Section 2.—Conceptual Understanding and Groundwater Quality of the Basin-Fill Aquifer in Salt Lake Valley, Utah

By Susan A. Thiros

in

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

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Basin Overview

Salt Lake Valley is an alluvial basin bounded by the Wasatch Range, the Oquirrh and Traverse Mountains, and Great Salt Lake in the northern part of Utah (fig. 1). The basin is about 28 mi long and 18 mi wide (about 417 mi^2) and is open at its northern end, where both surface and ground water drain to Great Salt Lake. Altitudes range from about 4,200 ft at Great Salt Lake to about 5,200 ft at the basin-fill deposit/mountain boundary. The hydrogeologic basin that surrounds the valley extends to the crests of the surrounding mountains and covers about 740 mi^2. Salt Lake Valley is within the Basin and Range Physiographic Province of Fenneman (1931) and is characterized by generally parallel, north- to northeast-trending mountain ranges separated by broad alluvial basins that are a result of regional extension. The normal faulting and subsequent mountain uplift and deposition of basin fill began in Miocene time and is ongoing (Mabey, 1992, p. C6). Topographic relief between the Wasatch Range and Salt Lake Valley along the Wasatch Fault is as much as 7,000 ft.

The climate in Salt Lake Valley is semiarid. Analysis of modeled precipitation data for 1971–2000 (PRISM Group, Oregon State University, 2004) resulted in an estimated average annual precipitation of about 17 in. over the alluvial basin as a whole (McKinney and Anning, 2009). Precipitation in the mountains can exceed 50 in/yr, falling mostly as snow in the winter. Recharge to the groundwater system is dependent primarily on the spring snowmelt runoff from the mountains. Water in the major mountain-front streams is diverted for municipal and agricultural use under current conditions. Lawns and gardens in the valley require irrigation to supplement precipitation during the growing season. The demand for water peaks during July through August, when lawns and gardens require more irrigation because of the summer heat. Public water systems that use surface-water sources also use groundwater during the summer to meet the increased demand. Water systems without surface-water sources rely on water from wells throughout the year.

Salt Lake Valley generally coincides with the populated part of Salt Lake County, which contains the Salt Lake City metropolitan area. The population in Salt Lake County in 2000 was about 898,000 (U.S. Census Bureau, 2002), and is growing rapidly. The population almost doubled between 1963 and 1994, corresponding to a large increase in land developed for residential and commercial use. Population in Salt Lake County is projected to be about 1,884,000 in 2050 (Utah Governor's Office of Planning and Budget, 2008). Analysis of LandScan population data for 2005 (LandScan Global Population Database, 2005) indicated a population of 944,000 for the alluvial basin as a whole (McKinney and Anning, 2009), equating to a population density in the valley of about 2,260 people per mi^2. Because the natural boundaries of the valley restrict much expansion of residential areas, population growth will occur mainly through increased population density and will include urbanization of the remaining agricultural and rangeland areas.

The area of agricultural land in Salt Lake Valley decreased from 145 mi^2 in 1960 to 44 mi^2 in 2002, while the area of urban land increased from 89 to 270 mi^2 during the same period (Utah Department of Natural Resources, Division of Water Resources, 1999, 2007). Many of the developed residential/commercial areas are along the mountain front bounding the east side of the valley (fig. 2) and more recent development is also replacing agricultural areas on the west side of the valley. The main crop types mapped in 2002 were grains, pasture, and alfalfa. Historically, much of the industrial land use in Salt Lake Valley was near the Jordan River, with the urban area centered in the northeastern part of the valley in Salt Lake City and agricultural land primarily near the mountain-front streams or downgradient from irrigation canals. A major industry in the valley was processing ore mined from the Wasatch Range and Oquirrh Mountains beginning in about 1870 (Calkins and others, 1943, p. 73).

