Cost-Benefit Analysis of Artificial Recharge in Las Vegas Valley, Nevada

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Abstract: An integral part of groundwater management in Las Vegas Valley, Nev., is artificial recharge. Artificial groundwater recharge started in the late 1980s and as of the year 2000, the Southern Nevada Water Authority entities have recharged over 246,000,000 m^3 (200,000 acre-ft) of water, which is in storage in the valley's aquifer system. Benefits from artificial recharge accrue to all valley residents, but in particular to municipal-industrial, domestic, public supply, and commercial well owners. The benefits are lower energy costs for pumping, decreased need to deepen wells, lower maintenance for wells that could potentially be damaged by subsidence, and additional water for the aquifer system. Although artificial recharge is currently a "free" benefit to all nonmunicipal groundwater pumpers, active management of the aquifer system would be enhanced by participation of all users in the artificial recharge program. In an effort to include all groundwater pumpers in the management of the aquifer system, a groundwater management program (GMP) was established. The costs and benefits for participation by nonmunicipal groundwater pumpers are presented, indicating a savings of about $700 annually for nonmunicipal members of the GMP.

DOI: 10.1061/(ASCE)0733-9496(2002)128:5(356)

CE Database keywords: Cost analysis; Nevada; Ground-water recharge; Ground-water management.

Introduction

Water is at the forefront of issues for southern Nevada, as it has been throughout the twentieth century. The management of water resources and the administration of water rights have changed in the 1990s, beginning with the establishment of the Southern Nevada Water Authority (SNWA) in 1991. SNWA is an organization of the major municipal water purveyors and wastewater treatment entities responsible for regional groundwater and surface-water concerns of interest to the member agencies. Member agencies forming the SNWA are Boulder City; Big Bend Water District; Clark County Sanitation District; the Cities of Henderson, Las Vegas, and North Las Vegas (CNLV); and the Las Vegas Valley Water District (LVVWD). Nellis U. S. Airforce Base (NAFB) is a minor municipal groundwater pumper, but not a member of SNWA.

Certain aspects of groundwater management within Las Vegas Valley do not actually fall within the charter of SNWA because many of these issues are of concern to nonmunicipal groundwater pumpers who are not members of SNWA. In order to include these non-SNWA groundwater pumpers, a Groundwater Management Program (GMP) was required and initiated in 1997. The GMP was chartered to assist well owners in Las Vegas Valley, but regulation of groundwater is governed by state water law.

The GMP advisory board consists of a variety of water users and is administered by SNWA. The purpose of the GMP, as originally chartered, was identification of the stakeholders, public education, a comprehensive well inventory, aquifer protection, and a cost-benefit analysis. The cost-benefit analysis described herein defines the role of the GMP within the existing framework of competing interests and defines a sound economic footing for this new organization. Thus, the purpose of this cost-benefit analysis is directed to just the nonmunicipal pumpers, with some obvious benefits accentuated for municipal pumpers. The expected role of the GMP within the political and regulatory environment was, at the time of this analysis in 1998, to provide financial assistance to members to offset connection charges and determine the level of its financial participation in the existing artificial recharge program. Artificial recharge for the GMP is accomplished by LVVWD for SNWA.

The groundwater system underlying Las Vegas Valley has served the valley well over the years by providing first abundant spring flow for early settlers and then a steady source of groundwater as development began. Today (2000), the groundwater system provides about 30% of the summer demand for the municipal purveyors (LVVWD, CNLV, and NAFB). Surface water is the

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Note. Discussion open until February 1, 2003. Separate discussions must be submitted for individual papers. To extend the closing date by one month, a written request must be filed with the ASCE Managing Editor. The manuscript for this technical note was submitted for review and possible publication on June 12, 2000; approved November 13, 2001. This technical note is part of the ***Journal of Water Resources Planning and Management***, Vol. 128, No. 5, September 1, 2002. ©ASCE, ISSN 0733-9496/2002/5-356–365/$8.00+$.50 per page.

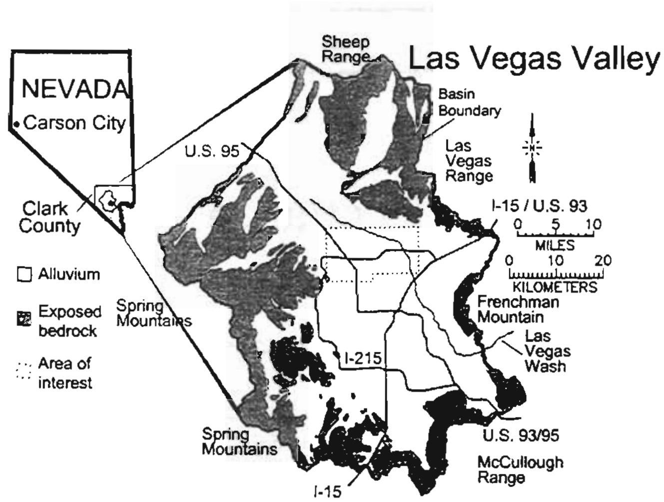

Fig. 1. Location of Las Vegas Valley and area of interest

major source of supply in other municipal purveyor's service area. Groundwater provides a year-round supply for domestic (single family residence) and public-supply users (2–15 residences), private water companies (over 15 residences), and the few included commercial pumpers (i.e., wells owned by private golf courses).

Domestic well owners do not have a water-right permit and are required by state law to connect to a municipal system only when their well fails and if there is a municipal line within a certain distance of their property. Nevada water law states that groundwater pumpers with temporary water right permits are under similar restrictions. The state granted these temporary rights with these provisions because the areas were beyond municipal purveyor facilities and no alternative water supply was then available. Users with permanent water rights are never required to connect to a municipal purveyor.

Before the 1990s, water levels had been declining for over 50 years, causing a large number of pumpers to deepen their wells at a cost of several thousand dollars per well. In the late 1980s, the LVVWD began the process of artificial groundwater recharge to increase the available water resources. Adding water to the groundwater system has also slowed or reversed the decline in water levels. The artificial recharge process has also reduced the rate of land subsidence, provided for drought storage, and allowed certain water demands to be met.

