# Section 3.—Conceptual Understanding and Groundwater Quality of the Basin-Fill Aquifer in Truckee Meadows, Nevada

By Jena M. Huntington

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

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## Basin Overview

Truckee Meadows is a north-south trending basin covering about 94 $mi^2$ in western Nevada that is undergoing the urbanization of its rangeland and irrigated agricultural areas. Groundwater quality in the basin is influenced by both natural and human-induced factors. Truckee Meadows is bordered on the west by the Carson Range, a spur of the Sierra Nevada Range; on the east by the Virginia Range; on the north by volcanic hills related to the Carson and Virginia Ranges; and on the south by the Steamboat Hills and Pleasant Valley (fig. 1). While the average elevation of the basin is 4,500 ft, Mount Rose to the west soars to 10,778 ft, Peavine Mountain to the north rises to 8,266 ft, and the Steamboat Hills to the south reach an elevation of 6,181 ft.

The Truckee River, which originates at Lake Tahoe in the Sierra Nevada Range, flows from west to east across Truckee Meadows and exits the valley through a deeply incised canyon within the Virginia Range. Steamboat Creek, which has the Truckee River's largest tributary area (Stockton, 2003), flows northward from Pleasant Valley. The basin experiences the "rain shadow" effect due to it's location on the leeward side of the Sierra Nevada Range. This effect, coupled with the elevation of the valley floor, generates an arid desert climate with low humidity (Gates and Watters, 1992). Analysis of modeled precipitation data for 1971–2000 (PRISM Group, Oregon State University, 2004) resulted in an estimated average annual precipitation of about 10.4 in. over the alluvial basin as a whole (McKinney and Anning, 2009). Up to about 40 in. of precipitation falls each year in the adjacent mountains, mostly as snow.

Truckee Meadows is home to the cities of Reno and Sparks and expanding suburbs. Analysis of LandScan population data for 2005 (Oak Ridge National Laboratory, 2005) indicated a population of about 263,000 for the alluvial basin as a whole (McKinney and Anning, 2009) and a population density of about 2,750 people/$mi^2$. Land cover for the alluvial basin in 2001 was about 3 percent agricultural, 55 percent urban, 24 percent range, and about 18 percent for other uses (fig. 1; U.S. Geological Survey, 2003).

The movement of water through the geologic materials of the basin, coupled with anthropogenic activities and recharge from the land surface to the aquifer, results in elevated concentrations of some chemical constituents and organic compounds in groundwater. Groundwater-quality issues identified in Truckee Meadows and described later in this section include naturally occurring arsenic and elevated concentrations of other dissolved constituents, and the presence of nitrate, volatile organic compounds, and pesticides associated with human activities and land-use practices in the basin.

## Water Development History

The Washoe Native American tribes were the first people to inhabit the Truckee Meadows area. Fur trading expeditions arrived in the basin in the 1820s and army expeditions began coming through Truckee Meadows en route to Sacramento, California in the 1840s. It was then that a Paiute Indian guide whose name sounded like "Truckee" became the namesake of the Truckee River (Rowley, 1984; Gates and Watters, 1992). Wagon trains followed the Truckee River Trail to California over what was to be called Donner Pass in the Sierra Nevada Range after the Donner Party starvation tragedy during the winter of 1846–47 (Gates and Watters, 1992). Gold was discovered in the Comstock Lode to the southeast of Truckee Meadows in 1859, and the town of Reno was formed to provide supplies (Rowley, 1984; Land and Land, 1995).

During the 1860s, livestock production and agriculture spread in the basin and Reno became the crossroads for the Transcontinental and Virginia and Truckee Railroads (Land and Land, 1995). Several irrigation ditches were constructed to divert water from the Truckee River to the western, southern, and northern parts of the basin. Electric companies also diverted water from the river into wooden aqueducts that hugged the canyon walls until they reached turbines downstream.