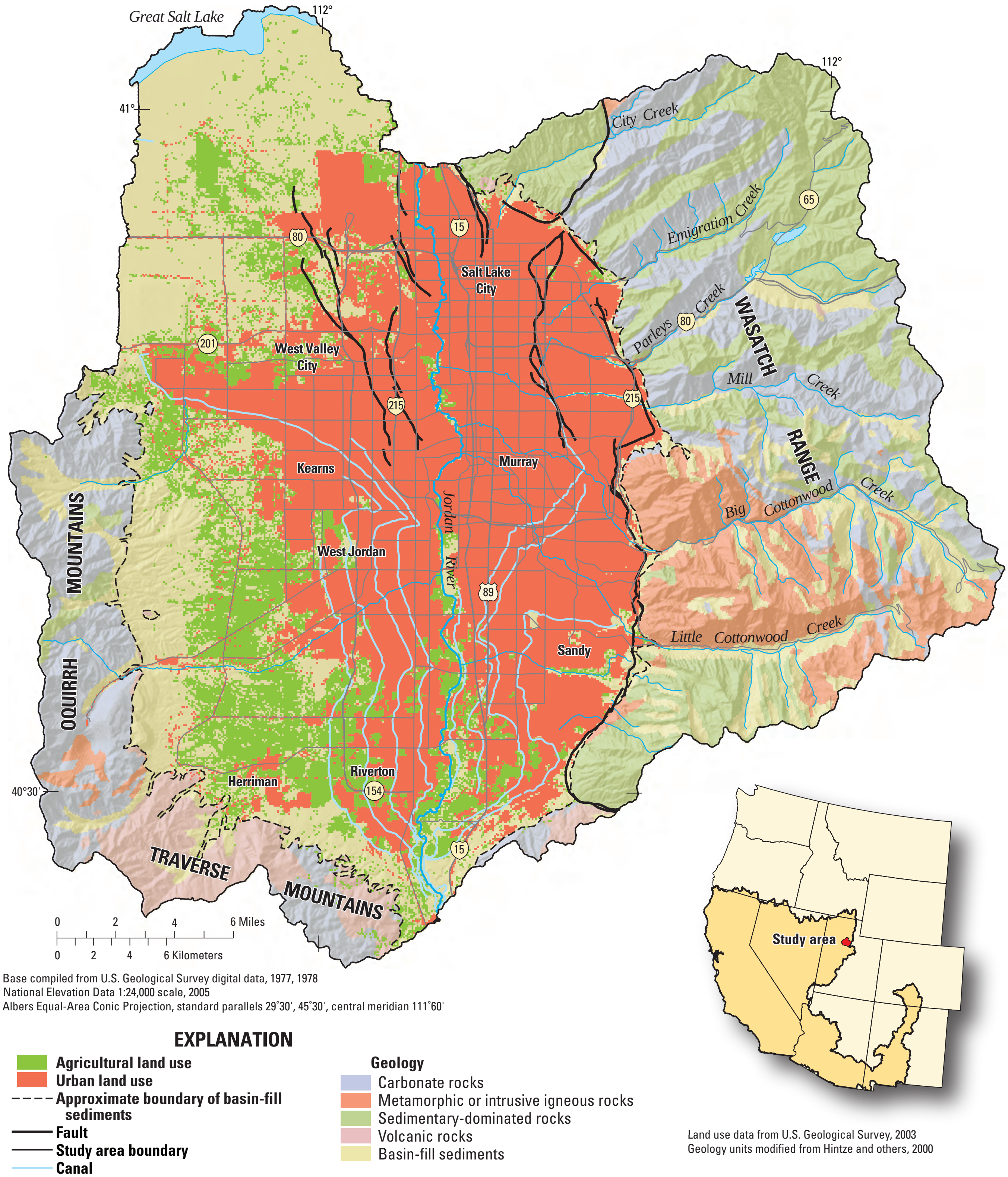


Figure 1. Physiography, land use, and generalized geology of Salt Lake Valley, Utah.

