET and adjusting up to obtain a mesquite ET. When such an approach was taken, however, the water use rate for mesquite became unrealistically high (6.83 ft or 2.1 m). Conversely, when we estimated ET for mesquite and back calculated ET for saltgrass using the 1.95 ratio, the ET values for saltgrass fell into the range reported in Table 1 (2.17 ft, 0.7 m), although they were lower than we directly estimated.

A total water use estimate for phreatophytes in the Las Vegas Valley in 1905 was generated by multiplying the ET estimate for each plant group by the area estimate (Table 2). For comparison, we estimated total ET using both the low and high values for mesquite and saltgrass in Table 1. A low estimate was 16,618 AFY (20,497,971 m^3), and a high estimate was 63,902 AFY (78,821,839 m^3). Using the approach outlined previously, our estimate would be 39,700 AFY (48,969,156 m^3). Interestingly, the average value for the high and low estimates would be 40,300 AFY (49,709,244 m^3), suggesting that our value is not unrealistic. More importantly, it was not based on a simple averaging of other reported data sets throughout the Southwest, but instead was based on a series of well founded approximations appropriate for LVV. Since plant stands were somewhat scattered in the valley and in many cases isolated from other stands by open desert land, however, the total water use estimate might need to be scaled up due to an advection factor. Wind speeds average more than 8 mph (3.6 ms^{-1}) (D. A. Devitt, unpublished results) during most months, suggesting that advection (both local and regional) may play a significant role in fueling higher ET rates if water availability is high. A lower ET rate also could have existed, however, if plant stands lost root contact with the capillary fringe during any part of the active growing period.

GROUND WATER OUTFLOW

Natural ground water outflow from LVV is not as straightforward as the ET estimates. There is potential for a significant amount of ground water to discharge from the valley through a series of faults that have fractured limestone rocks underlying alluvial sediments at great depth. These fracture zones extend to the surface through sediments, creating zones of discontinuities that have higher permeabilities than surrounding sediments, a phenomenon described by Bell and Katzer (1987). Ground water flow in

TABLE 2. Evapotranspiration Estimates in Las Vegas Valley for Predevelopment Year 1905.

	Malmberg (1965)			**This Study**		
		Evapotranspiration			**Evapotranspiration**	
Vegetation Type	**Area (acres)**	**Rate (feet)**	**Volume (AFY)**	**Area (acres)**	**Rate (feet)**	**Volume (AFY)**
Mesquite	3,400[a]	3.3	11,200	4,470c	4.2	18,500
	200[b]	2.8	600	710[d]	2.1	1,500
Saltgrass	5,200	3.0	15,600	5,100[c]	2.2	11,100
				6,715[d]	1.1	7,300
Cottonwood	240	5.4	1,300	240	4.8	1,200
Marsh	15	6.5	100	15	6.2	100
Totals	9,055[e]		28,800	17,300		39,700

[a] Lower valley floor.
[b] Upper valley floor.
[c] Area densities greater than 50 percent.
[d] Area densitites less than 50 percent.
[e] Malmberg vegetation area based on an adjusted 100 percent area density.

fractured carbonate rocks in southern Nevada has been discussed by Dettinger *et al.* (1995).

The theoretical model currently used by the Las Vegas Valley Water District (LVVWD) allows for water from these fault zones to fill the valley aquifer system and at the same time provide conduits for water to exit the basin along the Las Vegas Wash fault. As ground water moves upward from the deeper artesian aquifer to the shallow aquifer and then through sediments, it continuously dissolves minerals and salts out of the sediments. The thick section of gravels in Las Vegas Wash has a very high transmissivity, on the order of 100,000 ft^2 per day (9,290 m^2 per day), as reported by the U.S. Bureau of Reclamation (USBR, 1982). Water in the deeper part of the aquifer system continues to move along the fault zone out of the valley; however, in predevelopment conditions (based on this discussion), ground water probably never reached land surface in the wash.

If this model is correct, where is the discharge area for this ground water outflow? The most likely area for the discharge is into the Colorado River, although no springs have been mapped in the vicinity of the confluence of the wash and the river. A similar process, however, is evident on the nearby Virgin River in Arizona. Springs have been identified that discharge about 60 cubic feet per second (cfs) (1.7 m^3/s) into the Virgin River (Trudeau *et al.,* 1979; Cole and Katzer, 2000; Dixon and Katzer, 2002) throughout an approximately nine mile (14.5 km) stretch of the river. Many of the spring orifices are in the bed and low banks of the river and are visible only during very low water flows and when the suspended sediment load is virtually zero. Thus, a discharge to the Colorado River of 10 to 20 cfs (0.3 to 0.6 m^3/s) over several miles of fault controlled channel is a realistic assumption.