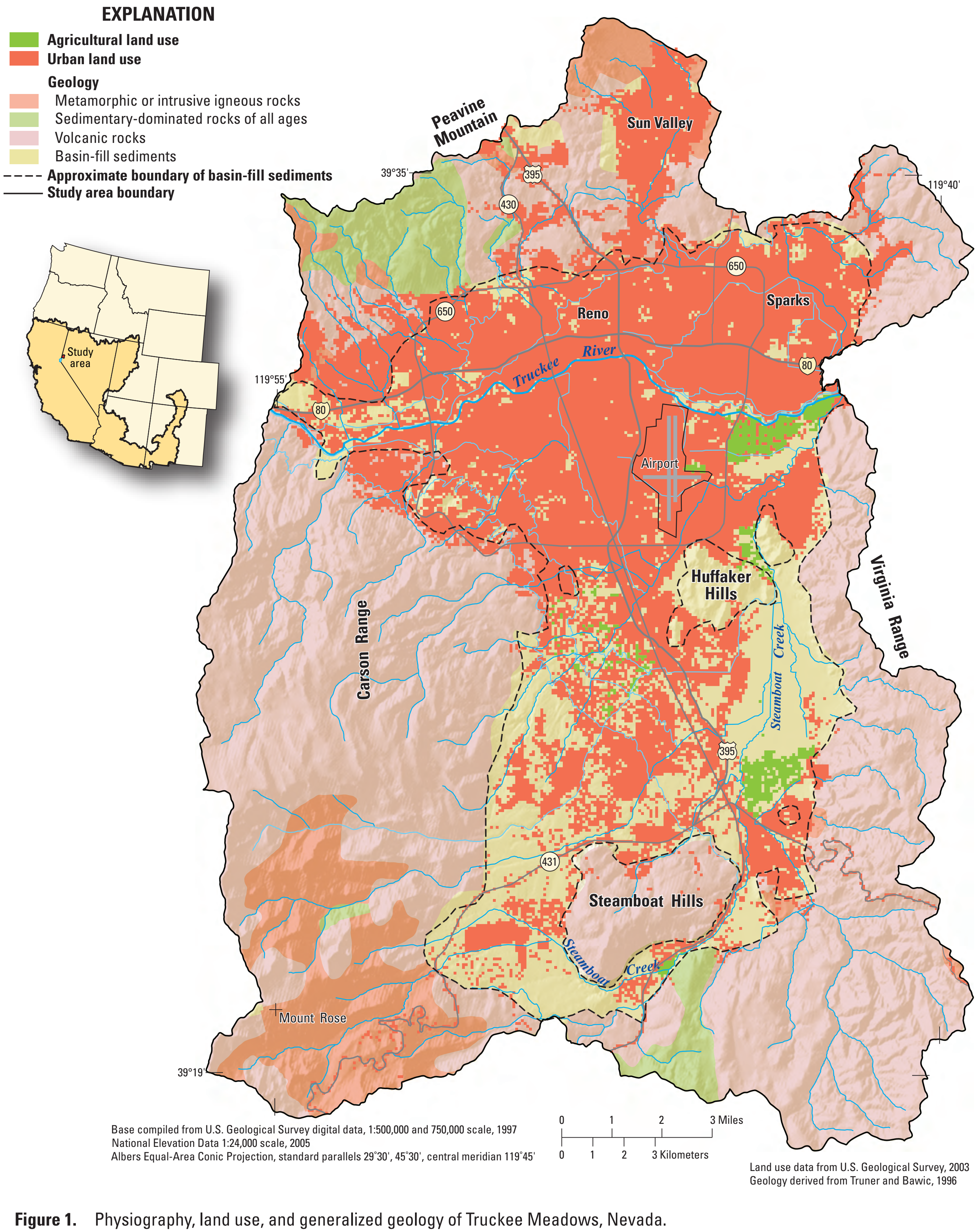


**Figure 1.** Physiography, land use, and generalized geology of Truckee Meadows, Nevada.

Drinking water used in Truckee Meadows historically came from the Truckee River, although contamination problems started as early as development did. Raw sewage was discharged directly into the river, and during the late 1880s, upstream sawmills began dumping sawdust into the river. Although the Truckee River served as the sole source of drinking water through the turn of the 20th century, the population in the basin grew quickly, and groundwater pumping was initiated in the late 1950s for municipal supply when a focused effort to provide a back-up source for surface water was implemented (Christopher Benedict, Washoe County Department of Water Resources, written commun., 1999). Most of the land previously used for agriculture in the basin has been urbanized. Currently, very little land is used for raising livestock or growing crops.

## Hydrogeology

Truckee Meadows, like most basins in the Basin and Range Physiographic Province, is a structural depression bounded by fault-block mountains. The Carson Range to the west is made up of diverse metavolcanic and metasedimentary rocks that were intruded by granitic rocks. This sequence of rocks was mostly covered by thick flows of Tertiary volcanic rocks that include rhyolite and andesite. The geology of the Virginia Range is similar, although extrusive rocks almost completely cover the granitic base rocks (Bateman and Scheibach, 1975). Most of the consolidated rocks bordering Truckee Meadows are of low permeability and do not store or transmit appreciable amounts of water (Cohen and Loeltz, 1964, p. S8). Volcanic rocks protrude from within the basin at the Huffaker Hills and Steamboat Hills. Normal faults, generally trending north, northwest, and northeast, have been mapped through much of the basin. Geothermal water occurs in association with these faults in the Reno area and in the Steamboat Hills area (Bateman and Scheibach, 1975).

Basin-fill deposits in the Truckee Meadows basin have been divided into three general units—sedimentary rocks of Tertiary age, older alluvium of Quaternary age, and younger alluvium of Quaternary age (Cohen and Loeltz, 1964, p. S11). The Tertiary material was deposited mainly in a fluvial environment and consists of unconsolidated to partly consolidated diatomaceous sediments interbedded with coarse-grained sandstones, shales, gravels, and tuffs (Bonham and Rogers, 1983; and Trexler and Cashman, 2006). Tertiary sedimentary rocks are considered to be relatively close to land surface, within 1,150 ft, especially in the eastern parts of the basin, and are thickest in the northwest, where sediment thickness is in places more than 2,000 ft (Widmer and others, 2007). On the basis of well yield data, these rocks are considered to be of low permeability, but recent research has indicated the presence of intervals within the Tertiary sediments that are capable of transmitting appreciable volumes of water. This is particularly true in the eastern parts of the basin, where it is likely that several municipal water-supply wells have been completed in these sediments (Widmer and others, 2007; and Trexler and others, 2000).

During the Quaternary period, glacial outwash—silt, sand, gravel, and boulders—from the mountains to the west was deposited in the Truckee Meadows basin along with poorly sorted pediment and alluvial-fan deposits. This alluvium unconformably overlies the Tertiary sediments and is exposed on the Mount Rose alluvial fan complex in the southwestern part of the basin and along the Truckee River. Younger alluvial deposits are present mostly in the valley lowlands along the floodplains of the Truckee River and Steamboat Creek, along the stream channels of tributary drainages entering the basin, and along the base of alluvial fans as thin, sheet-like aprons of reworked sediment (Bonham and Rogers, 1983). Compared to the thick deposits on the west side of the basin, a relatively thin section of Quaternary age alluvial-fan deposits skirts the base of the Virginia Range, and in the central part of the basin the maximum thickness of Quaternary age deposits is thought is be less than about 650 ft (Abbott and Louie, 2000).

Deposits of highest hydraulic conductivity to transmit water lie to the north of the Huffaker Hills (Cohen and Loeltz, 1964, p. S14). Hydraulic conductivity of the basin-fill material estimated from pumping-test data ranges from about 12 to 28 ft/d. Estimates of transmissivity for the basin-fill aquifer from pumping-test data listed by Cohen and Loeltz (1964, table 4) range from 200 to 7,000 $ft^2$/day.

## Conceptual Understanding of the Groundwater System

Truckee Meadows is an open basin drained by the Truckee River. The basin-fill aquifer system is made up primarily of unconsolidated Quaternary deposits and Tertiary sediments, although fractured bedrock influences groundwater flow and quality in some areas. Both semiconfined and unconfined conditions exist in the basin-fill aquifer. Relatively thick unsaturated zones underlie the alluvial fans to the south and north and become thinner toward the basin lowlands. Fine-grained flood plain deposits are interbedded with coarser grained stream channel deposits in the lower parts of the basin. In general, the occurrence of fine-grained sediment increases with depth due to the much lower depositional energy that was present prior to the uplift of the Sierra Nevada approximately 2 million years ago (Christopher Benedict, written commun., 2009). Because of aggradation and erosion, confining layers can be discontinuous, of variable thickness, and interbedded with more permeable deposits. Discontinuous, fine-grained fluvial deposits create confined conditions mostly in the northeastern part of the basin north of the Huffaker Hills, where they overlie saturated coarse-grained deposits. Flowing wells are present in this area, although more recent municipal well pumpage has reduced the number of flowing wells and (or) their discharge rates.