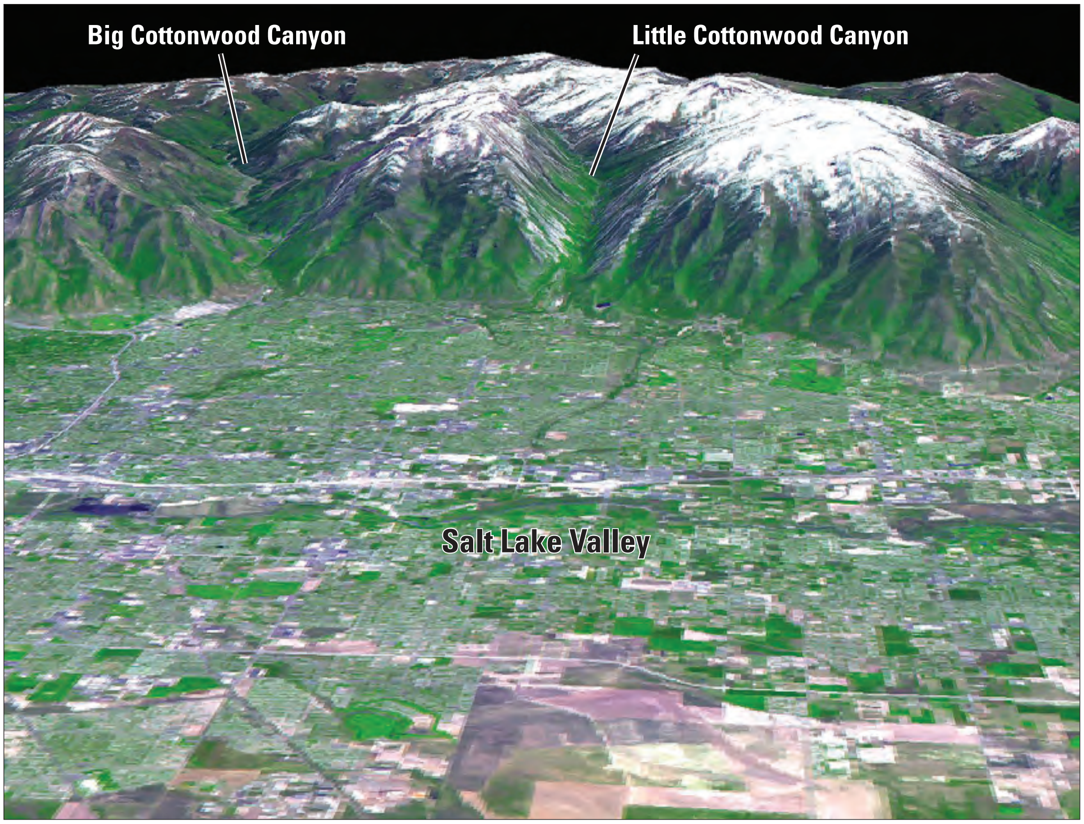


Figure 2. View of Salt Lake Valley, Utah, with Big and Little Cottonwood Canyons in the Wasatch Range in the background. Image acquired on May 28, 2000 with credit to the NASA/GSFC/METI/ERSDAC/JAROS and U.S./Japan ASTER Science Team (http://asterweb.jpl.nasa.gov/gallery-detail.asp?name=SaltLakeCity)

Changes in land use and water use in Salt Lake Valley have affected groundwater quality through changes in the sources, amount, and quality of water that recharges the basin-fill aquifer system. Human-related compounds such as volatile organic compounds (VOCs) and pesticides, and elevated concentrations of nitrate have been frequently detected in shallow ground water and to a lesser degree in the deeper basin-fill aquifer in areas of residential land use. Water that enters the aquifer in the valley (basin or valley recharge) is more susceptible to transporting man-made chemicals than is both surface flow and subsurface inflow from the adjacent mountains (mountain-front and mountain-block recharge). Seepage of excess water from irrigated crops, lawns, gardens, parks, and golf courses; and from leaking canals, water distribution pipes, sewer lines, storm drains, and retention basins are now sources of recharge to the basin-fill aquifer.

