Hydrogeologic Settings and Ground-Water Flow Simulations of the Eagle Valley and Spanish Springs Valley Regional Study Areas, Nevada

By Donald H. Schaefer, Jena M. Green, and Michael R. Rosen

Section 3 of

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

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Abstract

The transport of anthropogenic and natural contaminants to public-supply wells was evaluated in the Eagle and Spanish Springs Valleys, Nevada, as part of the U.S. Geological Survey National Water-Quality Assessment Program. The valley-fill aquifers in the Eagle and Spanish Springs Valleys regional study areas are representative of the Basin and Range basin-fill aquifers, are important sources of water for agricultural irrigation and public water supply, and are susceptible and vulnerable to contamination. Three-dimensional, steady-state ground-water flow models were developed for the Basin and Range basin-fill aquifers in each of the valleys and calibrated to average conditions for the period from 1997 to 2001. The calibrated models and advective particle-tracking simulations were used to compute ground-water flow paths, areas contributing recharge, and traveltimes from recharge areas for public-supply wells. The Eagle Valley ground-water flow model is a two-layer, steady-state finite-difference model modified from a previous finite-element model of the basin, and the Spanish Springs Valley ground-water flow model is a three-layer, steady-state finite-difference model modified from a previous two-layer finite-difference model of the basin. Modeling results for the Eagle Valley indicate ground-water recharge is primarily from streams flowing into the basin from the surrounding mountains (mountain-front recharge) and from subsurface flow from the adjacent mountains (mountain-block recharge); ground-water discharge is primarily to public-supply wells and evapotranspiration. Modeling results for the Spanish Springs Valley indicate ground-water recharge is primarily from precipitation, irrigation, and canal leakage; ground-water discharge is primarily to public-supply wells and evapotranspiration. Particle-tracking simulations for all 20 public-supply wells in Eagle Valley indicate that areas contributing recharge extend from the pumping wells in the valley to areas of mountain-block and mountain-front recharge along the edges of the basin with traveltimes from recharge areas on the order of 30 to 50 years. Particle-tracking results for all eight public-supply wells in Spanish Springs Valley were similar to those in the Eagle Valley with areas contributing recharge extending to the mountain front but with slightly greater traveltimes on the order of 50 to 100 years. In both the Eagle and Spanish Springs Valley models, areas contributing recharge extended to the general-head boundary cells along the mountain-front boundary of the alluvial aquifer indicating mountain-front and mountain-block recharge are important sources of water for the public-supply wells.

Introduction

Two regional study areas within the Nevada Basin and Range study unit of the U.S. Geological Survey National Water-Quality Assessment (NAWQA) Program were included in the study of the transport of anthropogenic and natural contaminants to public-supply wells (TANC). The first TANC regional study area is Eagle Valley, which includes Carson City and is part of the Carson River Basin. The second TANC regional study area is Spanish Springs Valley, north of Sparks, which is in the Truckee River Basin. The study areas are within the Basin and Range basin-fill aquifers, which are important water sources for agricultural irrigation and drinking-water supply throughout the region (fig. 3.1).

Purpose and Scope

The purpose of this Professional Paper section is to present the hydrogeologic setting of the Eagle Valley and Spanish Springs Valley regional study areas. The section also documents the setup and calibration of steady-state regional ground-water flow models for the study areas. Ground-water flow characteristics, pumping-well information, and water-quality data were compiled from existing data to develop a conceptual understanding of ground-water conditions in the study area. A two-layer steady-state ground-water flow model of the Eagle Valley basin-fill aquifer and a three-layer steady-state ground-water flow model of the Spanish Springs Valley basin-fill aquifer were developed and calibrated to average conditions for the period from 1997 to 2001. The 5-year

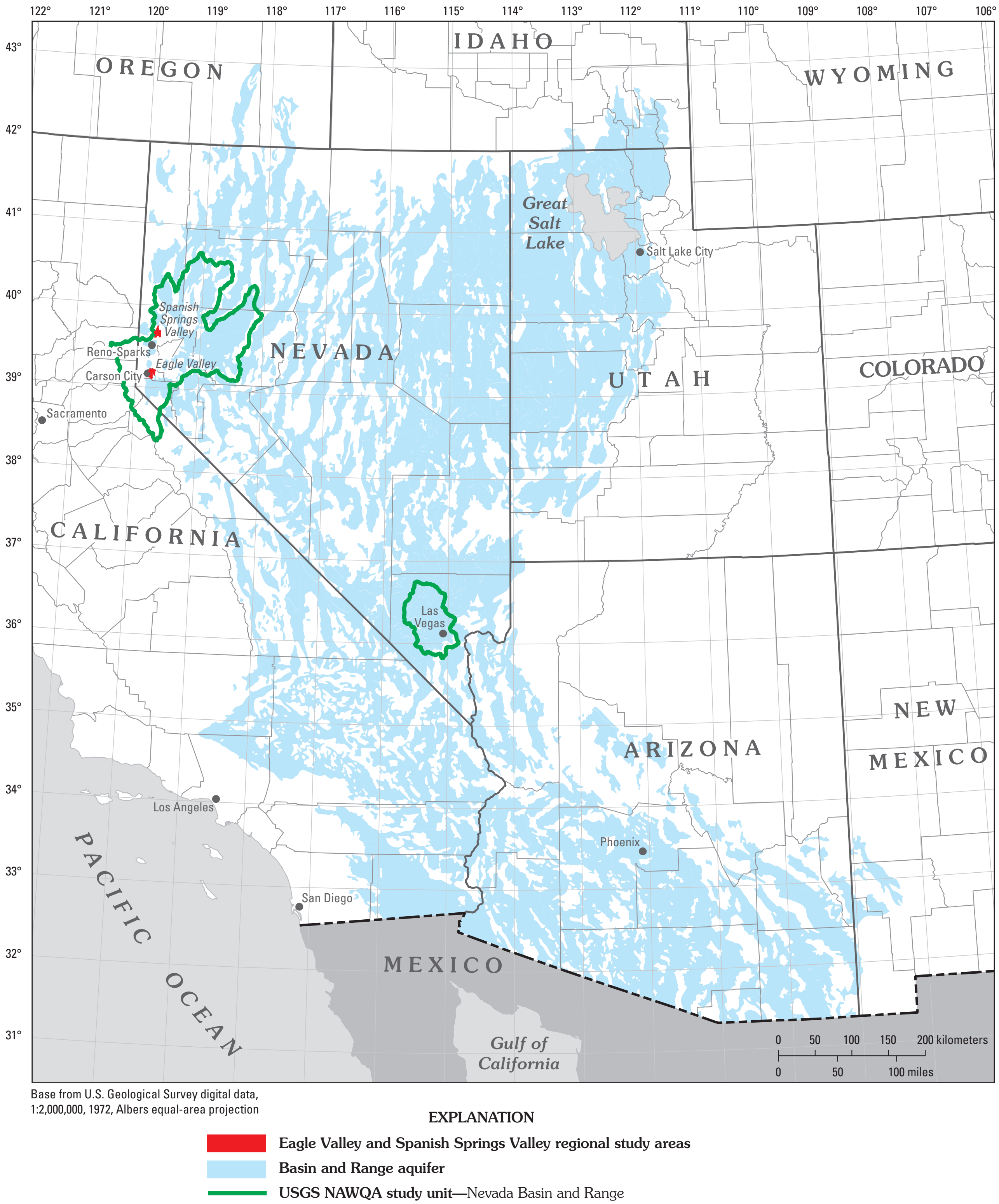


Figure 3.1. Location of the Eagle Valley and Spanish Springs Valley regional study areas within the Basin and Range basin-fill aquifers.

period 1997–2001 was selected for data compilation and modeling exercises for all TANC regional study areas to facilitate future comparisons between study areas. The calibrated ground-water flow models and associated particle tracking were used to simulate advective ground-water flow paths and to delineate areas contributing recharge to selected public-supply wells. Ground-water traveltimes from recharge to public-supply wells, oxidation-reduction (redox) conditions along flow paths, and presence of potential contaminant sources in areas contributing recharge were tabulated into a relational database as described in Section 1 of this Professional Paper. This section provides the foundation for future ground-water susceptibility and vulnerability analyses of the study areas and comparisons among regional aquifers.

Study Area Description

The Nevada Basin and Range NAWQA study unit includes the Truckee and Carson River Basins in northwestern Nevada and northeastern California and the Las Vegas Valley area in southeastern Nevada (fig. 3.1). These two areas represent many of the diverse environments found in the Basin and Range physiographic province, which is characterized by high mountains surrounding valleys underlain by thick, unconsolidated deposits (Covay and others, 1996). The Nevada Basin and Range study unit is located in the Basin and Range basin-fill aquifers, which are ranked fourth in total water use of the 62 principal aquifers in the United States (Maupin and Barber, 2005). The study areas were chosen because the aquifers are used extensively for public water supply, are susceptible and vulnerable to contamination, and are representative of the Basin and Range basin-fill principal aquifer (table 3.1).

Two study areas within the Nevada Basin and Range study unit were included in the TANC regional study. The first regional study area is the Eagle Valley, which includes Carson City and is part of the Carson River Basin (fig. 3.2*A*). The population of Carson City is greater than 50,000 (U.S. Census Bureau, 2003), and the area has experienced a steady population increase since the 1970s. The second regional study area is the Spanish Springs Valley, north of Sparks, which is in the Truckee River Basin (fig. 3.2*B*). The population of the Spanish Springs Valley has grown substantially since the early 1980s, and this growth has affected water quality in the basin (Seiler and others, 1999). The two areas were chosen for TANC regional studies because they have similar hydrologic and geologic characteristics, different rates of population increase, and different potential sources of ground-water contaminants.

Topography and Climate

The Eagle Valley is a semiarid basin in the west-central part of Nevada. The valley is bordered on the west by the Carson Range of the Sierra Nevada, on the north by the Virginia Range, on the east by Prison Hill and the Pine Nut Mountains and on the south by Carson Valley (fig. 3.2*A*). The floor of the Eagle Valley averages about 1,433 m above NAVD88, and the summit of Prison Hill is about 1,737 m. The Virginia Range is about 2,438 m in altitude; and the Carson Range is greater than 2,804 m in altitude (Maurer and others, 1996).

The Spanish Springs Valley is bounded on the west by Hungry Ridge and its unnamed southern extension with summits approaching 1,829 m. The northern boundary separating the Spanish Springs Valley from Warm Springs Valley is a narrow (less than 805 m) topographic divide lying between bedrock outcrops of the Hungry Ridge and the Pah Rah Range to the east (Berger and others, 1997). The southern boundary is bedrock and includes a low alluvial divide where an agricultural ditch (the Orr Ditch) enters and an agricultural drain (the North Truckee drain) exits the study area.

Climate in both valleys is similar, although the differing western boundaries (higher Carson Range and lower Hungry Ridge) affect precipitation in the valleys. Annual precipitation on the floor of the Eagle Valley averages about 25.4 cm (Arteaga and Durbin, 1979). Average annual precipitation along the crest of the Carson Range is about 96.5 cm. The Virginia Range receives much less precipitation than the Carson Range: average annual precipitation is slightly more than 35.6 cm (Arteaga and Durbin, 1979). In both ranges, most precipitation falls as rain or snow during November through April. Snow in the Carson Range accumulates to several meters during most winters and melts in early spring to early summer.

Average annual precipitation on the floor of the Spanish Springs Valley is generally less than 20.0 cm. The surrounding mountains receive 22.9 to 27.9 cm of precipitation in an average year, and as much as 33.0 cm of precipitation may fall in the higher altitudes of the Pah Rah Range (VanDenburgh and others, 1973).

Surface-Water Hydrology

One large river, the Carson River, crosses the Eagle Valley, and several streams discharge into the Carson River within the valley (fig. 3.2*A*). The Carson River acts as both a recharge and discharge boundary to the ground-water system on the south and east sides of the basin. The annual mean flow in the Carson River is 11.7 cubic meters per second (m^3/s) at the Carson City gage and 14.2 m^3/s, 11.3 km downstream at the Deer Run Road gage (periods of record 1940–2001 and 1979–2001, respectively (U.S. Geological Survey, 1939–00 and 1978–00). Streams in Ash and Kings Canyons drain the eastern flank of the Carson Range west of Carson City and provide perennial flow into the Eagle Valley during most years. The stream in Vicee Canyon flows downstream from the canyon mouth only during severe storms or during spring snowmelt in years with above-normal precipitation. The only other perennial stream is Clear Creek, which has the largest drainage area (40 km^2) of any stream entering the Eagle Valley. The remaining streams entering Eagle Valley are ephemeral, flowing only occasionally onto the valley floor.

Surface water in the Spanish Springs Valley consists almost entirely of Truckee River water imported by way of the

Table 3.1. Summary of hydrogeologic and ground-water-quality characteristics for the Basin and Range basin-fill aquifers and the Eagle and Spanish Springs Valleys regional study areas, Nevada.

[m, meters; cm/yr, centimeters per year; m^2/d, squared meters per day; m/d, meters per day; ET, evapotranspiration; mg/L, milligrams per liter]

Characteristic	Basin and Range basin-fill aquifers	Eagle and Spanish Springs Valleys regional study areas
	Geography	
Topography	Altitude ranges from about 46 m at Yuma, Arizona to more than 3,048 m at the crest of some mountain ranges (Robson and Banta, 1995).	Eagle Valley floor altitude ranges from 1,410 m to 1,460 m. Spanish Springs Valley floor ranges from about 1,356 m to 1,450 m.
Climate	Arid to semi-arid climate. Precipitation ranges from 10 to 20 cm/yr in basins and 40 to 76 cm/yr in mountains (Robson and Banta, 1995).	Arid climate. Eagle Valley floor precipitation is about 25.4 cm/yr with up to 96.5 cm/yr precipitation in surrounding mountains. Spanish Springs Valley floor precipitation is less than 20.0 cm/yr with up to 33.0 cm/yr in Pah Rah Range.
Surface-water hydrology	Streams drain from surrounding mountains into basins. Basins generally slope toward a central depression with a main drainage that is dry most of the time. Many basins have playas in their lowest depressions. Ground-water discharge to streams can occur in basin depressions. (Planert and Williams, 1995)	Carson River crosses south and east sides of Eagle Valley and is a recharge and discharge boundary. Spanish Springs Valley contains no natural streams, although the Orr Ditch, which imports irrigation water, crosses the valley.
Land use	Undeveloped basins are unused, grazing, and rural residential. Developed basins are urban, suburban and agricultural.	Eagle Valley—Urban, suburban, and rural residential. Spanish Springs Valley—Urban, suburban, rural residential, agricultural.
Water use	Ground-water withdrawals from wells supply water for agricultural irrigation and municipal use. Population increases since the 1960's have increased the percentage of water being used for municipal supply.	Eagle Valley—Approximately 30 percent of public supply provided by ground water and 70 percent provided by surface water. Spanish Springs Valley—Similar to Eagle Valley but with some agricultural irrigation ground-water use.
	Geology	
Surficial geology	Tertiary and Quaternary unconsolidated to moderately consolidated fluvial gravel, sand, silt and clay basin-fill deposits include alluvial fans, flood plain deposits, and playas. (Robson and Banta, 1995; Planert and Williams, 1995)	Eagle Valley—Tertiary and Quaternary unconsolidated fluvial basin-fill sediment up to 610 m in thickness. Sediments are coarse grained near the basin margins and finer grained near the basin center. Spanish Springs Valley—Similar to Eagle Valley with greater variation in basin-fill thickness.
Bedrock geology	Mountains surrounding basins are composed of Paleozoic to Tertiary bedrock formations. Tertiary volcanic and metamorphic rocks are in general impermeable. Paleozoic and Mesozoic carbonate rocks are cavernous allowing inter-basin flow in some areas. (Robson and Banta, 1995; Planert and Williams, 1995)	Eagle Valley—Carson Range west of Eagle Valley is composed of Mesozoic granitic and metamorphic rocks overlain by Tertiary volcanic rocks. Spanish Springs Valley—Surrounding ranges are composed of Mesozoic granitic and metamorphic rocks overlain by Tertiary volcanic rocks.