The aquifer is recharged naturally by the infiltration of precipitation falling on the surrounding mountains and basin margins and from human-related sources in the valley, such as seepage from surface-water diversions, excess irrigation water, and pumped groundwater from municipal wells that is discharged to the Truckee River and subsequently infiltrates (fig. 2). Groundwater generally flows from recharge areas in the west and south toward the Truckee River and Steamboat Creek, which may receive relatively minor amounts of groundwater seepage, and to discharge areas in the center and eastern parts of the valley, where evapotranspiration (ET) occurs. Geothermal water also enters the basin-fill aquifer along faults within the valley.

## Water Budget

Recharge to the basin-fill aquifer in Truckee Meadows is from the infiltration of precipitation on the surrounding mountains and alluvial slopes (mountain-front recharge), infiltration of precipitation on the basin floor, seepage of excess irrigation water, losses from the Truckee River and ditches that divert water from the river onto the margins of the basin, artificial recharge through injection wells, and by subsurface inflow from adjacent basins (table 1). Van Denburgh and others (1973, table 12) estimated recharge from precipitation along the mountain fronts above 5,000 ft to be about 24,400 acre-ft/yr using the Maxey-Eakin method ((Maxey and Eakin, 1949; Eakin and others, 1951), which applies a percentage of average annual precipitation within specified altitude zones to estimate recharge. Most of the natural recharge originates as precipitation at high altitudes on the western part of the drainage area and enters the basin-fill aquifer as seepage from snowmelt runoff. An unknown fraction of the precipitation eventually enters the basin-fill aquifer as subsurface inflow from the surrounding consolidated rocks where they are permeable or fractured. Recharge from the infiltration of precipitation on the basin floor was estimated to be 5 percent of the average precipitation, or about 2,100 acre-ft/yr (Van Denburgh and others, 1973, table 12).

Seepage from the Truckee River to the basin-fill aquifer was estimated by Cohen and Loeltz (1964, p. S21) to be about 4,000 acre-ft/yr. Subsurface inflow to Truckee Meadows from adjacent basins was estimated by Van Denburgh and others (1973, table 13) to be about 300 acre-ft/yr from Pleasant Valley to the south and 700 acre-ft/yr through the Truckee Canyon area to the west. Rush and Glancy (1967, p. 37) estimated about 100 acre-ft/yr from Spanish Springs Valley and 25 acre-ft/yr from Sun Valley to the north. Thus the total subsurface inflow from adjacent basins is estimated to be about 1,125 acre-ft/yr, and all of the natural recharge to the Truckee Meadows basin-fill aquifer, including that from infiltration of precipitation and inflow from adjacent basins, totals about 31,600 acre-ft/yr (table 1).

Groundwater discharges naturally by ET and by seepage to the Truckee River and Steamboat Creek (both to the north and south of the Huffaker Hills). 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). Although the quantities associated with the components of recharge to the basin-fill aquifer listed in table 1 are based on several assumptions and few data, they are considered to be within the correct order of magnitude and thus indicate the degree to which each component recharged the groundwater system.

Human related changes to the groundwater flow system beneath Truckee Meadows began in the late 1800s, when water diverted from the Truckee River for irrigation began recharging the aquifer (fig. 2). Inflow to Truckee Meadows from the Truckee River and its principal diversions averaged about 530,000 acre-ft/yr from 1919–69 (Van Denburgh and others, 1973, p. 30). Cohen and Loeltz (1964, p. S20) estimated that about 88,000 acre-ft/yr of Truckee River water was diverted and applied to 22,000 irrigated acres during the 1950s and early 1960s and that about 6,000 acre-ft/yr of canal losses recharged the basin-fill aquifer. They assumed that 25 percent of the applied irrigation water (mainly by flooding) recharged the aquifer, about 25,000 acre-ft/yr during that time. The recharge from excess irrigation water and canal losses to the groundwater system almost doubled the quantity of recharge from that of predevelopment conditions. This additional recharge resulted in a rise in groundwater levels, an increase in the volume of water stored in the aquifer, and an increase in groundwater discharge from ET and seepage to streams (Cohen and Loeltz, 1964, p. S27).

The area of irrigated agriculture in the basin has decreased since the 1960s in response to the expansion of urban land. An estimated 7,800 acre-ft/yr of water was applied to approximately 2,120 acres of irrigated fields in 2001 (McKinney and Anning, 2009). Assuming 25 percent of this amount infiltrates past the root zone, about 2,000 acre-ft/yr of excess irrigation water recharges the aquifer in agricultural areas under modern conditions. This estimate is less than one-tenth of the recharge from excess irrigation to the groundwater system in the 1960s. Only a fraction of the once expansive irrigated land remained in 2001 and even less acreage is irrigated today (2010), although diversions to ditches in the western and northern parts of the basin still averaged about 67,000 acre-ft/yr for the period from 1989 to 2002 (Regional Water Planning Commission, 2005, fig. 2-11 and p. 2-22). Many of these ditches are now lined (Christopher Benedict, written commun., 2009) and therefore the 6,000 acre-ft/yr of ditch losses, as estimated by Cohen and Loeltz, (1964) is likely less than 500 acre-ft/yr.