Water Development History

Salt Lake Valley was settled by Mormon pioneers beginning in July 1847 when they arrived in the valley and started building an irrigation system to distribute water from the mountain-front streams to croplands. City Creek, in what became downtown Salt Lake City, was the first stream to be diverted. By 1860, many farming communities had been established near the perennial Wasatch Range streams and the Jordan River. The 44-mi long Jordan River passes through the center of Salt Lake Valley, connecting two remnants of prehistoric Lake Bonneville: Utah Lake in Utah Valley to the south and Great Salt Lake to the north. Streamflow in the Jordan River averaged about 295,000 acre-ft/yr from 1914–1990 at the Jordan Narrows, just downstream from where the river enters the valley (Utah State Water Plan Coordinating Committee, 1997, p. 5-9).

As the population in Salt Lake City grew, a larger supply of mountain stream water was required to be transferred from agricultural use to municipal use. The farmers, however, needed a more consistent source of irrigation water through the summer months, when flow from the mountain streams diminished. Agreements were made to exchange water rights between Salt Lake City and area farmers that resulted in the diversion of Jordan River/Utah Lake water to the east side of the valley beginning in 1882. Water from the Jordan River is acceptable for irrigation, but not for potable uses because of turbidity and mineral content. Water in the Jordan River at the Jordan Narrows has higher concentrations of dissolved solids higher (1964–68 discharge-weighted average of 1,120 mg/L) than water that enters the valley from the major streams draining the Wasatch Range (1964–68 discharge-weighted averages range from 120 to 464 mg/L) due primarily to evaporation from Utah Lake. The effect of the water-rights exchanges was to spread water with higher concentrations of dissolved solids over a large part of the east side of Salt Lake Valley for irrigation and to distribute water with lower concentrations of dissolved solids from the mountain streams to residential areas along the east side of the valley rather than just along the natural stream channels.

Historically, water has been diverted from the Jordan River into a series of canals for subsequent diversion to irrigated land: four parallel canals traverse the west side of the valley and three parallel canals traverse the east side. Most of the canals were in operation by 1910. Parallel distribution systems allow for runoff from higher altitude irrigated areas to be collected and distributed by lower altitude canals. Canal companies generally start delivery of water for irrigation in May and end in October.

Surface water from local streams draining the Wasatch Range and imported from outside of the local drainage basin provided about 70 percent of the public supply in 2000 in Salt Lake Valley. This water is chlorinated and distributed for use across the valley. Under modern conditions, about 68,000 acre-ft/yr of water from local Wasatch Range streams is used for public supply, which is about 40 percent of the average streamflow rate (Utah State Water Plan Coordinating Committee, 1997, p. 9-7; table 5-4). About 75 percent (130,000 acre-ft) of the annual flow comes during the spring snowmelt runoff period from mid-April to mid-July. Most of this water ultimately discharges to the Great Salt Lake because of limited reservoir storage and treatment plant capacity. The feasibility of constructing surface reservoirs on the mountain streams is limited mainly because of environmental and safety concerns. The average annual flow for streams draining the Oquirrh Mountains on the west side of Salt Lake Valley is only about 4,400 acre-ft (Utah State Water Plan Coordinating Committee, 1997, table 5-4). Water rarely flows in these stream channels all the way to the Jordan River.

Water from the Weber and Duchesne Rivers is imported into the Utah Lake drainage basin as part of the Provo River Project and the Central Utah Project (CUP) to supplement surface-water supplies in Salt Lake and Utah Counties. The Salt Lake Aqueduct began conveying water from the Provo River drainage to Salt Lake Valley for public supply in 1951. The CUP consists of numerous diversions, dams, and conveyance systems that allow Utah to use a portion of its allotted share of Colorado River water under the Colorado River Compact. An average of about 111,000 acre-ft/yr was imported to the valley for public supply from these surface-water sources from 1997–2003 based on information provided by Isaacson (2004) and the Utah Division of Water Rights.

