# Fueling Population Growth in Las Vegas: How Large-scale Groundwater Withdrawal Could Burn Regional Biodiversity

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*Explosive growth in Las Vegas, Nevada, has stimulated demand for additional water supplies. To meet these needs, local officials hope to obtain rights to about 200,000 acre-feet (246.70 million cubic meters [$m^3$]) per year from a regional groundwater aquifer extending from Salt Lake City, Utah, to Death Valley, California. Officials from satellite communities are pursuing rights to an additional 870,487 acre-feet (1.07 billion $m^3$) per year. If granted, these new permits would trigger declines in groundwater across at least 78 basins covering nearly 130,000 square kilometers. Water-rights decisions have historically interpreted economic development as a more compelling public interest than maintenance of natural systems. If economic development continues to drive allocation decisions, consequent declines in the water table, spring discharge, wetland area, and streamflow will adversely affect 20 federally listed species, 137 other water-dependent endemic species, and thousands of rural domestic and agricultural water users in the region. Reducing consumption and implementing cost-effective technologies, such as recovery of urban runoff and shallow saline groundwater, indirect reuse of potable water, and desalinization, offer ways to meet metropolitan and ecological needs within the limits of the resource.*

*Keywords: groundwater, water rights, public trust, endangered species, ecological integrity*

**Some of the most rapid population growth in the** United States is occurring in intermountain western and southwestern urban areas, where water is in short supply and aquatic ecosystems are stressed (Naiman and Turner 2000, Fitzhugh and Richter 2004). As a result, municipal water consumption is on the rise, and water from rural areas is being shifted toward municipal uses. Competition for water is felt keenly in southern Nevada, where water is scarce, human population growth is explosive, and conflicts over biodiversity and the human need for water have a long and litigious history.

With an annual growth rate of 5.5 percent and a population exceeding 1.8 million, Las Vegas, Nevada, is among the fastest-growing metropolitan areas in the nation. After use of local groundwater produced up to 2 meters (m) of land subsidence and a 91-m decline in the water table in parts of the metropolitan area (Burbey 1995), the community became dependent primarily on the now drought-stricken Colorado River as its major source of fresh water. Water demand has reached the limits of the current supply, exacerbated by daily per capita consumption that ranks among the nation's highest (both in terms of single-family consumption, at 660 liters [L] per person per day, and of total systemwide consumption, at 971 L per person per day; Western Resource Advocates 2006).

The Southern Nevada Water Authority (SNWA) is pursuing a multipronged approach to meet the growing municipal water demand (SNWA 2005). As a stopgap measure, in 2004 the SNWA purchased 1.25 million acre-feet (1.54 billion $m^3$) of Colorado River water from Arizona to be delivered over the next 15 years. The SNWA has advocated vigorously for new operating rules, currently under review by the secretary of the Department of the Interior, to be used during severe drought conditions on the Colorado River. The SNWA also plans to

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tap a regional deep carbonate aquifer extending across central and southern Nevada from Utah to California (SNWA 2004), a tactic simultaneously being pursued by other Nevada counties (e.g., Lincoln, Nye, and White Pine).

Great Basin spring systems, although small and isolated, harbor a large proportion of the region's biodiversity and have received significant conservation attention (Deacon and Minckley 1991, Sada and Vinyard 2002). Twenty species and subspecies listed under the federal Endangered Species Act (ESA) depend on springs, spring-fed wetlands, and streams in the 78-basin area most likely to be affected by the proposed SNWA groundwater withdrawals (table 1). Many listed taxa are "umbrella species" that provide protection to little-known, nonlisted sympatric species, including at least 137 spring-dependent animal taxa—primarily locally endemic aquatic springsnails, insects, and fishes. The Nevada Natural Heritage Program (2005) identifies 347 sensitive taxa within the area.

Our purpose here is to critically examine the SNWA proposals for large-scale groundwater withdrawal, evaluate their potential impacts on aquatic biodiversity, and evaluate whether Nevada water law can avoid decisions that are detrimental to the public interest. The literature demonstrates that deep carbonate and shallow basin-fill aquifers are interconnected across the various basins likely to be affected by groundwater withdrawal, and that the approval of the SNWA applications for water rights is likely to reduce or eliminate many spring and wetland communities in the region, with consequent adverse impacts on the rich diversity of spring- and wetland-dependent endemic species. We contend that large-scale groundwater withdrawal in Nevada, the most arid state in the United States, poses a major underappreciated threat to biodiversity.

***Table 1. Native spring-dwelling and riparian species known from the area of projected groundwater decline in Lincoln, Clark, White Pine, Nye, and eastern Esmeralda counties, Nevada; eastern portions of Inyo and San Bernardino counties, California; western portions of Washington, Iron, Beaver, Millard, and Juab counties, Utah; and northwestern Mohave County, Arizona.***

| Taxon | Endangered species/ subspecies | Threatened species/ subspecies | Other species/ subspecies |
|---|---|---|---|
| Mammals | 1 | 0 | 2 |
| Birds | 2 | 0 | 1 |
| Fishes | 11 | 2 | 31 |
| Amphibians | 0 | 0 | 4 |
| Aquatic insects | 0 | 1 | 50 |
| Springsnails | 0 | 0 | 49 |
| Plants | 1 | 2 | NA |
| Total | 15 | 5 | 137 |

NA, not available.

*Note:* Species and subspecies listed as endangered or threatened include the following: mammals, *Microtus californicus scirpensis;* birds, *Empidonax trailii extrimus* and *Rallus longirostris yumanensis;* fishes, *Plagopterus argentissimus, Gila seminuda, Rhinichthys osculus nevadensis, Moapa coriacea, Empetrichthys latos, Cyprinodon nevadensis mionectes, C. nevadensis pectoralis, Cyprinodon diabolis, Lepidomeda mollispinis pratensis, Lepidomeda albivallis, Crenichthys baileyi grandis, Cr. baileyi baileyi,* and *Crenichthys nevadae;* insects, *Ambrysus amargosus;* plants, *Centarium namophilum, Ivesia kingii* var. *eremica,* and *Nitrophila mohavensis.* A complete species listing is available from the authors.