Of specific interest to nonmunicipal pumpers is the rapid rural growth in many parts of the valley, and in particular in the northwest (Fig. 1), where there is an extremely high density of domestic and public-supply wells (nearly 1,700 in one township). Much of this area is beyond municipal purveyors' distribution facilities, and growth has resulted in a large number of domestic and private/public-supply wells. This growth has also resulted in a corresponding large number of septic systems, which have the potential to contaminate the groundwater system. Due to both the low permeability of the aquifer system in this area and the lack of existing purveyor facilities, the existing recharge program is not as effective at raising water levels in this area as would be if specifically dedicated recharge wells are located within the area.

The artificial recharge programs conducted by SNWA purveyors (LVVWD and CNLV) provided benefits (i.e., higher water levels) to all groundwater users, with municipal customers of the purveyors funding these recharge activities. The 1997 Nevada Legislative Assembly Bill 436 provided for formation of the GMP and defined its responsibilities, including the requirement for a cost-benefit analysis of artificial recharge. The legislation specifies that SNWA may require a groundwater pumper to join the GMP. Thus, the program is designed to enlist the support of all nonmunicipal groundwater pumpers and expand the program to accommodate the interests of the GMP. However, if the program is expanded into new areas specifically for artificial recharge, requiring new well construction, those costs will be allocated to all GMP participants based on use. The GMP's participation in the artificial recharge program changes the area of interest but is not required for the viability of the program. The costs of GMP participation in the artificial recharge program in Las Vegas Valley are analyzed and the benefits to a "typical" GMP member determined herein.

Background

Development of the Las Vegas Valley groundwater basin began shortly after the turn of the twentieth century, when the first well was drilled. By 1910, there were about 100 wells in the valley, and by 1998, over 9,000 wells had been drilled, with more being drilled every year. A GMP well inventory in 1999 indicated about 4,000 wells in existence, with about 25% located in a single township (T 19 S, R 60 E) in the northwest part of the valley, the focus of this study. Groundwater pumpage records began in the mid 1950s and Fig. 2 shows annual pumpage through 1998 and distribution of pumpage by the various types of pumpers.

Artificial recharge began in the late 1980s and is regulated by the State of Nevada for quantity and quality. Conditions of the permit require measurements of the volume of water recharged or recovered and water quality sampling and analyses for a wide variety of constituents. The main municipal purveyors, LVVWD and the CNLV, hold about 55,350,000 m^3 (~45,000 acre-ft) per year of permanent groundwater rights, which they pump annually. Thus, some of the actual recharged water is pumped during the same season it is recharged. However, under state law, the artificially recharged water is not considered removed from storage until the purveyors pump in excess of their permitted groundwater rights.

Groundwater System and Water Level History

The aquifer system underlying Las Vegas Valley is a complex layering of saturated and unsaturated sediments with widely varying hydrologic properties. Previous investigators have grouped these interbedded sediments into aquifers based in part on permeability, thickness, depth below land surface, and water quality. Most recently, Donovan (1996) defined the aquifer sediments in terms of porosity and permeability (hydrostratigraphic units), and this has been useful in selecting areas for recharge. Unsaturated sediments, some of which were dewatered by extensive pumping, are also important and are included as part of the groundwater system. As artificial recharge continues, some of these dewatered sediments are being resaturated.

The earliest estimated water levels are for 1912 (Carpenter 1915; Malmberg 1965), and represent essentially predevelopment conditions [Fig. 3(a)]. As urbanization progressed (Fig. 3), groundwater pumpage increased, and by 1975 significant declines in the water table had occurred, as shown in Fig. 3(b) [U.S. Geological Survey (USGS) database], particularly near the centers of major pumping. Groundwater withdrawals throughout the valley continued to cause water levels to decline until about 1990. Fig.

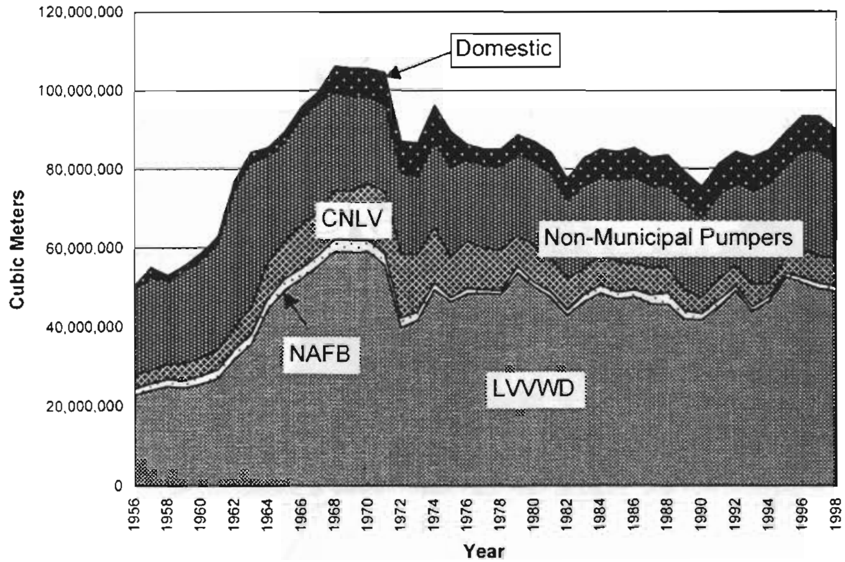

Fig. 2. Total groundwater pumpage in Las Vegas Valley, by type of pumper, 1956–1998

3(c) shows net groundwater level change between 1975 and 1990. The year 1989 is approximately the last year of total declines in the groundwater system throughout the valley, because at that time LVVWD began injecting millions of cubic meters (thousands of acre-feet) of treated Colorado River water into the groundwater system (Fig. 4). Groundwater level changes between 1990 and 1997 show a maximum rise [Fig. 3(d)] of about 15.24 m (50 ft) over a large area in the west and northwest part of the valley where most of the municipal pumping occurs. Water-level declines in the major production aquifer on the west side of the valley in coarse grained sediments are relatively easy to reverse; however, the declines are more difficult to reverse in the finer-grained sediments in other parts of the valley, particularly in the far northwest.