Previous investigators such as Maxey and Jameson (1948) and Malmberg (1965) assumed there was no ground water being discharged out of the valley, however, Malmberg did map phreatophytes along the wash to the vicinity of Three Kids Wash. Harrill (1976) estimated 1,200 AFY (1,480,176 m^3) of ground water exiting the valley under Frenchman and Sunrise Mountains, 2 to 5 miles (3.2 to 8.0 km) north of the wash. Morgan and Dettinger (1994) estimated ground water discharge at 1,500 AFY (1,850,220 m^3) from the valley at the same location designated by Harrill (1976) and an additional 500 AFY (616,740 m^3) discharged through sediments underlying Las Vegas Wash. Donovan and Katzer (2000) estimated 6,000 AFY (7,400,880 m^3) of outflow in this same area.

There are geophysical, hydrological, and chemical data that support the theory of ground water outflow from the LVV. Recent gravity data interpretations by the USGS (Langenheim *et al.,* 1998) define a major north-south trending fault structure about a mile west of the bedrock alluvial contact for Frenchman and Sunrise Mountains. Additionally, two northwest-southeast structures near the south end of the Frenchman-Sunrise fault are nearly in line with Las Vegas Wash. Las Vegas Wash is a west-east trending fault structure, even though it has not been mapped as such (Gary Dixon, USGS, personal communication, 1997).

The U.S. Bureau of Reclamation (1982), during the course of a salinity control study, conducted numerous aquifer tests on the edges of the wash. According to data reported from these studies, the horizontal hydraulic conductivities were extremely high, and transmissivities of 100,000 ft^2/day (9,290 m^2/day) were common. Gerald Edwards (Chief Engineer, Colorado River Commission, personal communication, 1998) indicated during the 1987 to 1989 construction of a new Southern Nevada Water System pipeline crossing the Las Vegas Wash, It was extremely difficult to dewater the underlying 30 ft (9.1 m) of sediments due to the large volume of water encountered. This flow was sampled and analyzed by the USGS, documenting a total dissolved solids (TDS) content of 4,500 milligrams per liter (mg/l). A TDS content in this range does not preclude discharge from the deeper artesian system, but as indicated previously, the quality of all water in this part of the valley is dominated by salts in the near surface.

The Darcy flow equation was solved for Las Vegas Wash using aquifer test data reported by the U.S. Bureau of Reclamation (USBR, 1982), a transmissivity (T) of 100,000 ft^2/day (9,290 m^2/day), a gradient (I) of 0.072, and a width (W) of 0.25 mile (402 m), equaling a discharge (Q) of about 8,000 AFY (9,867,840 m^3). An argument could be made that these values do not represent predevelopment conditions; however, the gradient is the land surface of the wash prior to the erosion in the mid-1970s and the water level gradient could be greater but probably not much less. Malmberg's (1965) water level map of LVV shows a water level gradient of about 0.018 in the southeast part of the valley just upgradient of where the wash exits the valley. The high T values reported by the USBR are indicative of high sediment permeability. The transmissivity of the fault zones that act as conduits is unknown, but based on USGS flow records there is at least a 10,000 AF (12,334,800 m^3) gain in just a mile of the lower wash. One could argue that this increase is a result of downcutting and subsequent drainage of gravels into the wash. The counter argument is, if the gravels are as transmissive as the aquifer tests indicate, why would they still be draining?

The senior author of this paper monitored salinity and ion concentrations in the water flowing in the wash during 1998. Based on monthly sampling, it was determined that a dilution was occurring between the Three Kids Wash site (2.63 dS/m) and at a sampling point just above where the wash water enters Lake Mead (2.43 dS/m). The USGS estimate for discharge from the wash in 1998 was 176,800 AF, or 218,079,264 m^3 (Preissler *et al.,* 1998). Salinity values for the Las Vegas Springs aquifer are approximately 0.4 dS/m. Conducting a simple salt balance with the known water quality and water quantity data suggests a ground water volume of approximately 16,000 AFY (19,735,680 m^3) entering the wash to cause the observed dilution. The source of this water would have to be from the Las Vegas Springs Aquifer flowing along the fault systems, starting at the base of Frenchman Mountain, as described previously. If the quality were poor and representative of today's shallow aquifer (approximately 8.0 dS/m), then a dilution in the wash would not be possible.