Richardson (1906, p. 35) speculated that the first flowing well was drilled in Salt Lake Valley in about 1878. Marine and Price (1964, p. 49) estimated that 7,700 flowing wells supplied about 35,000 acre-ft of water in 1957, mainly for domestic use. Many of the flowing wells have since been capped or abandoned and replaced by municipal water systems. Lowering the hydraulic head in the confined aquifer has caused a small decrease in the area of artesian conditions with time.

Large-yielding wells used for public supply in Salt Lake Valley were first installed in 1931 to supplement surface-water supplies. The estimated withdrawal of water from wells in the valley in 2000 was about 144,000 acre-ft: 93,800 acre-ft for public supply, 25,000 acre-ft for domestic and stock, 23,400 acre-ft for industry, and only 2,200 acre-ft for irrigation (Burden and others, 2001, table 2). Groundwater withdrawal from wells in 2000 was about 28 percent of that used for public supply. Springs and tunnels in the Wasatch Range provided about 2 percent of the water used in the valley for public supply.

Artificial recharge of some of the spring runoff water from mountain-front streams and from imported surface water to the basin-fill aquifer in the southeastern part of the valley is being done through injection wells. About 6,000 acre-ft/yr of water is planned to be injected (Utah Division of Water Rights, written commun., January 5, 2010) for use during periods of peak demand in the summer months. Potential future sources of water to supply the municipal needs of Salt Lake Valley include treated water from the Jordan River and adjacent shallow aquifer, and surface water imported from other areas outside the hydrogeologic basin, such as the Bear River near the Idaho border. Treated wastewater could be used for municipal irrigation and is another possible future water source in the valley.

Hydrogeology

The basin-fill deposits in the Salt Lake Valley consist of unconsolidated to semiconsolidated Tertiary-age deposits overlain by unconsolidated Quaternary-age deposits. The Tertiary-age sediments that crop out along the western and southern margins of the valley were deposited mainly as alluvial fans, in lakes, and as volcanic ash and are estimated to have a hydraulic conductivity of about 1 ft/d (Lambert, 1995, p. 15). On the basis of geophysical studies by Mattick (1970), the contact between these deposits and underlying consolidated rock is estimated to be as deep as 4,000 ft below land surface in areas near the Great Salt Lake and north of Salt Lake City. The permeable Tertiary-age deposits of sand and gravel yield water to wells in the Kearns area, and near Murray, Herriman, and Riverton (Hely and others, 1971, p. 107).

The unconsolidated sediments of Quaternary age were deposited mainly as alluvial fans, by streams, and as deltas and other lacustrine features associated with Lake Bonneville and older paleolakes that once covered the valley. The hydraulic conductivity of coarser grained deposits is estimated to be about 200 ft/d, compared to a value of about 1 ft/d for shallow lake-deposited clays (Lambert, 1995, p. 14). The Quaternary-age sediments are considerably more permeable than those of Tertiary age, but are thought to be less than 1,000 ft thick across most of Salt Lake Valley based on well data (Arnow and others, 1970; Lambert, 1995, fig. 4). The Quaternary-age deposits are thinnest along the margins of the valley and are less than 150 ft thick in the Kearns area. Nearly all the water wells in the valley are open to the Quaternary-age deposits. Lake-deposited clay layers occur throughout the valley, except near the mountain-front canyons, where coarser grained deposits predominate. Lake Bonneville covered much of the western half of Utah and the southeastern corner of Idaho during the late Pleistocene Epoch, with a water level about 1,000 ft above the present-day altitude of its remnant, Great Salt Lake (which is about 4,200 ft). As Lake Bonneville receded, wave-cut terraces on the lower slopes of the mountains and deposits of sand and gravel within the basin were exposed. Interlayered clay, silt, sand, and gravel were deposited as deltas in the lake by major streams as they flowed out of the mountains and are now deeply incised by modern stream channels emanating from the adjacent mountain blocks.

