Section 4.—Conceptual Understanding and Groundwater Quality of the Basin-Fill Aquifers in Eagle and Carson Valleys, Nevada

By Jena M. Huntington

in

Conceptual Understanding and Groundwater Quality of Selected Basin-Fill Aquifers in the Southwestern United States

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Section 4.—Conceptual Understanding and Groundwater Quality of the Basin-Fill Aquifers in Eagle and Carson Valleys, Nevada

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Basin Overview

Eagle Valley is a small valley about 30 mi south of Reno, Nevada that has undergone rapid urban development. The valley is bounded to the north by the Virginia Range, to the east by Prison Hill, and to the west by the Carson Range (fig. 1). These mountains rise to altitudes of about 8,000 ft, 5,700 ft, and greater than 9,200 ft, respectively (Maurer and others, 1996). To the south, the boundary between Eagle Valley and Carson Valley is marked by a subtle alluvial divide (Welch, 1994). The Eagle Valley floor has an area of about 15,000 acres (23 mi^2) and lies at an altitude of about 4,700 ft (Maurer and Berger, 1997).

Carson Valley is adjacent to and south of Eagle Valley (fig. 1). The Pine Nut Mountains bound the valley to the east and rise gradually to altitudes of about 8,000 to 9,000 ft. Like Eagle Valley, the Carson Range borders Carson Valley to the west rising abruptly to altitudes between 9,000 and 11,000 ft. The valley floor is oval-shaped with an area of about 104,000 acres or 162 mi^2, and slopes northward from an altitude of about 5,000 ft at its southern end to about 4,600 ft at its northern end (Maurer and others, 2004).

Eagle and Carson Valleys have a semiarid climate as a result of their location within the rain shadow of the Sierra Nevada Range. Annual precipitation on the floor of Eagle Valley averages about 10 in., while along the crest of the Carson Range precipitation averages about 38 in/yr. The Virginia Range receives much less precipitation than the Carson Range—slightly more than 14 in/yr (Schaefer and others, 2007). Annual precipitation on the floor of Carson Valley averages 8.4 in. (period of record 1971–2000; National Oceanic and Atmospheric Administration, 2002, p. 12). However, the Carson Range in this area receives 25.5 in. of precipitation per year (period of record 1971–2000, Western Regional Climate Center, 2003) and precipitation on the Pine Nut Mountains averages 15.7 in/yr (period of record 1984–2002; Dan Greenlee, Natural Resources Conservation Service, written commun., 2003). In both mountain ranges, most precipitation falls as rain or snow during November through April. Snow in the Carson Range accumulates to depths of many feet during most winters and melts in early spring to early summer. Other climatic characteristics of Eagle and Carson Valleys are prevailing westerly winds, large daily temperature fluctuations, and infrequent, but severe storms (Garcia and Carman, 1986).

Urban land occupies more than half of Eagle Valley while irrigated agricultural land and rangeland makes up nearly half of Carson Valley, according to the National Land Cover Database (NLCD) dataset for 2001 (U.S. Geological Survey, 2003). Analysis of LandScan population data for 2005 (Oak Ridge National Laboratory, 2005) indicated a population for the alluvial basin as a whole to be about 48,000 for Eagle Valley and 36,000 for Carson Valley (McKinney and Anning, 2009). This equates to a population density of about 2,055 and 220 people/mi^2 for Eagle and Carson Valley, respectively. The increase in population in Eagle Valley beginning in the early 1960s has slowly expanded Carson City's initial city limits in all directions and has caused a shift from a historically agrarian society to a more urban society (Covay and others, 1996). Eagle Valley supports about 1,100 acres of irrigated agricultural land, mostly consisting of pasture. This shift in land use from agriculture to urban will likely affect the basin-fill groundwater system due to changes in sources and quality of recharge. Total water use in the Eagle Valley in 2000 was about 20,000 acre-ft; 81 percent of which was for public supply (McKinney and Anning, 2009). Groundwater provides about 61 percent of public supply. In Carson Valley, diversions from the Carson River, which runs south to north, and pumped groundwater is used to irrigate about 45,000 acres of agricultural land, primarily alfalfa, pasture and flax. Groundwater is the sole source of public supply in Carson Valley.

The movement of water through geologic materials of the basins coupled with movement of water from the land surface to the basin-fill aquifers results in elevated concentrations of some constituents and compounds in groundwater. Groundwater-quality issues identified in Eagle and Carson Valley and described later in this section include naturally occurring uranium and other dissolved constituents, and the presence of nitrate, volatile organic compounds, and pesticides associated with anthropogenic sources in the basins.

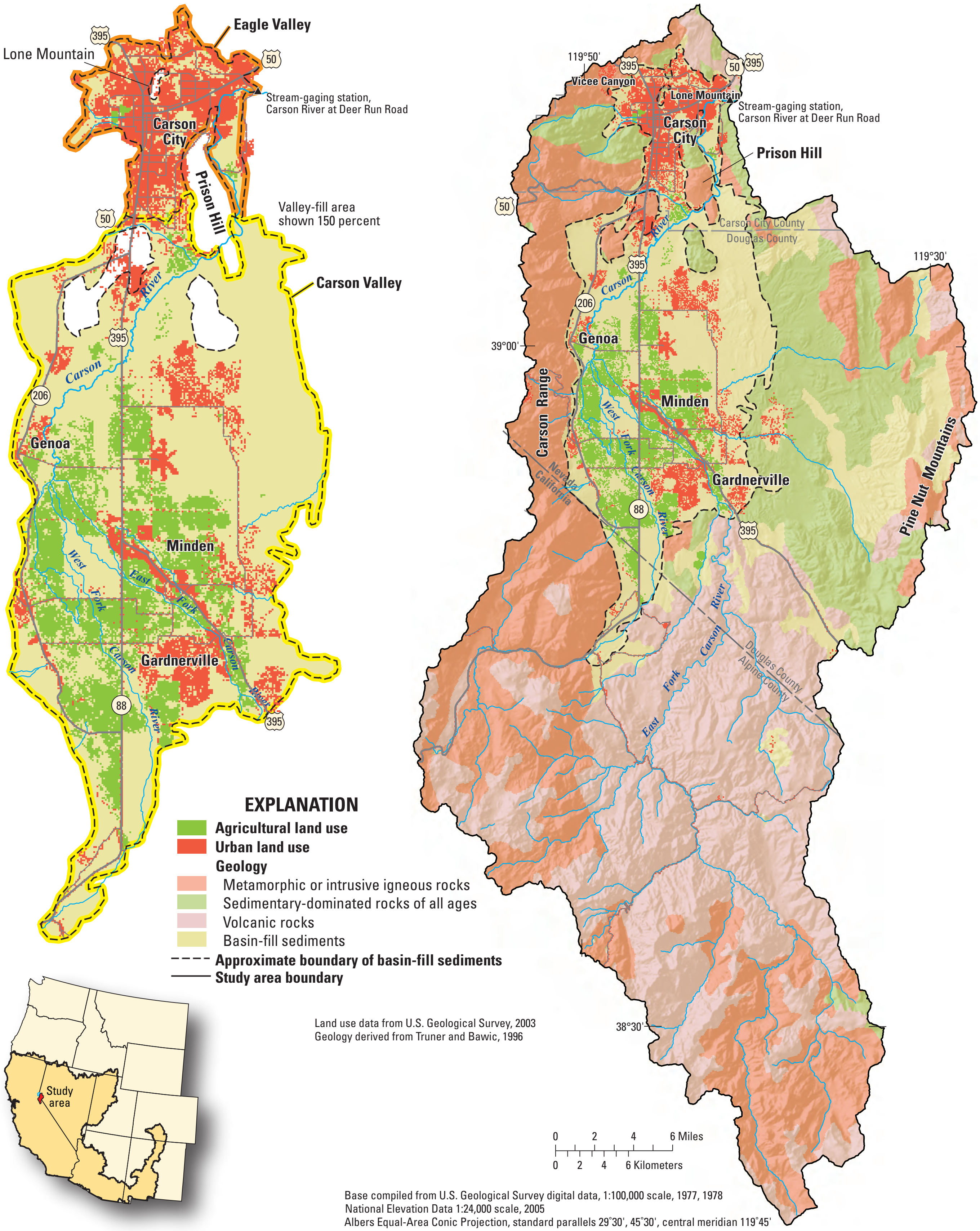


Figure 1. Physiography, land use, and generalized geology of Eagle and Carson Valleys, Nevada.

Water Development History

Eagle Valley

Accounts of early travelers through Eagle Valley in June 1859 describe it as being a small but fertile valley along the towering snow-covered Carson Range. A few acres of green meadows and cultivated fields irrigated with water from a small stream gave an inviting appearance upon entering the valley. Carson City was the only development within Eagle Valley and consisted of about a dozen small houses and two stores at that time (Simpson, 1876). Carson City expanded gradually to serve ranching, irrigated farming, and silver and other mineral mines in the area.

With the increase in population in Eagle Valley (fig. 2), water use has shifted from agricultural to domestic purposes. Historically, surface water was the major source of public supply and groundwater was used only intermittently. Groundwater has since become the major source of municipal supply, accounting for about 80 percent of that supply in 2004 (Kenneth Arnold, Carson City public works, oral commun., 2006) and public-water systems serve most of the population in Eagle Valley. Most homes are served by a wastewater-treatment plant that exports treated effluent to a reservoir in the Pine Nut Mountains (Schaefer and others, 2007). Since 1997, some of the effluent has been returned to Eagle Valley for irrigation of golf courses and alfalfa fields (Maurer and Thodal, 2000).

Carson Valley

Carson Valley was inhabited by the Washoe Indians in 1848, when a small party of Mormons arrived with plans to cut a shorter wagon route from Salt Lake City, Utah to Sacramento, California over the Sierra Nevada Range. The wagon route that they created, otherwise known as the California Trail, the Carson River Route, or the Emigrant Trail, became a highly traveled route that brought immigrants and prosperity to Carson Valley (Dangberg, 1972). In August 1853, a local newspaper reported that in May of that year at least 1,000 wagons and 300,000 cattle and sheep traveled through Carson Valley on the California Trail (Dangberg, 1972).

Diversions from the East and West Forks of the Carson River aided in turning southern Carson Valley into a productive agricultural area. Only 260 acres of land were irrigated in 1852, but more acres were added as an increased number of people traveled through the valley. Large mining operations on the Comstock Lode in Virginia City and Gold Hill to the northeast were accompanied by an increase in population and in irrigated acreage in Carson Valley (Dangberg, 1972).