Artificial Recharge Process

Artificial recharge began in Las Vegas Valley in the late 1980s and is documented by Katzer and Brothers (1989), Brothers and Katzer (1990), and Johnson et al. (1997). There are many reasons for and advantages, both direct and indirect, of artificially recharging groundwater, and these are documented by Katzer et al., (1988, p. 95). The primary advantages evaluated here are using the aquifer system for storage and stabilizing or raising water levels. Todd (1965, p. 252) lists only two direct reasons for artificial recharge; relief of overdraft and use of the aquifer as storage. These broad categories are consistent with the findings of other investigators, such as Reichard and Bredehoeft (1984, p. 929).

Artificial recharge in Las Vegas Valley is accomplished by taking potable Colorado River water from the treatment plant through the existing distribution facilities in the lower demand months (October–April) and injecting it into the groundwater system through wells. Well capacities vary widely depending on well construction and local groundwater hydraulics and range from 5–250 L/s (80–4,000 gal./min). This technique is in wide use in many states and has gained increasing popularity as a water resource management tool.

The major objective of the existing artificial recharge program in Las Vegas Valley is to build a storage bank for potential future use, which has the beneficial effect of raising the level of groundwater mostly in the west and northwest parts of the valley. The area of interest and focus of this study is the northwest part of the valley. Because the aquifer system is confined, this benefit will directly accrue to all pumpers in the valley by lowering pumping costs, reducing well deepening and redrilling costs, and providing the indirect benefit of slowing and perhaps halting land subsidence. Artificial recharge in the western part of the valley augments natural recharge. The southwestern part of the valley is not as adversely affected by pumpage, because the stress on the aquifer system is minimal. The aquifer system in the northeast part of the valley has extremely low permeabilities (Smith and Arden 1997) and artificial recharge is not planned for this area.

A goal of active basin management as practiced by the GMP and SNWA is to store water in the groundwater system for the express purpose of reducing the imbalance between natural recharge and discharge caused in part by pumping more water than is naturally recharged. Even though Donovan and Katzer (2000) have redefined the groundwater budget showing much more recharge and discharge than previously understood, there is still an imbalance in that more water is being discharged than recharged. Some percentage of the stored water, if purchased by the GMP and dedicated to the aquifer system, could not be tapped by municipal purveyors and could provide the indirect benefit of reducing or preventing subsidence. Thus, the dedicated water, if purchased, will be left in the aquifer system if and when the withdrawal of the recharged water begins.

Fig. 4 shows the total amount of water recharged in the valley, including the amount recharged by the CNLV, the only other municipal purveyor conducting an artificial recharge project in the valley. Even though the CNLV is a member of the SNWA and the GMP, it recharges for its own use. Since the start of 1990 through 1999, the LVVWD has averaged about 23,370,000 m^3/year (19,000 acre-ft/year) of recharge, and North Las Vegas has averaged about 1,476,000 m^3/year (1,200 acre-ft/year). This current year, 2000, will see artificial recharge by SNWA members of about 36,900,000 m^3 (30,000 acre-ft) (Erin Cole, SNWA Department of Resources, personal communication, 2000).

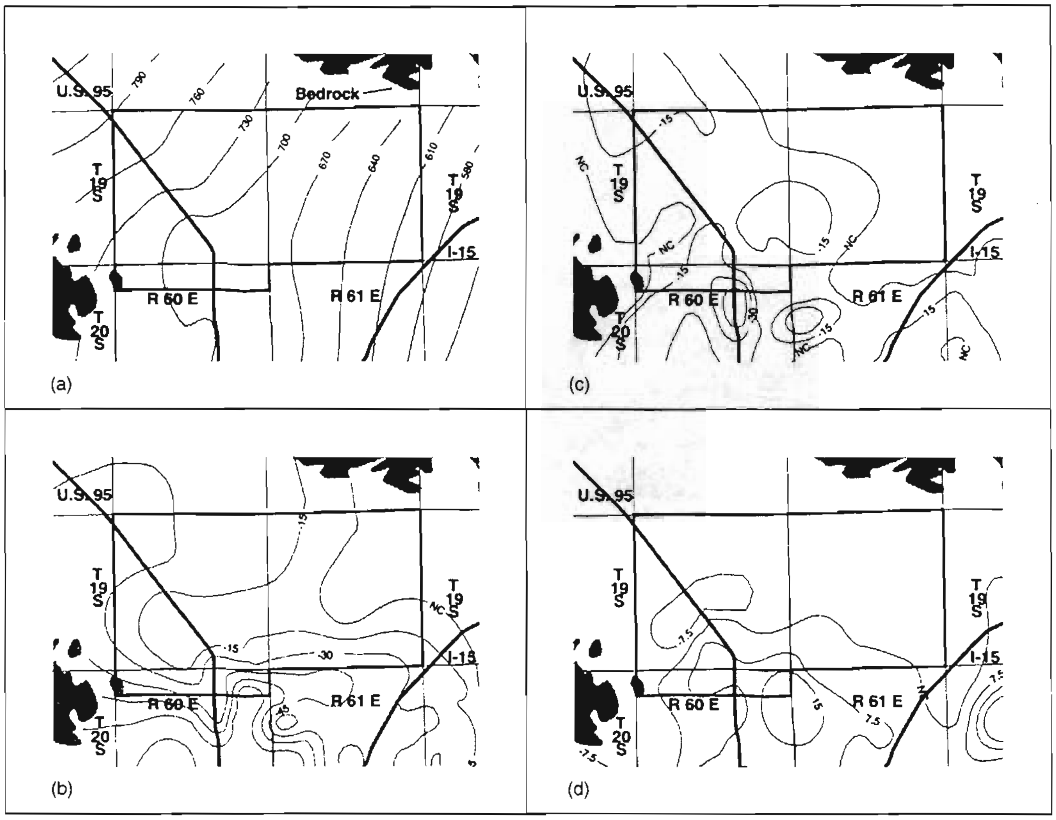

Fig. 3. Contour maps showing predevelopment water levels and water level changes, in meters [(−) decline, (+) rise, (NC) no change, variable intervals] in northwest part of Las Vegas Valley: (a) water level surface 1912 (predevelopment), in meters above mean sea level; (b) water level change 1912–1975, in meters; (c) water level change 1975–1990, in meters; (d) water level change 1990–1997, in meters