How could this discharge, if it was occurring in predevelopment times, not be seen on the 1930 air photos? The answer lies in the amount of downcutting form erosion in Las Vegas Wash that has taken place during the past 50 years. There has been as much as 25 to 30 feet (7.6 to 9.1 m) of vertical downcutting throughout much of the wash (Pat Glancy, USGS, personal communication, 2000). This erosion in the wash lowered the channel sufficiently to intercept ground water outflow of reasonably good water quality. The depth to ground water prior to the start of accelerated erosion in predevelopment times (1905) precluded the establishment of phreatophytes. One additional piece of evidence supports this. According to Bill Quinn (Southern Nevada Office of the State Engineer, personal communication, 1992), after numerous feet of earth were removed during excavation for the Lake of Las Vegas (between Three Kids site and Lake Mead) (Figure 1), several seeps and one flowing spring were encountered. The water quality of the spring reportedly was of better quality than in the shallow ground water system.

The discharge flow regime in Las Vegas clearly has changed with time. Longwell (1936) who mapped the geology of the area now covered in part by Lake Mead, stated that 1st. Lt. J. C. Ives explored this part of the Colorado River in 1858 and reached the mouth of Las Vegas Wash. Ives (1861) stated, "we ascended the river [from his March 12, 1858, camp on the Colorado River near present day Boulder Dam] a couple of miles and came to the mouth of a stream about the size of Bill William's Fork, as the latter was when we passed it. We disembarked, and followed for some distance along its border. The appearance of the bed and banks indicated the existence, during some seasons, of a wide and deep river. It was now but a few inches deep. The water was clear and had a strong brackish taste. This fact, and its position led me to suppose that we were at the mouth of the Virgen [*sic*], but I could scarcely believe that river could ever present so insignificant an appearance." Longwell (1936) concluded that Ives' campsite was located near the mouth of the Las Vegas Wash because he describes features in Boulder Basin (Las Vegas Bay) just north of Black Canyon (site of Hoover Dam). Although most of these features are now beneath the waters of Lake Mead, they were well known to Longwell who provided maps and photographs in his 1936 geologic report. Is this ground water outflow from Las Vegas Wash and is the description of the "wide and deep river" an ephemeral channel that would fit the description of the Las Vegas Wash? The answers probably are yes to both questions.

The hydrologic evidence indicates considerable ground water outflow occurring in the vicinity of the wash, which supports the numerical estimates in this paper. Thus the estimate for natural ground water outflow would be in the range from 1,200 to 16,000 AFY (1,480,176 to 12,735,680 m^3), with estimates generated in this study ranging from 8,000 to 16,000 AFY (9,867,840 to 19,735,680 m^3). This changes the water budget for LVV defined by Donovan and Katzer (2000), who used an estimate of 6,000 AFY (7,400,880 m^3) for outflow, but it does not change the amount of ground water recharge, which is briefly discussed here for continuity and to present a revised ground water budget.

GROUND WATER RECHARGE

Precipitation in the form of rain and snow is the sole source of ground water recharge for LVV. Hardman (1936) produced the first statewide precipitation map, which he revised in 1965. This 1965 map was further revised and published by the Nevada Department of Conservation and Natural Resources (see Hardman, 1965). Another statewide precipitation map was published by the Oregon Climatic Service (Daly *et al.,* 1994; Daly *et al.,* 1997) using the period of record from 1961 to 1990. Donovan and Katzer (2000) published yet another precipitation map of just LVV in the form of altitude precipitation relationships using local in-valley stations, including recently (1984) installed high altitude precipitation stations, that more accurately represents total annual precipitation. Precipitation totals from these three maps for LVV are compared in Table 3.

Maxey and Jameson (1948) first estimated the total primary (natural) recharge for LVV. Their technique was a variation of what was later to be known as the Maxey-Eakin method and is described further by

Maxey and Eakin (1949). Briefly, recharge was estimated using an iterative procedure that uses a percentage of the total precipitation within 1,000 foot altitude zones. The total estimate from all of these zones was designated as potential recharge from a given mountain block and was assumed to equal the estimated discharge. As altitude increases, so typically does precipitation, and a greater percentage of the precipitation is estimated as potential recharge. The validity of the estimating technique was evaluated several years ago by Avon and Durbin (1994), who concluded that the technique was the best developed to date, and the method is used extensively throughout Nevada. Other investigators in LVV used different techniques or variations of the Maxey-Eakin method, and these are compared in Table 4. Donovan and Katzer (2000) also used a slight variation of the Maxey-Eakin method to estimate ground water recharge from precipitation for LVV even though it is nonunique and empirical, and was developed using the earliest precipitation map by Hardman (1936). Despite limitations of the methodology, it appeared to work well with the new altitude precipitation relationships. Donovan and Katzer (2000) also observed that their spatial distribution by percentage of the natural recharge was nearly the same as that reported by the two previous models (Harrill, 1976; Morgan and Dettinger, 1994) for LVV (Table 4). These earlier modelers evaluated recharge in terms of aquifer dynamics, whereas Donovan and Katzer (2000) evaluated the relationship between precipitation and recharge. Both techniques provided a similar percentage distribution of recharge, and although this does not mean the estimate is defined precisely, it is supportive.