The consolidated rocks in the Wasatch Range bounding the northeastern part of Salt Lake Valley, from Mill Creek Canyon northward, are dominantly sedimentary Triassic-age shale and mudstone with bedding planes striking approximately perpendicular to the mountain front. The Wasatch Fault is inside of the valley west of the mountain front in this area, resulting in shallow depths to bedrock between the fault and the mountain front. This position of the fault is in contrast to that farther south, where it bounds the mountain front. The mountain block along the southeastern part of the valley consists of Precambrian-age quartzite and Tertiary-age intrusive rocks (quartz monzonite) that Hely and others (1971, plate 1) characterized as "rocks of lowest permeability."

The Oquirrh and Traverse Mountains are made up mostly of Late Paleozoic-age carbonate and quartzite (Oquirrh Formation) and Tertiary-age volcanic rocks. Tertiary-age igneous rocks intruded the Oquirrh Formation in the Oquirrh Mountains, forming deposits of copper and other metals that have been extracted in the Bingham mining district. Consolidated volcanic rocks crop out along the base of the Oquirrh Mountains and underlie the basin-fill deposits on the west side of the valley. The transmissivity of these rocks is dependent on the presence or absence of fractures and is highly variable. Hely and others (1971, plate 1) characterized the volcanic rocks as "rocks of lowest permeability."

Conceptual Understanding of the Groundwater System

The groundwater system in Salt Lake Valley's basin-fill deposits includes a shallow aquifer that is separated from a deeper aquifer by discontinuous layers or lenses of fine-grained sediment. A generalized model of the deeper basin-fill aquifer shows an unconfined part near the mountain fronts that becomes confined toward the center of the valley by clay lenses and layers (fig. 3). The extent of the unconfined part of the aquifer corresponds to that of the primary recharge area in the valley (fig. 4) and includes the area near the mountain fronts where no substantial layers of fine-grained materials impede the downward movement of water. The depth to water in the unconfined part of the deeper basin-fill aquifer is typically from 150 to 500 ft below land surface. The transmissivity of the basin-fill deposits is generally highest near the mountains where streams entering the valley deposit the coarsest-grained materials.

Ground water moves laterally from the unconfined part of the basin-fill aquifer to the adjacent confined part, and from the overlying shallow aquifer to the deeper basin-fill aquifer, where the hydraulic gradient is downward and the confining layers are discontinuous. The latter conditions can exist in the secondary recharge area and were mapped by Anderson and others (1994, p. 6). The distinction between the shallow and deeper basin-fill aquifers is not clear in some parts of the valley. Many domestic wells and some public-supply wells are in the secondary recharge area, where water levels are about 100 ft below land surface.