## The groundwater flow system

Carbonate rocks, deposited in a shallow sea during the Paleozoic, underlie a 259,000-square-kilometer (km$^2$) carbonate-rock province in the eastern two-thirds of the Great Basin (Fiero 1986). During the late Mesozoic, compression, uplift, and low-angle thrust faulting deformed this carbonate layer. East–west extension in the mid-Tertiary thinned the carbonate section, caused block faulting, and gave rise to the north–south orientation of mountain ranges characteristic of the basin and range. Later, predominantly northeast–southwest-oriented fractures and joints formed throughout the brittle limestone and dolomite deposits (Winograd and Thordarson 1975).

Although much of the original 12-km-thick carbonate layer in Nevada has become deformed, dismembered, and thinned, there remains a 110- to 160-km-wide central corridor of contiguous carbonate rocks, typified by an extensive interconnected subterranean fracture network extending 1 to 1.5 km or more below land surface. This corridor integrates a regional-scale drainage network extending from near the Utah–Nevada border through southern Nevada's Spring Mountains and into California, and is capable of transporting large volumes of water (Riggs et al. 1994).

Groundwater typically flows from high-elevation montane recharge areas to discharge areas in basin-fill sediments of valley lowlands. Flow occurs at various scales, resulting in the superimposition of numerous relatively shallow, localized basin-fill aquifers on the regionally integrated deep carbonate aquifer. Because of the fractured nature of the underlying carbonate rocks, water carried in the deep aquifer may originate from all elevations throughout the central corridor. Regardless, shallow aquifers discharge primarily by means of evapotranspiration and through local springs, whereas deep aquifers discharge mostly at regional warm springs (Prudic et al. 1995).

Regional springs in the 78 basins we examined are the primary natural discharge points from eight major groundwater flow systems (figure 1). Springs from Preston Big Spring southward to Ash Spring are supplied principally from montane recharge areas in east-central Nevada at the top of the regional drainage net. Muddy River springs are supplied principally from the north through the central corridor, but also may receive some recharge from nearby Sheep Mountains. Ash Meadows springs are supplied predominantly from recharge areas on the northern and northeastern slopes of the nearby Spring Mountains but, along with springs on the eastern side of Death Valley, are partially dependent on regional groundwater movement from the north-northeast through the central corridor (Dettinger et al. 1995). Las Vegas Valley and Pahrump Valley receive most of their groundwater from recharge in southern Nevada's Spring Mountains.