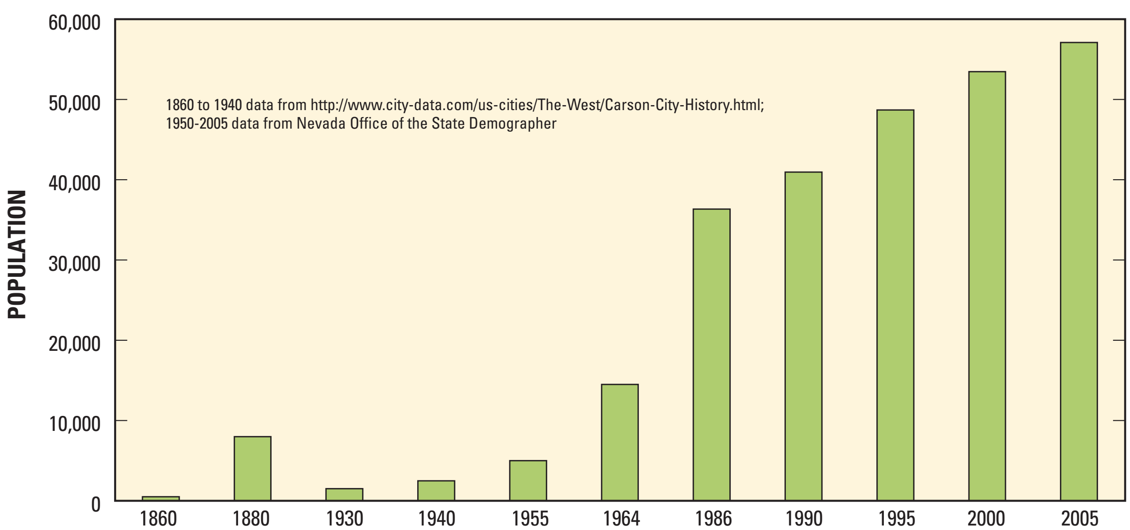


Figure 2. Population in the Carson City area of Eagle Valley, Nevada from 1860 to 2005.

Three main towns lie within Carson Valley: Genoa, the first settlement along the Sierra Nevada front; Gardnerville, established in the 1860s as an agricultural town in the center of the valley; and Minden, adjacent to Gardnerville and established in 1905 as the railroad hub for the valley (Toll, 2008). Captain Simpson of the U.S. Army Corps of Topological Engineers described Carson Valley during a visit to Genoa in 1859. He stated that Carson Valley was beautiful, "fenced off, as it appears, into inclosures, and dotted with cattle" (Simpson, 1876).

Although Carson Valley has been a major agricultural area since the 1850s, urbanization around Gardnerville, Minden, Genoa and subdivisions around Johnson Lane, Indian Hills, and Gardnerville Ranchos have grown steadily (fig. 3). Development is also increasing along the eastern and western sides of the valley. Most of the newly urbanized land was historically agricultural land. Factors responsible for population increases are available residential property, desirable aesthetic qualities, and growth in Nevada's gaming industry (Thodal, 1996).

Surface water, in the form of treated effluent, has been imported to Carson Valley from the Lake Tahoe Basin since the late 1960s and from Eagle Valley since 1988 (Maurer and Berger, 2006; Nevada State Demographer's Office, accessed on September, 11, 2006). Imported effluent is applied as irrigation water and is stored in reservoirs and wetlands (Maurer and Berger, 2006). Groundwater is exported from Washoe Valley to the north into Eagle Valley to supply Carson City's municipal uses (Nevada State Water Plan, 1999).

Hydrogeology

The mountains surrounding Eagle and Carson Valleys were created during Basin-and-Range faulting, which began about 17 million years ago (Stewart, 1980). They consist of consolidated rocks that have been uplifted by extensional tectonics near the base of the mountains while the valley floor was dropped. This faulting formed a basin that is partly filled with sediments eroded from the surrounding mountains during the Quaternary period. Movement along some faults within the last 300 to 12,000 years (Trexler, 1977) indicates that uplift of the mountains is continuing (Maurer and others, 1996).

Mesozoic-age granite and metamorphosed rocks crop out to the north and west of Eagle Valley and near Prison Hill, and most likely underlie most of the valley floor (Moore, 1969). In the Virginia Range, Tertiary sandstone and volcanic rocks consisting mostly of rhyolite, andesite, and basalt flows, flow breccias, and tuffs overlie the granite and metamorphosed rocks (Moore, 1969; Trexler, 1977).

Quaternary sediments of two ages are present in Eagle Valley. The older sediments form fans at the mouths of deeply incised canyons on the western side of the valley. Small individual fans merge into one wide fan extending as much as 1 mi eastward into the valley from the mountain front and are made up of partly consolidated to unconsolidated gravel, sand, and silt, with discontinuous clay layers (Maurer and others, 1996). Similar fans are present at the base of the Virginia Range to the north and Prison Hill to the east (Trexler and

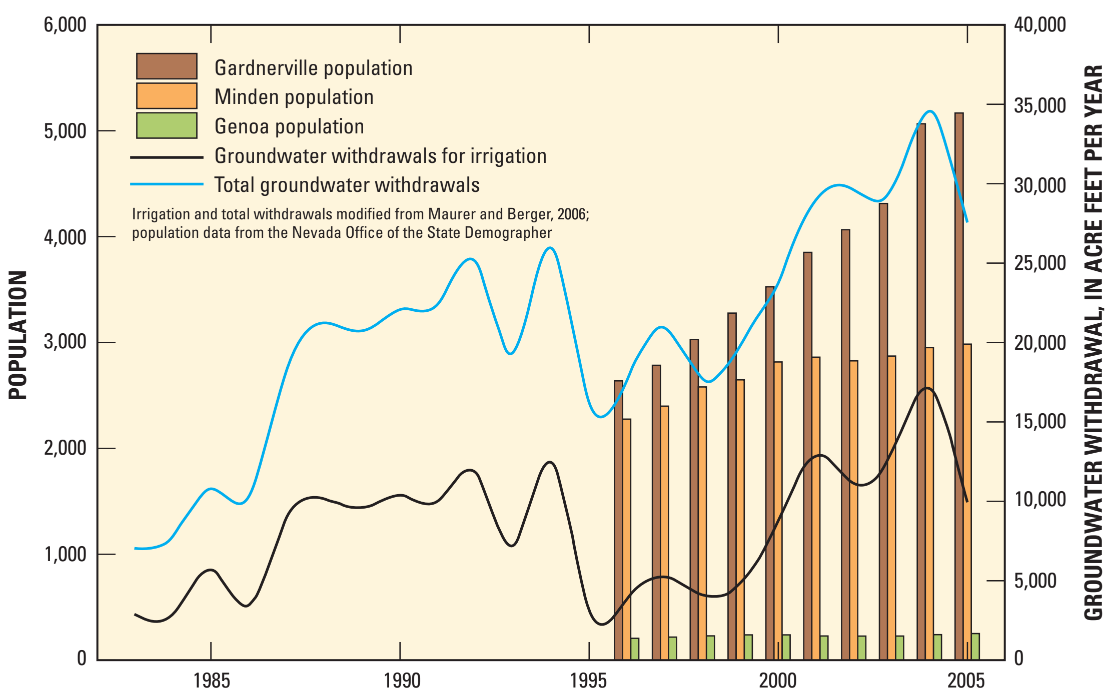


Figure 3. Population in Gardnerville, Minden, and Genoa, Nevada from 1996 to 2005 and annual groundwater pumping in Carson Valley, Nevada and California, 1983-2005.

others, 1980). The discontinuity of clay layers in the central part of the basin enable a direct hydraulic connection from the land surface to the basin-fill aquifer and make the aquifer susceptible to contamination from sources at the surface (Lico, 1998, p. 1). The younger sediments in the valley lowlands consist of fine-grained sands, silty and muddy sands, and clay (Arteaga, 1986; Trexler and others, 1980). Overall, basin-fill sediments are coarse-grained near the base of the mountains and finer grained near the center of the valley. The basin-fill sediments are estimated to be about 1,200 ft thick at a point 1.5 mi west of Lone Mountain, about 400 to 800 ft thick beneath the northeastern and southern parts of Eagle Valley, and about 2,000 ft thick about 1 mi northwest of Prison Hill (Arteaga, 1986). In general, the deepest part of the alluvial basin is in the center of the Eagle Valley (Schaefer and others, 2007).

Similar to the rocks in Eagle Valley, exposed consolidated rocks in Carson Valley are mostly granitic, metavolcanic, and metasedimentary, and make up most of the Carson Range and the Pine Nut Mountains (Covay and others, 1996). These same rocks underlie the floor of Carson Valley (Moore, 1969, p. 18). Volcanic rocks are exposed on the northeastern and southeastern end of the valley; westward dipping, semiconsolidated rocks are exposed on the eastern side of the valley (Maurer and Berger, 2006).

Both semiconsolidated Tertiary sediments and unconsolidated Quaternary basin-fill sediments are present in Carson Valley (Maurer, 1986). Poorly sorted coarse- to fine-grained unconsolidated sediments deposited by tributary streams form alluvial fans at the base of the mountain blocks (Maurer and Berger, 2006). The alluvial aquifer is made up of Quaternary sediments that were deposited on the valley floor by the Carson River and its tributary streams. Most of those sediments are well-sorted sand and gravel, interbedded with fine-grained silt and clay from overbank flood deposits (Maurer, 1986; Maurer and Berger, 2006). Thickness of the basin-fill sediments generally exceeds 1,000 ft (Maurer, 1986). Due to the downward tilting to the west of the Pine Nut Mountains relative to the uplift along the eastern margin of the Carson Range, the thickest section of the basin-fill deposits, more than 5,000 ft, lies west of the valley axis (Moore, 1969; Maurer, 1986).

Estimated hydraulic conductivities of the basin-fill sediments in Eagle Valley, those values used in the most recent groundwater flow model, range from about 1 to 31 ft/d in shallow sediments and from 0.03 to 155 ft/d in the deeper, coarser sediments that constitute the more transmissive part of the aquifer (Schaefer and others, 2007). In Carson Valley, hydraulic conductivity values estimated from pump-test data range from 14.7 to 16.4 ft/d (U.S. Bureau of Reclamation, written commun., 1981). Maurer (1986) calculated hydraulic conductivity values ranging from about 1 to 9 ft/d in sediments between 300 and 500 ft deep and from 86 to 865 ft/d in sediments less than 300 ft deep on the basis of proportions of coarse- and fine-grained material indicated in well logs.

Conceptual Understanding of the Groundwater System

Eagle Valley is small open basin with no surface-water drainage, although the Carson River flows just beyond the southeastern basin boundary (fig. 1). The river acts as both a recharge and discharge boundary to the groundwater system on the south and east sides of the basin, respectively. The mean annual flow in the Carson River from 1979–2001 was 501 ft^3/s at the streamgaging station at Deer Run Road (fig. 1) (Schaefer and others, 2007).