Artificial recharge will likely always be used as a water management tool in Las Vegas Valley when water is available. The availability of Colorado River water is dependent on climatic cycles, political environment, and economics, which vary from year to year. SNWA members can take advantage of available capacity and slightly lower energy rates during the winter to move water into the valley that can be used to meet part of the summer demand. Additionally, there is a large capital cost savings of over $200 million (Nick Braybrooke, Director, LVVWD Resources, personal communication, 2000) by using recharged groundwater to help meet the summer demand rather than building the additional capacity in the treatment and distribution system to supply the same demand from surface-water sources.

Artificial recharge during the last several years has slowed the decline in water levels and has resaturated much of the previously dewatered aquifer system, resulting in a general rise in the water table in the western and northern portions of the valley [Fig. 3(d)]. Amelung et al. (1999) have attributed the slowing of subsidence and local small rises <3 mm (<0.01 ft) in land surface to rises in groundwater levels. Bell and Price (1991), who reached the same conclusion, have also documented these impacts. Land that has subsided due to dewatering of aquitards cannot recover or rebound, according to John Bell (Nevada Bureau of Mines and Geology, personal communication, 1998) and Randy Laczniak (USGS, personal communication, 1998), but elasticity of the aquifers within the groundwater system may cause insignificant small rises in the land surface. As long as water levels continue to rise, the rate of subsidence will be less and ultimately subsidence will cease; however, according to Amelung et al. (1999), minor subsidence and recovery will continue during seasonal pumping and recharge. A similar problem of land subsidence in Santa Clara Valley, Calif., was halted by artificial recharge and the land surface did not recover (Reichard and Bredehoeft 1984, p. 931).

Economic Analysis

Cost-Benefit Assumptions

The following assumptions provide the basis for determining costs and benefits and is one alternative, among many, to arrive at an equitable base and starting point (Boardman et al. 1996). First, it is assumed that the stakeholders are those who pump groundwater and they are made up of municipal purveyors, domestic single-family units relying on a single well, private/public-supply providers for two or more households, and commercial pumpers. The number and type of wells and the average depth drilled by decade are shown in Fig. 5. It is anticipated that permits for new wells will increase to about 600 (between 2000 and 2010) with an average depth of around 183 m (600 ft). Since the 1950s, well depth has increased by about 70%.

The second assumption is that the only alternative project is a *no action* alternative, where artificial recharge does not take place. This alternative is undesirable because it decreases the available water resources and greatly reduces the flexibility of water resource management. Under the terms of the contracts with the U. S. Bureau of Reclamation (USBR) for Colorado River

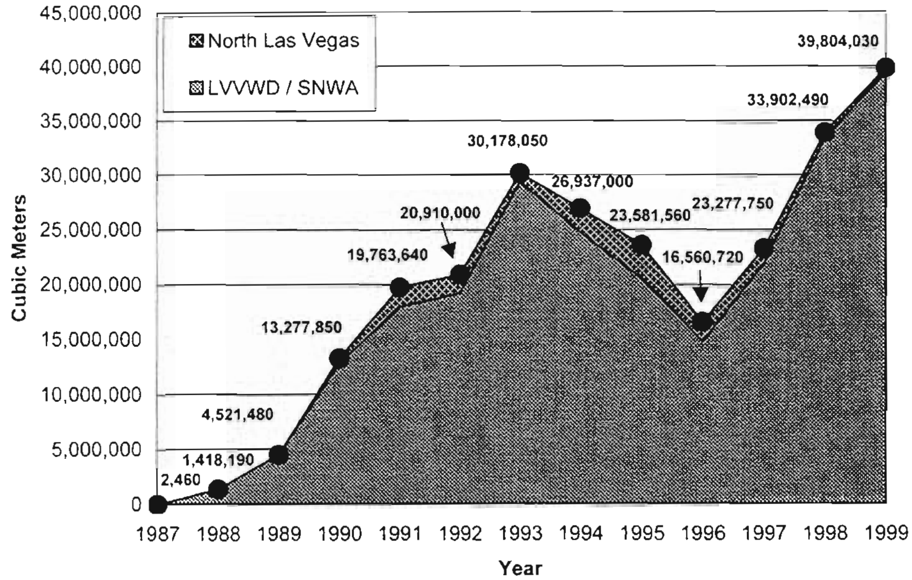

Fig. 4. Amount of water artificially recharged, 1987–1999, in Las Vegas Valley

water, the yearly allocation *cannot* be stored in Lake Mead from year to year. Thus, artificial recharge is the only way to store part of Nevada's unused allocation, and the more water that can be recharged, the lower the unit cost and the higher the benefits. Preliminary analysis indicated it is impractical to even consider above-ground storage in tanks or surface reservoirs as an alternate action because of the high dollar and environmental costs of constructing facilities for storing the large volumes that are recharged each year.

The current (2000) above-ground storage capacity is about 2,460,000 m^3 (2,000 acre-ft). This is nearly the amount used in a single day during the peak demand in the summer. Thus, the amount recharged during a single year is 10 times the above-ground storage capacity. To maintain drinking water standards, stored water must be distributed in a relatively short period of time, thereby precluding long-term above ground storage. Similarly, high evaporation rates, coupled with the high cost of land, rule out the construction of surface reservoirs.