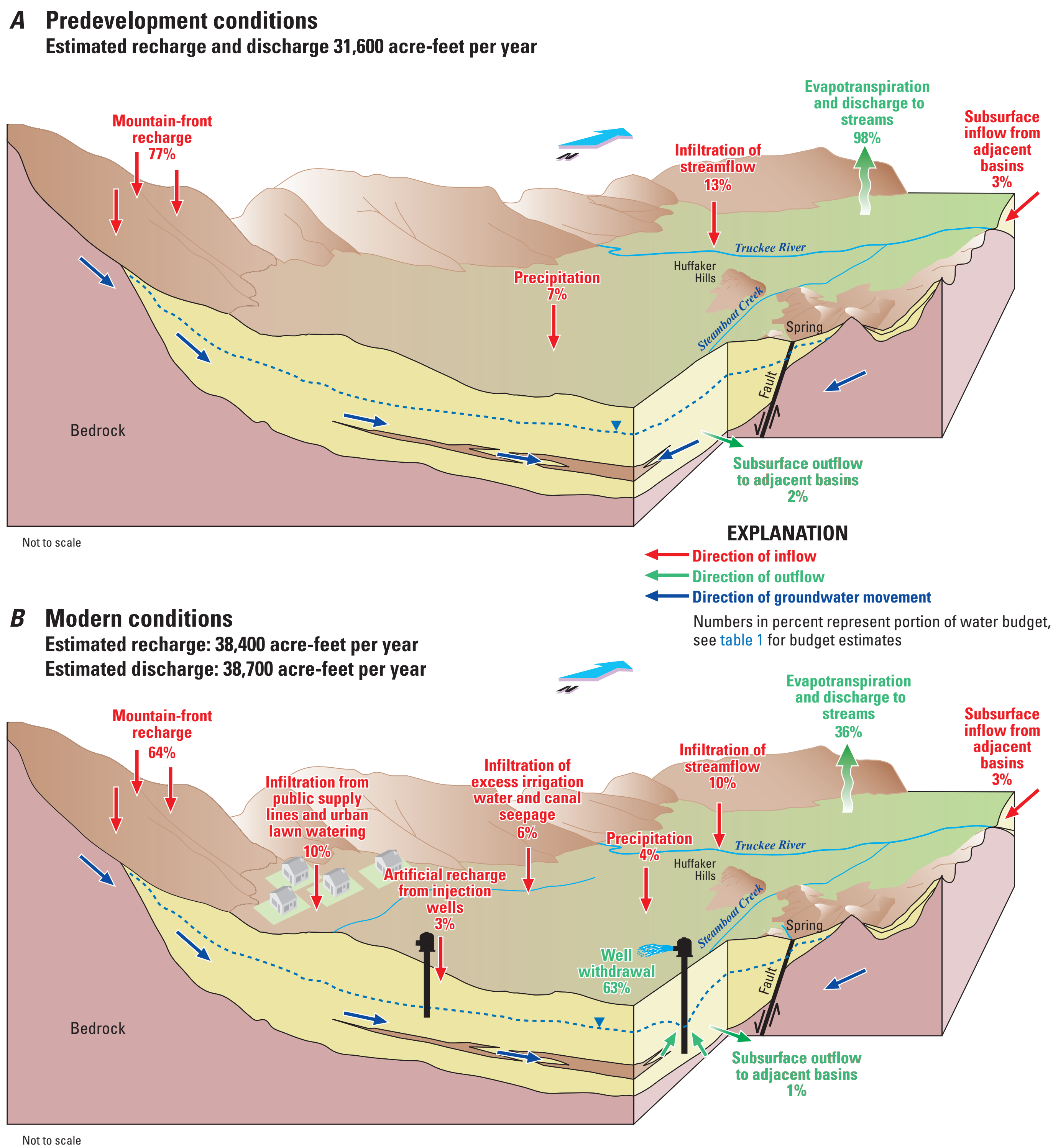


**Figure 2.** Generalized diagrams for Truckee Meadows, Nevada, showing the basin-fill deposits and components of the groundwater system under (*A*) predevelopment and (*B*) modern conditions.

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

[All values are in acre-feet per year 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 2. <, less than]

| | Predevelopment conditions | Modern conditions | Change from predevelopment to modern conditions |
|---|---|---|---|
| **Budget component** | | **Estimated recharge** | |
| Mountain-front recharge | [1]24,400 | [1]24,400 | 0 |
| Infiltration of precipitation on alluvial basin | [1]2,100 | [9]1,600 | -500 |
| Infiltration of streamflow from the Truckee River | [2]4,000 | [2]4,000 | 0 |
| Subsurface inflow from adjacent basins | [1,3]1,100 | [1,3]1,100 | 0 |
| Infiltration of excess irrigation water and canal seepage | 0 | [11, 8]2,500 | 2,500 |
| Infiltration from public supply lines | 0 | [12]2,100 | 2,100 |
| Infiltration of excess urban lawn water | 0 | [11]1,700 | 1,700 |
| Artificial recharge from injection wells | 0 | [4, 10]1,000 | 1,000 |
| **Total recharge** | **31,600** | **38,400** | **6,800** |
| **Budget component** | | **Estimated discharge** | |
| Evapotranspiration and discharge to streams | [5]31,100 | [6]13,800 | -17,300 |
| Subsurface outflow to adjacent basins | [2]< 500 | [2]< 500 | 0 |
| Well withdrawals | 0 | [7]24,400 | 24,400 |
| **Total discharge** | **31,600** | **38,700** | **7,100** |
| Change in storage (total recharge minus total discharge) | 0 | -300 | -300 |

[1] Van Denburgh and others (1973).

[2] Cohen and Loeltz (1964).

[3] Rush and Glancy (1967).

[4] Regional Water Planning Commission, Washoe County Department of Water Resources (2005).

[5] Assumed to equal the recharge total for predevelopment conditions minus estimated subsurface outflow.

[6] Assumed to be the residual between total recharge and discharge from wells under modern conditions minus estimated subsurface outflow.

[7] Lopes and Evetts (2004).

[8] Written communication from Christopher Benedict, Washoe County Department of Water Resources, 2009.

[9] Estimated as 75 percent of predevelopment conditions, due to 49 percent urban land use in 2001 (McKinney and Anning, 2009).

[10] Truckee Meadows Water Authority (2009).

[11] Calculated from McKinney and Anning (2009).

[12] CDM and Bouvette Consulting (2002).

In 2000, about 68,000 acre-ft of water from streams and wells was supplied for public use to about 29,500 acres of urban land in Truckee Meadows (McKinney and Anning, 2009). Some of this water is used to irrigate vegetation in urban/residential areas, and depending on how efficiently the water is used, a small fraction likely infiltrates to the aquifer. Assuming that one half of the publicly supplied water is used for irrigation by sprinklers and that 5 percent of this water infiltrates into the subsurface past the root zone, then recharge from excess irrigation water in urban areas is estimated to be about 1,700 acre-ft/yr. Water also leaks from the pipes used to distribute water throughout the urban area and about 2,100 acre-ft/yr was estimated to recharge the aquifer in the central part of the basin (CDM and Bouvette Consulting, 2002).