Carson Valley is an open basin drained by the Carson River. The East and West Forks of the river enter Carson Valley from the south, join near Genoa and continue north. A long period of record, dating back to the turn of twentieth century, is available to determine the mean annual inflow of the Carson River (Maurer and others, 2004). The East Fork inflow (period of record 1890–2002) was 276,400 acre-ft and the West Fork inflow (period of record 1901–2002; Berris and others, 2003, p. 178 and 185) was 80,320 acre-ft, which totals to 356,720 acre-ft. Mean annual outflow of the mainstem of the Carson River for the period 1940–2002 (Berris and others, 2003, p. 191) was 296,500 acre-ft.

Water Budgets

Eagle Valley

Prior to agricultural and urban development, recharge to the basin-fill aquifer in Eagle Valley was from the infiltration of precipitation—on the surrounding mountains, the alluvial slopes (mountain-front recharge), and the basin floor—and by infiltration of flow through the channels of canyon creeks entering the valley from the west (fig. 4 and table 1). Worts and Malmberg (1966, table 2) used the method of Maxey and Eakin (1949) to estimate recharge from precipitation along the mountain fronts at about 8,300 acre-ft/yr. The method applies a percentage of the average annual precipitation within specified altitude zones to estimate recharge. The bulk of this natural recharge from precipitation originates at high altitudes on the western part of the drainage area and enters the basin-fill aquifer as seepage from snowmelt runoff. The aquifer is also recharged by an estimated 3,000 to 6,000 acre-ft/yr of snowmelt that infiltrates consolidated rocks where they are permeable or fractured and moves along flow paths into basin fill (Maurer and Berger, 1997, p. 32). Recharge from the infiltration of precipitation on the basin floor was estimated to be about 400 acre-ft/yr (Worts and Malmberg, 1966). Infiltration of water from the channels of canyon creeks to the basin-fill aquifer was estimated by Maurer and Thodal (2000) to be about 2,600 acre-ft/yr based on an estimated average conditions (table 1).

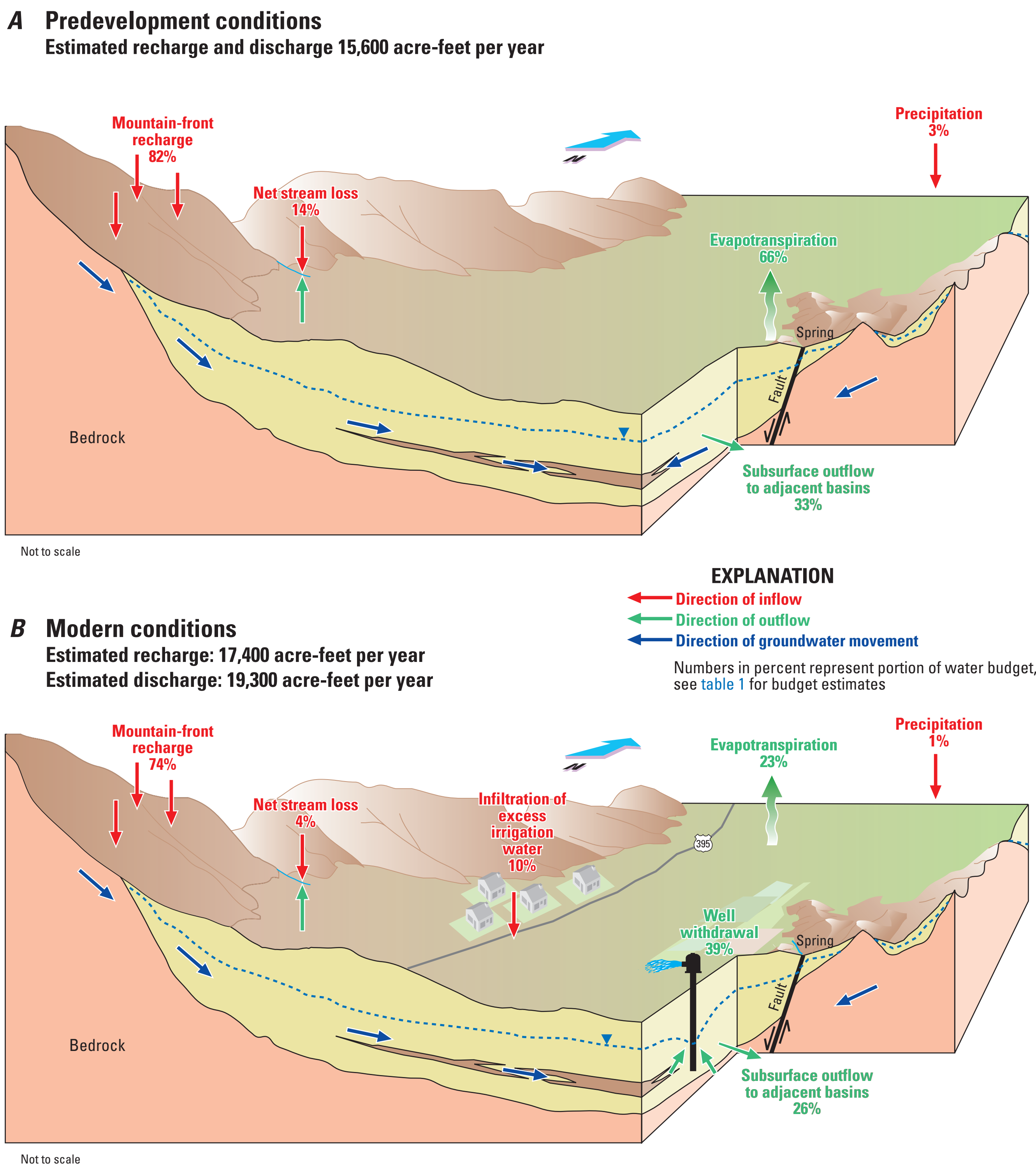


Figure 4. Generalized diagrams for Eagle Valley, Nevada, showing the basin-fill deposits and components of the groundwater system under (*A*) predevelopment conditions and (*B*) modern conditions.

Table 1. Estimated groundwater budget for the basin-fill aquifer in Eagle Valley, Nevada, under predevelopment and modern conditions.

[All values are in acre-feet per year (acre-ft/yr) and are rounded to the nearest hundred. Estimates of groundwater recharge and discharge under predevelopment and modern conditions were derived from the footnoted sources. The budgets are intended only to provide a basis for comparison of the overall magnitudes of recharge and discharge between predevelopment and modern conditions, and do not represent a rigorous analysis of individual recharge and discharge components. Percentages for each water budget component are shown in figure 4]

	Predevelopment conditions	Modern conditions	Change from predevelopment to modern conditions
Budget component		**Estimated recharge**	
Mountain-front recharge	[5]12,800	[1]12,900	100
Infiltration of preciptation on basin	[2]400	[4]100	-300
Infiltration of streamflow	[4,6]2,400	[4,6]2,600	200
Infiltration of excess irrigation water	0	[4]1,800	1,800
Total recharge	**15,600**	**17,400**	**1,800**
Budget component		**Estimated discharge**	
Subsurface outflow to adjacent basins	[4]5,100	[4]5,100	0
Evapotranspiration	[3]10,300	[1]4,500	-5,800
Well withdrawals	0	[1]7,500	7,500
Discharge to streams	[4,6]200	[1,6]2,200	2,000
Total discharge	**15,600**	**19,300**	**3,700**
Change in storage (total recharge minus total discharge)	0	-1,900	-1,900

[1] Simulated by calibrated groundwater flow model for 1997-2001 average conditions (Schaefer and others, 2007).

[2] Estimated natural conditions by Worts and Malmberg (1966).

[3] Assumed to equal estimated residual between predevelopment recharge and discharge.

[4] Estimates from Maurer and Thodal (2000), averages are shown here where estimated ranges of values were documented.

[5] Maurer and Berger estimated recharge from snowmelt infiltrating consolidated rock and moving along flow paths into the basin fill from 3,000 to 6,000 acre-ft/yr (1997, p. 32), an average of 4,500 acre-ft/yr was assumed here, in addition to the 8,300 acre-ft/yr estimated by Worts and Malmberg (1966, table 2) using the Maxey-Eakin method.

[6] Net stream loss is represented in figure 4A & B and was calculated as gross stream loss - gross stream gain; under predevelopment conditions 2,400 acre-ft/yr - 200 acre-ft/yr = 2,200 acre-ft/yr net stream loss; under modern conditions 2,600 acre-ft/yr – 2,200 acre-ft/yr = 400 acre-ft/yr net stream loss.

Groundwater discharges in Eagle Valley through subsurface outflow to adjacent basins and by evapotranspiration (ET). Maurer and Thodal (2000) estimated that 2,900 acre-ft/yr of subsurface outflow from Eagle Valley enters Carson Valley to the south—about 400 acre-ft/yr of outflow beneath Clear Creek and, based on water yield deficiencies, an additional 2,500 acre-ft/yr flows out of the valley beneath the upper part of the Clear Creek watershed. Maurer and Berger (1997) also estimated about 2,200 acre-ft/yr of subsurface outflow to Dayton Valley to the east. Under predevelopment conditions, the relative quantity of discharge equaled that of recharge because the system was assumed to be in equilibrium (no change in the average volume of storage).

Human-related changes to the Eagle Valley groundwater flow system first began when mountain creeks were diverted for irrigated agriculture and more recently as a consequence of the conversion of farmlands to urban use. This land-use change resulted in a reduction in ET by phreatophytes (phreatophyte-area reductions from 7.7 mi^2 in 1964 to about 1.7 mi^2 in 2000) and an increase in recharge from irrigated lawns, infiltration of treated waste-water effluent on golf courses, and effluent from septic tanks (Maurer and Thodal, 2000; McKinney and Anning, 2009; Schaefer and others, 2007). Infiltration of excess urban irrigation was estimated by Maurer and Thodal (2000) to range from 1,300 to 2,300 acre-ft/yr. Increases in groundwater pumping since the 1970s, mostly for municipal supply, has diverted groundwater that was historically discharged by phreatophytes or flowed to the Carson River. Therefore the decrease in ET is attributed to both fewer phreatophytes and increases in groundwater pumping (table 1; Schaefer and others, 2007).

Additional groundwater (not indicated in table 1) is imported to Eagle Valley from other basins, including Washoe Valley to the north, Dayton Valley to the east, and Carson Valley to the south (Nevada Division of Water Resources, 1999). Surface-water transfers are received from the Lake Tahoe Basin to the west and from the Carson River in Dayton Valley. All transferred water is used for Carson City municipal supply. Beginning in 1991, artificial recharge (through infiltration beds) was initiated in Vicee Canyon on the northwestern side of Eagle Valley.