Table 3.1. Summary of hydrogeologic and ground-water-quality characteristics for the Basin and Range basin-fill aquifers and the Eagle and Spanish Springs Valleys regional study areas, Nevada.—Continued

[m, meters; cm/yr, centimeters per year; m^2/d, squared meters per day; m/d, meters per day; ET, evapotranspiration; mg/L, milligrams per liter]

Characteristic	Basin and Range basin-fill aquifers	Eagle and Spanish Springs Valleys regional study areas
	Ground-water hydrology	
Aquifer conditions	Unconfined basin-fill aquifers surrounded by relatively impermeable bedrock mountains and foothills. Basin ground-water flow systems are generally isolated and not connected with other basins except in some locations where basins are hydraulically connected via cavernous carbonate bedrock.	Eagle Valley—Unconfined basin-fill aquifer surrounded by bedrock mountains. Recharge originates as precipitation in the mountains. Ground-water flow is generally eastward across the valley because there is greater precipitation in the Carson Range to the west. Spanish Springs Valley—Unconfined basin-fill aquifer surrounded by bedrock mountains.
Hydraulic properties	Transmissivity ranges from less than 93 m^2/d to greater than 2,790 m^2/d. In general, alluvial fan deposits near basin margins are more conductive than flood plain and lacustrine deposits near basin centers. (Robson and Banta, 1995; Planert and Williams, 1995)	Eagle Valley—Transmissivity ranges from 42 to 77 m^2/d (Johnson and others, 1996). Hydraulic conductivity ranges from 0.12 to 1.6 m/d for basin fill (Arteaga, 1986). Spanish Springs Valley—Hydraulic conductivity ranges from 0.15 to 3.6 m/d (Berger and others, 1997).
Ground-water budget	Recharge to basin fill deposits is from surface-water runoff in mountains where precipitation is highest. Ground-water discharges naturally as evapotranspiration (ET) to playas and stream channels in basin depressions. Ground-water withdrawal from wells is largest component of discharge from Basin and Range aquifers. (Robson and Banta, 1995)	Eagle Valley—Recharge to basin fill is from surface-water runoff in mountains. Runoff from Carson Range is largest component of recharge. Discharge to ET, base flow to Eagle Valley Creek, and municipal pumping wells. Pumping has decreased ET. Spanish Springs Valley—Less precipitation than Eagle Valley. Recharge is from imported surface water and local precipitation. Discharge is to ET, ground-water underflow, and pumping wells.
	Ground-water quality	
	Water quality varies between basins. Dissolved solids can range from less than 500 mg/L to over 35,000 mg/L. Generally, low-dissolved solids, oxic water occurs near recharge areas of basin margins. High-dissolved solids anoxic water occurs with depth or near basin centers and playa lakes (Robson and Banta, 1995; Planert and Williams, 1995).	Eagle Valley and Spanish Springs Valley exhibit similar water quality of calcium-bicarbonate type water. Dissolved solids range from 100 to more than 3,000 mg/L and averages 250 mg/L. Eagle Valley pH range is 6.5 to more than 8. Spanish Springs pH generally is greater than 8. Eagle Valley redox conditions are generally oxic with some iron and manganese reducing conditions near basin center. Spanish Springs Valley is predominantly oxic.

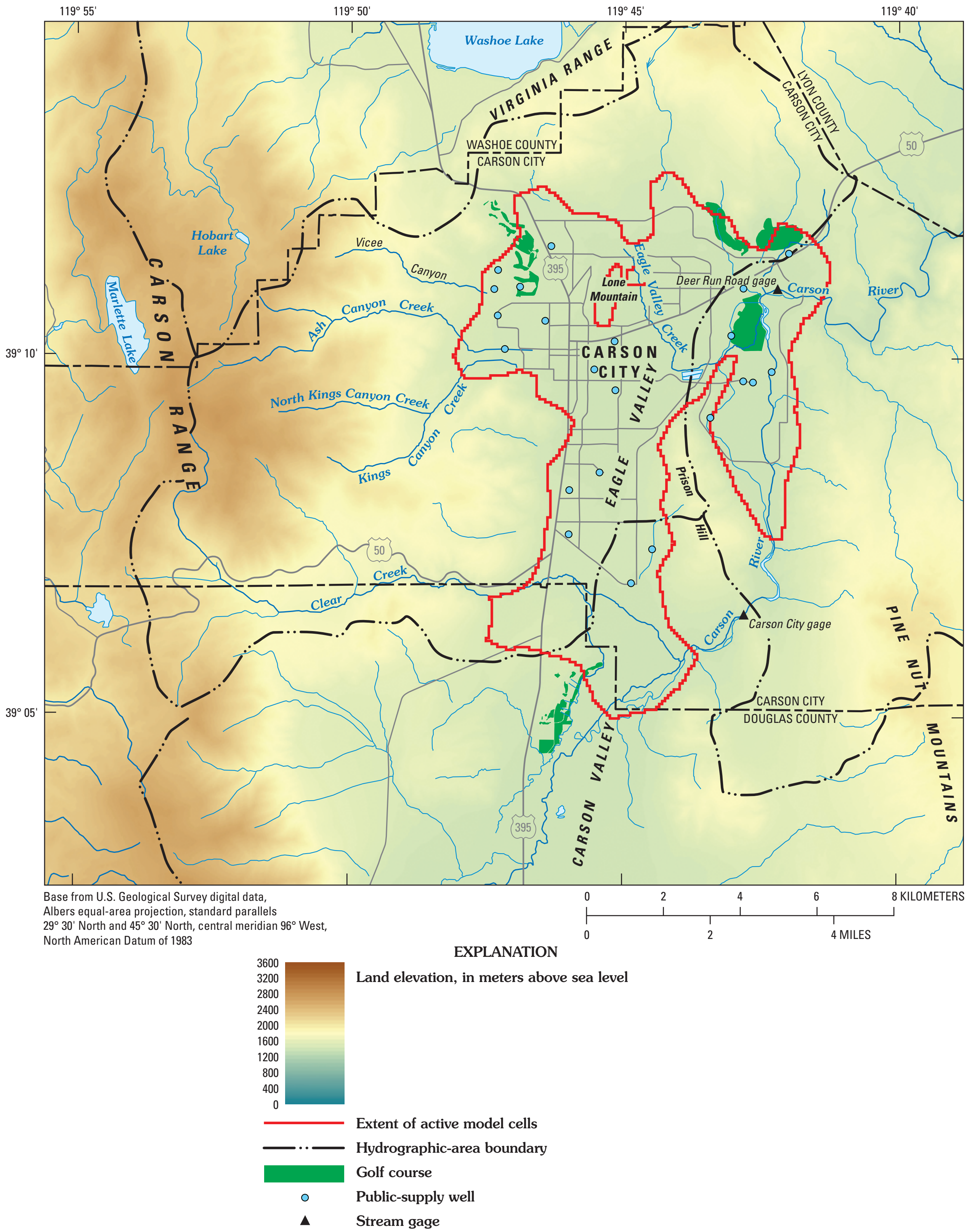


Figure 3.2*A*. Topography, hydrologic features, and locations of public-supply wells, Eagle Valley regional study area, Nevada.

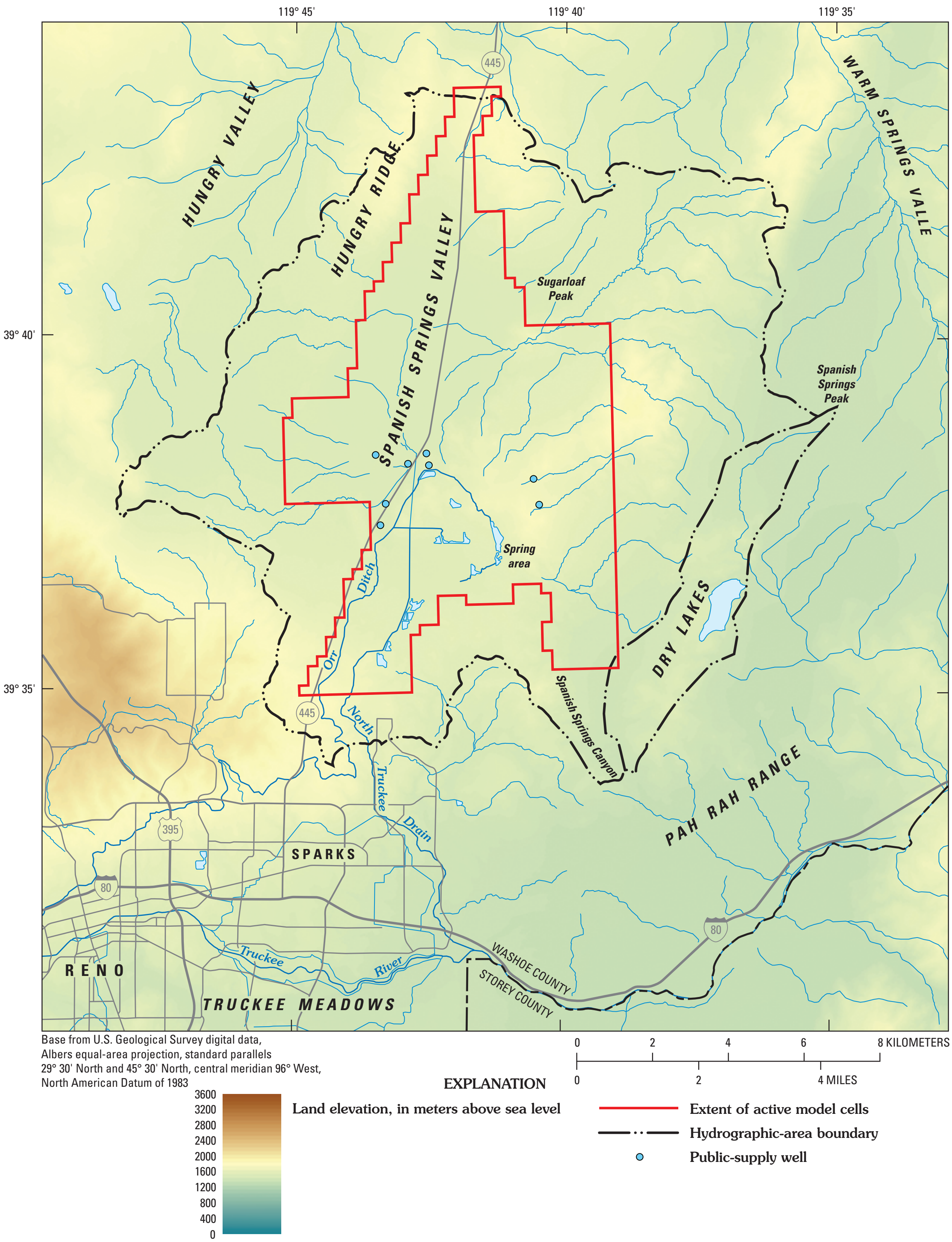


Figure 3.2*B*. Topography, hydrologic features, and locations of public-supply wells, Spanish Springs Valley regional study area, Nevada.

Orr Ditch, which is used to support agriculture in the southern part of the valley (fig. 3.2*B*). Several dry channels throughout the study area, however, indicate sufficient precipitation occasionally falls to produce runoff from surrounding mountains. The Orr Ditch has delivered water from the Truckee River through the southern boundary of the valley since 1878 (Berger and others, 1997). The ditch is unlined throughout its 11.2-km length in the valley and has numerous take-out gates to smaller ditches used for flood irrigation and stock watering. The North Truckee Drain originates near the center of the irrigated lands within the area encompassed by the Orr Ditch. The drain conveys unused irrigation water and, to a lesser extent, ground-water discharge out of the study area.

Land Use

Land use in the Eagle Valley slowly changed from unused scrubland to urban and residential development over the past several decades. The population of Carson City was estimated at 35,000 in 1979 and was more than 50,000 by 2001 (U.S. Census Bureau, 2003). The initial city limits slowly expanded in all directions as urban development progressed, and little land in the valley is currently (2006) used for pasture or agriculture.

Development in the Spanish Springs Valley was virtually nonexistent before about 1960, except for a small number of agricultural homesteads in the southern part of the valley. Based on comparison of aerial photographs taken in 1956, 1977, and 1994 and assessor parcel maps, general agricultural land use within the area serviced by the Orr Ditch has remained relatively unchanged, although some acreage has been developed in the southwest part of the valley. Urban growth and development in the Spanish Springs Valley increased sharply after 1979 when the population increased from less than 800 in 1979 to more than 4,000 in 1990 (Berger and others, 1997). Most subdivisions are located around the northern perimeter of the Orr Ditch with smaller subdivisions in the southern part of the valley. Individual homes also are scattered in the northern part of the basin in and adjacent to the surrounding mountains.

Water Use

Water use in the Eagle Valley is primarily for domestic purposes and is supplied though public water systems. Ground-water pumping provides about 30 percent of the public water supply, and surface-water sources supply the remaining 70 percent (Welch, 1994). Lesser amounts of water are provided by domestic wells. Very little water is used for agriculture or manufacturing. Most of the homes in the Eagle Valley are served by a wastewater-treatment plant that exports effluent out of the basin.

The Spanish Springs Valley has water-use characteristics similar to those in the Eagle Valley, although there is slightly more agricultural water use in the Spanish Springs Valley. As of 1994, more than 3,000 subdivision houses had water supplied by a public utility; however, nearly 1,000 of these received water from a supplier outside of the valley (Berger and others, 1997). Of the total number of houses with public water supply, 1,600 have septic systems and about 1,400 are served by wastewater-treatment facilities located outside the basin. Nearly 200 houses had domestic wells with septic systems. Although no new septic systems are allowed in the basin, there are now approximately 2,300 parcels with septic systems in Spanish Springs Valley (Rosen and others, 2006).

Conceptual Understanding of the Ground-Water System

Unconfined to confined ground water is present in the Eagle Valley Quaternary basin-fill sediments and the surrounding bedrock, although most wells are completed in the basin-fill deposits (fig. 3.3*A*). Ground-water recharge originates as precipitation in the surrounding mountains, and ground water generally flows eastward through the Eagle Valley basin-fill sediments because there is greater precipitation at higher altitudes, especially in the Carson Range (Worts and Malmberg, 1966; Arteaga, 1986; Maurer and Fisher, 1988). Prior to ground-water development in Eagle Valley, ground water discharged by evapotranspiration through phreatophytes and pasture grasses and by subsurface flow to the Carson River flood plain. Ground-water pumping, mostly for municipal supply, has diverted ground water that would have historically discharged through phreatophytes or flowed eastward to the Carson River flood plain.

Similar to Eagle Valley, ground water in the Spanish Springs Valley is present in the Quaternary basin-fill alluvial sediments and the surrounding bedrock both under water-table and confined conditions. However, in contrast to Eagle Valley, ground-water recharge in the Spanish Springs Valley is derived from imported surface water and precipitation falling within the drainage basin (fig. 3.3*B*). Ground water flows generally in an eastward direction toward the North Truckee Drain, irrigated areas, and areas of evapotranspiration (Berger and others, 1997).