Since 1993, chlorinated surface water has been injected during the winter months into several public-supply wells in the central part of the basin. The aquifer is used to store the injected water until it is needed during summer months when demand is highest, or during drought, when the groundwater is pumped. The total amount of water artificially recharged through injection wells from 1993 (81 acre-ft) to 2003 (2,400 acre-ft) was 10,800 acre-ft, and averaged about 980 acre-ft/yr (Regional Water Planning Commission, 2005, p. 2-13; Truckee Meadows Water Authority, 2009, p. 69).

The extraction and artificial recharge of groundwater for geothermal production in the basin is not listed in table 1. Geothermal water is pumped for power generation and then reinjected after use to approximately the same depth from which it was removed. Typically there is little or no loss between extraction and reinjection. In 2000, about 39,600 acre-ft of geothermal water was pumped and 37,700 acre-ft was reinjected (Lopes and Evetts, 2004, table 1). Steamboat Creek receives natural discharge from the Steamboat Springs geothermal area that is not included in this groundwater budget.

The Truckee River is the main source of water for public supply to the central part of Truckee Meadows. Groundwater is used to supplement the surface-water supply in the basin with about 21,200 acre-ft pumped from public-supply wells and about 2,800 acre-ft from domestic wells in 2000 (Lopes and Evetts, 2004, table 1). Withdrawals for irrigation and stock watering under modern conditions are minimal (about 380 acre-ft in 2000).

## Groundwater Movement

Groundwater moves from topographically high recharge areas to lower areas of Truckee Meadows, where under natural conditions the water discharges. The general direction of groundwater flow in the basin is from southwest to northeast, toward the Truckee River (fig. 3) (Covey and others, 1996, p. 58). Groundwater naturally discharges to the Truckee River and Steamboat Creek and in areas north of the Huffaker Hills and near the Reno International Airport. Water-level contours indicate that the consolidated rock of the Huffaker Hills may transmit water through fractures.

The presence of chlorofluorocarbons (CFCs) in groundwater is used as an indicator of young water and as a tool for estimating specific groundwater ages. CFCs are man-made organic compounds that are used in industrial processes and in the home. After their introduction in the 1930s, atmospheric concentrations increased nearly exponentially until the 1990s (Plummer and Busenberg, 2000). Chlorofluorocarbons were detected in samples collected from ten wells in the Truckee Meadows from 2002 to 2008 (table 2). The ten wells ranged in depth from 14 to 760 ft, and all contained CFCs at a concentration(s) that indicates 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 (i.e. tritium, carbon-14) were conducted to interpret a more refined recharge date.

Additional sources and paths of recharge and discharge under modern conditions have had an effect on groundwater levels in the Truckee Meadows. Water-level declines in domestic wells in the southern part of the basin have been attributed to diminished recharge from excess irrigation in the area as agricultural land is urbanized (Regional Water Planning Commission, 2005, p. 2-19). Groundwater pumping for public supply has resulted in several changes to the groundwater flow system, primarily on a local scale. Vertical hydraulic gradients near pumping centers seasonally change from an upward to a downward gradient. Municipal well pumping has also likely caused water-level declines in parts of the basin-fill aquifer and consequently increased water loss from the Truckee River to the groundwater system (Christopher Benedict, written commun., 2009), although the volume of such loss has not been quantified.

Although the estimated groundwater budget for modern conditions (table 1) does not show a significant overall change in storage in the basin, the reduction in recharge from excess irrigation water and the increase in discharge from well withdrawals would result in the removal of water from storage in areas where other processes of discharge or recharge have not changed. Under these conditions, groundwater levels would decline, and in areas of natural discharge, ET and seepage to streams would be reduced before any water would be removed from storage. These effects are observed more frequently in areas further away from the Truckee River, as the river tends to buffer changes in storage near its channel (Christopher Benedict, written commun., 2009).