Groundwater pumping has caused water-level declines in the northwestern and southern parts of Eagle Valley (Maurer and Thodal, 2000; Schaefer and others, 2007; Arteaga, 1986, fig. 3), whereas water-level fluctuations in the center of the valley reflect variations in annual precipitation. Although water levels have increased in a few wells, no change in hydraulic gradients in the valley have been detected. Of the wells with higher water levels, a few are near golf courses and the increases are probably a response to irrigation, whereas water-level increases in other wells may be a consequence of land-cover changes from native vegetation (phreatophytes) to residential development (Maurer and Thodal, 2000).

Carson Valley

Prior to agricultural and urban development, the basin-fill aquifer in Carson Valley was recharged by subsurface inflow from adjacent basins, the infiltration of precipitation on the surrounding mountains and alluvial slopes (mountain-front recharge), infiltration of precipitation on the basin floor, and infiltration of stream water from the Carson River (fig. 5 and table 2). Maurer and Thodal (2000) estimate approximately 2,900 acre-ft/yr of groundwater inflow from Eagle Valley to the north. Four methods have been used to estimate the amount of recharge to the aquifer from the mountains and alluvial slopes of Carson Valley:

Method	Recharge (acre-ft/yr)	Reference
Water yield	22,000	Maurer and Berger, 2006
Chloride balance	40,000	Maurer and Berger, 2006
Altitude precipitation	25,000	Glancy and Katzer, 1976
Watershed modeling	35,000	Jeton and Maurer, 2007

For the purposes of this report, a value of 30,500 acre-ft/yr, the average of the four estimates, is used to represent mountain-front recharge (table 2). Precipitation that falls near the valley floor is recharged on the western alluvial fans (about 300 acre-ft/yr) and in Quaternary gravels and eolian sand deposits (at an average rate of 500 acre-ft/yr, Maurer and Berger, 2006, table 6). Infiltration of water from the Carson River and other smaller streams is difficult to quantify, as most estimates were made after diversion of streamflow began for irrigation in the basin. Maurer and Berger (2006, table 22) estimate a minimum of 10,000 acre-ft/yr of groundwater recharge by infiltration through stream channels, mostly during summer months, when groundwater levels are low; for the purposes of this report, about one-fourth of that value, or 2,500 acre-ft/yr, is assumed to occur. These components of groundwater recharge to the Carson Valley groundwater system under pre-development conditions total about 36,700 acre-ft/yr (table 2).

Natural groundwater discharge in Carson Valley occurs by means of discharge to streams, ET, and springs (table 2). Very little groundwater, less than 100 acre-ft/yr, flows from Carson Valley into Dayton Valley to the northeast (Glancy & Katzer, 1976). Groundwater discharge to streams from the basin-fill aquifer (mainly to the Carson River), about 15,000 acre-ft/yr, occurs mostly during winter months, when groundwater levels are high (Maurer and Berger, 2006, table 22). Spring discharge was calculated on the basis of flow rates reported in Glancy and Katzer (1976, table 27) as about 1,000 acre-ft/yr. Under predevelopment conditions, the relative quantity of discharge was assumed to equal that of recharge because the system was considered to be in equilibrium; therefore, the estimate of ET calculated here represents the residual of 20,600 acre-ft/yr (table 2).

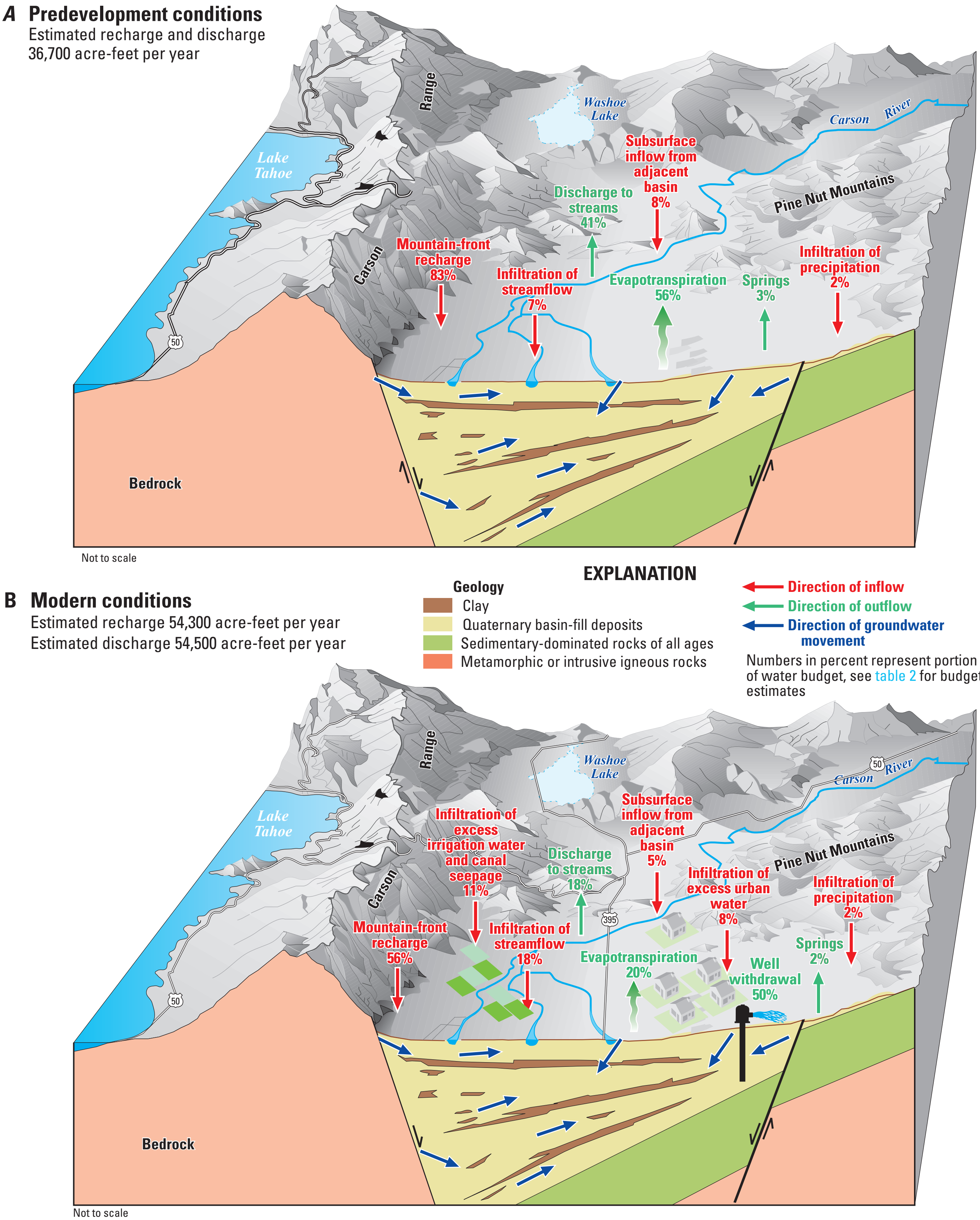


Figure 5. Generalized diagrams for Carson Valley, Nevada, showing the basin-fill deposits and components of the groundwater system under (*A*) predevelopment conditions and (*B*) modern conditions.

Table 2. Estimated groundwater budget for the basin-fill aquifer in Carson Valley, Nevada, under predevelopment and modern conditions.

[All values are in acre-feet per year (acre-ft/yr) and are rounded to the nearest hundred. Estimates of groundwater recharge and discharge under predevelopment and modern conditions were derived from the footnoted sources. The budgets are intended only to provide a basis for comparison of the overall magnitudes of recharge and discharge between predevelopment and modern conditions, and do not represent a rigorous analysis of individual recharge and discharge components. Percentages for each water budget component are shown in figure 5. <, less than]

	Predevelopment conditions	Modern conditions	Change from predevelopment to modern conditions
Budget component		**Estimated recharge**	
Subsurface inflow from adjacent basin	[1]2,900	[1]2,900	0
Mountain-front and mountain-block recharge	[5]30,500	[5]30,500	0
Infiltration of precipitation on basin	[2]800	[2]800	0
Infiltration of excess irrigation water and canal seepage	0	[2]6,000	6,000
Infiltration of streamflow	[8]2,500	[2]10,000	7,500
Infiltration of excess urban irrigation water and septic tanks	0	[7]4,100	4,100
Total recharge	**36,700**	**54,300**	**17,600**
Budget component		**Estimated discharge**	
Evapotranspiration	[4]20,600	[2]11,000	-9,600
Springs	[6]1,000	[6]1,000	0
Well withdrawals	0	[2]27,400	27,400
Discharge to streams	[2]15,000	[2]15,000	0
Subsurface outflow to adjacent basin	[3]< 100	[3]< 100	0
Total discharge	**36,700**	**54,500**	**17,800**
Change in storage (total recharge minus total discharge)	0	-200	-200

[1] Maurer and Thodal (2000, table 9).

[2] Maurer and Berger (2006, table 22).

[3] Glancy and Katzer (1976).

[4] Assumed to equal estimated residual between predevelopment recharge and discharge.

[5] Averaged value of estimates using different methods from Maurer and Berger (2006), Glancy and Katzer (1976) and Jeton and Maurer (2007).

[6] Calculated from spring discharge estimates (Glancy & Katzer, 1976, table 27).

[7] Average of range given in Maurer and Berger (2006, table 18) for secondary recharge from lawn watering and septic tanks.

[8] Estimated as one-quarter of 10,000 acre-ft/yr published in Maurer and Berger (2006).

Human-related changes to the Carson Valley groundwater flow system started as early as 1850, when the Carson River was first diverted for irrigated agriculture. Maurer and Berger (2006) estimate about 6,000 acre-ft/yr of return flow from irrigation pumping and about 4,100 acre-ft/yr of urban irrigation return from lawn watering and seepage from septic tanks (table 2). Groundwater discharge by ET was estimated to be about 11,000 acre-ft/yr (Maurer and Berger, 2006). This is considerably less than the estimated ET under predevelopment conditions, when areas of natural wetlands, greasewood, and riparian vegetation were more extensive, and prior to construction of the irrigation-ditch system and the clearing of fields. Total groundwater pumping in Carson Valley was about 27,400 acre-ft/yr in 2005 (fig. 3; Maurer and Berger, 2006). Because of the uncertainty in the estimates of these groundwater budget components, a numerical model of groundwater flow in Carson is being developed by the U.S. Geological Survey to help refine the estimates.