TABLE 3. Comparison of Total Precipitation From Published Precipitation Maps for Las Vegas Valley.

Investigator(s)	Date	Precipitation Estimate (acre feet/year)
Hardman (1936)	1936*	561,000*
PRISM (Daly *et al.*, 1994, 1997)	1997	613,000
Donovan and Katzer (2000)	2000	708,000

*This number was calculated from digitized version of the 1965 revision of this map as published in the 1972 Nevada State Water Plan.

Three different altitude precipitation relationships shown in Figure 3 were used by Donovan and Katzer (2000) to define different climatic conditions between and in the mountain blocks. Correlation coefficients

TABLE 4. Comparison of Natural Recharge Estimates for the Las Vegas Valley Ground Water System (one acre foot of water is equal to approximately 326,000 gallons or 1,233 m^3). (P = Precipitation; D = Darcy; G = Conservative ion or stable isotope; AFY = Acre feet per year; Percent = Percent of investigator(s) total; * = No value reported.)

Investigator(s)	Basis of Estimate	Date	Spring Mountains		Sheep and Las Vegas Ranges		Ivanpah Valley and McCullough Range		Totals (rounded)
			AFY	Percent	AFY	Percent	AFY	Percent	AFY
Maxey and Jameson[a]	P	1948	27,200	79	7,200	21	*	*	34,000
Malmberg	D	1965	19,700	94	1,300	6	100	< 1	21,000
Harrill[b]	P	1976	16,300	56	13,000	44	*	*	29,000
Harrill[b]	D	1976	24,100	82	2,300	8	3,000	10	29,000
Dettinger	G	1989	17,000	61	11,000	39	*	*	28,000
Morgan and Dettinger	D	1994	27,700	84	2,900	8	2,500	8	33,000
Thomas *et al.*	G	1996	29,000	92	2,500	8	*	*	32,000
			Las Vegas Valley Only						
Donovan and Katzer	P	2000	47,300	93	3,500	7	100	< 1	51,000
			Las Vegas Plus Ivanpah Valley						
Donovan and Katzer	P	2000	47,300	84	3,500	6	5,800	10	57,000

[a] Calculated from original precipitation and recharge efficiencies of Maxey and Jameson (1948, p. 107-107).

[b] Reported by Dettinger (1989).