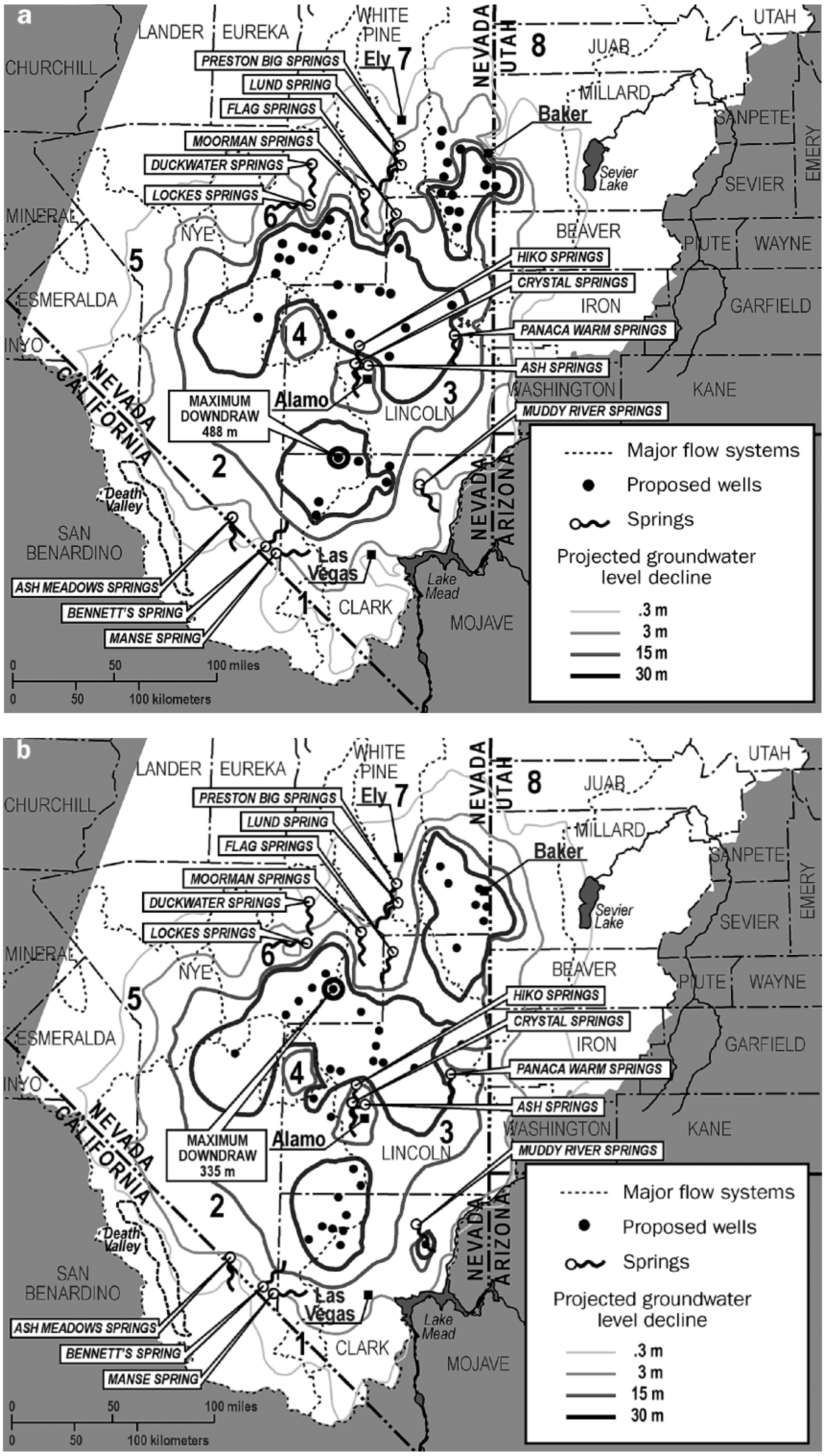



*Figure 1. Simulated final steady-state groundwater level in (a) valley-fill and (b) deep carbonate aquifers in eight major flow systems of Nevada, Utah, and California, projected to occur as a consequence of pumping 180,800 acre-feet (223.01 million cubic meters) per year of water from specific well locations in specific quantities as proposed by the Southern Nevada Water Authority (SNWA). This simulation assumes no groundwater removal other than the 180,800 acre-feet (223.01 million cubic meters) per year projected to be pumped by the SNWA from 17 basins of east-central and southern Nevada. The eight major groundwater flow systems affected are numbered as follows: 1, Mesquite Valley; 2, Death Valley Flow System; 3, Colorado Flow System; 4, Penoyer Valley; 5, South-central Marshes Flow System; 6, Railroad Valley Flow System; 7, Goshute Valley Flow System; and 8, Great Salt Lake Desert Flow System. Modified from Schaefer and Harrill (1995) and Harrill and Prudic (1998).*

The estimated annual groundwater recharge to the eight flow systems is about 900,000 acre-feet (1.11 billion $m^3$) per year (Harrill and Prudic 1998), with about 80 percent of that recharge attributable to the 78 basins we examined (table 2). Subsurface movement of water from one flow system to another supplements groundwater recharge from local sources. For example, approximately 21,000 acre-feet (25.90 million $m^3$) of water per year, principally from the White River flow system (a northern subdivision of the Colorado River flow system), supplements groundwater in the Death Valley flow system (Dettinger 1989). Because there is equilibrium between aquifer recharge and natural discharge, wells continuously extracting any part of the annual recharge virtually guarantee equivalent reductions in natural discharge (Dettinger et al. 1995).

## Spring systems and groundwater withdrawal

The large number of endemic species occurring at regional springs in the carbonate-rock province is due in no small part to the reliability, consistency, and predictability of these wetland and aquatic habitats over millions of years. The springs in Ash Meadows, for example, have been major discharge points from the deep aquifer for the past two million to three million years, although three million years ago those springs were more widespread and discharge was greater than at present (Hay et al. 1986).

Climatic variation produced changes in groundwater levels in Ash Meadows over the past 116,000 years, including a 9-m decline in groundwater in the last 15,000 years as Pleistocene lakes disappeared (Szabo et al. 1994). Over the past century, the water table in the adjacent Pahrump and Las Vegas valleys has experienced an extreme drop attributable to groundwater pumping that dwarfs this climatically induced decline.

Development in Las Vegas Valley began in the early 1900s. Groundwater pumping led directly to the failure of major valley springs in about 1957 (Harrill 1976), causing extinction of the endemic Las Vegas dace (*Rhinichthys deaconi;* Miller 1984). Development in Pahrump Valley to the west of Las Vegas proceeded more slowly. Nonethe-

*Table 2. Water rights currently allocated and applied for, expressed in acre-feet (and cubic meters) and as a percentage of perennial yield, in 78 basins likely to be affected by proposed large-scale groundwater pumping.*

| Flow system | Area in km$^2$ | Basins with groundwater declines | Perennial yield in acre-feet (m$^3$) | Current rights in acre-feet (m$^3$) | Current rights, as percentage of perennial yield | Current rights plus rights applied for, in acre-feet (m$^3$) | Current rights plus rights applied for, as percentage of perennial yield |
|---|---|---|---|---|---|---|---|
| South-central Marshes | 17,586 | 4 | 31,000 (38,237,937) | 41,516 (51,209,232) | 134 | 44,076 (54,366,946) | 142 |
| Death Valley | 40,922 | 24 | 86,610 (106,831,862) | 112,590 (138,877,720) | 130 | 128,619 (158,649,200) | 149 |
| Railroad Valley | 10,697 | 4 | 91,500 (112,863,588) | 30,792 (37,981,373) | 34 | 242,407 (299,004,632) | 265 |
| Penoyer Valley | 1813 | 1 | 4000 (4,933,927) | 14,461 (17,837,381) | 362 | 17,662 (21,785,756) | 442 |
| Colorado | 42,217 | 35 | 248,800 (306,890,281) | 312,916 (385,976,203) | 126 | 911,964 (1,124,891,030) | 367 |
| Goshute Valley | 9428 | 1 | 70,000 (86,343,729) | 95,928 (118,325,446) | 137 | 119,349 (147,214,824) | 170 |
| Mesquite Valley | 611 | 1 | 2200 (2,713,660) | 1099 (1,355,597) | 50 | 4407 (5,435,954) | 200 |
| Great Salt Lake Desert | 46,620 | 8 | 185,500 (228,810,881) | 125,700 (155,048,667) | 68 | 480,489 (592,674,455) | 259 |
| Total | 169,894 | 78 | 719,610 (887,625,865) | 735,003 (906,612,851) | 102 | 1,948,973 (2,404,022,800) | 271 |

*Note:* Groundwater level decline is projected by Schaefer and Harrill (1995) only for parts of the South-central Marshes, Goshute Valley, and Great Salt Lake Desert flow systems, but is anticipated throughout all basins in the other five flow systems. Columns may not sum to totals because of rounding.

*Source:* Nevada Division of Water Resources Water Rights Database (20 February 2006; *http://water.nv.gov/Water%20Rights/permitdb/permitdb_index.cfm*); data for Snake and Hamlin valleys obtained from Utah Division of Water Rights, August 2005.

less, Raycraft Spring failed in 1957. Bennett's Spring dried in 1958, and Manse Spring followed in 1975 (Soltz and Naiman 1978, Harrill 1986), extirpating the endemic Pahrump poolfish (*Empetrichthys latos*) throughout its historic range (Deacon 1979) and eliminating a local population of the Spring Mountains pyrg (*Pyrgulopsis deaconi;* Hershler 1998). Groundwater declines of up to 30 m occurred by 1975 in Pahrump Valley (Harrill 1986), and declines of up to 91 m occurred by 1990 in Las Vegas Valley (Burbey 1995).