The largest change since the early 1900s in Carson Valley that affects the groundwater system has been the conversion of agricultural land or areas of natural phreatophytic vegetation to residential or commercial use. Other changes are those in water use and use patterns, for example, increased application of treated wastewater and groundwater for irrigation, and changes in the configuration of the surface-water irrigation distribution system (Maurer and Berger, 2006). Converting agricultural land to residential or commercial land would have the effect of decreasing ET (table 2) as well as increasing flow in the Carson River—via runoff from impervious surfaces—that subsequently discharges from Carson Valley. Water levels on the eastern side of Carson Valley have declined by nearly 20 ft since the early 1980s due to changes in the configuration of the irrigation distribution system, namely the discontinued use of a reservoir that was active since the early 1900s (Maurer and Berger, 2006). No groundwater gradient reversals have been observed.

Groundwater Movement

Eagle Valley

In the northern part of the Eagle Valley, groundwater flows eastward and southeastward beneath the topographic divide into Dayton Valley (fig. 6; Worts and Malmberg, 1966; Arteaga, 1986; Maurer and Berger, 1997). In the southern part of the Eagle Valley, some groundwater flows northeastward around the northern end of Prison Hill and southeastward beneath the topographic divide into Carson Valley (Worts and Malmberg, 1966; Arteaga, 1986). Unconfined to confined conditions are present in the basin-fill sediments. Clay lenses throughout Eagle Valley separate the shallow water-table aquifer from the one or more deeper confined alluvial aquifers (Arteaga, 1982). The degree of confinement varies spatially through the valley due to the clay lenses being discontinuous at different depths. The area of thickest basin-fill sediment, northwest of Prison Hill, has the most pronounced confined conditions. It is here that groundwater flow from the north, northwest and southwest converge and generally move east toward the Carson River (Welch, 1994).

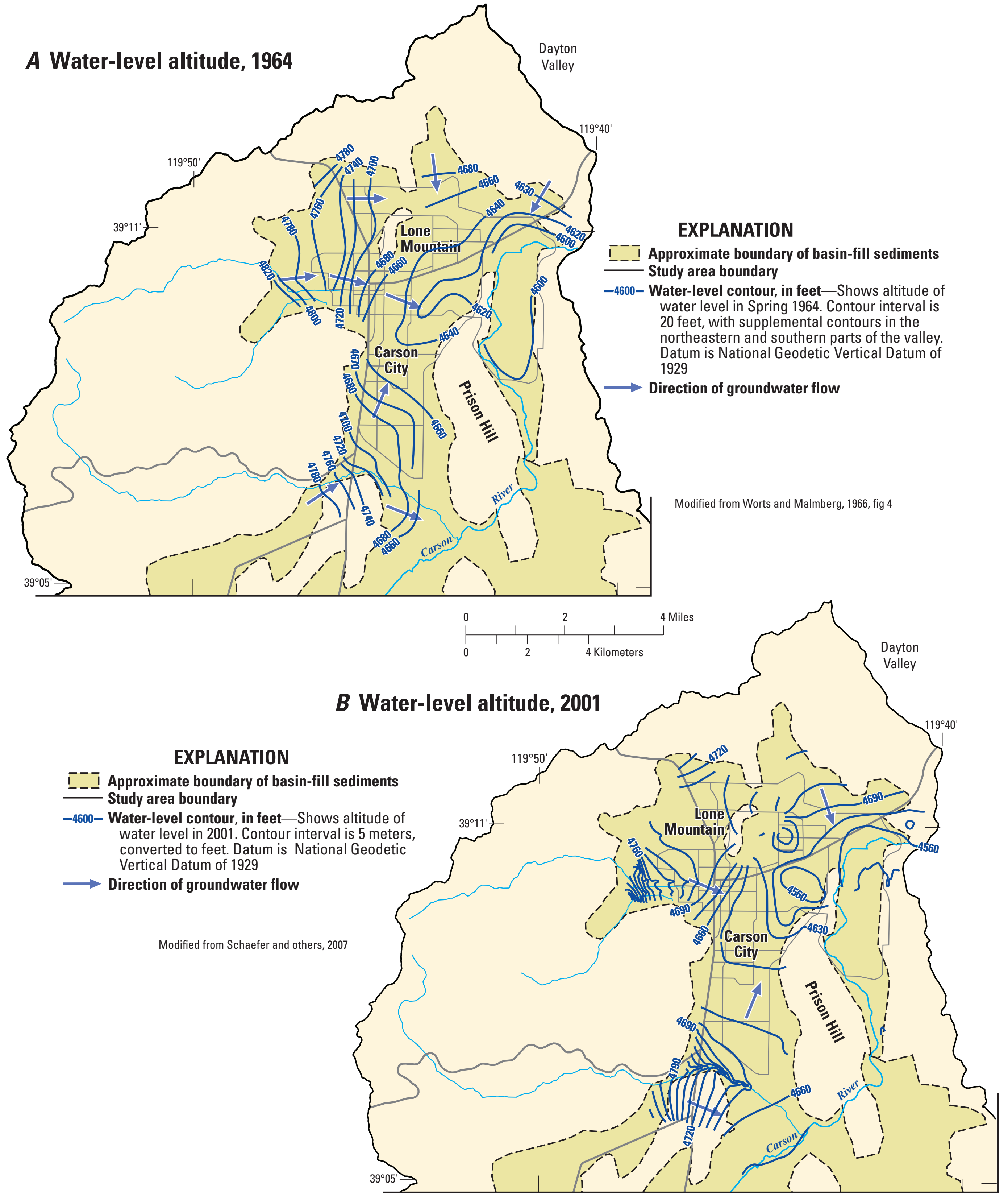
Modern groundwater (less than about 50 years old) typically indicates an aquifer is susceptible to human activities at the land surface. Chlorofluorocarbons (CFCs), an indicator of young groundwater, were analyzed in samples collected from 13 wells ranging in depth from 20 to 700 ft in Eagle Valley from 2002–2008. Table 3 shows that water from the wells contained concentrations of CFCs such that each has a fraction of modern water recharged less than about 50 years ago. A more specific age date is not reported because no other forms of age-dating (such as tritium, carbon-14) were conducted to interpret a more refined recharge date.

Carson Valley

Depth to groundwater is generally deeper to the east and west, near the mountain ranges, and shallower in the center of Carson Valley. The shallow groundwater table of about 5 ft below land surface along the center of the valley is maintained by infiltration of Carson River water that is diverted across the valley floor through canals, ditches, and flood-irrigated fields (Maurer and Peltz, 1994, sheet 2). Beneath alluvial fans to the west, depth to water is greater than 200 ft within 1 mi of the Carson Range, and groundwater moves eastward (fig. 7). Depth to water beneath alluvial fans to the east is about 200 ft within 3 mi of the Pine Nut Mountains, and groundwater moves westward (Maurer and Peltz, 1994, sheet 2). Groundwater, therefore, moves generally toward the Carson River (fig. 7) and then continues northward parallel to the river (Berger and Medina, 1999).

Samples collected from seven wells in Carson Valley in 2003 were analyzed for CFCs. Samples from all of the wells contained concentrations of CFCs such that each has a fraction of its water recharged less than about 50 years ago (table 3). A more specific age date is not reported because no other forms of age-dating were conducted to interpret a more refined recharge date. The presence of such young groundwater indicates relatively rapid infiltration and downward movement from the land surface, and the potential for any contaminants in the water to move deeper into the aquifer.

Although groundwater exists under both confined and unconfined conditions in Carson Valley, no single confining layer extends across the entire valley (Covey and others, 1996). Rather, the confining layers occur mainly as scattered, discontinuous clay beds, 30 to 70 ft thick, at a depth of 200 to 300 ft. Artesian conditions exist on the west side of the valley, although at shallower depths of about 100 ft (Maurer and Berger, 2006).



Base compiled from U.S. Geological Survey digital data, 1:100,000 scale, 1977, 1978
National Elevation Data 1:24,000 scale, 2005
Albers Equal-Area Conic Projection, standard parallels 29°30', 45°30', central meridian 119°45'

Figure 6. Water-level altitudes and general direction of groundwater flow in Eagle Valley, Nevada, in (*A*) 1964 and (*B*) 2001.

Table 3. Designation of groundwater age in selected wells in Eagle and Carson Valleys, Nevada.

[Modern, groundwater sample contained chlorofluorocarbons at concentrations that indicate a fraction of modern water recharged less than about 50 years ago]

Station identifier	Well depth (feet)	Sample date	Water age
Eagle Valley			
391030119480701	185	05-28-2002	Modern
390943119474801	108	06-26-2002	Modern
391110119460601	98	05-13-2002	Modern
391110119460602	20	05-13-2002	Modern
390834119450701	28	06-11-2002	Modern
390708119450301	140	08-29-2006	Modern
391127119442501	32	08-29-2006	Modern
391231119442901	238	10-15-2003	Modern
391231119442903	130	08-31-2006	Modern
391111119481901	117	07-07-2003	Modern
390637119472301	312	07-02-2003	Modern
390637119472303	120	07-02-2003	Modern
391014119450701	700	07-29-2008	Modern
Carson Valley			
385606119412201	245	07-15-2003	Modern
385304119460601	27	05-30-2003	Modern
385612119464101	20.5	05-30-2003	Modern
385655119413101	200	07-09-2003	Modern
385815119500301	16	05-01-2003	Modern
385816119482401	21	05-02-2003	Modern
390315119403201	64	07-15-2003	Modern