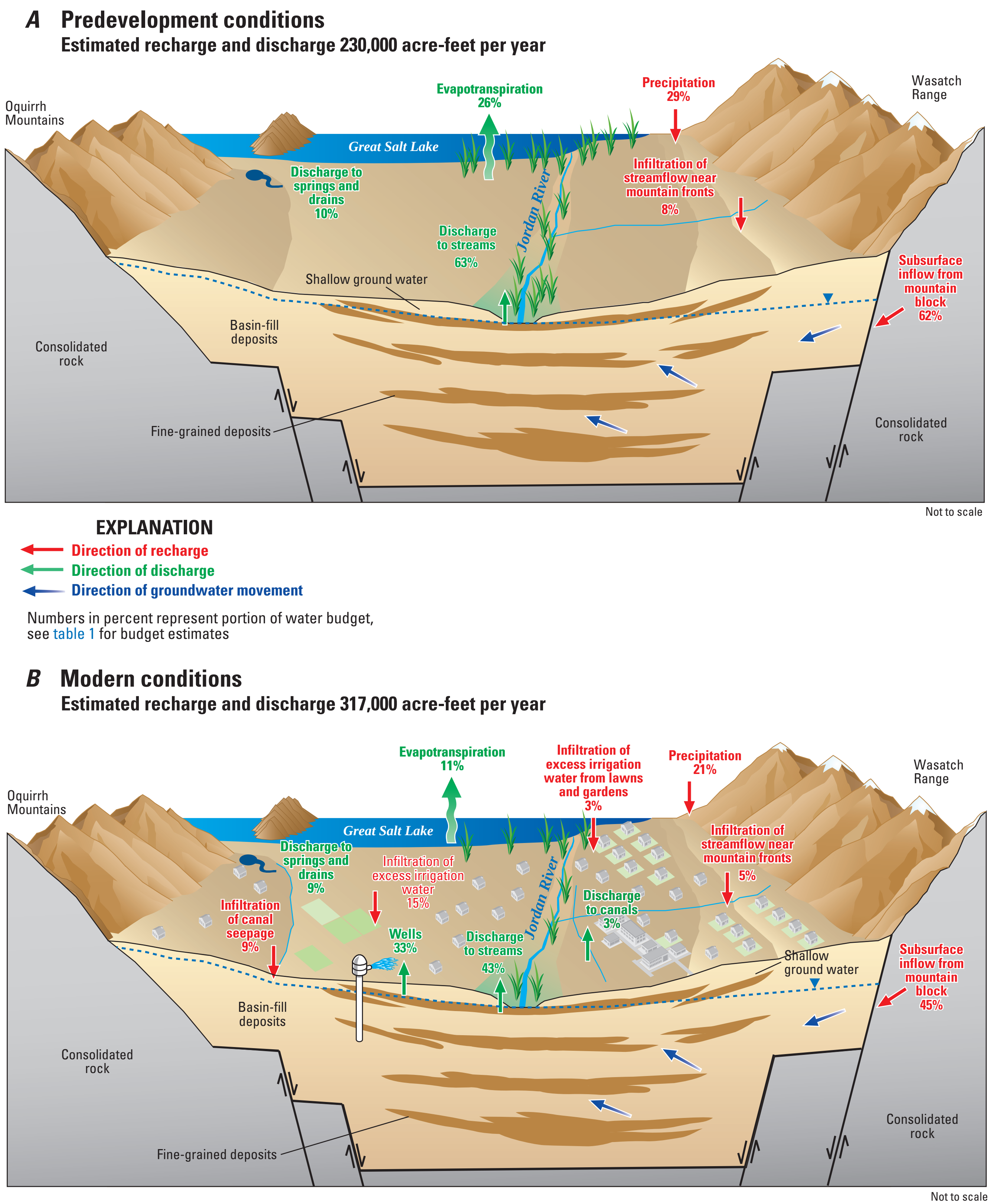


Figure 3. Generalized diagrams for Salt Lake Valley, Utah, showing the basin-fill deposits and components of the groundwater flow system under (*A*) predevelopment and (*B*) modern conditions.