In Ash Meadows, after major groundwater development (initiated in the late 1960s) reduced both spring discharge and the water table (Dudley and Larson 1976), it was curtailed in 1977 and stopped by 1982 (Dettinger et al. 1995). Spring discharge recovered (e.g., Fairbanks Spring; figure 2), and the groundwater table rose steadily through 1987, but a slow decline began in 1988 and continues to the present (Riggs and Deacon 2004). An analysis by Bedinger and Harrill (2006) indicates that the decline is unrelated to climatic variation, and instead is due to groundwater withdrawal for irrigation at the Amargosa farms area about 25 to 30 km northeast of Devils Hole. Though some springs throughout the carbonate province tend to demonstrate

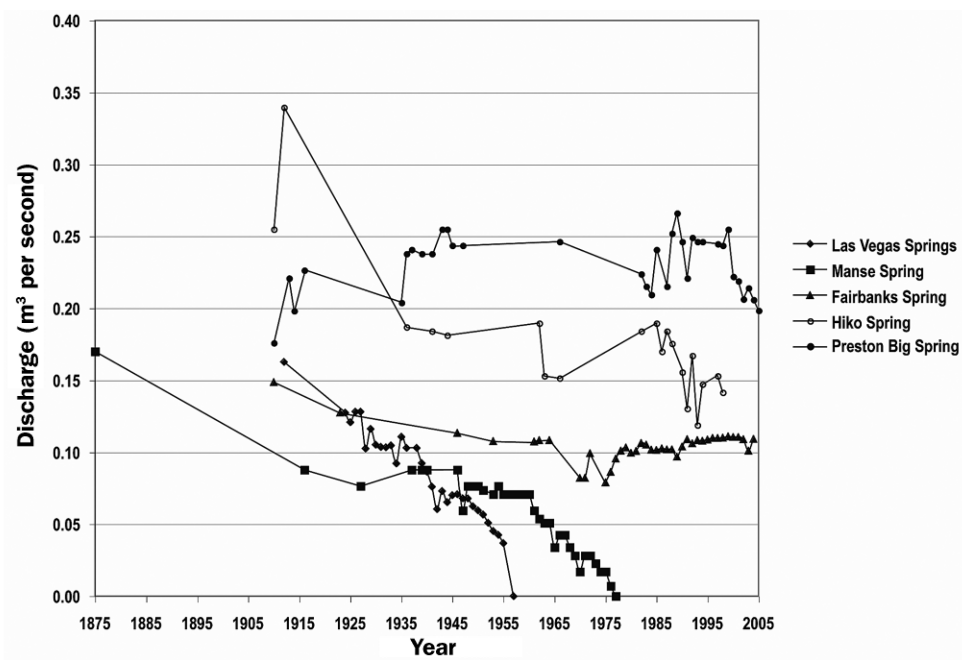



*Figure 2. Annual mean discharge (cubic meters per second) from five representative springs in Nevada from 1875 to 2005. Data provided by Jon Wilson, US Geological Survey, Las Vegas, Nevada.*

stable flow, in many valleys there is evidence of decline (figure 2).

As of February 2006, existing groundwater permits authorized withdrawal of 735,003 acre-feet (906.61 million $m^3$) per year from the 78 basins we examined (table 2). This included 156,908 acre-feet (193.54 million $m^3$) per year for municipal uses in the urban areas of Las Vegas and Pahrump and about 578,095 acre-feet (713.07 million $m^3$) per year supporting the present agricultural and rural livelihoods of the area's residents.

These existing permits appropriate 102 percent of the 78-basin area's cumulative perennial yield, slightly more water than the state engineer has determined is available each year over the long term. However, permitted withdrawals are not spaced evenly across the landscape, but range from 0 to 1660 percent of the perennial yields estimated for individual basins. For example, valid groundwater rights now exist for 376 percent of perennial yield in Las Vegas Valley, 331 percent in Pahrump Valley, and 113 percent in the seven basins (combined in the state engineer's records) that include Ash Meadows. Existing rights exceed 100 percent of perennial yield in five of the eight major flow systems underlying the 78-basin area.

## Looming threats

The Las Vegas Valley Water District (now the SNWA) filed 147 applications in 1989 for rights to unappropriated groundwater from 26 of the 78 basins overlying the region's major groundwater flow systems. Since they were originally submitted, some applications have been withdrawn and others modified to accommodate rural interests (SNWA 2004). At present, the SNWA hopes to obtain rights to 180,800 of the 330,000 acre-feet (223.01 million of the 407.05 million $m^3$) per year of groundwater for which they have applied. Wells to supply the water are to be drilled into shallow valley-fill aquifers as well as the deep carbonate aquifer of central, eastern, and southern Nevada. The first phase is planned to begin supplying water to Las Vegas as early as 2007, with additional wells and associated pipelines proposed over the coming 50 years (SNWA 2004).

The SNWA estimates that by 2050, it will need to add 375,000 to 475,000 acre-feet (462.56 million to 585.90 million $m^3$) per year to the 471,786 acre-feet (581.94 million $m^3$) per year now supplied predominantly from the Colorado River (SNWA 2005). Negotiations with other Colorado River basin states reached an agreement in principle on 3 February 2006 that the SNWA would not exercise its right to about 120,000 acre-feet (148.02 million $m^3$) per year of surface water from the Virgin and Muddy rivers so long as efforts by all basin states to augment flows of the Colorado River provide Nevada with the equivalent of 75,000 acre-feet (92.51 million $m^3$) per year (Jenkins 2006). The agreement also permits Nevada and other basin states to claim "augmentation credit" for water added to the river from other sources. If this augmentation credit is included in the final Colorado River drought condition operations rule, the SNWA can claim a credit for any Nevada groundwater that passes through the Las Vegas sewage system, including any water resulting from the new permits for which it has applied. This results in a 70 percent bonus and constitutes a substantial additional incentive to develop the proposed groundwater project.