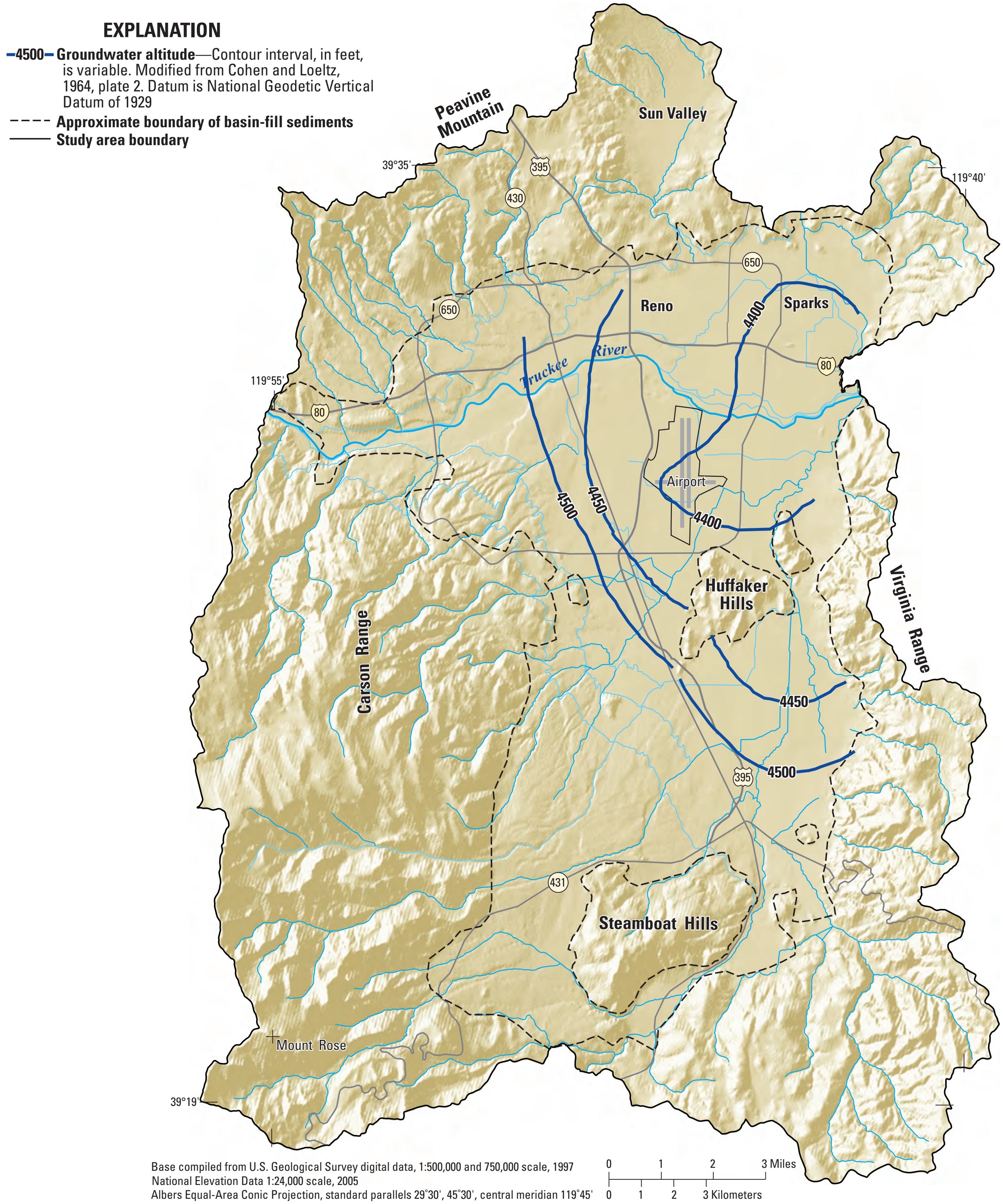


**Figure 3.** Generalized groundwater levels in 1962 in Truckee Meadows, Nevada.

**Table 2.** Designation of groundwater age in selected wells in Truckee Meadows, 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 |
|---|---|---|---|
| 392837119485901 | 159 | 06-03-2002 | Modern |
| 392918119464901 | 21 | 06-27-2002 | Modern |
| 392944119440301 | 20 | 06-06-2002 | Modern |
| 392937119452601 | 14 | 06-12-2002 | Modern |
| 393023119513701 | 49 | 08-26-2006 | Modern |
| 393108119415102 | 26 | 08-30-2006 | Modern |
| 392506119462201 | 530 | 10-29-2003 | Modern |
| 392414119474701 | 760 | 11-13-2003 | Modern |
| 392231119501901 | 236 | 11-30-2003 | Modern |
| 393053119445601 | 191 | 04-08-2008 | Modern |

# Effects of Natural and Human Factors on Groundwater Quality

Groundwater quality in the Truckee Meadows basin is influenced by both natural and human-induced factors. The movement of water through the geologic materials in the basin, coupled with the movement of water from the land surface to the aquifer, results in elevated concentrations of some constituents and compounds in groundwater. The addition of recharge sources at the land surface and increased pumping from wells facilitates the movement of water and contaminants to parts of the aquifer used for water supply. Areas in the basin most susceptible to movement of water between the land surface and the aquifer are in the western part and near the Truckee River, where confining layers are likely to be thin, discontinuous, or not present. Groundwater withdrawals also can induce the lateral movement of poor quality water to parts of the basin-fill aquifer used for water supply in the basin.

The following description of groundwater quality in Truckee Meadows is based mainly on results of the analyses of samples collected in 1994 and 1995 from 28 shallow monitoring wells and 18 water-supply (principal) wells as part of the NAWQA Program (Covay and Bevans, 1997; Bevans and others, 1998) and from other water-quality data from the basin reported by Cohen and Loeltz (1964, table 5) and Van Denburgh and others (1973, table 18). The shallow monitoring wells, which range in depth from 15 to 78 ft, were in an urban setting. The water-supply wells were from 185 to 760 ft deep. Many of these wells were resampled in 2002 and 2003, and in addition to a few wells sampled by the program for the first time, are shown on figure 4 (data listed in Berris and others, 2003; Stockton and others, 2003).

## General Water-Quality Characteristics and Natural Factors

The general water-quality characteristics as well as the occurrence and concentrations of individual chemical constituents and organic compounds of groundwater in Truckee Meadows varies areally across the basin. Groundwater near the Truckee River and other streams entering the basin is generally a calcium bicarbonate type with dissolved-solids concentrations typically less than 300 mg/L. Away from streams and upland recharge areas, dissolved-solids concentrations increase and sodium bicarbonate becomes the dominant water type. Sulfate-rich groundwater is associated with hydrothermally altered consolidated rocks at several places along the margins of the basin. Sodium-chloride groundwater with high dissolved-solids concentrations occurs in the geothermal area near Steamboat Hills in the southern part of the basin. Radon concentrations (or activities) in water from the public-supply wells ranged from 300 to 1,500 pCi/L, with a median of 760 pCi/L, and uranium concentration ranged from less than 1.0 to 7.0 µg/L (Covay and Bevans, 1997). Other natural contaminants, such as iron, manganese, boron, and antimony have been detected in both shallow monitoring wells and in several public-supply wells, although concentration data are not yet available (John Hulett, Washoe County Department of Water Resources and Paul Miller, Truckee Meadows Water Authority, written commun., 2009).

Concentrations of dissolved-oxygen concentrations in water from the water-supply wells sampled by NAWQA ranged from 0.4 to 5.5 mg/L, with a median of 3.8 mg/L; pH ranged from 7.0 to 8.1, with a median of 7.6; and dissolved-solids concentrations ranged from 149 to 548 mg/L, with a median of 228 mg/L. Dissolved-oxygen concentrations in water from the shallow monitoring wells ranged from 0.1 to 6.6 mg/L, with a median of 0.3 mg/L; pH ranged from 6.5 to 8.1, with a median of 7.1; and dissolved-solids concentrations ranged from 137 to 1,460 mg/L, with a median of 420 mg/L (Covay and Bevans, 1997).

Geothermal activity in the Truckee Meadows area has an effect on the temperature and chemistry of the groundwater. The temperature of water in the sampled public-supply wells ranged from 58°F to 104°F, with the higher temperatures probably owing to geothermal activity. Geothermal systems in Truckee Meadows have contributed to naturally high concentrations of arsenic in water from the basin-fill deposits. Arsenic in groundwater (and springs) also can come from the volcanic rocks bounding the basin and from the sediment derived from these rocks. Arsenic in water samples from wells in the basin has been reported at concentrations as high as 640 µg/L (Bateman and Scheibach, 1975).