The third assumption is that all costs and benefits are based on fiscal years (FY) 1996-1998 dollars, which are considered to represent the current value. The costs of most of the items evaluated are calculated for FY 1996 and 1997. Some costs, such as for well drilling, are for 1998, but these are nearly the same as for FYs 1996 and 1997. Thus, current value was used and no attempt was made to compound or discount costs and benefits for future conditions. However, interest on capital expenditures, such as the cost a domestic well owner would likely pay for borrowing money for well drilling, was taken into consideration, as was interest on borrowing money to pay connection fees. Inflation was not considered, because it was assumed to equally impact all nominal costs and benefits.

The fourth assumption was to arrive at an annual unit price per user (costs/water use amount/time) for GMP participation in the artificial recharge program. The yearly water use amount for a typical domestic well owner is estimated to be about 1,230 m^3 (1 acre-ft) (Robert Coache, Nevada Division of Water Resources, personal communication, 1998). All well owner and GMP costs and benefits are based on this unit price per user of "dollars/1,230 m^3/year." To estimate the value of a unit price per user, both the total amount of artificial recharge and groundwater pumpage must be determined to prorate costs. In terms of capital costs for non-municipal pumpers, such as well construction, the total cost was amortized over a 20-year period, the assumed life of any given well.

Finally, downstream impacts to the Colorado River resulting from artificial recharge in Las Vegas Valley are not addressed in this analysis, because diversions from the Colorado River are determined annually by the Secretary of the Interior and may exceed contractual amounts depending on legal arrangements and hydrologic conditions. Downstream impacts to the Colorado River system by Nevada's diversions are no more or less than any other Colorado River state on a per cubic meter basis and were not considered for this analysis. Nevada's total allocation from the Colorado River is about 4% of the annual flow of the river, so, from a regional perspective, this limited amount of water is inconsequential as compared with states downstream from Nevada.

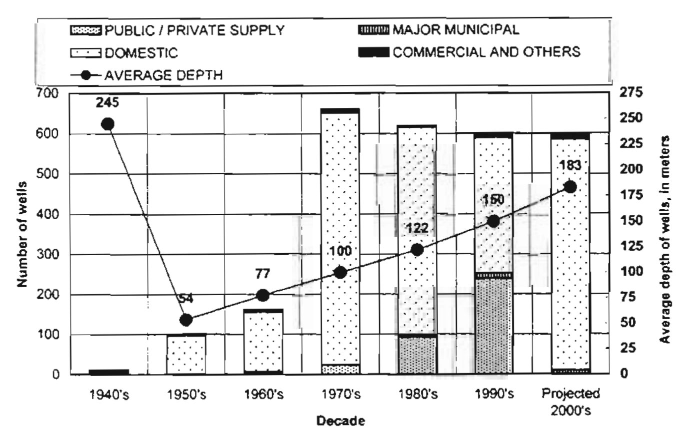

Fig. 5. Number, type, and depth of new wells drilled by decade, in area of interest

Table 1. Southern Nevada Water Authority Members' Costs for Artificial Recharge

Item	Cost[a] (dollars/1,230 m^3/year)
Wholesale water charge[b]	199
Operation and maintenance purveyor cost[c]	
Facilities and distribution	5
Wells	6
Artificial recharge annual permit fees[d]	3
Permit requirements for reporting[e]	5
Total	218

[a]Rounded to nearest dollar, 1,230 m^3 = 1 acre-ft.

[b]SNWA Municipal Water Purveyors (1993). Includes payment to USBR for water, payment for treatment and distribution to purveyor turnouts in the valley, and energy needed by LVVWD to deliver water from turnout to wellhead.

[c]Operation and maintenance of pump stations, distribution system, and wells for artificial recharge by LVVWD.

[d]State Water Resources Division ($2.00) and Department of Environmental Protection ($1.00).

[e]Data collection, interpretation, and reporting required by terms of permits.

Cost of Water

The total cost of artificial recharge through existing facilities is listed in Table 1. The wholesale cost of water to municipal purveyors in Las Vegas Valley is the largest component and represents the total charge to water purveyors for purchase of water from the USBR, pumping from Lake Mead to the treatment plant located on the western shore of Lake Mead, treatment to drinking water standards, and pumping it into the valley for distribution to the municipal purveyors. Added to the wholesale cost are the costs for operation and maintenance, artificial recharge fees, and permit requirements that are based on an assumed 24,600,000 m^3 (20,000 acre-ft) per year of artificial recharge through existing facilities, for a total of $218/1,230 m^3 (1 acre-ft).

The Advisory Board to the GMP considered the purchase of 3,690,000 m^3/year (3,000 acre-ft/year) to recharge wherever existing facilities allowed, and these costs are listed in Table 1. This is water that will be dedicated to the aquifer system for an indefinite period of time. The Board also considered purchasing an additional 2,460,000 m^3/year (2,000 acre-ft/year) to be recharged specifically in the northwest area. This requires the construction of two new wells; therefore, this additional water would cost $283/1,230 m^3 (1 acre-ft) (amortized over 20 years at 6% interest), as listed in Table 2.

Annual pumpage in the valley is about 92,250,000 m^3/year (75,000 acre-ft/year); using this to allocate the unit price per user for 1,230 m^3 (1 acre-ft) of water equals about $9.00 per 1,230 m^3 (1 acre-ft) for the 3,690,000 m^3/year (3,000 acre-ft/year) and an additional $8.00 per 1,230 m^3 (1 acre-ft) for the 2,460,000 m^3/year (2,000 acre-ft/year). Thus, the unit price per user to recharge 6,150,000 m^3/year (5,000 acre-ft/year) is about $17.00 per 1,230 m^3 (1 acre-ft).

The number, type, and average depth of new wells constructed per decade are shown in Fig. 5. A continuation of this rate of well construction without additional artificial recharge will cause a continued decline in groundwater levels, resulting in greater cost to all pumpers. Artificial recharge will help offset this cost, but it takes time to raise water levels. Undoubtedly groundwater levels in the far northern parts of the area will continue to decline even if new recharge wells are constructed and artificial recharge begins.