Groundwater to be removed from regional aquifers by the SNWA does not represent the total anticipated new demand on those aquifers. Stimulated by Las Vegas's growth, satellite communities within a few hours' drive of Las Vegas (e.g., Coyote Springs, Mesquite, Pahrump, Sandy Valley, Prim, and Lincoln County communities) are being planned or are expanding rapidly. As of 20 February 2006, those satellite communities were responsible for most of the pending applications for an additional 870,500 acre-feet (1.07 billion $m^3$) per year of groundwater from the 78 basins.

## Probable future effects of groundwater development

Following the 1989 applications by the Las Vegas Valley Water District for rights to all unappropriated groundwater in much of eastern, central, and southern Nevada, considerable effort was directed toward evaluating the probable impacts of removing a total of 180,800 acre-feet (223.01 million $m^3$) of groundwater annually from the locations, and in quantities desired by the SNWA. Schaefer and Harrill (1995) produced a conceptual model of the effects on the regional groundwater table, based on the assumption that the project now administered by the SNWA was the only source of groundwater removal throughout the region. Their work suggested that effects would be evident throughout the 78 basins examined here. Schaefer and Harrill's work was evaluated and compared with the SNWA's ongoing modeling efforts by Principia Mathematica (1997), which developed its own numerical model. Several groundwater models have been developed for specific basins within the area of probable impact (Durban 2006, Elliott et al. 2006, Myers 2006), most recently focusing on Spring Valley, from which the SNWA hopes to extract about half of the 180,800 acre-feet (223.01 million $m^3$) per year it seeks.

Except for the SNWA model, all research models produced results consistent with those of Schaefer and Harrill (1995), which projected groundwater level declines of about 0.3 to 488 m throughout 78 basins extending from Sevier Lake, Utah, to Death Valley, California. They suggested that a new steady state might be reached in 100 to 200 years, with groundwater level declines of 15 to 152 m predominating in both shallow and deep aquifers. Evapotranspiration throughout the region would decline as water tables dropped below the level of phreatophytic root penetration. Over the first 100 years, regional springs fed by the carbonate aquifer would lose about 2 to 14 percent of their flow. They would continue to decline over the next 100 years, and might not stabilize before failing. The divergence of these conclusions from those of the SNWA is due largely to the fact that SNWA modelers tended to estimate higher levels of precipitation-induced recharge and evapotranspiration-induced discharge than other modelers. This tendency is particularly evident when comparing the model submitted by the SNWA in support of the application for water rights in Spring Valley (Durban 2006) with the models submitted by the Western Environmental Law Center (Elliott et al. 2006, Myers 2006) in support of the center's protest against those applications.

## Development dreams

While the location, depth, and quantity of withdrawal strongly influence the response in the aquifer, even the addition of only the incremental amount sought by the SNWA to the amount withdrawn under existing rights will produce greater evapotranspiration, spring discharge, and reductions in the groundwater table than those simulated by Schaefer and Harrill (1995). Within the 78 basins examined herein, total water demand would be increased to 127 percent of perennial yield by adding only the 180,800 acre-feet (223.01 million $m^3$) per year sought by the SNWA. Addition of the 870,487 acre-feet (1.07 billion $m^3$) per year sought by satellite communities would push demand to about 1.8 million acre-feet per year (2.2 billion $m^3$), or 250 percent of the region's estimated perennial yield. Approval of all applications pending as of February 2006 would put aquifer demand at 271 percent of perennial yield, although the state engineer, in accordance with decisions based on state law, is likely to authorize permits for less water than has been requested.

In Lincoln County, applications for groundwater rights by Vidler Water Company tend to locate points of withdrawal closer to regional discharge areas than do applications by the SNWA. Consequently, groundwater pumping by Vidler most likely will affect regional spring discharge more quickly than will SNWA's pumping, the impacts of which probably will manifest only decades later. Regional springs most likely to be influenced first by Vidler and later by SNWA wells include the Muddy River Springs and the large warm springs in Panaca Valley (Panaca Warm Springs), Pahranagat Valley (Ash, Crystal, and Hiko springs), and White River Valley (Preston Big, Lund, Moorman, and Flag springs).

In Nye County, proposed SNWA wells are likely to affect regional spring discharge in Railroad Valley (Duckwater, Lockes, and other springs) and Ash Meadows. Though the response will be long delayed by distance from the wellhead, regional springs in Ash Meadows are most likely to be adversely influenced by SNWA wells proposed for Indian Springs, Three Lakes, and Tikaboo valleys in the northeastern portion of the Ash Meadows flow system (Riggs and Deacon 2004). Even before a substantial reduction in spring discharge occurs in Ash Meadows, the first impact on existing water rights may be a lowering of the water level at Devils Hole, the one place in the entire carbonate-rock province where a surface-water right is objectively tied to groundwater level. In fact, there is mounting evidence to suggest that groundwater pumping from the regional aquifer already is producing a decline in the water level at Devils Hole (Bedinger and Harrill 2006).

## State water management

The state engineer manages groundwater and surface waters under Nevada laws, which recognize connections between the two. Conflicts between users, whether of surface water or groundwater, are resolved according to prior appropriation principles. Thus, senior water rights, both surface and groundwater, limit junior water rights—a limitation that would constrain the groundwater withdrawal plans discussed above.

In evaluating the potential impacts of proposed groundwater permits on existing rights, the state engineer must make a determination of water availability based on the aquifer's perennial yield (similar to, but distinct from, sustainable yield). Permits beyond the perennial yield of the target aquifer may not be issued.

The Nevada Division of Water Resources' (1992) definition of perennial yield (i.e., "the amount of usable water from a ground-water aquifer that can be economically withdrawn and consumed each year for an indefinite period of time...[so long as it does] not exceed the natural recharge to that aquifer and ultimately is limited to maximum amount of discharge that can be utilized for beneficial use") can be a substantial barrier to conservation efforts. Although this definition conceptually prohibits the mining of groundwater, it offers little or no protection for surface water and thus is not a standard amenable to the maintenance of wetlands, springs, stream flows, or biodiversity. It also fails to maintain the groundwater table or subsurface interbasin flows. Furthermore, the technical accuracy of perennial yield estimates for some local and regional aquifers has been questioned (SNWA 2003).