Geology

The mountains surrounding the Eagle Valley consist of Mesozoic granitic and metamorphic rocks overlain by Tertiary volcanic rocks (Welch, 1994). The mountains were uplifted and the valley floor was lowered relative to the mountains by extensional tectonics, forming a basin that is partly filled with Quaternary sediments eroded from the surrounding mountains. In this chapter, the consolidated rocks exposed in the mountains and buried beneath the sediments in the valley are collectively called bedrock; the sediments in the valley are collectively called basin-fill sediments. The basin-fill sediments

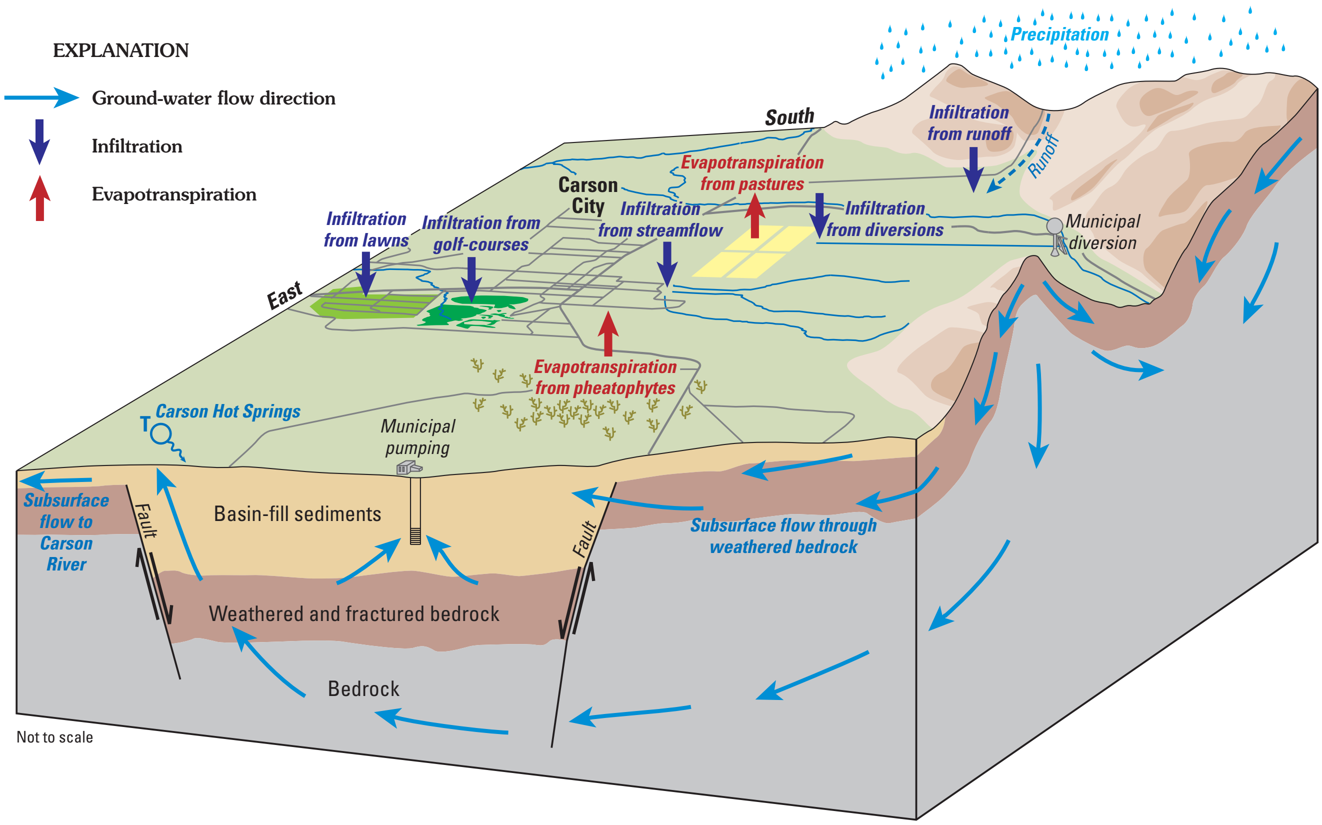


Figure 3.3*A*. Basin-fill ground-water flow system of the Eagle Valley regional study area, Nevada.

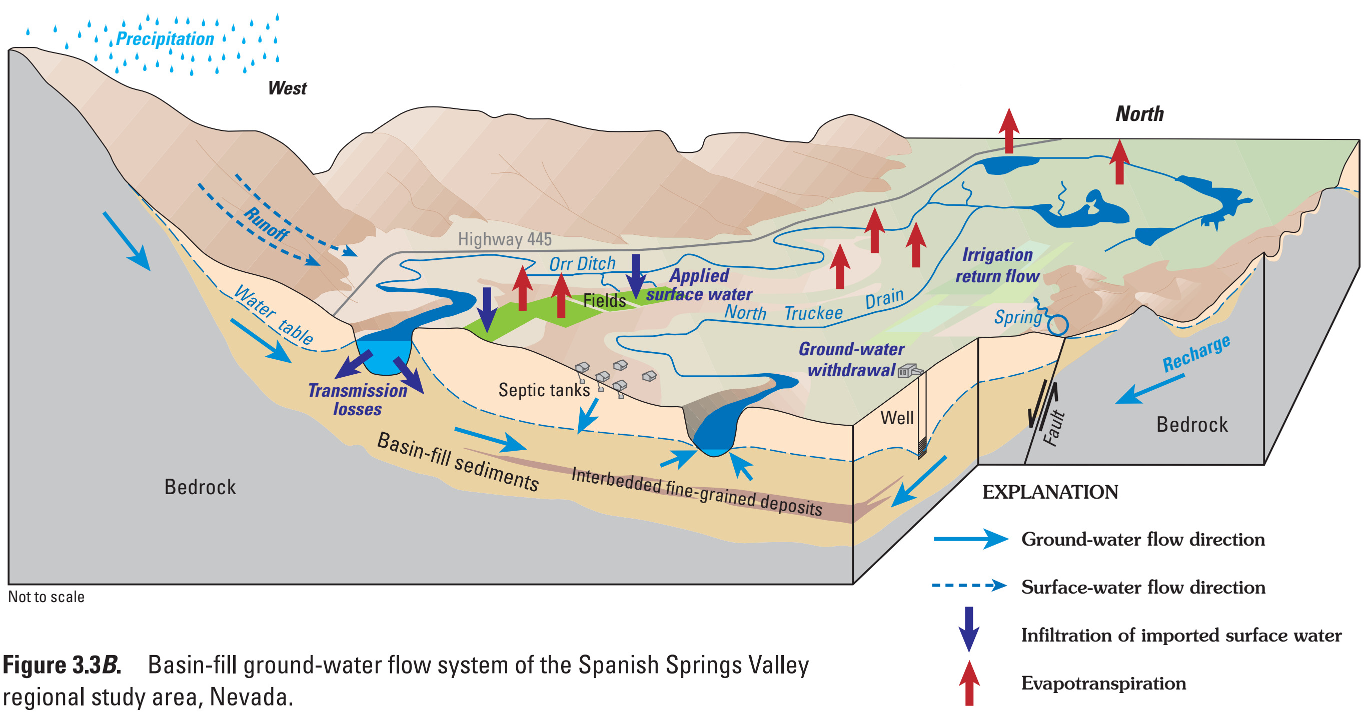


Figure 3.3*B*. Basin-fill ground-water flow system of the Spanish Springs Valley regional study area, Nevada.

consist primarily of poorly sorted sands and gravels with small boulders and intervening clay layers. Basin-fill sediments are generally 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 366 m thick 2.4 km west of Lone Mountain, about 122 to 244 m thick beneath the northeastern and southern parts of the Eagle Valley, and about 610 m thick about 1.6 km northwest of Prison Hill (Arteaga, 1986). In general, the deepest part of the alluvial basin is in the center of the Eagle Valley.

The geologic setting of the Spanish Springs Valley is similar to that of the Eagle Valley, consisting of basin-fill sediments surrounded by mountains composed of Mesozoic granitic and metamorphic rocks overlain by Tertiary volcanic rocks (Berger and others, 1997). For purposes of this report, the major geologic units identified in the Spanish Springs Valley were subdivided into two general groups on the basis of their hydrogeologic properties: (1) consolidated igneous and metamorphic bedrock, which commonly has low porosity and permeability except where fractured, and (2) basin fill, which is highly porous and transmits water readily. The structural depression occupied by the Spanish Springs Valley is filled in part by interbedded deposits of sand, gravel, clay, and silt derived primarily from adjacent mountains. These deposits form the basin-fill aquifer, which is bounded and underlain by consolidated rock. The areal extent of the basin-fill aquifer is approximated by the contact between consolidated rock and basin fill along the periphery of the valley floor. Total surface area of basin fill is about 88 km^2, or almost 43 percent of the total drainage area of Spanish Springs Valley (Berger and others, 1997). On the north, an alluvium-covered topographic divide exists between the Spanish Springs and Warm Springs Valley. At the southern boundary of the study area the saturated basin fill in the Spanish Springs Valley may be continuous with saturated basin fill of Truckee Meadows (fig. 3.2*B*). This boundary, which is not a topographic divide, is underlain by consolidated rock at depths of less than 6 m. Basin fill also occupies the structurally controlled Dry Lakes area in the southeast part of the Pah Rah Range (Berger and others, 1997).

Wells drilled in the Spanish Springs Valley range in depth from several meters to more than 240 m, and most wells are completed in basin fill (Berger and others, 1997). Discrepancies in basin-fill thickness reported on drillers' logs for several wells limit the use of these logs to estimate areal distribution of basin-fill thickness. Basin-fill sediments are thickest along a northeast-trending trough close to the mountain front of Hungry Ridge, where depth to bedrock reaches a maximum value of about 305 m (Berger and others, 1997). In general, the greatest depth to bedrock is beneath the west part of the Spanish Springs Valley, and the basin-fill sediments thin toward the east. In the southern part of the valley, depth to bedrock is less than 30 m, and basin-fill sediments thin toward the southern boundary (Berger and others, 1997).

Ground-Water Occurrence and Flow

In the northern part of the Eagle Valley, ground water flows eastward and southeastward beneath the topographic divide into Dayton Valley (fig. 3.4*A*) (Worts and Malmberg, 1966; Arteaga, 1986; Maurer, 1997). In the southern part of the Eagle Valley, some ground water flows northeastward around the northern end of Prison Hill and southeastward beneath the topographic divide into the Carson Valley (Worts and Malmberg, 1966; Arteaga, 1986). Figure 3.4*A* shows the potentiometric surface for 2001 as simulated in the upper layer of the Eagle Valley model.

Ground water flows both north and south from the ground-water divide that has developed beneath the center of the Spanish Springs Valley (fig. 3.4*B*). Ground water flows south out of the valley through the basin fill and probably through fractured bedrock to Truckee Meadows. Ground water also flows from the ground-water divide toward the northern part of the study area. Geochemical data from a municipal well, which is screened in more than 37 m of saturated basin fill, indicates the source of ground water is a mixture of local recharge and water from the Truckee River. Stable isotope and chlorofluorocarbon data (Berger and others, 1997) support the conclusion that imported Truckee River water moves northward from the Orr Ditch. Figure 3.4*B* shows the potentiometric surface for 2001 as simulated in the upper layer of the Spanish Springs Valley model.

Aquifer Hydraulic Conductivity

The hydraulic conductivity and transmissivity of basin-fill sediments in the Eagle Valley have been estimated by Arteaga (1986), Johnson and others (1996), and Maurer and others (1996). Values of hydraulic conductivity reported by Arteaga (1986) ranged from 0.12 to 1.6 m/d. Transmissivities of 42, 45, and 77 m^2/d for three wells were reported by Johnson and others (1996). Dividing transmissivity values by aquifer saturated thickness in the perforated interval of the respective wells results in hydraulic conductivities of 0.98, 0.91, and 0.98 m/d, respectively. Maurer and others (1996) estimated hydraulic conductivities of lithologic units in the Eagle Valley basin-fill sediments and in fractured and weathered bedrock from correlations between slug-test analyses and borehole resistivity logs. In the basin-fill sediments, hydraulic conductivity ranged from 0.006 to 0.027 m/d for clay and from 10 to 14 m/d for sand and gravel (Maurer and others, 1996). Hydraulic conductivity of weathered and unweathered granitic bedrock closed fractures ranged from 0.02 to 0.28 m/d, whereas hydraulic conductivity of open-fractured metamorphic rocks was up to 18 m/d (Maurer and others, 1996) indicating that metamorphic rocks with open fractures can be more permeable than basin-fill sediments and weathered granitic rocks.

In the Spanish Springs Valley, hydraulic conductivity was calculated from several aquifer tests completed in the upper 100 m of saturated basin fill and ranged from 0.15 to about 3.6 m/d (Berger and others, 1997). Analyses of geophysical and lithologic logs and grain-size distributions collected from observation wells drilled as part of the study by Berger and others (1997) and Washoe County (1993) provided additional qualitative estimates of the ability of the basin-fill aquifer to transmit water. In general, basin fill derived from volcanic rocks tends to be dominated by fine-grained deposits resulting in an overall lower hydraulic conductivity than basin fill derived from granitic bedrock, which is dominated by sand and gravel. Hydraulic conductivity in the deepest part of the basin fill is unknown but is probably less than that of the upper 100 m owing to sediment compaction and induration. The distribution of hydraulic conductivity within the basin-fill aquifer was refined during ground-water flow model calibration, as discussed in the section “Ground-Water Flow Modeling.”

Water Budget

Historical recharge estimates for the Eagle Valley were based on precipitation data. Original estimates of recharge to Eagle Valley (Worts and Malmberg, 1966) used an empirical relation between altitude, precipitation, and recharge (Maxey and Eakin, 1949) to estimate ground-water recharge to basins in eastern Nevada. Worts and Malmberg (1966) estimated 29,300 m^3/d (15 cm/yr over the modeled area of 71 km^2) of potential recharge to the Eagle Valley in 1965. A subsequent recharge estimate of 18,900 m^3/d (9.7 cm/yr over the modeled area) for the period 1967–77 was made for Eagle Valley using a relation between precipitation and surface runoff from Clear Creek and creeks in Ash and Kings Canyons (Arteaga and Durbin, 1979).

Sources of recharge and inflow to the Eagle Valley considered by this study include subsurface inflow from the mountains (mountain-block recharge); infiltration of streamflow from Clear, Kings Canyon, and Ash Canyon Creeks and ephemeral streams (mountain-front recharge); infiltration of precipitation; infiltration of lawn and golf course irrigation; and effluent from septic tanks. Estimates of inflow made for 1997–2001 conditions were made from inflow estimates for the period 1995–1998 (Maurer and Thodal, 2000), which were wet years. Average annual precipitation from the two periods was used to scale the 1995–1998 inflow estimates to the period 1997–2001. Mountain-block recharge was estimated to be about 15,600 m^3/d for 1995–98 (Maurer and Thodal, 2000) and about 12,900 m^3/d for 1997–2001 average conditions, and mountain-front recharge from infiltration of streamflow was about 11,800 m^3/d during 1995–98 (Maurer and Thodal, 2000) and about 8,800 m^3/d for 1997–2001 average conditions. Recharge from precipitation on open areas of the valley floor ranged from 110 to 300 m^3/d (0.06 to 0.15 cm/yr over the modeled area) for 1997–2001 average conditions. Recharge from lawn irrigation is estimated to range from 3,300 to 8,200 m^3/d for 1995–98 (Maurer and Thodal, 2000) and from about 2,700 to 7,700 m^3/d for 1997–2001 average conditions. Recharge from irrigation of golf courses with treated effluent is about 2,000 m^3/d (Maurer and Thodal, 2000). An estimated 900 septic tanks were functioning in the Eagle Valley in 1997 with an estimated use and infiltration rate of 0.95 m^3/d per tank for a total of about 855 m^3/d. (Leanna Stevens, Carson City Public Utilities Department, oral and written communs., 1998). Summing the recharge components results in a total recharge estimate from sources on the valley floor (excluding mountain-block recharge) ranging from 18,000 to 23,200 m^3/d (9.3 to 12 cm/yr over the modeled area) for 1995–98 (Maurer and Thodal, 2000) and from about 14,500 to 19,600 m^3/d (7.5 to 10.1 cm/yr over the modeled area) for 1997–2001 average conditions. Estimates for the total for all sources of ground-water recharge and subsurface inflow to the Eagle Valley basin-fill aquifer range from approximately 27,400 to 32,500 m^3/d for 1997–2001. Estimates of ground- water-budget components are probably within 20 percent of their actual values. Water-budget components of greatest uncertainty are subsurface inflow, recharge from ephemeral streamflow, and recharge from lawn irrigation.