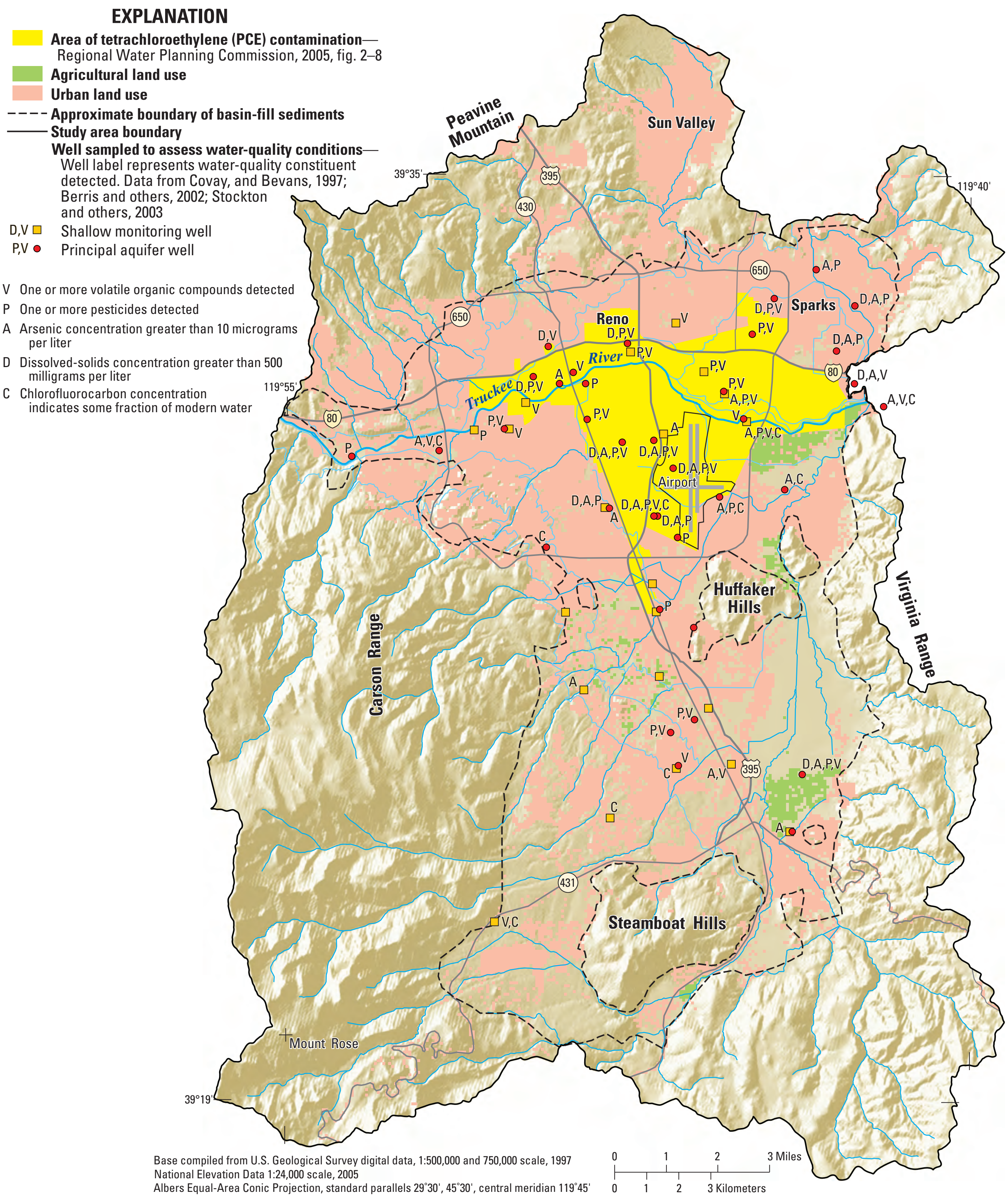


**Figure 4.** Location of wells in Truckee Meadows, Nevada, sampled by the NAWQA Program.

In samples collected by NAWQA investigators, concentrations of dissolved arsenic ranged from less than 1 to 92 µg/L, with a median of 5.5 µg/L, in water from 18 water-supply wells, and from less than 1 to 230 µg/L, with a median of 7.0 µg/L, in water from the 28 shallow monitoring wells (Covay and Bevans, 1997). Arsenic concentrations in water from 23 wells (7 used for water supply and 16 used for monitoring), primarily in the central and northeastern parts of the basin and sampled by the NAWQA Program between 1994 and 2003, exceeded the U.S. Environmental Protection Agency's (USEPA) maximum contaminant level (MCL) of 10 µg/L for arsenic in drinking water (U.S. Environmental Protection Agency, 2008; each time "MCL" is mentioned in this chapter, it denotes the citation USEPA, 2008). Pumping from the basin-fill groundwater system may change flow directions and gradients, resulting in the potential for movement of such arsenic enriched geothermal water to supply wells in the basin.

## Potential Effects of Human Factors

The major chemical constituents and organic compounds detected in groundwater in Truckee Meadows and the processes or sources that affect their presence and concentrations are summarized in table 3. Concentrations of nitrate plus nitrite (as nitrogen) ranged from less than 0.05 to 3.6 mg/L with a median of 0.88 mg/L in water from the water-supply wells, and from less than 0.05 to 10 mg/L with a median of 1.85 mg/L in water from the shallow monitoring wells. The MCL for nitrate plus nitrite as nitrogen in drinking water is 10 mg/L, which is enforceable only in public-supply systems (USEPA, 2008). Reducing conditions caused by denitrification likely affect nitrate concentrations in some of these wells. Elevated concentrations of nitrate measured in groundwater in the southern part of Truckee Meadows were attributed to the recharge of septic system effluent (Regional Water Planning Commission, 2005, p. 2-3).

At least one pesticide was detected in 68 percent (19 of 28) of the shallow monitoring wells and in 44 percent (8 of 18) of the water-supply wells in the basin sampled by NAWQA (Covay and Bevans, 1997). The herbicide atrazine was detected in 10 monitoring wells and 3 supply wells and its degradation product deethylatrazine was detected in 11 monitoring wells and 6 supply wells, all at concentrations one to three orders of magnitude smaller than the MCL for atrazine (3 µg/L). The herbicides prometon and simazine also were detected at small concentrations in water from 5 and 7 shallow monitoring wells, respectively. Although the concentrations of these compounds are very small and not currently a health concern, their presence in the aquifer indicates the potential for their movement from the land surface and the possibility that higher concentrations may occur in the future. It is not known what proportion of pesticide contamination is residual from agricultural activities that have since decreased in extent compared to domestic and municipal landscaping activities.