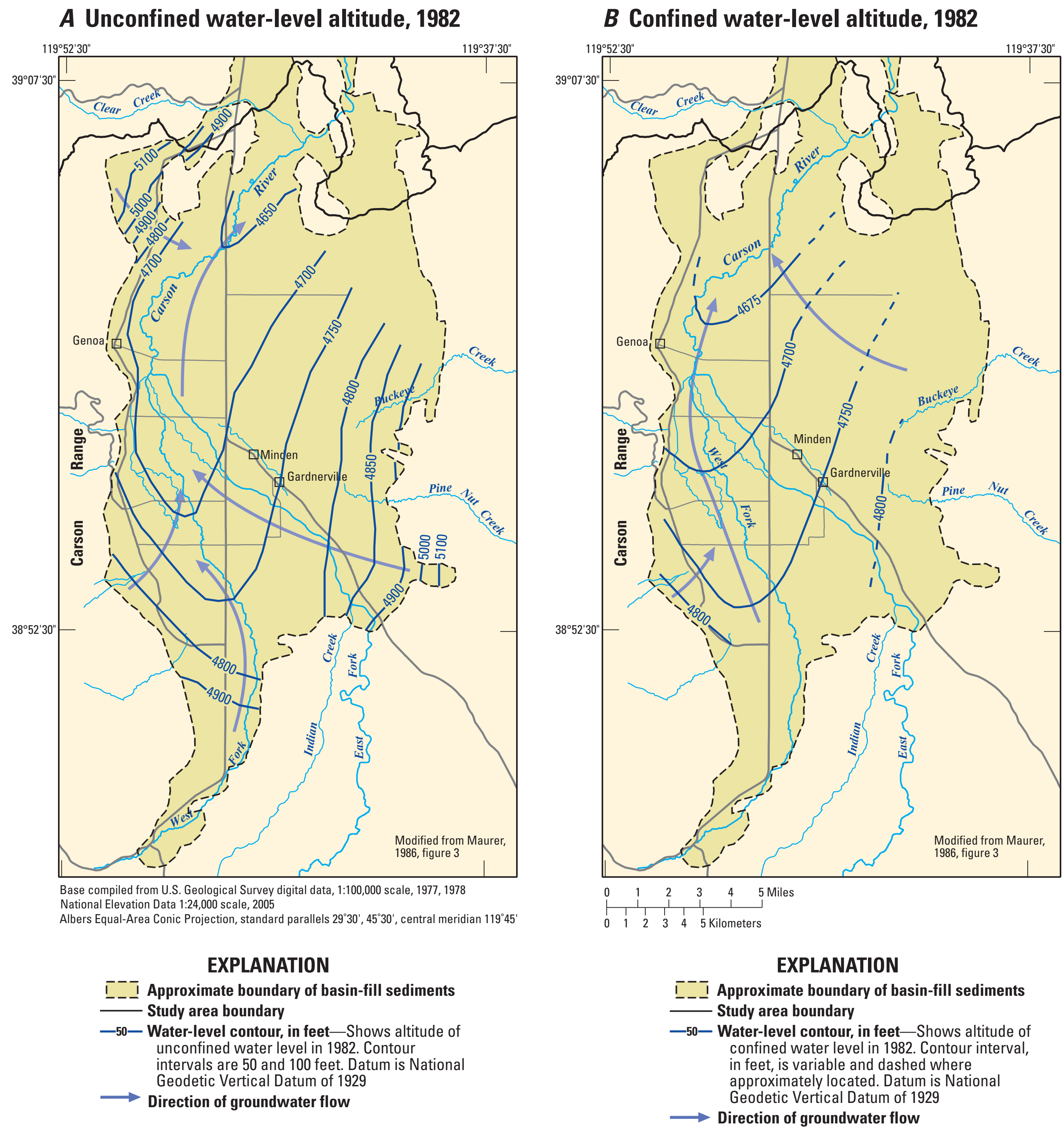


Figure 7. Water-level altitudes and general direction of groundwater flow under (*A*) unconfined conditions and (*B*) confined conditions in Carson Valley, Nevada and California, 1982.

Effects of Natural and Human Factors on Groundwater Quality

The occurrence and concentrations of contaminants in water within the basin-fill aquifer system in the Eagle and Carson Valleys are influenced by both natural and human-related factors. The movement of water through geologic materials of the basin coupled with movement of water from the land surface to the aquifer results in elevated concentrations of some constituents and compounds in groundwater. Water diverted from the Carson River, which enters the groundwater system by infiltration along irrigation canals and ditches and as excess irrigation water, as well as seepage from septic-tank systems, are new sources of recharge to the basin-fill aquifer that accompanied development. Although the shallow aquifer intercepts, stores, and transports some of this water, with a consequent increase in the concentration of nitrate and other dissolved constituents within that aquifer, the concern is for the deeper aquifer, which is a source of drinking-water supply in this growing residential area. Groundwater withdrawals also can induce the movement of poorer quality water laterally and from underlying strata into the area and depth interval of the basin-fill aquifer used for water supply in the valley.

The following description of groundwater quality in Eagle and Carson Valleys is based primarily on the results of analyses of samples collected from about 30 wells (shallower monitoring and domestic wells and deeper wells typically used for public supply) in each valley from 1987 to 1990 as part of the U.S. Geological Survey's National Water-Quality Assessment (NAWQA) Program (fig. 8; Welch, 1994). Other data used in the interpretation of water quality were collected prior to the NAWQA sampling and can be found in Garcia (1989). A report by Schaefer and others (2007) focuses on the effect of urbanization on water quality in the principal aquifers in Eagle Valley.

General Water-Quality Characteristics and Natural Factors

Generally, the waters in the principal aquifers in Eagle and Carson Valleys are dilute, with dissolved-solid concentrations less than 1,000 mg/L, and are acceptable for drinking on the basis of standards set by the U.S. Environmental Protection Agency (2008; each time a drinking-water standard is mentioned in this section, it denotes this citation). The chemical characteristics of groundwater on the west side of Eagle and Carson Valleys most likely reflect the composition of the minerals in the igneous rocks and the natural geochemical reactions between the water and those minerals. Groundwater in an isolated area in northeastern Carson Valley has elevated concentrations of sulfate (greater than 50 mg/L) and fluoride (0.8 to 1.8 mg/L) and a higher proportion of sodium than does groundwater in the rest of the valley. This may be due to low-temperature reactions of the water with aquifer sediments derived from local metamorphic rocks that include marine evaporites containing gypsum.

Dissolved oxygen was detected at concentrations less than 1 mg/L in 6 of 37 (about 16 percent) wells on the western sides of Eagle and Carson Valleys, and in 9 of 18 wells (50 percent) on the eastern sides of the valleys (Welch, 1994, p. 43). The pH in groundwater in both valleys ranged from approximately 6.5 to greater than 8 pH units. Oxidation-reduction conditions in the basin-fill aquifer in Eagle Valley generally are controlled by the chemistry of the water entering the aquifer from the surrounding mountain blocks, with the most oxygenated water near recharge areas around the edges of the basin and less oxygenated water near the center of the basin (fig. 9; Schaefer and others, 2007). Chloride concentrations in groundwater along the Carson Range were lower (4 to 6 mg/L) than in water at sites farther east into the valleys (11 to 64 mg/L) (Welch, 1994, p. 41). This higher range in chloride to the east may be due to the interaction of groundwater with weathered granitic bedrock in that area.

Few groundwater samples collected in Carson and Eagle Valleys by NAWQA in 1988–89 exceeded the drinking-water standard of 30 µg/L for uranium (1 of 26 wells in Carson Valley and 4 of 23 wells in Eagle Valley) (Welch, 1994, table 11). The highest measured concentrations generally were along the western edges of Eagle and Carson Valleys. In these areas, uranium-222 seems to be concentrated on iron and manganese oxides that coat grains and fractures in granitic bedrock and in organic matter within the basin-fill sediments. Arsenic exceeded the drinking-water standard in less than 1 percent of samples collected from wells completed in the principal aquifer throughout Eagle and Carson Valleys (Welch, 1994, p. 58). Water samples from most of the sites exceeded the proposed drinking-water standard for radon of 300 pCi/L (97 of 103 sites; Welch, 1994, p. 72).

Potential Effects of Human Factors

Selected chemical constituents and organic compounds detected in groundwater in Eagle and Carson Valleys and the processes or sources that affect their presence and concentrations are summarized in table 4. Concentrations of dissolved solids in water in Eagle Valley's principal aquifer range from about 100 mg/L to more than 500 mg/L, with an average of about 270 mg/L (Anning and others, 2007). The use of treated sewage effluent to irrigate a golf course in the northeastern part of Eagle Valley has caused locally higher concentrations of dissolved solids in groundwater in that part of the valley (Anning and others, 2007). Sewage effluent used as recharge was found to be one of the most likely sources of groundwater contamination among all sources of recharge in Eagle Valley (Maurer and Thodal, 2000, p. 42).

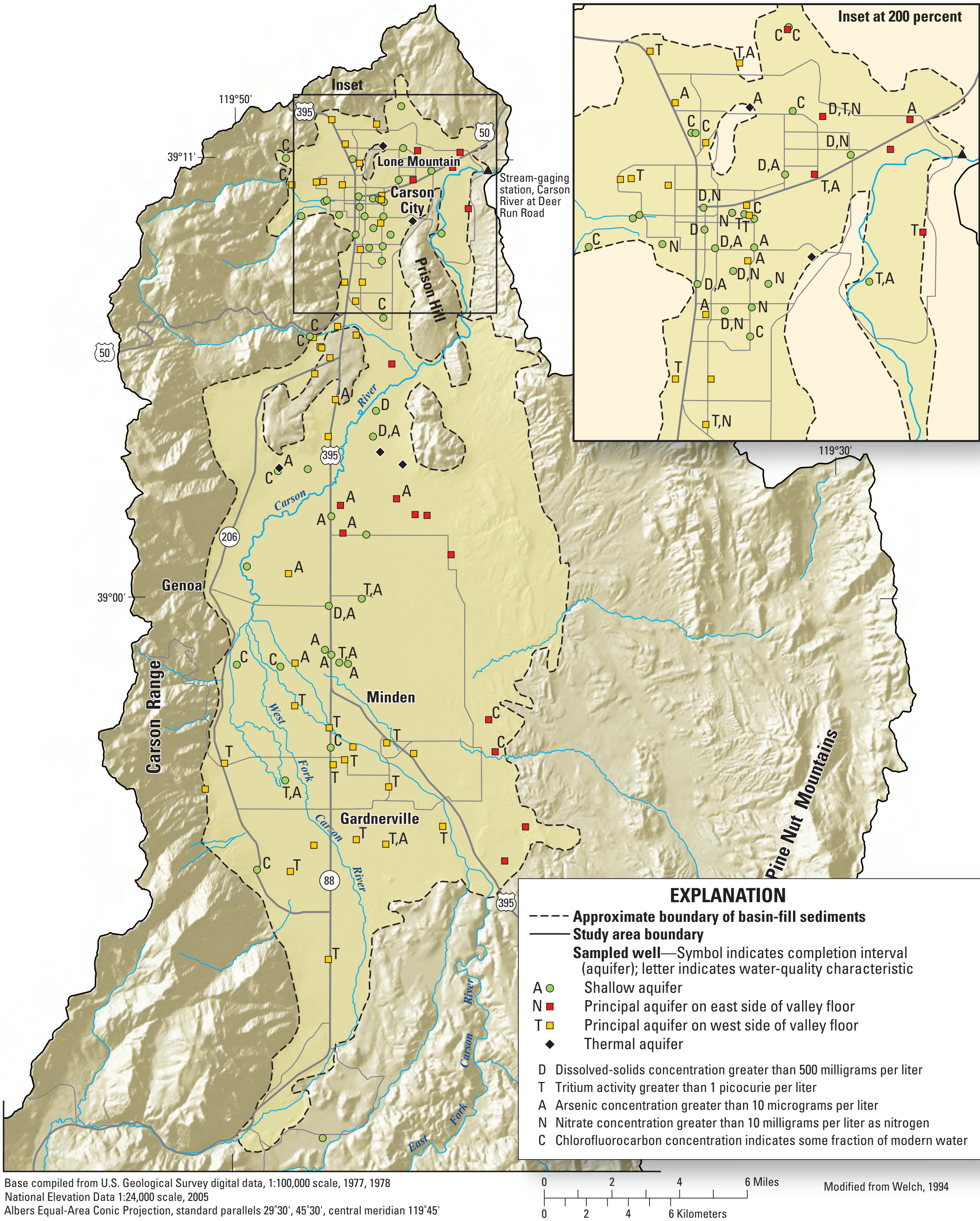


Figure 8. Location and completion interval (aquifer) of wells sampled in Eagle and Carson Valleys, Nevada, by the NAWQA Program.