Malmberg's (1967) estimate of perennial yield for Pahrump Valley provides an excellent example of the methods and assumptions commonly used. The maximum "salvageable discharge" available for appropriation included (a) all net spring discharge, (b) estimates of evapotranspiration from areas of shallow groundwater, (c) estimates of water salvageable from the amount that leaves the shallow aquifer as subsurface outflow from the basin, and (d) estimates of water salvageable from the amount that leaves the basin as subsurface outflow in the deep aquifer.

This method of determining perennial yield anticipates that permits issued will dry all springs and kill all phreatophytes, with attendant losses in biodiversity. It anticipates lowering of the groundwater table, a consequent increase in pumping costs, and the likelihood of land subsidence. It foresees reductions in both shallow and deep interbasin subsurface flows that supply down-gradient basins and their springs, thereby establishing a drain on shallow aquifers in surrounding valleys and in the regional deep carbonate aquifer (figure 3). These predictable consequences result directly from the issuance of permits equivalent to 100 percent of perennial yield. Unfortunately, despite the clear requirements of the law, permits commonly are issued for many times that amount.

Clearly, several factors confound attempts to unambiguously quantify the extent of expected detrimental impacts. Predicting the final steady state of the groundwater system in response to massive groundwater removal is complicated by disagreement over recharge from precipitation, discharge from evapotranspiration, connectivity among aquifer components, and the time required to reach a new equilibrium. There is no question, however, that the state's definition of, and methodology for determining, the quantity of water that legally may be withdrawn fails to envision the maintenance of natural systems. As a result, it is nearly impossible for the state engineer to issue groundwater permits in support of urban development while protecting existing water rights, including those concerning recreational resources and biodiversity.

## How might protection be achieved?

In the 1976 US Supreme Court case *Cappaert v. United States* (426 U.S. 128), the court ruled that Devils Hole had an implied reservation of water, noting that a 1952 presidential proclamation (Proclamation no. 2961, 3 CFR 147 [1949–1953 comp.]) made Devils Hole a disjunct part of Death Valley National Monument (now Death Valley National Park; Deacon and Williams 1991). The court stated that "when the Federal Government withdraws its land from the public domain and reserves it for a federal purpose, the Government, by implication, reserves appurtenant water then unappropriated to the extent needed to accomplish the purpose of the reservation." The presidential proclamation specified that the withdrawal of Devils Hole from the public domain was intended to protect the "unusual features of scenic, scientific, and educa-

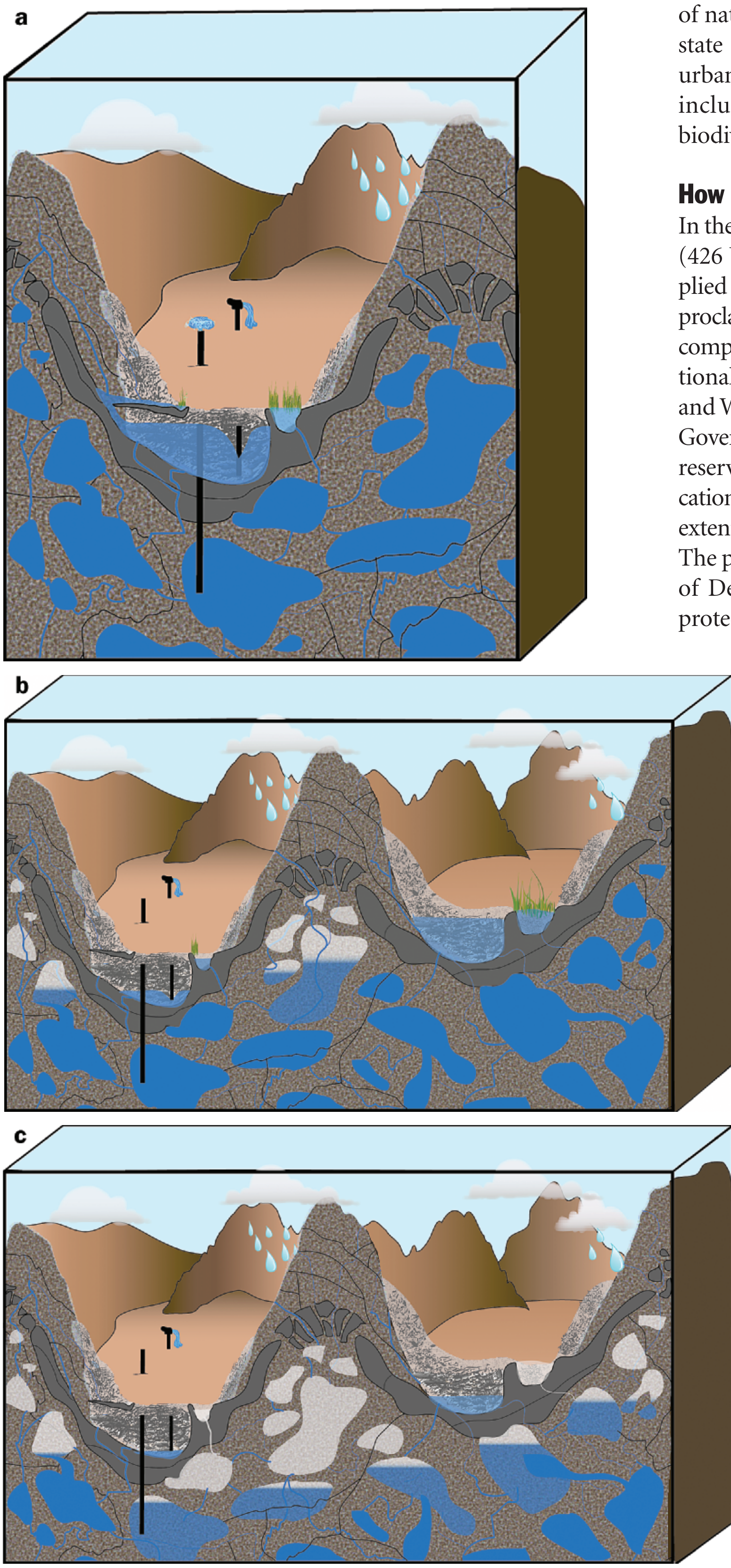
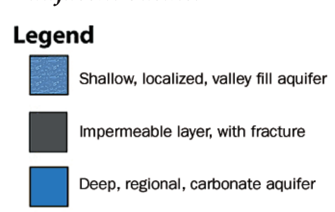