The estimated annual costs for a well owner to operate a well "*with GMP*" and accompanying artificial recharge or "*without GMP*" and no artificial recharge are listed in Table 3. In both cases, construction costs for new wells are the same, but rehabilitation costs are much higher if groundwater levels continue to decline, as is likely in the northern part of the valley. The costs and benefits described herein are unevenly distributed because of either local site-specific conditions or primary concerns of the individual well owners. Because GMP members are assessed uniformly per 1,230 m^3 (1 acre-ft) of water rights, Tables 2 and 3 use "typical" costs and benefits rather than the specific problems of any individual well owner. Some wells may never fail or go dry depending on site characteristics, but some wells will fail in a few years due to a variety of reasons, even with artificial recharge.

The average life of a well is estimated at 20 years, which is a reasonable length of time, but certainly not absolute. Rehabilitation costs for the "with GMP" conditions are expected to be minimal. Minor repair costs, such as for pump wiring, discharge and distribution pipe, and storage tank, are estimated. The cost of bringing electricity to the wellhead (for nonmunicipal pumpers), which in some cases may be considerable, was not evaluated, because of widely varying site characteristics. Thus, the minimum benefit is estimated to be about $700 a year for the well owner to operate a well with the GMP. Because breaches are caused by a variety of problems, they cannot be eliminated by artificial recharge, although recharge will minimize the threat from subsidence. It is unknown how much damage is caused by subsidence alone, not only to wells, but to all other facilities and structures.

The number of wells deepened or replaced by decade is shown in Fig. 6. There has been a steady increase in the number of wells

Table 2. Cost of Expansion for Artificial Recharge to Stabilize Water Levels

Item	Cost[a] (dollars/1,230 m^3/year)
Wholesale water charge[b]	199
Operation and maintenance purveyor cost[c]	
Facilities and distribution	5
Wells	6
Artificial recharge annual permit fees[d]	3
Permit requirements for reporting[e]	5
New artificial recharge well construction[f]	65
Total	283

[a]Rounded to nearest dollar, 1,230 m^3 = 1 acre-ft.

[b]SNWA Municipal Water Purveyors (1993). Includes payment to USBR for water, payment for treatment and distribution to purveyor turnouts in the valley, and energy needed by LVVWD to deliver water from turnout to wellhead.

[c]Operation and maintenance of pump stations, distribution system, and wells for artificial recharge by LVVWD.

[d]State Water Resources Division ($2.00) and Department of Environmental Protection ($1.00).

[e]Data collection, interpretation, and reporting required by terms of permits.

[f]Based on two new wells, 30.5 cm (12 in.) diameter casing, 274.3 meters (900 ft) deep, annual capacity 2,460,000 m^3 (2,000 acre-ft), $750,000/well, includes equipping; amortized over 20 years at 6.0%, utilizing proposed or existing LVVWD facilities and associated easements cost.

Table 3. Domestic Well Owner's Costs to use Groundwater

	Cost[a] (Dollars/1,230 m^3/Year)	
Item	With GMP and artificial recharge	Without GMP and artificial recharge
Wells:		
New construction[b]	1,688–2,531	1,688–2,531
Rehabilitation[c]	40	775
Energy[d]	77–99	82–104
GMP fee	27	na
Total	1,832–2,697	2,545–3,410

[a]Rounded to nearest dollar, 1,230 m^3 = 1 acre-ft.

[b]Based on 20.3 cm (8 in.) diameter well 182.9 and 274.3 m (600 and 900 ft) deep, $27/0.305 m (1 ft), includes equipping and interest on 8.5% loan amortized over 20 years for 1,230 m^3(1 acre-foot)/year. Cost varies with driller.

[c]Based on deepening a well 300 ft as $20/0.305 m (1 ft) amortized over 20 years with 8.5% interest. Includes new pump as $2,200 [3.73 kW (5 hp), life 15 years], only applies to "without" conditions; annual minor repair costs of about $40/year (based on 7 years of record furnished by La Mancha Water Users Association); applies to both "with" and "without" conditions.

[d]Based on average pumping lifts of 61 and 122 m (200 ft and 400 ft), a pumping rate of 57 L/min (15 gal./min) with a 60% efficient pump, and a cost of $0.065/kW/h. (Nevada Power Company, personal communication, 1998). A 15.24 meter (50 ft) rise in water table results in a yearly savings of about $5.00.

deepened since the 1950 and the number of replaced wells has ranged from about 5 in the 1970s to nearly 20 in the 1990s, with a projected 15 in the current decade.

The economics of small public supply systems, commonly called quasimunicipal systems, such as the La Mancha Water Users Association, are similar to the domestic well costs in Table 3 but may be higher, because there are administrative fees that may add an additional $10–20 per residence per year (Leo Connolly, Quasi-Municipal Well Representative of GMP, personal communication, 1998). Private water companies like the Hillcrest Manor Water Users Association (Dirick Van Gorp, Private Water Company Representative of GMP, personal communication, 1998), which is larger than fifteen residences, generally have costs that are nearly comparable to costs in Table 3. Maintenance costs, however, are about half the cost shown in Table 3, but there is an additional administrative charge that includes mandatory water testing. In general, the total costs for public-supply and private water companies are slightly higher than those for domestic well owners shown in Table 3. Energy costs per well are a function of the pump efficiency, well hydraulics, and depth to water, which vary widely throughout the valley.

The costs for nonmunicipal well owners to connect to the LVVWD's facilities are listed in Table 4 and are similar for other purveyors. The costs begin with a formal/legal/proper well abandonment procedure, which is estimated to be $5,000. This cost does not include ripping the casing, which is required under state law, but may be waived by the State Engineer. This cost is listed in Table 4 as $4,000, because the LVVWD's Service Rules (adopted January 27, 1997, Sections 7.25, p. 40, and 8.22, p. 51) provide for a cash rebate of $1,000 as an incentive for residential well owners when they convert from a well to LVVWD's system and follow the State Engineer's legal abandonment procedures.