Ground water in the basin-fill aquifer of the Eagle Valley is discharged by evapotranspiration from bare soil and plants, by pumping, and to base flow of Eagle Valley Creek and unnamed creeks. In 1964, about 20 km^2 near the center of the valley were covered with phreatophytes (plants that use ground water) and pasture grasses (Worts and Malmberg, 1966, p. 27). Since that time, many acres of phreatophytes and pasture grasses have been replaced by urban and residential development. Based on indirect evidence, phreatophytes covered about 4.4 km^2 in 1997. In addition, ground-water pumping has caused water levels to decline, further reducing the amount of ground water discharged by phreatophytes. Since 1964, ground-water discharge to public-supply wells has increased and discharge by evapotranspiration has decreased. For this study, evapotranspiration within the Eagle Valley was estimated as about 15,100 m^3/d based on output from the ground-water flow model and a known acreage where evapotranspiration occurs. Ground-water pumping was 25,397 m^3/d from 1997 to 2001 (table 3.2). Where the water table is close to land surface, ground water also discharges as seepage to Eagle Valley Creek and two unnamed creeks and as evapotranspiration from phreatophytes. Base flow in Eagle Valley Creek averaged 21 m^3/d for 1997–2001 (U.S. Geological Survey, 1997–01). Estimated total ground-water discharge for the Eagle Valley basin-fill aquifer is approximately 47,900 m^3/d with about 15,100 m^3/d going to evapotranspiration, 25,400 m^3/d going to pumping, and 7,400 m^3/d going to surface-water base flow based on ground-water flow model results.

Table 3.2. Average ground-water pumping rates for public-supply wells, 1997–2001, Eagle Valley regional study area, Nevada (Nevada State Engineer's office, written commun., 2001).

[m^3/d, cubic meters per day]

Well	Pumping rate (m^3/d)
3	1,740
4	723
5	970
6	2,301
7	668
8	1,397
9	882
10	3,123
11	1,175
24	2,219
33	277
34	932
38	879
40	1,937
43	1,537
44	408
45	1,504
46	2,408
47	304
48	0
Total, all wells	**25,397**

Sources of ground-water recharge and inflow to the Spanish Springs Valley considered by this study include infiltration from the Orr Ditch (canal leakage), infiltration of precipitation, subsurface inflow from the surrounding mountains (mountain-block recharge), infiltration of water from lawn irrigation, and effluent from septic tanks. Ground-water recharge from precipitation takes place in or adjacent to the mountains in the Spanish Springs Valley through weathered or fractured bedrock or when intermittent runoff infiltrates dry channel deposits (fig. 3.3*B*). Precipitation that falls on the valley floor is considered a negligible source of recharge, although some recharge may be generated during heavy and localized rain showers. In eastern and western parts of the valley, ground water in basin-fill deposits generally flows toward the center of the basin, away from recharge-source areas in the mountains. Potential recharge, generated from nearly 11,800 m^3/d of annual precipitation (Berger and others, 1997) estimated to fall within the topographically closed Dry Lakes area (fig. 3.2*B*), may enter the basin fill at depth through fractures within the Pah Rah Range along the southeastern part of the study area.

Berger and others (1997) estimated anthropogenic sources of recharge to the Spanish Springs Valley on the basis of the amount of ground-water recycled from municipal and domestic uses. Water applied to outdoor lawn and shrub watering is mostly consumed by evapotranspiration and was considered an insignificant contributor to ground-water recharge (Berger and others, 1997). Recharge from septic systems (indoor uses) was estimated as 75 percent of the total amount of water delivered to the household during winter months, when outdoor watering is at a minimum. This monthly volume of water was assumed constant and was prorated over an entire year to arrive at an annual estimate of recharge from septic systems, which was approximately 1,600 m^3/d for 1994 (Berger and others, 1997). In Spanish Springs Valley, based on field and empirical techniques, total recharge from all sources is estimated at about 14,800 m^3/d (Berger and others, 1997). An estimated 54 percent of recharge is from canal leakage from the Orr Ditch (Truckee River water that is diverted into the Spanish Springs Valley) with the remainder coming from mountain-block recharge, infiltration of precipitation, infiltration from lawn irrigation, and septic-tank effluent.

Prior to urban development and ground-water withdrawal for water supply, evapotranspiration was the principal mechanism of ground-water discharge from Spanish Springs Valley. In areas where the water table is less than one meter below land surface, ground water can be discharged by evaporation. Under natural conditions, bare-soil evaporation in the Spanish Springs Valley probably took place in the area surrounding the springs, where the water table is near land surface. Transpiration by phreatophytes has been documented in other arid basins in Nevada to consume relatively large quantities of ground water (Robinson, 1970; Harrill, 1973, table 9; Berger, 1995, p. 35). Rush and Glancy (1967) estimated about 7.7 km^2 of phreatophytes discharged nearly 3,000 m^3/d of ground water by evapotranspiration under natural conditions in the Spanish Springs Valley (conditions without the Orr Ditch). Berger and others (1997) estimated 1,200 m^3/d of ground-water discharge from areas surrounding the Orr Ditch. The total estimate of ground-water discharge by evapotranspiration in Spanish Springs Valley is about 8,400 m^3/d.

Similar to the Eagle Valley, ground-water discharge to public-supply wells has increased and discharge by evapotranspiration has decreased as urban development occurred in the Spanish Springs Valley. Average 1997–2001 ground-water pumping rates for public-supply wells in the Spanish Springs Valley are listed in table 3.3 and total approximately 4,850 m^3/d.

Table 3.3. Average ground-water pumping rates for public-supply wells, 1997–2001, Spanish Springs Valley regional study area, Nevada, Nevada (Nevada State Engineer's office, written commun., 2001).

[m^3/d, cubic meters per day]

Well name	Pumping rate (m^3/d)
DS1	838
DS2	27
DS3	1,458
DS4	540
SC2	975
SC3	121
SC4	581
SC5	310
Total	**4,850**

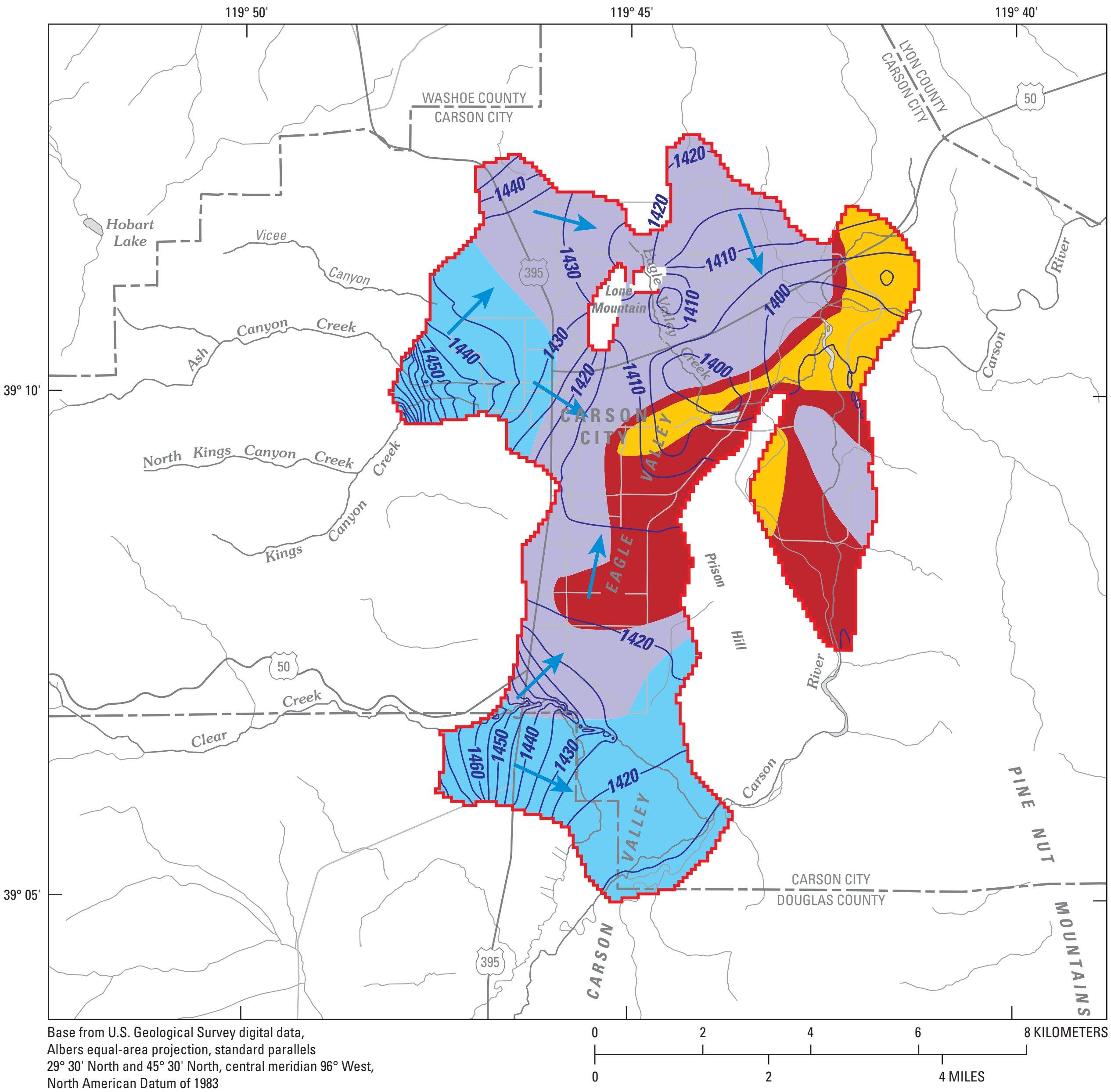
Subsurface outflow from Spanish Springs Valley to the Truckee Meadows was estimated between 330 and 500 m^3/d (Cohen and Loeltz, 1964, p. 23; Rush and Glancy, 1967). These investigators evaluated subsurface outflow through the basin fill and did not attempt to estimate flow volumes through fractured bedrock. However, subsurface flow to the Truckee Meadows probably moves through fractured or weathered bedrock, as indicated from stable isotope data (Berger and others 1997, p. 48). Total discharge from the Spanish Springs Valley from evapotranspiration, pumping, and subsurface outflow is estimated at about 13,750 m^3/d.

Ground-Water Quality

The ground-water quality of the Eagle Valley and Spanish Springs Valley is similar, although there is considerable variability in the major-ion composition of both areas. Calcium and sodium are the predominant cations, and bicarbonate and sulfate are the predominant anions, although most ground water is dominated by calcium and bicarbonate. Dissolved-solids concentrations range from approximately 100 mg/L to more than 3,000 mg/L with a median of about 250 mg/L. The pH within the Eagle Valley Basin ranges from approximately 6.5 to greater than 8 pH units, and the pH of the Spanish Springs Valley ground water is more basic than Eagle Valley ground water, with most values greater than 8 pH units (Welch, 1994; Christian Kropf, Washoe County Department of Water Resources, written commun., 2001).

Oxidation-reduction (redox) conditions in Eagle Valley tend to follow trends that are controlled by the mountain-front and mountain-block recharge (fig. 3.4*A*). The most oxygenated ground water occurs around the edges of the basin near the mountain recharge areas, regardless of depth, and less oxygenated water is located near the center of the basin. Some areas near the basin center exhibit conditions consistent with manganese- and iron-reducing redox conditions, but oxygen and nitrate-reducing conditions predominate in the basin. Depth-related trends in redox conditions are not apparent in the Eagle Valley.

The Spanish Springs Valley aquifer is dominantly oxygen reducing (fig. 3.4*B*), although there are relatively few available water-quality analyses for redox classification. Two wells exhibited concentrations consistent with iron-reducing conditions, but these wells are completed in fractured bedrock and are probably not related to the redox conditions in the basin-fill aquifer (Christian Kropf, Washoe County Department of Water Resources, written commun., 2001).



Base from U.S. Geological Survey digital data,
Albers equal-area projection, standard parallels
29° 30' North and 45° 30' North, central meridian 96° West,
North American Datum of 1983

EXPLANATION

- Oxygen reduction
- Nitrate reduction
- Manganese reduction
- Iron reduction with high sulfate
- Direction of ground-water flow
- 1420 — Line of equal potentiometric-surface elevation, 1997–2001. Contour interval 5 meters. Datum is sea level.
- Extent of active model cells

Figure 3.4*A*. Basin-fill aquifer potentiometric surface and oxidation-reduction classification zones, Eagle Valley regional study area, Nevada.

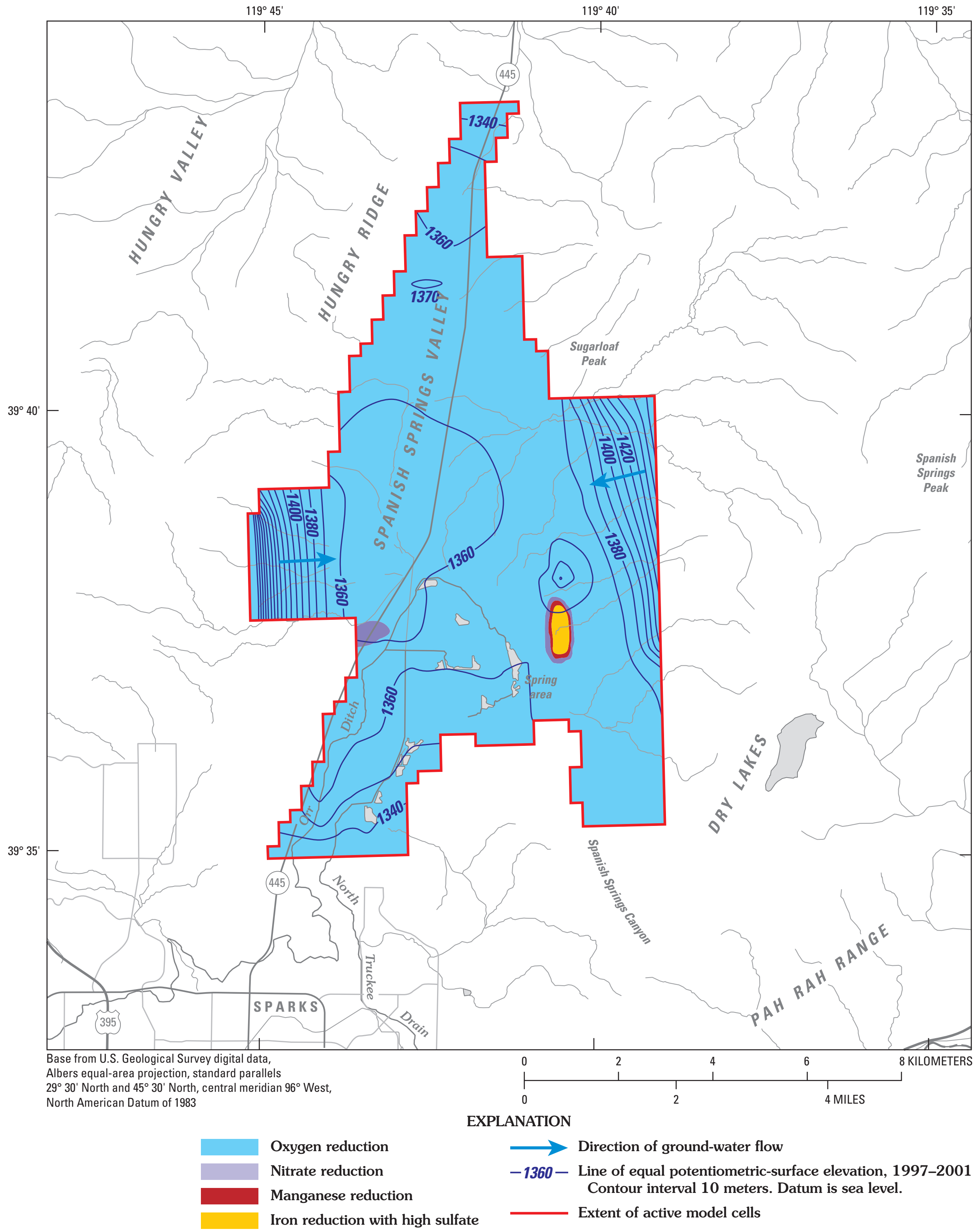


Figure 3.4*B*. Basin-fill aquifer potentiometric surface and oxidation-reduction classification zones, Spanish Springs Valley regional study area, Nevada.