*Figure 3. Conceptual diagrams of the effects of groundwater withdrawal on the variously integrated valley-fill and deep carbonate aquifers in Nevada. (a) Near-term effects: Wells in the valley-fill aquifer create a localized cone of depression; wells in the carbonate aquifer produce artesian flow; surface waters and biotic communities are imperceptibly affected. (b) Midterm effects: The water table in the valley-fill aquifer is substantially lowered, and local springs supported by this shallow aquifer fail; the carbonate aquifer loses its artesian pressure as the deep water table declines, and regional springs supported by this deep aquifer decline; groundwater from adjacent basins flows downgradient toward the reduced pressure caused by the lowering deep water table. (c) Late-term effects: A new steady state develops in both shallow and deep aquifers within the basin subjected to groundwater withdrawal; the downhill groundwater gradient toward the sites of withdrawal causes lowering of water tables and failure of local and regional springs in adjacent basins.*



tional interest...[including] a remarkable underground pool...[and] a peculiar race of desert fish." By this language, the federal government secured its right to the groundwater required to maintain the pool in Devils Hole and the endemic Devils Hole pupfish (*Cyprinodon diabolis*), vesting the right with a 1952 priority date. This implied reservation prohibits subsequent junior water users from receiving water rights that undermine conservation of the unique features of Devils Hole that led to its withdrawal, thereby benefiting not only the pupfish but also the endemic Devils Hole riffle beetle (*Stenelmis calida calida*), other species in the system, and the unique local ecology and geology.

The federal government also has reserved other centers of aquatic biodiversity because of their unique water resources and accompanying wildlife. Pahranagat National Wildlife Refuge (NWR), established in 1963 to provide habitat for migratory waterfowl, also protects an endemic subspecies of speckled dace (*Rhinichthys osculus* ssp.). Moapa NWR, established in 1979, provides habitat for the endangered Moapa dace (*Moapa coriacea*) and other rare aquatic spring endemics. Ash Meadows NWR, established in 1984 "to provide water habitat resources in Nevada for the protection of waterfowl and fish," protects a total of 15 federally listed species, including 9 that depend on springs or spring-fed wetlands, as well as 103 "at-risk" plant and animal taxa (USDOI 1982). If pressed, the courts would most likely determine that the federal government has implied rights to groundwater that are germane to the purposes of all these reservations, with a priority date corresponding to each reservation's date of withdrawal from the public domain. It is possible the implied reservation-of-water doctrine also would apply to lands acquired—as opposed to reserved—after statehood; however, that application has never been tested in court.

While the principles learned from *Cappaert* provide some protection when a species inhabits an area within reserved lands, the federal ESA may afford additional protection to threatened and endangered species that depend on habitat supported by discharge from groundwater aquifers. Current large-scale groundwater plans do not include the expenditure of federal monies, but the proposals do envision many well sites on and pipeline corridors across lands administered by the Bureau of Land Management, necessitating a federal permit and triggering the ESA's section 7 consultation provisions to ensure that federal actions do not jeopardize listed species. Furthermore, section 9 of the ESA prohibits "take" of listed species regardless of whether a federal action is involved.

All water within Nevada belongs to the public. The Nevada state engineer has a "continuing responsibility as a public trustee to allocate and supervise water rights so appropriations do not 'substantially impair the public interest in the lands and waters remaining'" (*Mineral County v. State Dep't of Conservation and Natural Res.,* 20 P.3d 800, 808–809 [2001], quoting *Illinois Central R.R. v. Illinois,* 146 U.S. 387, 452 [1892]). Traditionally, the public trust doctrine protected the public's interest in navigation, fishing, and commerce. However, the doctrine has evolved to encompass additional public values, including recreational and ecological uses.

Fahmy (2005) observed that, since the *Cappaert* decision, the state engineer increasingly has interpreted the "public interest" to include environmental values, such as endangered species. Beyond helping conserve "at-risk" species, Fahmy suggests that continuing judicious use of the public interest standard also could help maintain state sovereignty over water resources allocation and administration.

## Achieving ecologically sustainable water use

Providing for the water needs of a growing Las Vegas Valley by relying on historical practices is a recipe for an ecological disaster involving loss of wetlands, spring-dependent species, and phreatophytic communities. New technologies can help increase water availability and efficiency of use, but in the long run they are futile unless combined with reduced growth of human populations. Reducing per capita consumption, however, could align Las Vegas residents' water use with the levels already realized in other major southwestern US cities (e.g., Albuquerque and Tucson; figure 4).