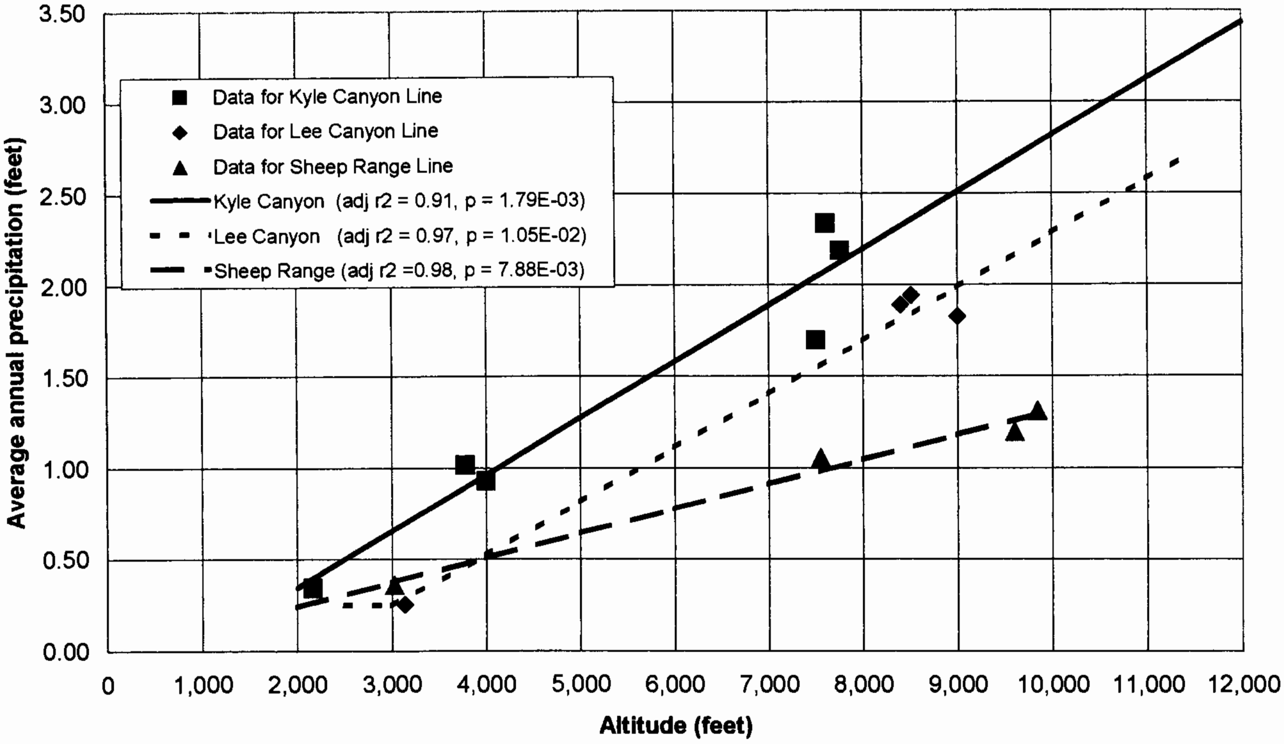

Figure 3. Altitude/Precipitation Relationships for Las Vegas Valley (Donovan and Katzer, 2000).

for the altitude precipitation relations ranged from 0.95 to 0.99, at the 0.001 level of significance.

Based on these new altitude precipitation relationships, ground water recharge to LVV was estimated by Donovan and Katzer (2000) to be about 51,000 AFY (62,907,480 m^3), with an additional 6,000 AFY (7,400,880 m^3) of ground water recharge from Ivanpah Valley to the south. The total recharge for the valley is shown in Table 4, along with the recharge values estimated by all previous investigators.

WATER BUDGET CLOSURE

The recharge and discharge estimates were brought together in a final ground water budget for LVV (Table 5) and compared with earlier estimates made by Maxey and Jameson (1948) and Malmberg (1965). Other budget estimates made by the USGS are variations based on these earlier investigators and are not listed. Although all estimates should be regarded as approximations, the three budget estimates listed in Table 5 differ significantly. Based on the new recharge estimates and the range in discharge estimates, water budget closure could be within 9 percent (current estimate) or closure could be complete or off by as much as 71 percent, based on selected discharge estimates from other investigators. The estimates associated with the various components of the water budget are subject to error, which is not reflected in the implied accuracy of a water budget closure within 9 percent. Greater confidence, however, is attached to the more recent recharge estimates of Donovan and Katzer (2000), based on a more robust sampling size and higher elevation precipitation estimates that indicate that a large error (58 percent) would be attached to the earlier discharge estimate of Malmberg (1965).

SUMMARY

The steady state water budget for LVV has been out of balance since the first wells were drilled and pumped nearly 100 years ago. The natural hydrologic system is difficult to define for predevelopment conditions. Earlier studies grossly underestimated ground water recharge because the distribution and amount of higher altitude precipitation was unknown. Ground water discharge also was underestimated because empirical relationships were used that were based on research in more moderate climates with little or no adjustment for the unique soil, plant, water, and climatic conditions that existed in LVV in 1905.

Additionally, data obtained over the past 20 years indicates that significant ground water outflow occurs from the valley.

TABLE 5. Ground Water Budgets for Las Vegas Valley in Acre Feet Per Year (AFY).

	This Study	Malmberg 1965	Maxey and Jameson 1948
	Inflow		
Groundwater			
Recharge	51,000	24,000	30-35,000
Inflow	6,000	~100	0
TOTAL	57,000*	24,000	~32,500
	Outflow		
Phreatophytes (ET)	40,000	24,000	14,400
Ground Water Outflow	12,000	0	0
TOTAL	52,000	24,000	14,400
Imbalance	~5,000	0	~18,000

*Donovan and Katzer, 2000.

Based on the newly published recharge values, closure can occur only if higher values are assigned to ground water discharge and/or ET components of the balance. Although we cannot provide a complete water balance closure with this assessment (52,000 AFY or 64,140,960 m^3 discharge; and 57,000 AFY or 70,308,360 m^3 recharge), this evaluation provides the rationale for future studies to be conducted based on a more rigorous scientific assessment of these water balance components.

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