Ground-Water Flow Simulations

The modular ground-water flow simulation code MODFLOW-2000 (Harbaugh and others, 2000) was used to construct steady-state finite-difference ground-water flow models for the Eagle and Spanish Springs Valleys representing average conditions for the 5-year period from 1997 to 2001. Both models were modified from previously existing models and recalibrated to average conditions for 1997–2001. The following sections present details of the modeled areas, model input, model calibration, and particle-tracking simulations.

Modeled Areas and Spatial Discretizations

The Eagle Valley model simulates ground-water flow in the basin-fill deposits. The modeled area covers the entire valley floor of approximately 70 km^2 where basin-fill deposits are exposed at the surface, and the model perimeter coincides with the horizontal extent of the basin-fill aquifer. The model grid (fig. 3.5*A*) contains 186 rows and 130 columns with grid cells 76 m on a side. The model contains 48,360 cells of which 24,356 cells are active. Vertically, the model is discretized into two layers. The top layer (layer 1) represents coarse-grained alluvial material in the upper 30 m of the basin fill, and layer 2 represents the underlying coarse-grained alluvial material. Layer 2 thickness extends to the base of basin-fill sediments as determined from gravity and seismic surveys (Arteaga, 1986) ranging from 50 to 2,160 m. Both layers are simulated as confined. The intervening fine-grained confining layer is simulated by a vertical leakance coefficient, which allows some flow between the two coarse-grained layers. The Eagle Valley MODFLOW finite-difference model was converted from a finite-element model constructed in the late 1970s (Arteaga, 1986) by overlaying the finite-difference grid on the finite-element mesh and interpolating the hydrologic properties to the finite-difference grid.

The Spanish Springs Valley finite-difference ground-water flow model used for this study was originally developed by Berger and others (1997) and later modified by the Washoe County Department of Water Resources (Wyn Ross, Washoe County Department of Water Resources, written commun., 2003). The original Spanish Springs Valley model grid contained 37 rows, 28 columns, and 2 layers that divided the saturated basin fill into discrete three-dimensional model cells. Variable node spacing was used to provide higher resolution in areas of concentrated ground-water recharge and discharge related to the importation of Truckee River water. Model-cell size ranged from a minimum of 62,500 m^2 (250 m by 250 m) to a maximum of 250,000 m^2 (500 m by 500 m). Of the 1,036 cells in each model layer, 625 were active in layer 1 and 282 were active in layer 2. The top 100 m of saturated basin fill was represented as unconfined by layer 1, and the processes of ground-water recharge and discharge were simulated in layer 1. Layer 2 extended from the bottom of layer 1 to the top of consolidated bedrock, functioning as a conduit for deep flow and as a reservoir of stored water. Layer 2 was simulated as convertible from confined to unconfined, which allowed conversion to unconfined conditions if water levels dropped below the bottom of layer 1. The original Spanish Springs Valley model (Berger and others, 1997) was slightly altered by Washoe County Department of Water Resources to facilitate their management of ground-water resources in the valley (Wyn Ross, Washoe County Department of Water Resources, written commun., 2003). The altered model now contains 71 rows, 35 columns, and 3 layers (fig. 3.5*B*). The grid cells throughout the entire model are now 250 m on a side. The altered model contains 7,455 model cells of which 2,917 are active. Layer 3 represents a basalt layer at depth penetrated by several newer supply wells on the east side of the valley. The altered model provides better coverage of the modeled area especially for the purposes of this study.

Boundary Conditions

Model stresses for both modeled areas include areal recharge from precipitation and irrigation, subsurface recharge from the surrounding mountains (mountain-block recharge), recharge from and discharge to streams, discharge to evapotranspiration, and discharge to pumping wells.

Recharge

Recharge boundaries in the Eagle Valley model consist of recharge cells to simulate precipitation and irrigation recharge to the land surface, general-head boundary cells to simulate mountain-block recharge, and river cells to simulate surface-water infiltration (fig. 3.5*A*). The MODFLOW General-Head package is used to simulate the edges of the model where basin-fill deposits lie adjacent to consolidated bedrock and mountain-block recharge of winter snow contributes significant recharge to the basin. General-head cells are located in layer 1, although some mountain-block recharge may occur at greater depths. Precipitation recharge is insignificant in the Eagle Valley, but the MODFLOW Recharge package is used to simulate small amounts of lawn and golf course irrigation with rates on the order of 7.3 cm/yr. The MODFLOW River package cells are used to represent recharge from surface-water flow in the Carson River, and Clear Canyon, Ash Canyon, and Kings Canyon Creeks.

In the Spanish Springs Valley model, ground-water recharge from septic systems, precipitation, and imported surface water were simulated in the model as assigned recharge rates based on either empirical estimates or measured quantities. Recharge rates from precipitation and septic systems were assumed constant. Mountain-block recharge was simulated using 18 recharge nodes. Recharge nodes and rates for the model are shown in figure 3.5*B*. Recharge from septic systems and irrigation return flows were simulated using well nodes with a positive discharge. For cells containing a domestic well (discharge) and a septic system (recharge), values of domestic pumping were input to the model as the net difference between well discharge and septic-system recharge.

Discharge

Discharge boundaries in the Eagle Valley model included evapotranspiration discharge, river discharge, and public-supply well pumping (fig. 3.5*A*). Evapotranspiration (ET) was the primary discharge component and was simulated using the MODFLOW ET package. Evapotranspiration was simulated as a linear function of depth computed from a maximum rate, which was decreased linearly to the depth at which evapotranspiration is assumed to cease (the evapotranspiration extinction depth). An evapotranspiration extinction depth of 12 m was used in the model and provided a reasonable calculation of evapotranspiration, which generally was simulated for the center portion of the basin where evapotranspiration historically occurred. Discharge to rivers and creeks in the valley was represented using the MODFLOW River package (319 river cells) and public-supply well pumping was represented using the MODFLOW Well package (20 well cells). Average pumping rates for 1997–2001 for public-supply wells in Carson City were used as model input (table 3.2).

The Spanish Springs Valley model also included discharge by evapotranspiration. Ground-water discharge by evapotranspiration was specified in model layer 1 as head-dependent flow boundaries using the ET package and was assigned to selected active cells on the basis of plant distribution from field observations. In Spanish Springs Valley, evapotranspiration is limited to the area encompassed by the Orr Ditch and along the outside of the Orr Ditch near the central and southeast part of the valley. Inside the area encompassed by the Orr Ditch, the depth to water is shallow and vegetation consists of meadow grasses and alfalfa separated by large areas of bare soil (fig. 3.5*B*). A maximum evapotranspiration rate of 0.005 m/d at land surface and an extinction depth of 3 m were used to simulate evapotranspiration inside the area of the Orr Ditch. Assuming evapotranspiration is at a maximum when depth to ground water is 1 m, the maximum evapotranspiration rate used in the model for the area outside the Orr Ditch was 5 X 10^{-4} m/d and the extinction depth was 10 m.

In the Spanish Spring model, the simulation of ground-water discharge to domestic and public-supply wells was accomplished using the MODFLOW Well package. Average pumping rates for 1997–2001 for the eight public-supply wells in the Spanish Springs Valley were input to the model (table 3.3).

Aquifer Hydraulic Conductivity

Aquifer properties used in the Eagle Valley model were taken from the original model done in the late 1970s (Arteaga, 1986). The transmissivity values used by that model ranged from 1 to 940 m^2/d in layer 1 and from 5 to 11,600 m^2/d in layer 2. The areal distribution of transmissivity and hydraulic conductivity values coincides in general with grain size of the alluvial deposits. In layer 1, the coarser, more conductive deposits tend to be near creeks coming from the mountainous areas surrounding the valley (fig. 3.6*A*). The finer, less conductive deposits tend to be in the center of the valley. For layer 1, the aquifer thickness was held constant at 30 m; hydraulic conductivity ranged from 0.01 to 9.4 m/d with an average value of approximately 0.3 m/d. In general, layer 2 was simulated as coarser grained and as more transmissive than layer 1 (fig. 3.6*B*). Hydraulic conductivity of layer 2 ranged from 0.009 to 47.2 m/d with an average value of approximately 2 m/day.

In the Spanish Springs Valley model, transmissivity values determined from several aquifer tests were used to calculate hydraulic conductivities, which ranged from 0.5 to about 4 m/d (Berger and others, 1997). Figure 3.7*A* shows the hydraulic-conductivity distribution for layer 1 where values ranged from less than 0.01 to 15 m/d. Figure 3.7*B* shows the hydraulic-conductivity distribution for layer 2 where values ranged from less than 0.01 to 5 m/d, and figure 3.7*C* shows the hydraulic-conductivity distribution of layer 3 where values also varied from less than 0.01 to 5 m/d.

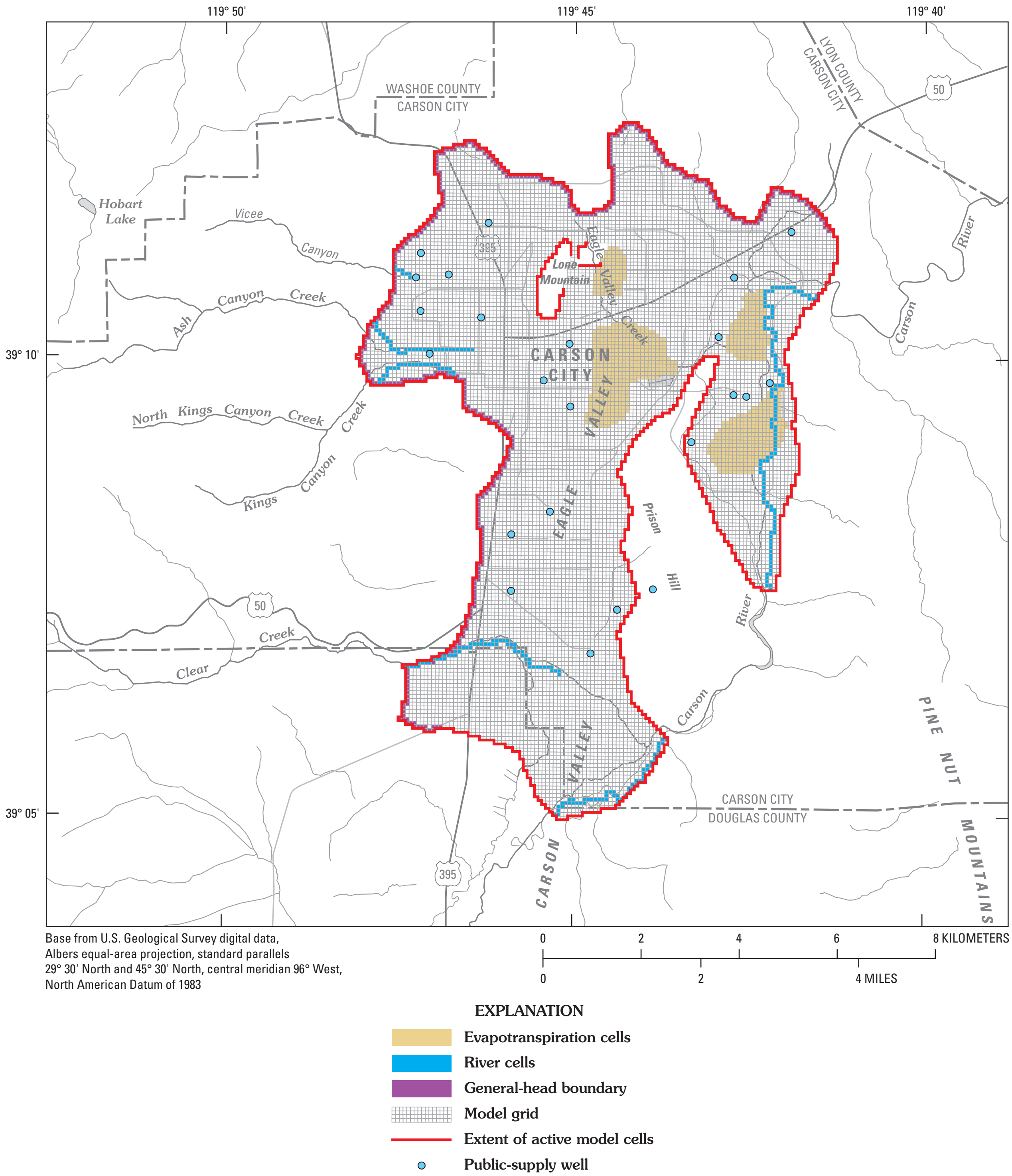


Figure 3.5*A*. Ground-water flow model grid, boundary conditions, and location of public-supply wells, Eagle Valley regional study area, Nevada.