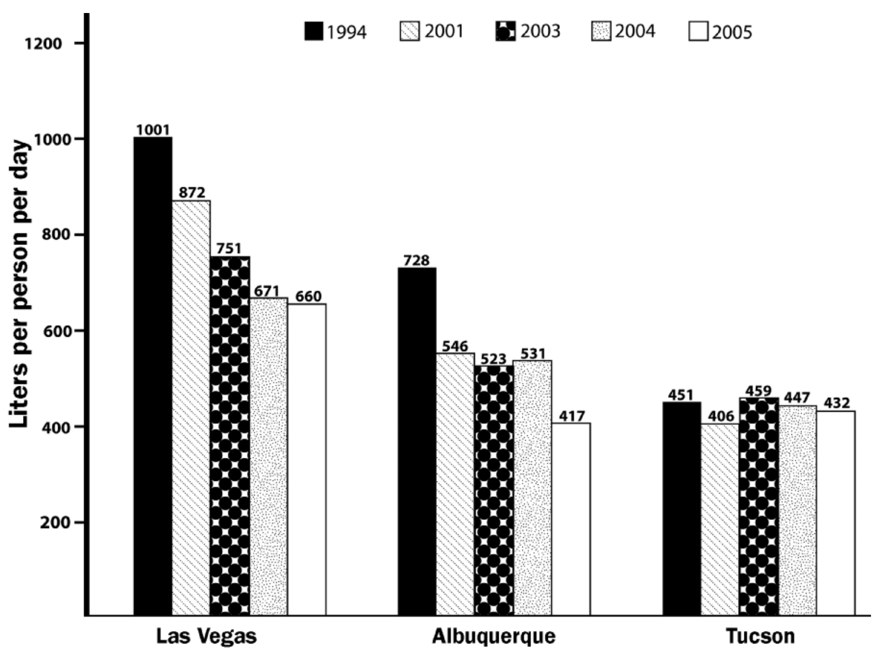



***Figure 4. Changes in single-family, residential per capita water consumption in selected southwestern US cities from 1994 to 2005. Data from Western Resource Advocates (2006).***

Water for lawns and other external uses outside the home offers the largest opportunity for cutting back single-family residential consumption. Mayer and colleagues (1999) calculated that approximately three-fourths of the residential water consumed in Las Vegas could be attributed to external rather than internal use. Western Resource Advocates (2006) calculated that, by 2030, converting 50 percent of the Las Vegas Valley's single-family residential landscaping to xeriscape would reduce demand by 80,000 acre-feet (98,678,547 $m^3$) per year, while indoor water conservation could reduce demand by more than 70,000 acre-feet (86,343,729 $m^3$) per year.

As in other southwestern cities, substantially lower consumption rates would result from increasing the price differential between tiers in the tiered rate structure already in place, and by implementing a range of other widely recognized measures to improve the efficiency of water use (Western Resource Advocates 2003, 2006). For new developments where retrofitting is unnecessary, low per capita consumption can be achieved even more easily simply by requiring serious water efficiency as a condition of development. Opportunities to reduce per capita water consumption to the low rate of 380 L per person per day have been identified for a new 648-hectare development in Las Vegas (Rocky Mountain Institute 2003). Comparable opportunities are available throughout the Las Vegas Valley.

As a reuse or recycling strategy for Las Vegas's tertiary effluent, membrane treatment could recover an amount of water comparable to that presently being obtained through "return-flow credit," a water-accounting system allowing Las Vegas to reuse water of Colorado River origin that is pumped from and then returned to Lake Mead. In addition, a membrane treatment system would make it possible to use saline water (originating as landscape irrigation water) from above the valley-fill aquifer. This shallow saline groundwater reportedly is accumulating at about 100,000 acre-feet (123,348,184 $m^3$) per year (SNWA 2006) and increasingly is flooding basements and creating other problems. Combined with urban runoff (which equals approximately 35,000 acre-feet [43,171,864 $m^3$] per year) and intermittently available floodwaters, both of which currently move through flood control channels to Las Vegas Wash and into Lake Mead, these sources have an apparent cumulative recovery potential of more than 135,000 acre-feet (166,520,048 $m^3$) per year. Following membrane treatment, this water could be used directly in the potable supply or indirectly as groundwater recharge. Membrane treatment would have the additional advantage of removing approximately 700,000 metric tons of salt per year (an amount approximating the total removed by all Bureau of Reclamation Colorado River Basin salinity control projects implemented to date), as well as a number of other environmental contaminants presently identified as problematic—including endocrine-disrupting compounds, personal care and pharmaceutical products, pesticides, chemicals used in plastic manufacturing, and artificial fragrances (Hinck et al. 2006)—and could substantially improve water quality in the Las Vegas Valley and the lower Colorado River.

One approach taken by several communities to manage consumption more efficiently is the direct or indirect reuse of highly treated effluent, a method that is becoming increasingly attractive as costs increase for water development, importation, and disposal. Reuse projects based on membrane treatment (microfiltration or reverse osmosis) of tertiary effluent are in place or under construction in Los Angeles, El Paso, Scottsdale, and many other places around the world (Durham et al. 2003). Such projects produce water that could be reused immediately in potable or irrigation supplies (direct reuse), reused later after recharging groundwater aquifers that are tapped to support domestic water supplies (indirect reuse), or both. Currently, most direct reuse projects are designed to meet irrigation water demands, whereas reuse projects designed to supply potable water generally involve indirect reuse. Preliminary calculations demonstrate that a membrane treatment system for Las Vegas would cost no more than a proposed effluent dilution project (about $800 million), would recover as much water as is recoverable by "return flow credit," and would improve water quality in Las Vegas and in the Colorado River downstream from Lake Mead (Walter Johnson, Clark County Water Reclamation District [retired], Las Vegas, Nevada personal communication, 17 November 2005).

Although the hydrogeology in southern Nevada is unique, concerns regarding the ecological impacts of groundwater withdrawal exist across the western United States. For example, the dependence of San Antonio, Texas, on groundwater from the Edwards Aquifer for municipal water supplies has had a growing impact on the endangered fountain darter (*Etheostoma fonticola*). Ultimately, minimum spring flows needed to avoid jeopardizing the darter's existence were established, and the Texas legislature mandated that the Edwards Aquifer Authority improve water management and conservation, leading San Antonio residents to reduce per capita water use by 24 percent between 1984 and 2000 (Fitzhugh and Richter 2004).

Richter and colleagues (2003) suggested defining ecologically sustainable water management as "protecting the ecological integrity of affected ecosystems while meeting intergenerational human needs for water and sustaining the full array of other products and services provided by natural freshwater ecosystems." Whether adhering to that standard of sustainability or to Nevada's considerably riskier standard of "perennial yield," we must acknowledge limits to water availability as we strive to strike a balance between human water demand and the needs of natural systems and future generations. Adherence to traditional standards virtually guarantees immediate ecological crises and unnecessary adversity for future generations. Those crises will manifest in litigation, "water wars," federal–state conflicts, and loss of springs, wetlands, phreatophytic communities, and biodiversity. Only through changed personal and community relationships with the Earth and its waters are we likely to succeed in conserving our ecological heritage while building a sustainable society.

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