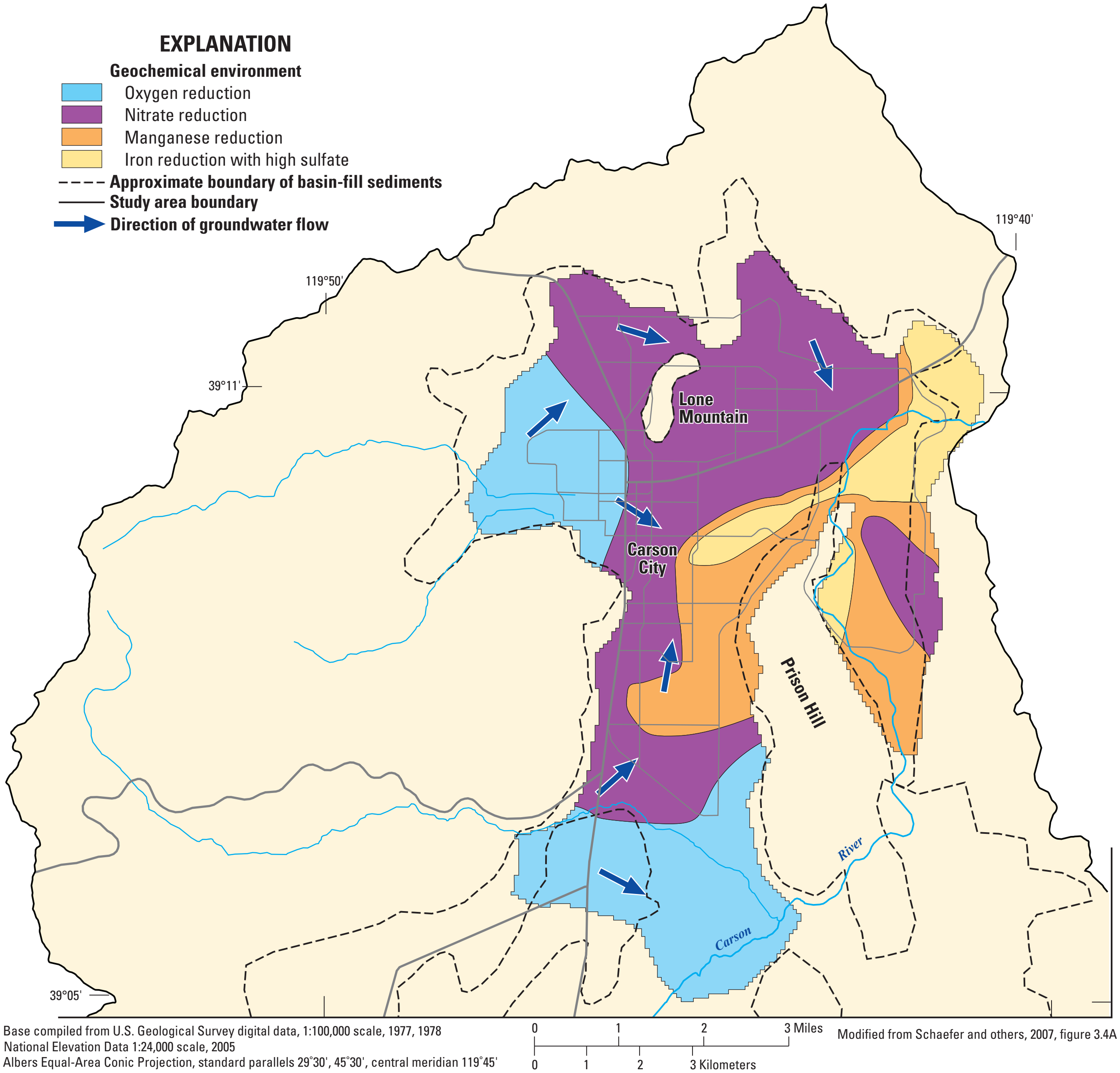


Figure 9. Oxidation-reduction classification zones in Eagle Valley, Nevada.

Table 4. Summary of selected constituents in groundwater in Eagle and Carson Valleys, Nevada, and sources or processes that affect their presence or concentration.

[All data from Welch (1994) unless otherwise noted. mg/L, milligrams per liter; n/a, not applicable]

Constituent	General location	Median value or detections	Possible sources or processes
		EAGLE VALLEY	
		Shallow aquifers	
Dissolved solids	Western and central basin	434 mg/L	Evapotranspiration and dissolution
Sulfate	Western basin	57 mg/L	Associated with altered consolidated rocks
Nitrate	West-central basin	0.17 mg/L	Treated wastewater, leaky sewer pipes, septic systems
Volatile organic compounds	Near urban areas	10	Point sources including underground gasoline tanks and solvents from repair shops and dry cleaners
Pesticides	Near irrigated land	9	Irrigated crop fertilizers
		Principal aquifers	
Dissolved solids	Eastern basin	160 mg/L	Evapotranspiration and dissolution
Sulfate	Eastern basin	10 mg/L	Associated with altered consolidated rocks
Nitrate	North-western basin	0.49 mg/L	Natural sources, fertilizers, treated wastewater, leaky sewer pipes, septic systems
Volatile organic compounds	Northern basin	[1]5	n/a
Pesticides	North-eastern basin	[1]2	n/a
		CARSON VALLEY	
		Shallow aquifers	
Dissolved solids	North-western basin	451 mg/L	Lawn irrigation, agricultural runoff, and sewage effluent
Sulfate	North-western basin	54 mg/L	Associated with altered consolidated rocks
Nitrate	North-western basin	0.36 mg/L	Natural sources, fertilizers, treated wastewater, leaky sewer pipes, septic systems
		Principal aquifers	
Dissolved solids	Eastern basin	179 mg/L	Evapotranspiration and dissolution
Sulfate	Eastern basin	25 mg/L	Associated with altered consolidated rocks
Nitrate	West-central basin	0.97 mg/L	Natural sources, fertilizers, treated wastewater, leaky sewer pipes, septic systems
Volatile organic compounds	n/a	0	n/a
Pesticides	n/a	0	n/a

[1] From Berris and others (2003).

Groundwater contamination as a result of human activity is more common (and commonly detected) in the shallow rather than the deeper (principal) aquifer, although nitrate concentrations exceeded the drinking-water standard in water from 3 percent of sampling sites (wells) in the principal aquifer throughout Eagle and Carson Valleys (Welch, 1994, p. 58). Those sites with elevated nitrate concentrations were in areas in which septic systems were in use and may have been leaking to deeper groundwater (Welch, 1994; Rosen, 2003).

Shallow aquifers in Eagle and Carson Valleys contained arsenic, fluoride, and nitrate concentrations that exceeded drinking-water standards, and concentrations of dissolved solids, iron, manganese, and sulfate all locally exceeded secondary drinking-water standards (Welch, 1994). The drinking-water standard for arsenic was exceeded in samples from 3 of 39 sampling sites, and the standards for fluoride and nitrate were exceeded in samples from 2 of 40 and 41 sites, respectively (Welch, 1994, p. 58–60). Manganese had the most common exceedance of the secondary standard of 0.1 mg/L, in samples from 21 of 40 sites, followed by iron, which exceeded the secondary standard of 0.6 mg/L in samples from 8 of 40 sites (Welch, 1994, p. 60). Elevated concentrations of manganese and iron may be a result of irrigation water wetting previously dry sediments that have oxide coatings. The rise in water level resulting from excess irrigation water may have allowed the dissolution of organic matter, which reacted with oxygen from the recharge water and in turn the oxide coating on the sediments.

Urban development in Eagle and Carson Valleys has been accompanied by an increase in use of, and amounts of, fertilizers, pesticides, and other manmade chemicals applied to the land. These chemicals can enter and degrade the quality of the shallow aquifer and move downward through the groundwater system, particularly in areas with shallow depth to water. Eagle Valley had 10 and 5 detections of a volatile organic compound (VOC) in water from shallow and deep wells, respectively, and 2 and 9 detections of a pesticide in water from shallow and deep wells, respectively (Berris and others, 2003). Volatile organic compounds were detected most frequently in wells near urban areas and pesticides in wells near irrigated areas. The most frequently detected VOC was trichloromethane, better known as chloroform. Chloroform, a byproduct of the reaction of organic material in source water with chlorine added during treatment, can potentially be found in groundwater as a result of infiltration of treated wastewater used to irrigate lawns and golf courses (Rosen and others, 2006). The herbicide atrazine and its degradation product, deethylatrazine, were the most frequently detected pesticide compounds. Atrazine is commonly used to control broadleaf and grassy weeds.

Summary

Eagle and Carson Valleys are hydraulically connected adjacent basins along the eastern front of the Sierra Nevada Range in northwestern Nevada and east-central California. The Carson River bisects Carson Valley from south to north and acts as a groundwater discharge zone for Eagle Valley as the river skirts its southern border. Precipitation that falls mostly as snow in the mountains recharges the basin-fill aquifers by infiltration within the mountain blocks and along the mountain fronts. Under natural conditions, groundwater discharges as evapotranspiration in the central part of the basins. The Carson River acts as both a source and a sink for groundwater in Carson Valley. In both valleys, clay lenses that commonly form confining layers are discontinuous and groundwater occurs under confined and unconfined conditions. Depth to water is typically deeper along the basin margins than near the basin center of the basin.

Both Eagle and Carson Valley have historically been agricultural basins, and although Carson Valley still supports agriculture, urban development has resulted in a reduction in irrigated acreage and a substantial increase in areas of impervious surfaces. Consequently, groundwater discharge by evapotranspiration has been reduced. Limited surface-water supplies have forced the use of groundwater as the main source of municipal supply and groundwater discharge in both valleys.