Other major costs for connection include water meters, the cost of which are dependent on size. Generally, the larger lots in the northwest part of the valley require a 2.54 cm (1 in.) meter as

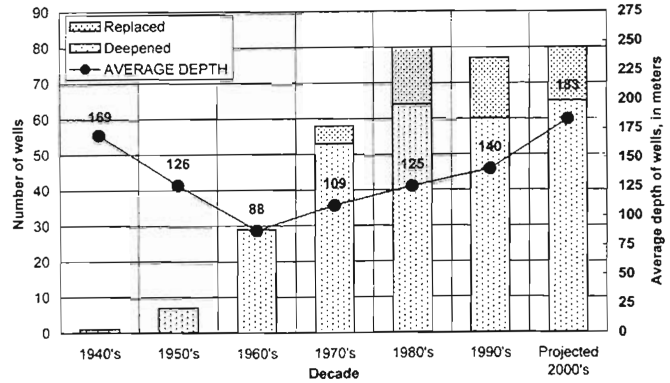

Fig. 6. Number and average depths of deepened and replaced wells by decade, in area of interest

opposed to a 1.905 cm (3/4 in.) meter, with both costs listed in Table 4. Additional costs are the SNWA regional connection fees, the LVVWD connection fees, and other associated charges. The costs of extending a residential main or connecting into an existing line are based on actual records compiled during 1996-1997. The cost of water per residential lot varies depending on the amount of irrigated landscape and individual conservation ethic. In Table 4, the amount is based on 1,230 m^3 (1 acre-ft) and taken from actual records of 0.405 ha (1 acre) lots, for the year 1997, which are typical for domestic well users.

It is assumed in this analysis that nonmunicipal pumpers will take out a 20-year loan to pay for all fees, excluding the water bill, at the prevailing interest rate. The interest rate fluctuates with time, but for this analysis is estimated to be about 8.5%. The total cost to finance the change over from a well to a municipal purveyor system, as listed in Table 4, ranges from $2,307/year to $3,166/year.

Finally, in comparing average costs between Tables 3 and 4, it is slightly more beneficial for a groundwater pumper to connect to a municipal purveyor system than to continue pumping groundwater if a low-interest loan is made available. The difficulty with average costs is that they are made up of extremes, both high and low, and there will be many cases where it would be cost prohibitive for a groundwater pumper to connect to a municipal purveyor's system. As a member of the GMP, low-interest loans may be available to assist in funding connection charges. Potential low interest loans have not been adopted by the GMP, but are represented in Table 4 as 6%.

Benefits of Artificial Recharge

Although benefits of artificial recharge accrue to all users of water in Las Vegas Valley, the focus here is on describing benefits to two types of water users: (1) nonmunicipal groundwater pumpers; and (2) municipal pumpers and ratepayers. The case of a groundwater pumper that does not join the GMP was not considered, because membership is mandatory.

Nonmunicipal Groundwater Pumpers Continuing to Pump Groundwater

Because artificial recharge will stabilize water levels in some areas (mostly in the northern areas), but in general raise them throughout the entire groundwater basin, the following will result:

1. Energy savings: Raising the water level 15.24 m (50 ft) (a base rise for cost estimates) represents a minimal savings in pumping costs of about $5/year/1,230 m^3 (1 acre-ft) for all

Table 4. Domestic Well Owner's Costs to Connect to Las Vegas Valley Water District Facilities

Item	Total costs (dollars)	Cost[a] (Dollars/1,230 m^3/Year)	
		Principal and interest at 8.5% for 20 years	Principal and interest at 6.0% for 20 years
Well plugging[b]	4,000	8.331	6,878
Connection to public-supply purveyor meter[c]	5,000–10,200	10,414–21,244	8.597–17,538
Residential main extension/connection	8,724–10,032[f]	18,170–20,894	15,000–17,249
Subtotals	17,724–24,232	36,915–50,469	30,475–41,665
Cost per year for 20 years	n/a	1,846–2,523	1,524–2,083
Water bill for one year[d]	461–643	461–643	461–643
Total cost/year including water bill			
Total cost/year including water bill	—	2,307–3,166	1,985–2,726

[a]Rounded to nearest dollar, 1,230 m^3 = 1 acre-ft.

[b]Average cost is about $ 4,000; includes rebate of $1,000.

[c]Total costs for a service connection includes all connection fees and other associated charges as defined in LVVWD Service Rules (1997), excluding frontage and main extension fees and are dependent on water meter size as follows. A 2.54 cm (1 in.) meter required for large lots characteristic of northwest area costs $10,200; if a 1.905 cm ($\frac{3}{4}$ in.) meter is used for a smaller lot size, the cost is $5,000.

[d]Based on actual records for 1997, adjusted for 1,230 m^3 (1 acre-ft), average is $526. Rate is minimally driven by meter size; $56 for a 1.905 cm ($\frac{3}{4}$ in.) and $70 for a 2.54 cm (1 in.). Rate not increased for inflation.

[d]Average costs to connect to existing facilities (residential main in place) for last two years is $8,724 (maximum is $16,132, minimum is $4,833). No costs estimated to connect residence to water meter.

[f]Average cost to extend Residential Main for last two years is $10,032 (maximum is $15,029, minimum is $6,700).

pumpers. In some areas, the water-level rise will be greater and the corresponding energy savings greater, whereas in other areas the rise will be less with correspondingly less energy savings.

2. Maintenance savings: Even with artificial recharge, there is no assurance that rehabilitation (i.e., deepening in this case) and replacement wells will not be needed. If they are needed, it is likely at a reduced frequency under the condition of a rising or stable water table. It is estimated that, with the GMP, there will be on the average about 10 well failures a year requiring deepening or replacement. This rate of well failure assumes that pumpers in mostly fine-grained sediments in the northwest part of the valley, where the frequency of failure is greater than other parts of the valley, will connect to a municipal purveyor's system.