**Table 3.** Summary of selected constituents in groundwater in Truckee Meadows, Nevada, and sources or processes that affect their presence or concentration.

[mg/L, milligrams per liter]

| Constituent | General location | Median value or detections | Possible sources or processes |
|---|---|---|---|
| | | Shallow aquifers | |
| Dissolved solids | Mostly in the north | 420 mg/L | Evapotranspiration and dissolution. |
| Sulfate | Basin margins | 61 mg/L | Associated with altered consolidated rocks. |
| Nitrate | Highest in the south | 1.85 mg/L | Natural sources, fertilizers, treated wastewater, leaky sewer pipes, septic systems. |
| Volatile organic compounds | Basin wide | 19 | Point sources including underground gasoline tanks & solvents from repair & dry cleaners. |
| Pesticides | Mostly in the north | 19 | Lawn fertilizer. |
| | | Principal aquifers | |
| Dissolved solids | Mostly in the north | 228 mg/L | Evapotranspiration and dissolution. |
| Sulfate | Central | 21 mg/L | Associated with altered consolidated rocks. |
| Nitrate | Highest in the south | 0.88 mg/L | Natural sources, fertilizers, treated wastewater, leaky sewer pipes, septic systems. |
| Volatile organic compounds | Mostly in the north | 10 | Potential downward movement from shallow aquifers. |
| Pesticides | Mostly in the north | 8 | Potential downward movement from shallow aquifers. |

Volatile organic compounds (VOCs) were detected in water from 68 percent of the shallow monitoring wells and 55 percent of the water-supply wells sampled by NAWQA in the basin (Covay and Bevans, 1997). These compounds originate near land surface, usually in urban areas, such as at gasoline stations with leaking underground-storage tanks and at dry cleaners that use solvents. The most commonly detected compounds were chloroform, tetrachloroethylene (PCE), and methyl *tert*-butyl ether (MTBE). Chloroform, a trihalomethane, was detected in samples from 6 shallow monitoring wells and 5 water-supply wells. Its presence in the aquifer is most likely from the recharge of chlorinated water used for public supply through seepage from distribution lines and infiltration of excess landscape irrigation water. PCE was detected at concentrations ranging from 0.8 to 20 ug/L in samples collected as part of NAWQA studies in 1994–95 from 4 shallow monitoring wells and from 3 water-supply wells; the MCL for PCE is 5 µg/L. Studies conducted as part of a study by the Central Truckee Meadows Remediation District have documented PCE in groundwater (fig. 4) to depths greater than 350 ft in an area of about 16 $mi^2$ (Regional Water Planning Commission, 2005, p. 2-17). Remediation plans and treatment facilities are in place to remove the PCE from the water supply. MTBE, a gasoline additive that is water-soluble and therefore can readily reach the water table through permeable sediments, was detected in samples from 6 shallow monitoring wells. Although MTBE is an unregulated compound, the U.S. Environmental Protection Agency (1997) advises that concentrations of MTBE in drinking water should be less than 20 to 40 µg/L to avoid an unpleasant taste and odor as well as the potential for adverse health effects. Water samples from two shallow monitoring wells had MTBE concentrations of 140 and 220 µg/L, but MTBE was not detected in samples collected from the deeper water-supply wells (Covay and Bevans, 1997).

## Summary

The Truckee Meadows basin in western Nevada is undergoing the urbanization of its rangeland and irrigated agricultural areas. The Truckee River provided most of the water used in the basin in 2000 while groundwater supplied about 27 percent. The complex basin-fill aquifer system, consisting of both unconsolidated Quaternary and Tertiary sediments, is under both leaky-confined and unconfined conditions. The aquifer is recharged naturally by the infiltration of Truckee River water, precipitation falling on the surrounding mountains and basin margins, and by human-related sources of water in the valley, such as seepage from surface-water diversions and excess irrigation water. Natural recharge to the basin-fill aquifer in Truckee Meadows is estimated at about 31,600 acre-ft/yr. Groundwater generally flows from recharge areas in the west and south toward the Truckee River and Steamboat Creek, which may receive relatively minor amounts of groundwater seepage, and to discharge areas in the center of the valley where the water is lost to ET.

Human-related changes to the Truckee Meadows groundwater flow system began in the late 1800s when water diverted from the Truckee River for irrigation increased recharge to the basin-fill aquifer. By the early 1960s, seepage from excess irrigation water and canal losses to the groundwater system almost doubled the quantity of recharge from that of predevelopment conditions and resulted in a rise in groundwater levels, an increase in the volume of water stored in the aquifer, and an increase in groundwater discharge through ET and seepage to streams. The area of irrigated agriculture in the basin has decreased since the 1960s, resulting in a decrease in recharge associated with irrigation, although this decrease was accompanied by an increase in municipal groundwater pumping since the late 1950s.

Groundwater quality in the Truckee Meadows basin is influenced by both natural and human-induced factors. The addition of recharge sources at the land surface and increased pumping from wells facilitates the movement of water and contaminants to parts of the aquifer used for water supply. Areas most susceptible to the movement of water and any included contaminants from land surface are in the western part of the basin and near the Truckee River, where the confining layers are likely to be thin, discontinuous, or not present.

Groundwater near the Truckee River and other streams entering the basin typically has dissolved-solids concentrations less than 300 mg/L. Sodium-chloride groundwater with high dissolved-solids concentrations occur in geothermal areas within the basin. These geothermal systems have contributed to naturally high arsenic concentrations in water from the basin-fill deposits and from springs issuing from volcanic rock. Arsenic in groundwater also can come from the volcanic rocks bounding the basin and from the sediment derived from these rocks. Concentrations of arsenic in water from 23 wells sampled by the NAWQA Program, mostly in the central and northeastern parts of the basin, exceeded the drinking-water standard for arsenic of 10 µg/L.

Reducing conditions in the aquifer likely affect nitrate concentrations through denitrification, although elevated concentrations measured in groundwater in the southern part of Truckee Meadows were attributed to the recharge of septic system effluent. At least one pesticide was detected in 68 percent of the shallow monitoring wells and in 44 percent of the water-supply wells in the basin sampled by NAWQA. Volatile organic compounds were detected in water sampled from 50 percent of the shallow monitoring wells and 39 percent of the supply wells sampled. Remediation plans and treatment facilities are in place to remove tetrachloroethylene from groundwater in the central part of the basin.

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