Water in the principal aquifers in Eagle and Carson Valleys is fairly dilute, and with few exceptions meets established quality standards for drinking water. The effects of urbanization on groundwater quality are most apparent in the shallow aquifer. Wastewater effluent from the Lake Tahoe basin is applied as irrigation water in Carson Valley and treated wastewater in Eagle Valley is used to irrigate golf courses and parks. Chlorine used in the treatment of wastewater can react with organic material in the source water to create chloroform before application to the land surface, and, as a result, chloroform is the most frequently detected volatile organic compound in samples of groundwater. Infiltration of treated wastewater has degraded the quality of water within the shallow aquifer, which poses the risk of consequent downward movement into the principal aquifer. Elevated levels of nitrate also were detected in water in the principal aquifers throughout Eagle and Carson Valleys in areas where septic systems were in use and may have been leaking to the deeper aquifers.

References Cited

Anning, D.W., Bauch, N.J., Gerner, S.J., Flynn, M.E., Hamlin, S.N., Moore, S.J., Schaefer, D.H., Anderholm, S.K., and Spangler, L.E., 2007, Dissolved solids in basin-fill aquifers and streams in the southwestern United States: U.S. Geological Survey Scientific Investigations Report 2006–5315, 168 p. Available at http://pubs.usgs.gov/sir/2006/5315/.

Arteaga, F.E., 1982, Mathmatical model analysis of the Eagle Valley ground-water basin, west-central Nevada: U.S. Geological Survey Open-File Report 80–1224, 55 p.

Arteaga, F.E., 1986, Mathematical model analysis of the Eagle Valley ground-water basin, west-central Nevada: State of Nevada Department of Conservation and Natural Resources Division of Water Resources Water Resources Bulletin 45. Available at http://water.nv.gov/home/publications/bulletins.cfm.

Berger, D.L., and Medina, R.L., 1999, Spatial ground-water data base in Carson Valley, Douglas County, Nevada, and Alpine County, California, development and documentation: U.S. Geological Survey Water-Resources Investigations Report 99–4188.

Berris, S.N., Crompton, J.E., Joyner, J.D. and Ryan, R., 2003, Water resources data, Nevada, water year 2002: U.S. Geological Survey Water Data Report NV–02–1. Available at http://pubs.usgs.gov/wdr/WDR-NV-02-1/.

Covay, K.J., Banks, J.M., Bevans, H.E., Watkins, S.A., 1996, Environmental and hydrologic settings of the Las Vegas Valley area and the Carson and Truckee River basins, Nevada and California: U.S. Geological Survey Water-Resources Investigations Report 96–4087, 72 p.

Dangberg, G., 1972, Carson Valley: historical sketches of Nevada's first settlement: Carson Valley Historical Society, Minden, Nevada, 144 p.

Garcia, K.T., 1989, Ground-water quality in Douglas County, western Nevada: U.S. Geological Survey Water-Resources Investigations Report 87–4269, 107 p.

Garcia, K.T., and Carman, R.L., 1986, Water quality characteristics and nutrient and suspended-sediment loads, Carson River and Truckee Canal, western Nevada, water year 1980: U.S. Geological Survey Water-Resources Investigations Report 85–4147, 107 p.

Glancy, P.A. and Katzer, T.L., 1976, Water-resources appraisal of the Carson River basin, western Nevada: U.S. Geological Survey Open-File Report 75–179, 177 p.

Jeton, A.E, and Maurer, D.K., 2007, Precipitation and runoff simulations of the Carson Range and Pine Nut Mountains, and updated estimates of ground-water inflow and the ground-water budgets for basin-fill aquifers of Carson Valley, Douglas County, Nevada, and Alpine County, California: U.S. Geological Survey Scientific Investigations Report 2007–5205, 57 p. Available at http://pubs.usgs.gov/sir/2007/5205/.

Lico, M.S., 1998, Quality of ground water beneath urban and agricultural lands in Las Vegas Valley and the Carson and Truckee River Basins, Nevada—Implications for water supply: U.S. Geological Survey Water-Resources Investigations Report 97–4259, 24 p.

Maurer, D.K, 1986, Geohydrology and simulated response to groundwater pumpage in Carson Valley, a river-dominated basin in Douglas County, Nevada, and Alpine County, California: U.S. Geological Survey Water-Resources Investigations Report 86–4328, 109 p.

Maurer, D.K. and Peltz, L.A., 1994, Potential for, and possible effects of, artificial recharge in Carson Valley, Douglas County, Nevada: U.S. Geological Survey Water-Resources Investigations Report 94–4126, 87 p.

Maurer, D.K., Berger, D.E., and Prudic, D.E., 1996, Subsurface flow to Eagle Valley from Vicee, Ash, and Kings Canyons, Carson City, Nevada, estimated from Darcy's Law and the chloride-balance method: U.S. Geological Survey Water-Resources Investigations Report 96–4088, 74 p.

Maurer, D.K. and Berger, D.E., 1997, Subsurface flow and water yield from watersheds tributary to Eagle Valley hydrographic area, west-central Nevada: U.S. Geological Survey Water-Resources Investigations Report 97–4191, 56 p.

Maurer, D.K. and Thodal, C.E., 2000, Quantity and chemical quality of recharge, and updated water budgets, for the basin-fill aquifer in Eagle Valley, western Nevada: U.S. Geological Survey Water-Resources Investigations Report 99–4289, 46 p.

Maurer, D.K., Lopes, T.J., Medina, R.L. and Smith, J.L., 2004, Hydrogeology and hydrologic landscape regions of Nevada: U.S. Geological Survey Scientific Investigations Report 2004–5131, 41 p. Available at http://pubs.usgs.gov/sir/2004/5131/.

Maurer, D.K. and Berger, D.E., 2006, Water budgets and potential effects of land- and water-use changes for Carson Valley, Douglas County, Nevada, and Alpine County, California: U.S. Geological Survey Scientific Investigations Report 2006–5305, 64 p. Available at http://pubs.usgs.gov/sir/2006/5305/.

Maxey, G.B., and Eakin, T.E., 1949, Ground water in White River Valley, White Pine, Nye and Lincoln Counties, Nevada: Nevada State Engineer Water Resources Bulletin 8, 59 p. Available at http://water.nv.gov/home/publications/bulletins.cfm.

McKinney, T.S., and Anning, D.W., 2009, Geospatial data to support analysis of water-quality conditions in basin-fill aquifers in the southwestern United States: U.S. Geological Survey Scientific Investigations Report 2008–5239. Available at http://pubs.usgs.gov/sir/2008/5239/.

Moore, J.G., 1969, Geology and mineral deposits of Lyon, Douglas, and Ormsby Counties, Nevada: Nevada Bureau of Mines Bulletin 75, 45 p.

National Oceanic and Atmospheric Administration, 2002, Monthly station normals of temperature, precipitation, and heating and cooling degree days, 1971–2000, Climatology of the United States, No. 81, Nevada: National Climatic Data Center, Asheville, North Carolina, 26 p.

Nevada Division of Water Resources, 1999, Nevada State Water Plan, part 3, section 1, water supply and allocation, accessed February 28, 2010 at http://water.nv.gov/WaterPlanning/wat-plan/con-main.cfm.

Nevada State Demographer's Office, accessed September 11, 2006 at http://www.nsbdc.org/what/data_statistics/demographer/pubs/estimates/.

Oak Ridge National Laboratory, 2005, LandScan Global Population Database, accessed September 2006 at http://www.ornl.gov/landscan/.

Rosen, M.R., 2003, Trends in nitrate and dissolved-solids concentrations in ground water, Carson Valley, Douglas County, Nevada, 1985–2001: U.S. Geological Survey Water-Resources Investigation Report 03–4152, 6 p.

Rosen, M.R., Schaefer, D.H., Toccalino, P.L. and Delzer, G.C., 2006, Occurrence of anthropogenic compounds in ground water and finished water of community water systems in Eagle and Spanish Springs Valleys, Nevada, 2002–2004: U.S. Geological Survey Scientific Investigations Report 2006–5210, 31 p. Available at http://pubs.usgs.gov/sir/2006/5210/.

Schaefer, D.H., Green, J.M., and Rosen, M.R., 2007, Section 3. Hydrogeologic settings and ground-water flow simulations of the Eagle Valley and Spanish Springs regional study areas, Nevada, *in* Paschke, S.S., ed., Hydrogeologic settings and ground-water flow simulations for regional studies of the transport of anthropogenic and natural contaminants to public-supply wells—Studies begun in 2001: U.S. Geological Survey Professional Paper 1737–A, p. 3-1 to 3-33. Available at http://pubs.usgs.gov/pp/2007/1737a/.

Simpson, J.H., 1876, Report of Explorations Across the Great Basin in 1859: Government Printing Office, Washington D.C.

Stewart, J.H., 1980, Geology of Nevada: Nevada Bureau of Mines and Geology Special Publication 4, 135 p.

Thodal, C.E., 1996, Trends in chloride, dissolved-solids, and nitrate concentrations in ground water, Carson Valley and Topaz Lake areas, Douglas County, Nevada, 1959–88: U.S. Geological Survey Water-Resources Investigations Report 95–4254, p. 32.

Toll, D.W., 2008, Complete Nevada Traveler: Gold Hill Publishing Co., 256 p., accessed May 26, 2010 at http://www.nevadaweb.com/cnt/.

Trexler, D.T., 1977, Geologic map, Carson City quadrangle: Nevada Bureau of Mines and Geology Urban Map Series, Carson City folio, Map 1Ag, scale 1:24,000.

Trexler, D.T., Koenig, B.A., Flynn, T., and Bruce, J.L., 1980, Assessment of geothermal resources of Carson-Eagle Valleys and Big Smoky Valley, Nevada—First annual report, May 1, 1979–May 30, 1980: Nevada Bureau of Mines and Geology and University of Nevada, Reno, report no. DOE/NV/10039–2, 162 p.

Truner, R.M., and Bawic, W.J., 1996, Digital map of Nevada at scale of 1:500,000, digital dataset for Nevada geology.

U.S. Environmental Protection Agency, 2008, List of drinking water contaminants & their MCLs, accessed November 11, 2008 at http://www.epa.gov/safewater/contaminants/index.html.

U.S. Geological Survey, 2003, Multi-Resolution Land Characteristics (MRLC) Consortium, National Land Cover Database (NLCD 2001), accessed February 2007 at http://www.mrlc.gov/.

Welch, A.H., 1994, Ground-water quality and geochemistry in Carson and Eagle Valleys, western Nevada and eastern California: U.S. Geological Survey Open-File Report 93–33, 99 p.

Western Regional Climate Center, 2003, 1971–2000 Climate summary, accessed December 1, 2010 for Minden at http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?nv5191.

Worts, G.F. Jr. and Malmberg, G.T., 1966, Hydrologic appraisal of Eagle Valley, Ormsby County, Nevada, Water Resources—Reconnaissance Series, Report 39. Available at http://water.nv.gov/home/publications/recon.cfm.

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