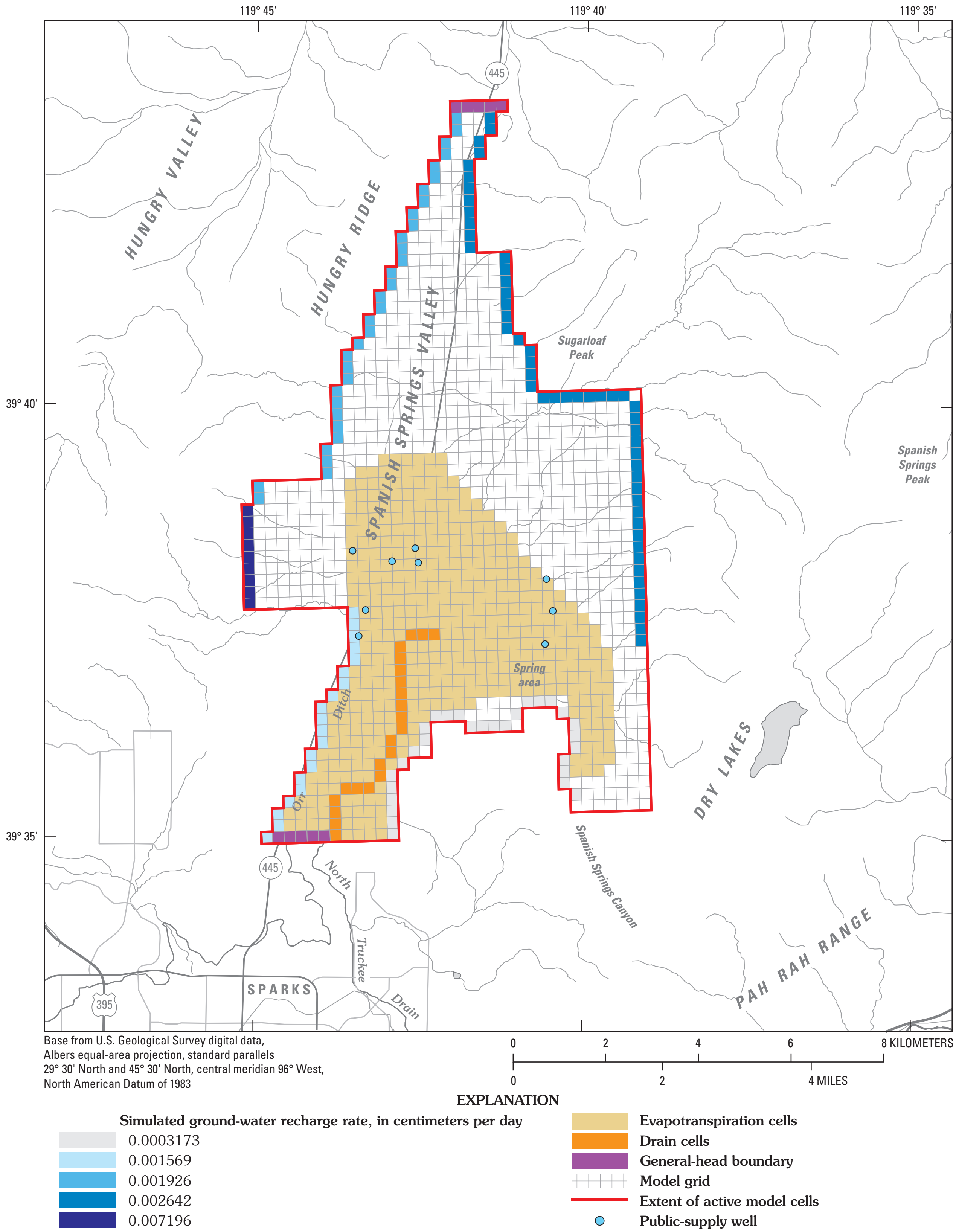
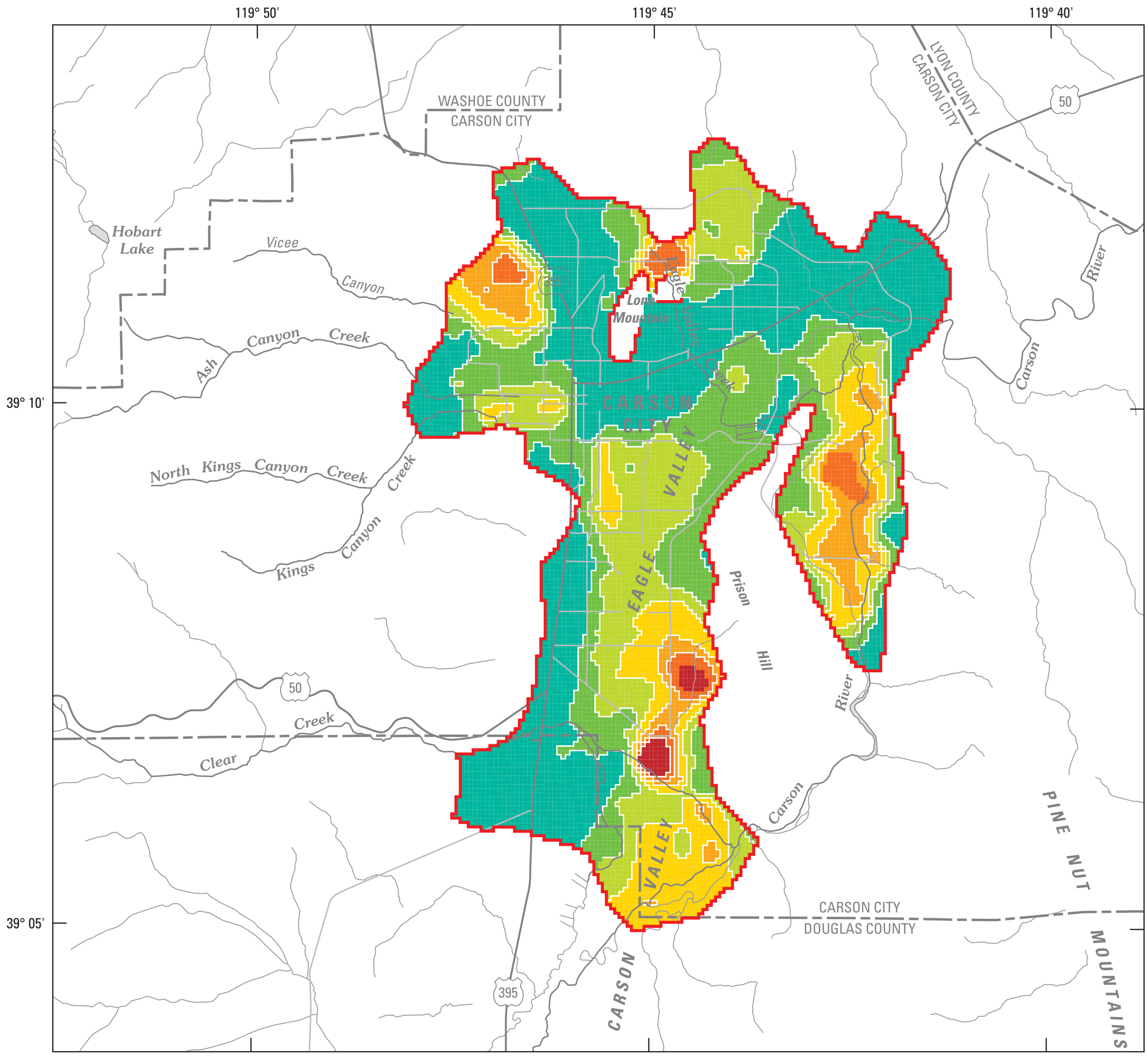


Figure 3.5*B*. Ground-water flow model grid, boundary conditions, and location of public-supply wells, Spanish Springs Valley regional study area, Nevada.



Base from U.S. Geological Survey digital data,
Albers equal-area projection, standard parallels
29° 30' North and 45° 30' North, central meridian 96° West,
North American Datum of 1983

0 2 4 6 8 KILOMETERS

0 2 4 MILES

EXPLANATION

Hydraulic conductivity, in meters per day

- 0.01 to 0.16
- 0.161 to 0.350
- 0.351 to 0.550
- 0.551 to 0.850
- 0.851 to 1.20
- 1.201 to 1.85
- 1.851 to 9.41

Extent of active model cells

Figure 3.6*A*. Distribution of hydraulic conductivity for model layer 1, Eagle Valley regional study area, Nevada.

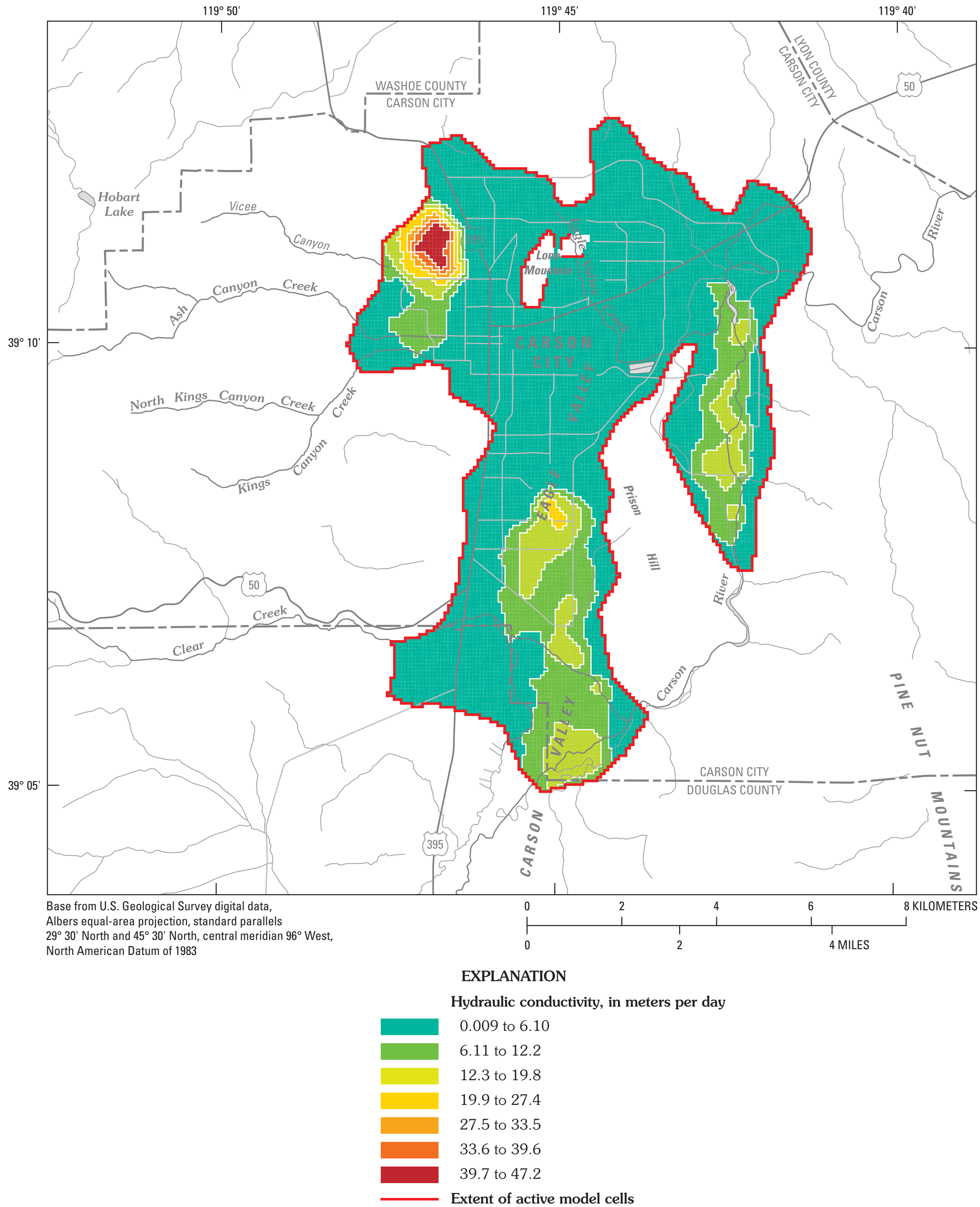
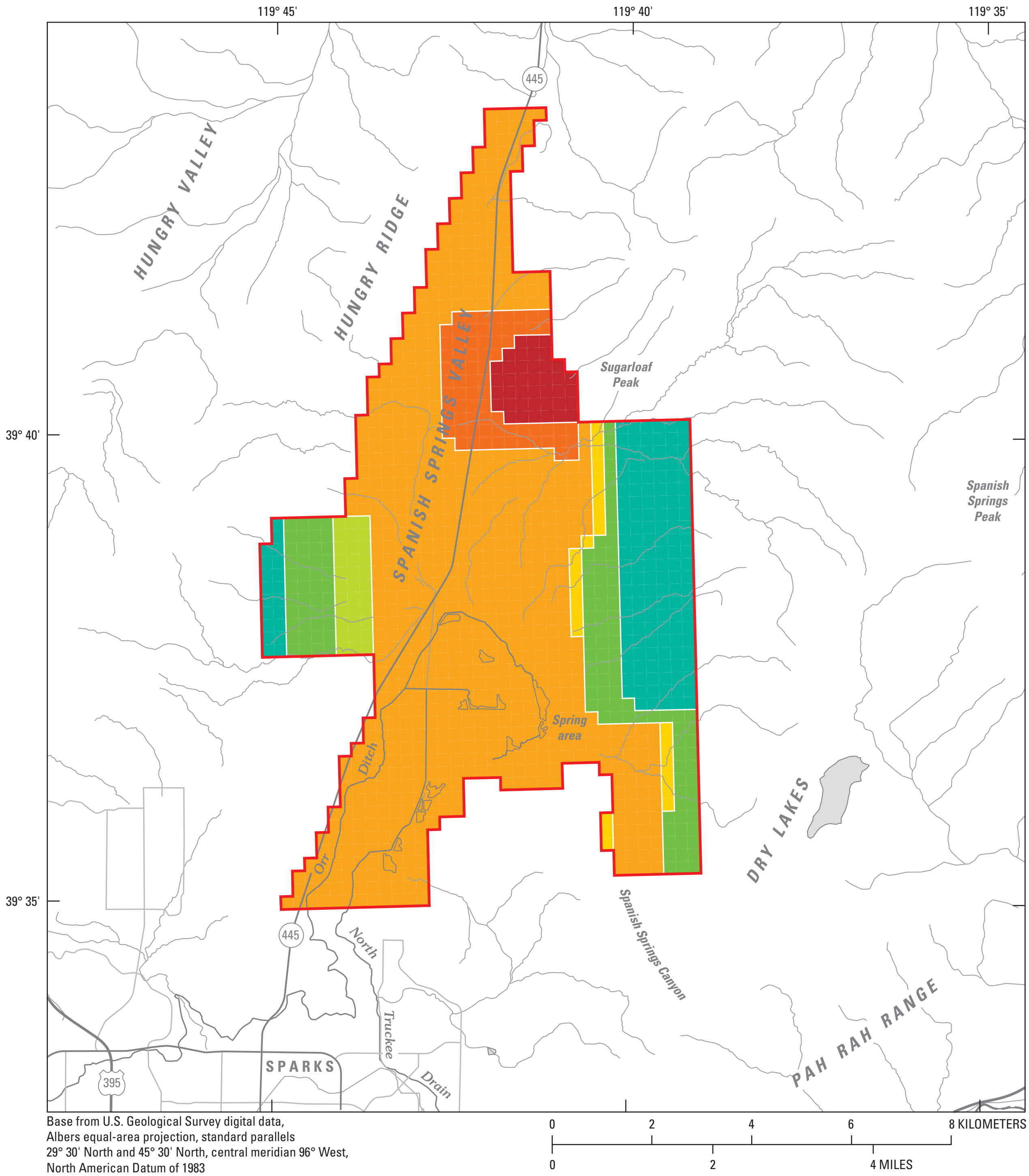


Figure 3.6*B*. Distribution of hydraulic conductivity for model layer 2, Eagle Valley regional study area, Nevada.



EXPLANATION

Hydraulic conductivity, in meters per day

- Less than 0.01
- 0.011 to 0.03
- 0.031 to 0.09
- 0.091 to 0.5
- 0.051 to 1.0
- 1.1 to 5.0
- 5.1 to 15.0
- **Extent of active model cells**

Figure 3.7*A*. Distribution of hydraulic conductivity for model layer 1, Spanish Springs Valley regional study area, Nevada.