The costs defined in Table 3 show estimated savings of about $700 per year for well owners receiving benefits from the GMP and artificial recharge, as compared to not having this program. This illustrates specifically how an average individual groundwater pumper benefits from the GMP. The benefits vary by geographic area and are greatest for groundwater users in the northern and western parts of the valley because of the fine-grained nature of the aquifer sediments.

3. Connection costs: A member of the GMP can probably expect financial assistance in the form of low-interest loans in meeting these costs or, alternatively, may be eligible for a State grant. The benefits in this case are not a result of artificial recharge, but of membership in the GMP.

The savings from energy and maintenance are listed in Table 3. Table 4 defines and annualizes the connection costs and assumes a specific level of financial assistance. Table 5 summarizes the relative benefits of artificial recharge to an individual groundwater pumper and the relative costs to the GMP.

Benefits to Municipal Purveyors and Ratepayers

There are indirect benefits from artificial recharge to the valley, although these benefits were not quantified for this analysis. The first benefit is efficiency in the existing distribution system because of the stability of the water level surface, which allows efficient use of well facilities. The western side of the valley is both much higher and farther from the surface source at Lake Mead than the east side. Thus, during the summer, residents in the lower pressure zones of the distribution system are served with surface water, but residents in the far west and northwest (i.e., higher-pressure zones), where most of the municipal wells are, receive some groundwater from the distribution system. During the winter, when there is less water use than in the summer, there is more capacity in the distribution system and the higher-pressure zones are served solely with surface water. Thus, water from artificial recharge increases the viability of not only the groundwater system, but also the total water resource. Recharging into the groundwater bank provides an additional supply, which in turn guarantees that surface water will be available to the rest of the valley during the summer peak season.

The second major benefit is the savings in capital cost resulting from not constructing the water-supply infrastructure needed to supply surface water in place of recharged water that will be used to ultimately meet the summer demand. This infrastructure consists mostly of additional capacity in the distribution system and a reservoir storage system that currently (2000) would have to impound over 246,000,000 m^3 (200,000 acre-ft), the amount of water recharged and in storage in the aquifer system that may not be used for several years.

Third, there is also a minor energy cost savings in conveying water during the winter for artificial recharge, rather than in the summer. This in itself is not sufficiently large to make an artificial recharge program viable. Thus, while the pumping costs to recover the water are much greater than the energy savings, they are in turn dwarfed by the cost to increase the summer capacity, which would otherwise be created by significant additional capital expenditures.

Fourth, there are unquantified benefits resulting from a slowing or cessation of land subsidence. Subsidence has been docu-

Table 5. Qualitative Summary of Benefits and Costs of Ground Management Program (GMP) Participation in Artificial Recharge

Benefits to individual GMP members	Costs to GMP
• Reduced energy costs to pump groundwater from higher water levels	• Wholesale water costs of artificial recharge through existing wells
• Deferment of well rehabilitation costs	• Operation and maintenance costs of existing wells
• Deferment of well replacement costs	• Operation and maintenance costs of new wells for specific areas of concern
• Deferment of well abandonment costs	• Capital costs of new wells and pipelines
• Reduced operation and maintenance cost (partly energy and partly deferred costs)	• Administrative costs
• Reduction of subsidence hazard to wells	
• Financial assistance in the event of well failure	

mented in the past as causing damage to structures, roads, and utilities; however, data are not available to estimate the cost.

Finally, if the water was not stored, it would be lost forever from Nevada's ownership. Water stored at today's prices will be much more valuable in the future. In Las Vegas Valley, the market price of permanent groundwater rights (i.e., water that can be used each year in perpetuity) has more than doubled in the last ten years and is currently approximately \$10,000 per 1,230 m^3 (1 acre-ft) (Greg Febbo, SNWA Research Analyst, personal communication, 2000). The value of the stored water may be offset somewhat by the fact that some percentage of water will likely be dedicated to the basin's groundwater system forever. Directly related to this, however, is the benefit of having a significant amount of water in storage in the event of a long-term drought in the Colorado River drainage, or even to meet a short-term emergency if the surface-water treatment facility was temporally inoperable.

Conclusions

Artificial groundwater recharge is an excellent water-resources management tool and provides numerous direct and indirect benefits not only to all groundwater pumpers, but to all water users in Las Vegas Valley. This analysis indicates that the benefits of artificial recharge are greater than the costs and there is a net savings of about \$700 per year over a 20-year period for nonmunicipal members of the GMP that continue to use groundwater. A rising or stable water table will be a benefit to all pumpers from an energy perspective, and the cost of deepening wells, due to declining water levels, will no longer be as much of concern. Also, the threat of subsidence, which carries an unknown cost, will be greatly reduced. The costs of these benefits to a GMP member are estimated to be about \$27 per 1,230 m^3 (1 acre-ft) of water pumped per year. This fee can also be thought of as insurance to help defray certain potential costs and to maintain a viable groundwater system. Benefits slightly exceed costs for those groundwater pumpers who abandon their wells in favor of a municipal purveyor's facilities, particularly if low-interest loans are made available to cover all costs associated with connection charges.

Epilogue

The Advisory Board of the GMP accepted this analysis in the fall of 1998 and the Board forwarded it to the 1999 Nevada Legislature. The Legislature passed Assembly Bill 347, which was subsequently signed into law. This Bill increased the existing flat fee from \$10.00 per 1,230 m^3 (1 acre-ft) to \$30.00 per 1,230 m^3 (1 acre-ft) and specified the money was to be used by SNWA to provide certain services and functions such as total funding for well abandonment and assistance in funding up to 85% of the cost to connect to a public supply water purveyor. Additionally the fee is to be used for education, conservation, administration, and groundwater recharge. The \$30.00 per 1,230 m^3 (1 acre-ft) is composed of \$17.00 for artificial recharge; a minimum of \$3.00 for assistance in funding connections; and the balance to support technical activities, conservation education, well abandonment, and program administration. The legislative changes in the GMP charter are additional economic incentives for participation.

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