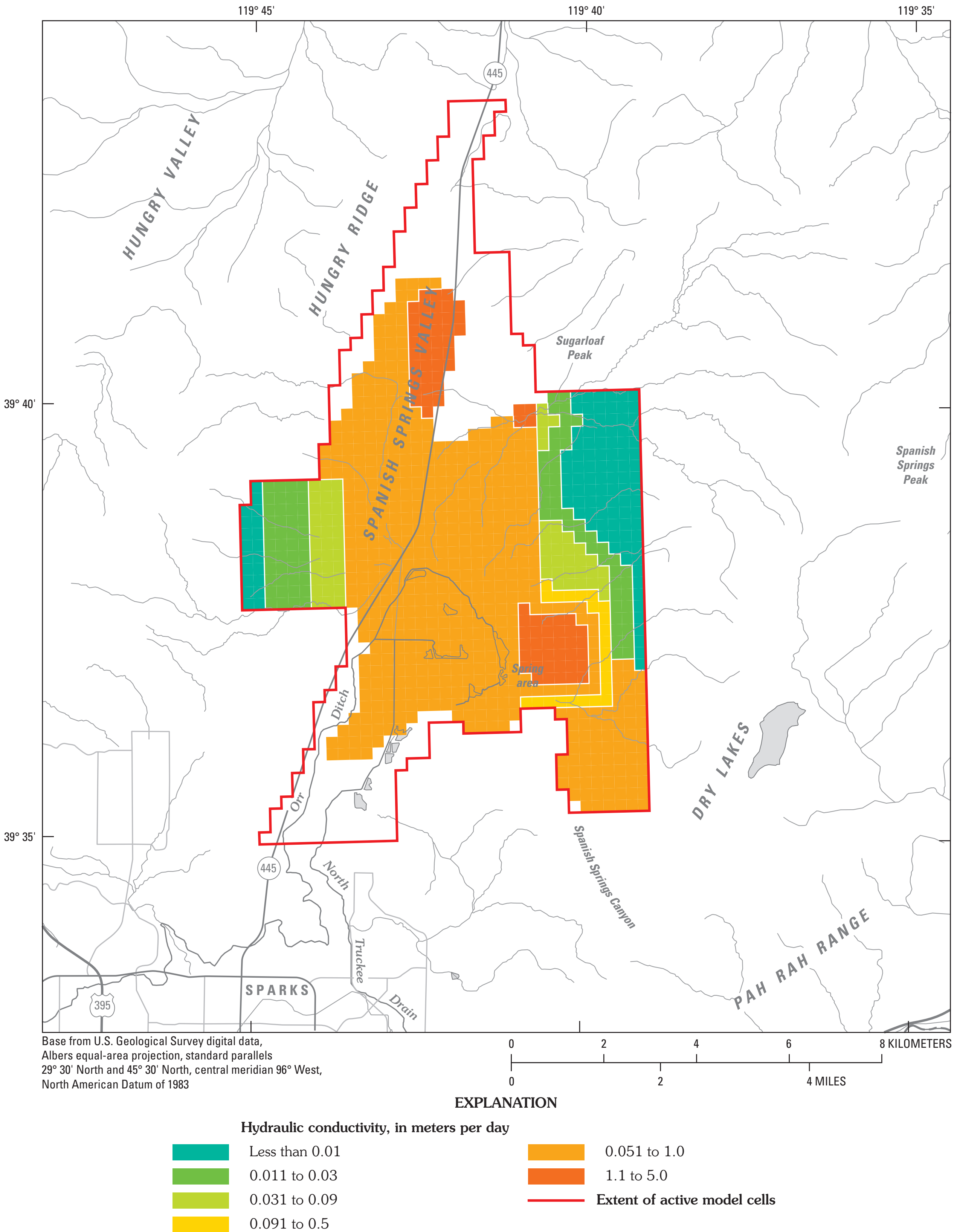


Figure 3.7*B*. Distribution of hydraulic conductivity for model layer 2, Spanish Springs Valley regional study area, Nevada.

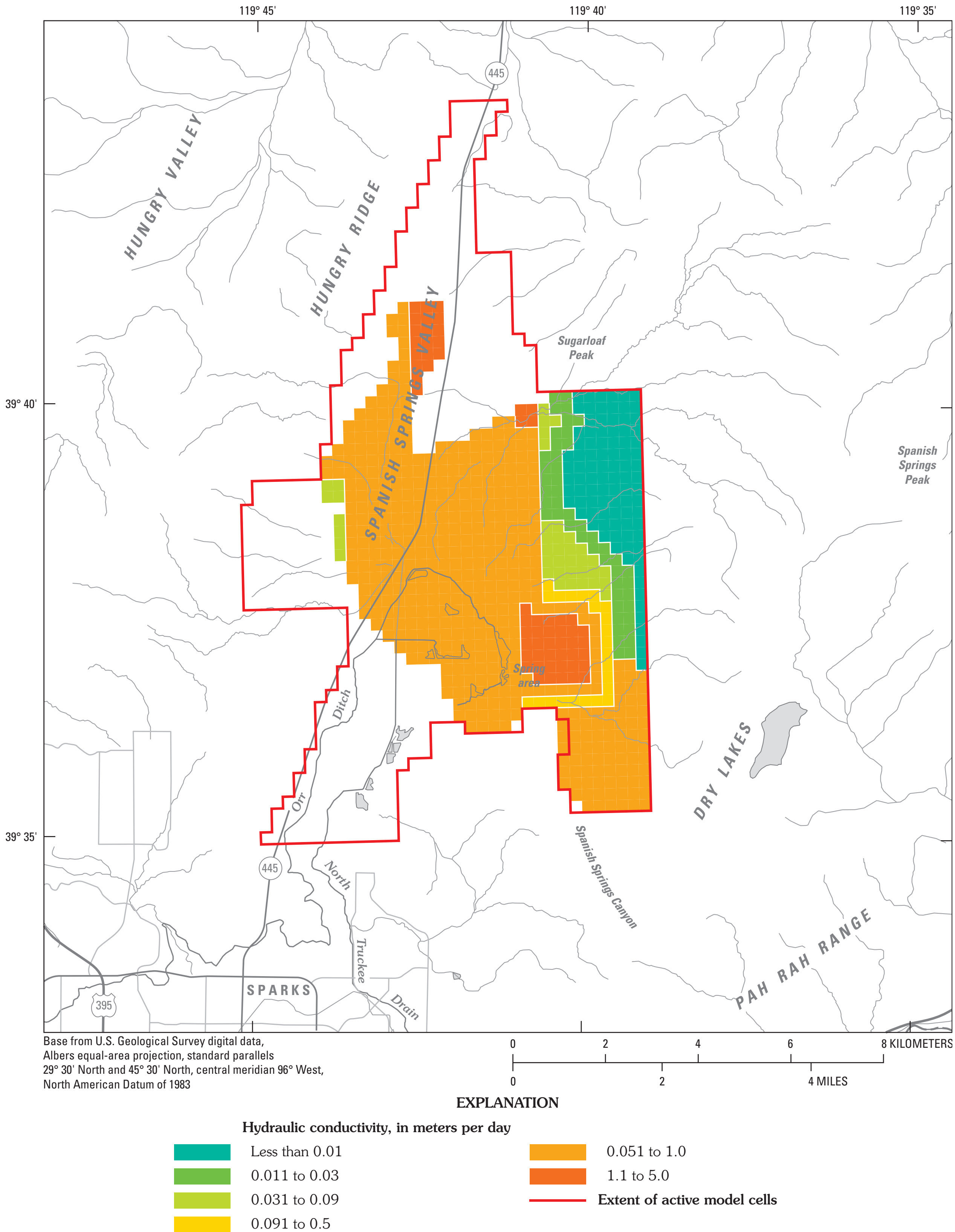


Figure 3.7*C*. Distribution of hydraulic conductivity for model layer 3, Spanish Springs Valley regional study area, Nevada.

Model Calibration

Both the Eagle Valley and Spanish Springs Valley steady-state models were calibrated by comparing model-computed hydraulic heads to measured hydraulic heads for 1997–2001. Hydraulic conductivity and recharge values were manually adjusted within a prescribed range until a reasonable match was obtained between model-computed and measured hydraulic heads. There were no surface-water flow data available for use in model calibration.

The overall goodness of fit of the model to the observation data was evaluated using summary measures and graphical analyses. The root-mean-squared error (RMSE), the range of head and residuals, the standard deviation, and the standard-mean error of the residuals (SME) were used to evaluate the model calibration. The RMSE is a measure of the variance of the residuals and was calculated as:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N} (h_{meas} - h_{sim})i^2}{N}}$$

where h_{meas} is the measured hydraulic head, h_{sim} is the model-computed (simulated) hydraulic head, $(h_{meas} - h_{sim})$ is the head residual, and N is the number of observations used in the computation. If the ratio of the RMSE to the total head change in the modeled area is small, then the error in the head calculations is a small part of the overall model response (Anderson and Woessner, 1992).

The SME was calculated as:

$$SME = \frac{\sigma(h_{meas} - h_{sim})}{\sqrt{N}}$$

where $\sigma(h_{meas} - h_{sim})$ is the standard deviation of the residuals.

Model-Computed Hydraulic Heads

The model-computed hydraulic heads compared favorably with measured hydraulic heads for the Eagle Valley model. The average residual was 0.14 m and residuals ranged from 13.6 to -18.6 m with the largest errors occurring along the model boundary representing the contact between the basin fill and mountain front. The standard deviation of the residuals is 5.77 m, and the SME is 0.58 m. The root-mean-squared error (RMSE) for the entire model was 5.7 m, which is approximately 6 percent of the 99-m range of measured hydraulic head. Measured hydraulic heads ranged from 1,397 to 1,496 m above NAVD88 and were similar to model-computed hydraulic heads, which ranged from 1,407 to 1,489 m above NAVD88. Figure 3.8*A* shows the relation between the residual head calculated as the difference between model-computed and measured hydraulic heads for both model layers and indicates the head residuals appear to be randomly distributed about zero at all values of measured head.

For the Spanish Springs Valley model, model-computed hydraulic heads also compare favorably with measured hydraulic heads. The average residual was 2.96 m and residuals ranged from -2.58 to 9.38 m with the largest errors generally occurring along the model boundary representing the contact between the basin fill and mountain front. The standard deviation of the residuals is 3.14 m, and the SME is 0.55 m. The RMSE for the entire model was 4.28 m, which is approximately 9 percent of the 50-m range of measured hydraulic head. Measured hydraulic heads ranged from 1,351 to 1,401 m above NAVD88 and were similar to model-computed hydraulic heads, which ranged from 1,352 to 1,396 m above NAVD88. Figure 3.8*B* shows the relation between the residual head calculated as the difference between model-computed and measured hydraulic heads for model layers 1 and 2 and indicates residuals are greatest in areas of highest hydraulic head.

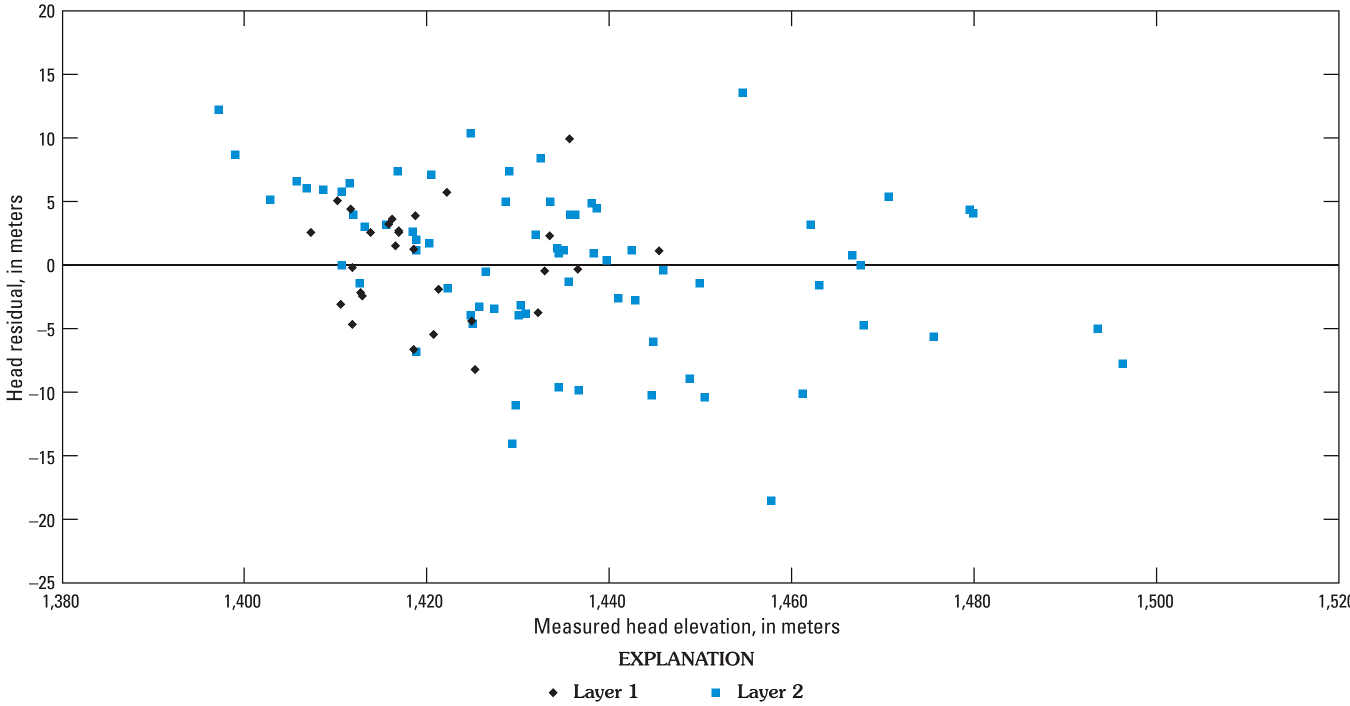


Figure 3.8*A*. Relation between residual head and measured hydraulic head, Eagle Valley regional study area, Nevada.

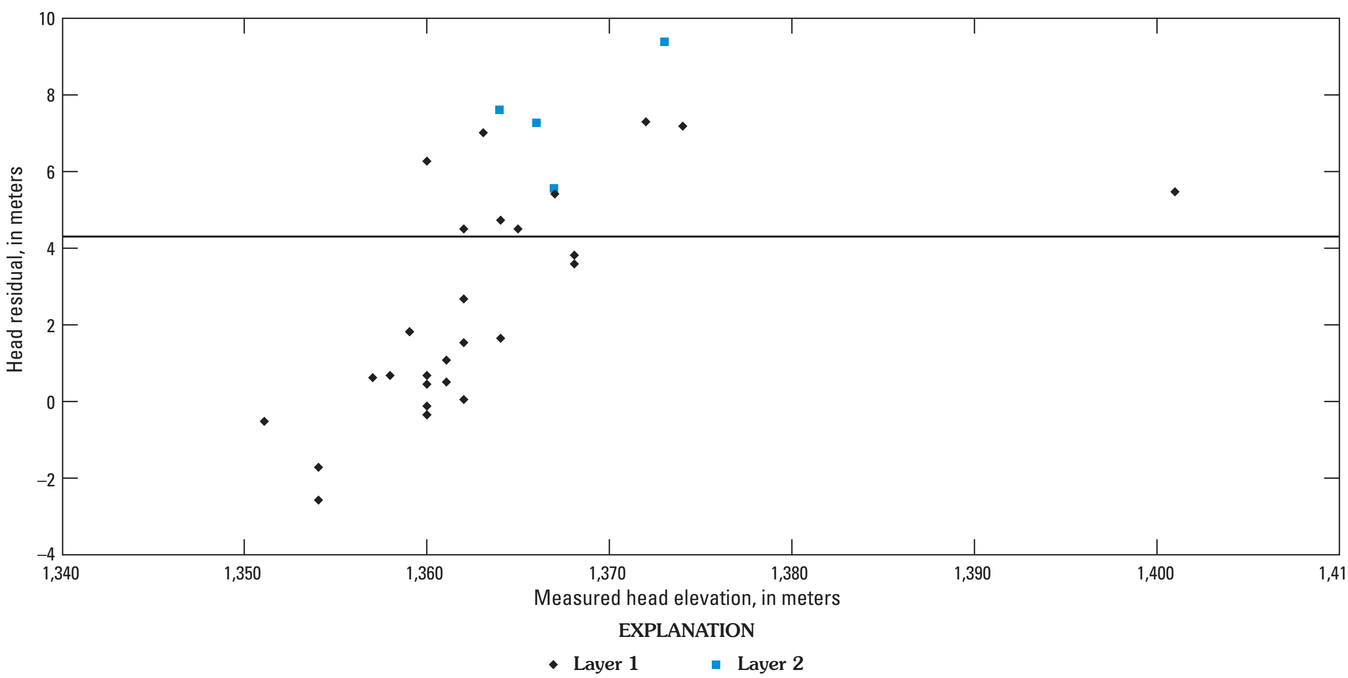


Figure 3.8*B*. Relation between residual head and measured hydraulic head, Spanish Springs Valley regional study area, Nevada.

Model-Computed Water Budget

The model-computed water budget for the Eagle Valley model is presented in table 3.4, and the model-computed water budget for the Spanish Springs Valley model is presented in table 3.5. In the Eagle Valley, infiltration of streamflow from the surrounding mountains (mountain-front recharge—62.9 percent of inflow) and mountain-block recharge (28.1 percent of inflow) were the primary sources of recharge to the basin-fill aquifer. Recharge from precipitation and irrigation provided 9 percent of the ground-water inflow. Discharge to public-supply wells (52.9 percent of outflow) and evapotranspiration (31.9 percent of outflow) were the primary ground-water outflows from the Eagle Valley. In the Spanish Spring Valley, canal leakage from the Orr Ditch (42.7 percent of inflow) and precipitation and irrigation (39.3 percent of inflow) were the primary sources of recharge to the basin-fill aquifer. Mountain-block recharge accounted for 13.3 percent of the ground-water inflow. Similar to the Eagle Valley, discharge to evapotranspiration (56 percent of outflow) and public-supply wells (34.7 percent of outflow) were the primary ground-water outflows from the Spanish Springs Valley. In general, both budgets compare fairly well with the conceptual water budgets discussed in the Water Budget section of this section.

Table 3.4. Model-computed water budget for 1997–2001 average conditions, Eagle Valley regional study area, Nevada.

[m^3/d, cubic hectometers per year]

Water-budget component	Flow (m^3/d)	Percentage of inflow or outflow
Model inflow		
Streams (mountain front recharge)	30,200	62.9
Mountain-block recharge	13,500	28.1
Precipitation, lawn and golf course watering	4,300	9.0
TOTAL INFLOW	**48,000**	**100**
Model outflow		
Wells	25,400	52.9
Evapotranspiration	15,300	31.9
Streams	7,300	15.2
TOTAL OUTFLOW	**48,000**	**100**

Table 3.5. Model-computed water budget for 1997–2001 average conditions, Spanish Springs Valley regional study area, Nevada.

[m^3/d, cubic hectometers per year]

Water-budget component	Flow (m^3/d)	Percentage of inflow or outflow
Model inflow		
Canal leakage	6,400	42.7
Precipitation and lawn irrigation	5,900	39.3
Mountain-block recharge	2,000	13.3
Head-dependent boundaries	700	4.7
TOTAL INFLOW	**15,000**	**100**
Model outflow		
Evapotranspiration	8,400	56.0
Wells	5,200	34.7
Head-dependent boundaries	1,100	7.3
Streams	300	2.0
TOTAL OUTFLOW	**15,000**	**100**

Simulation of Areas Contributing Recharge to Public-Supply Wells

The calibrated steady-state regional flow models were used to estimate areas contributing recharge and zones of contribution for public-supply wells using the MODPATH (Pollock, 1994) particle-tracking post processor and methods outlined in Section 1 of this Professional Paper. The model-computed areas contributing recharge represent advective ground-water flow and do not account for mechanical dispersion. Advection-dispersion transport simulations would likely yield larger areas contributing recharge than advective particle-tracking simulations because the effects of dispersion caused by aquifer heterogeneity would be included.

Along with flux output from the models, the MODPATH simulations require effective porosity values to calculate ground-water flow velocities. There are no porosity data available for the study areas, so a reasonable porosity value of 0.15 from the literature (Fetter, 2001) was used for all layers in both the Eagle Valley and Spanish Springs Valley particle-tracking simulations.

Particle-tracking simulations were used to outline areas contributing recharge for all 20 public-supply wells in the Eagle Valley. Areas contributing recharge are irregular in shape and extend to the mountain front on the north and west sides of the valley because a large amount of water enters the model as mountain-front or mountain-block recharge (fig. 3.9*A*). Traveltimes from recharge areas to public-supply wells were on the order of 5 to 140 years.

Particle-tracking simulations for the eight public-supply wells in the Spanish Springs Valley provided results similar to those for the Eagle Valley. In general, areas contributing recharge were along the mountain front on the east and west sides of the valley (fig. 3.9*B*). Traveltimes from recharge to discharge areas were somewhat longer in the Spanish Springs Valley than in the Eagle Valley, ranging from 10 to 2,600 years.

The areas contributing recharge in both the Eagle and Spanish Springs Valleys models extend to the general-head boundary cells along the mountain-front boundary of the alluvial aquifer indicating mountain-front and mountain-block recharge are the primary source of water for the public-supply wells.

Limitations and Appropriate Use of the Model

The ground-water flow models for the Eagle Valley and Spanish Springs Valley regional study areas were designed to evaluate the water budgets and delineate contributing areas to public-supply wells for hydrologic conditions in 1997–2001. A numerical ground-water model is a simplification of a physical system, and the intent in developing these regional models was not to reproduce every detail of the natural systems, but rather to portray their general characteristics. Sources of error in the model may include the steady-state flow assumption and errors in the conceptual model of the system, hydraulic properties, and boundary conditions.

The assumption of steady-state conditions for these models is a source of model uncertainty because the steady-state model may not be representative of ground-water flow conditions as time progresses and there were limited water-level data with which to evaluate long-term water-level trends. As water continues to be pumped from public-supply wells, water may be removed from aquifer storage especially in this arid climate where recharge is limited. The result may be a considerable delay before land-use practices in contributing areas delineated by this analysis could actually affect water quality in supply wells.

In some cases, model data were derived from sparse data or data of questionable quality (for example some drillers' logs) or by empirical methods that are inherently uncertain (such as estimating recharge as a percentage of precipitation). Other properties of the system had to be estimated without observation or measurement (for example, hydraulic properties of deep basin fill) and are another source of model uncertainty.

Although substantial information exists on some system stresses (for example, public-supply pumping), others such as evapotranspiration rates and septic-system recharge were estimated from literature values. It was not possible to identify the uncertainties, or the magnitude of the uncertainties, in the model data sets that contributed to the lack of complete agreement between simulated and measured hydraulic heads and ultimately to limitations of the results.

Computed areas contributing recharge and traveltimes through zones of contribution are based on a calibrated model and estimated effective porosity values. In a steady-state model, changes to input porosity values do not change the area contributing recharge to a given well. Changes to input porosity values will change computed traveltimes from recharge to discharge areas in direct proportion to changes of porosity because there is an inverse linear relation between ground-water flow velocity and effective porosity and a direct linear relation between traveltime and effective porosity. For example, a one-percent decrease in porosity will result in a one-percent increase in velocity and a one-percent decrease in particle traveltime. There are no available porosity data for these study areas, so a reasonable estimated values were used. A detailed sensitivity analysis of porosity distributions was beyond the scope of this study, although future work could compare simulated ground-water traveltimes to ground-water ages to more thoroughly evaluate effective porosity values.

Despite their limitations, the Eagle Valley and Spanish Springs Valley regional ground-water flow models use justifiable aquifer properties and boundary conditions and provide reasonable representations of average ground-water flow conditions for 1997-2000. The models are suitable for evaluating regional water budgets and ground-water flow paths in the study area for the time period of interest but may not be suitable for long-term predictive simulations. These regional models provide useful tools to evaluate aquifer vulnerability at a regional scale, to facilitate comparisons of ground-water traveltime between regional aquifer systems, and to guide future detailed investigations in the study areas.

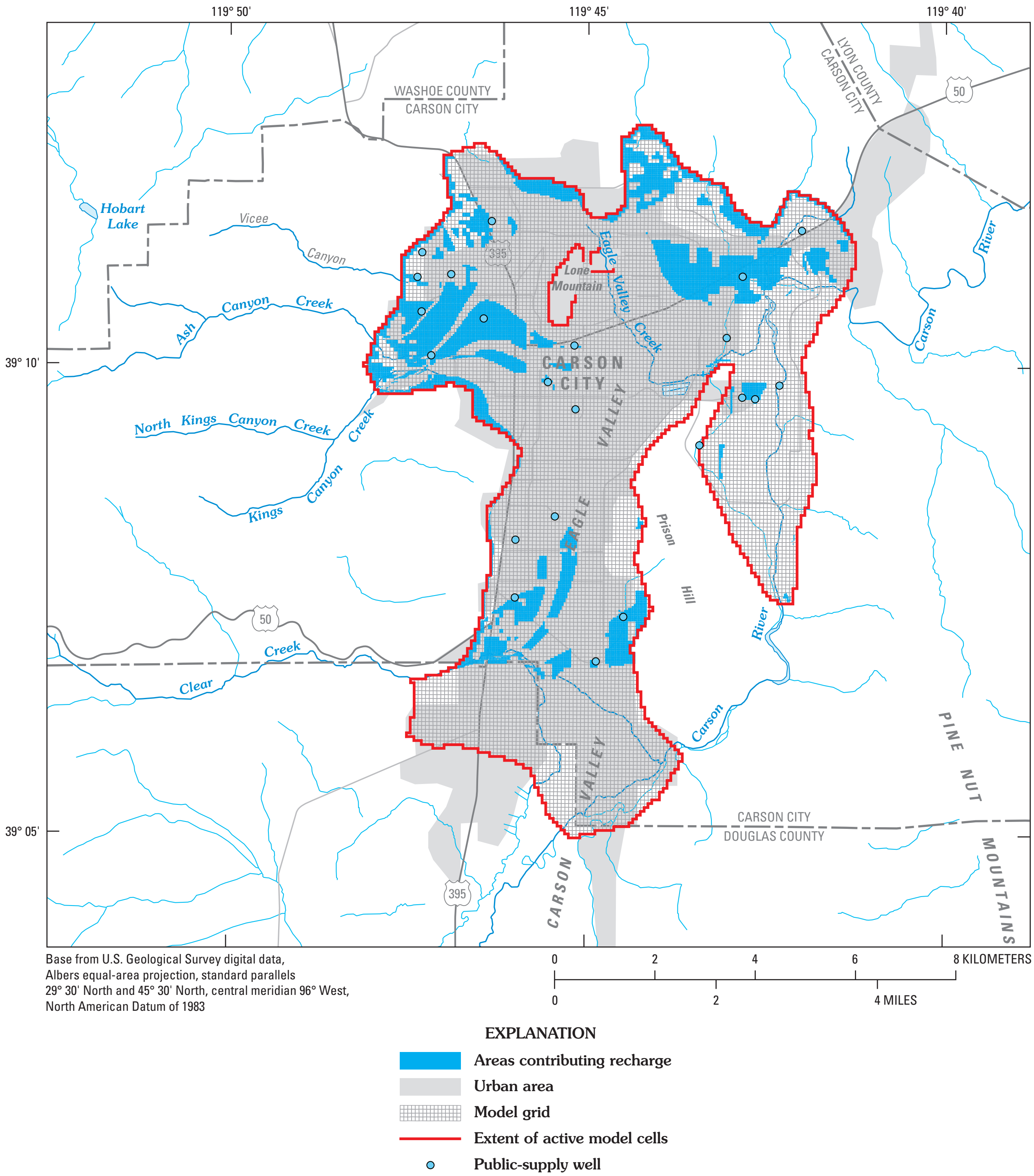


Figure 3.9*A*. Model-computed areas contributing recharge to public-supply wells, Eagle Valley regional study area, Nevada.

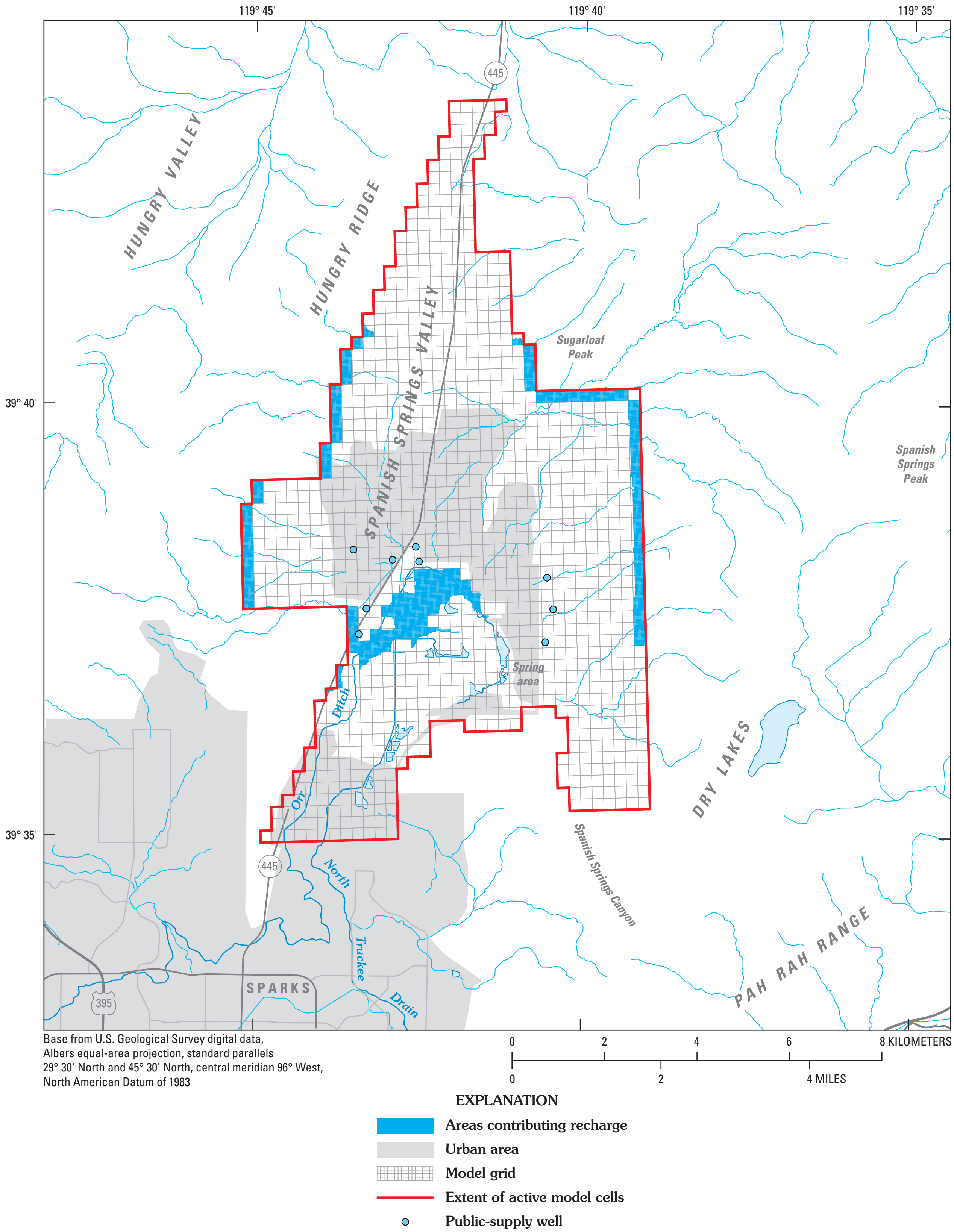


Figure 3.9*B*. Model-computed areas contributing recharge to public-supply wells, Spanish Springs Valley regional study area, Nevada.

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