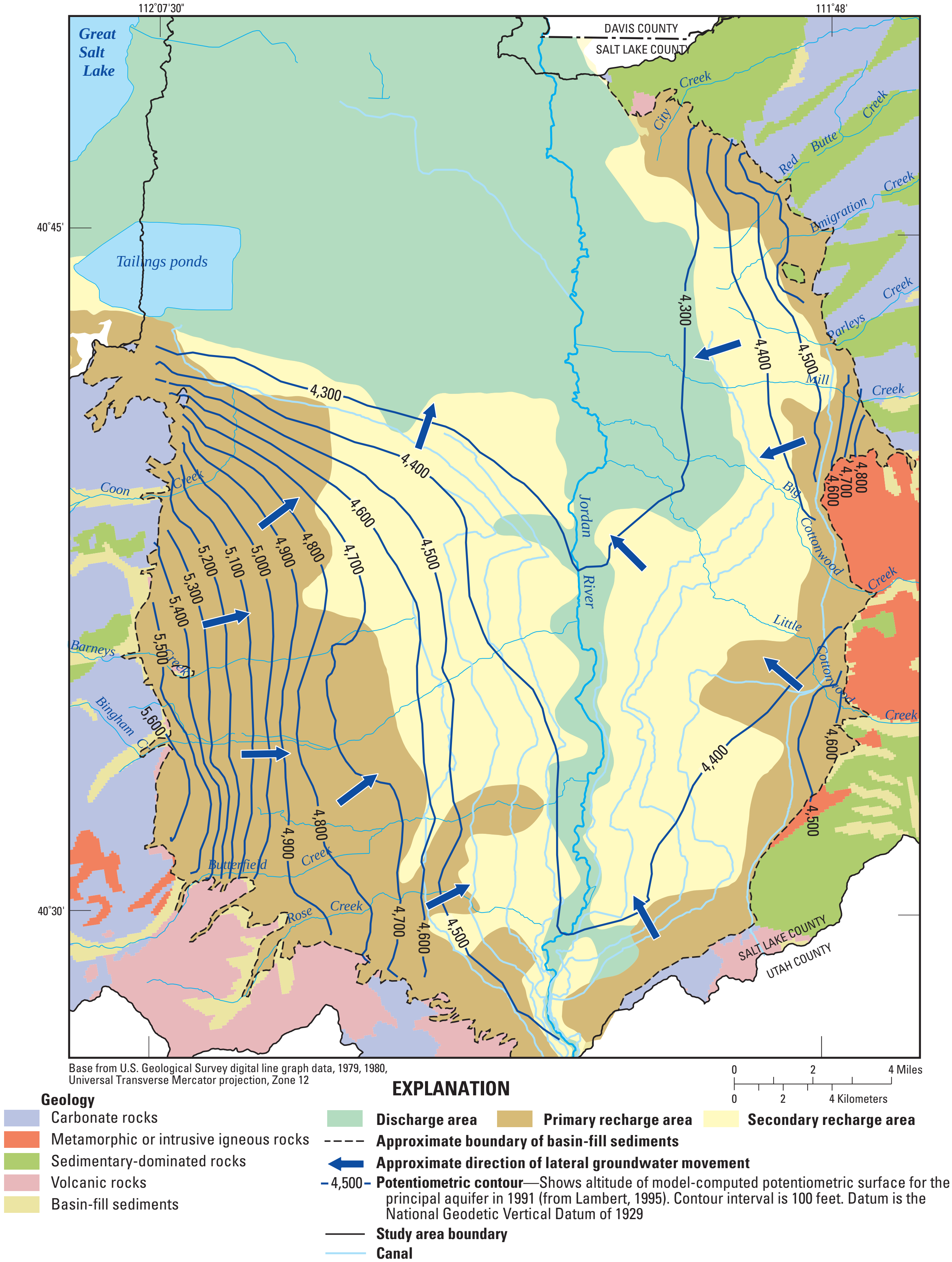


Figure 4. Location of groundwater recharge and discharge areas and approximate direction of lateral groundwater flow in Salt Lake Valley, Utah.

Groundwater discharges in areas where there is an upward hydraulic gradient from the confined part of the deeper aquifer toward the overlying shallow aquifer; such areas are generally in the center of the valley along the Jordan River and in the topographically lowest parts of the valley. This upward gradient and the presence of confining layers prevent water with relatively high concentrations of dissolved solids or other contaminants from moving downward. The confined part of the aquifer can still be susceptible to contamination where the confining layers are discontinuous or where the hydraulic gradient has been reversed (is downward), allowing water from the shallow aquifer to move downward to the confined aquifer. This reversal can result from withdrawals from wells (pumpage) over time and can permit the downward movement of water around an improperly completed well or over a larger area. Both the confined and unconfined parts of the deeper basin-fill aquifer are important sources of drinking water for Salt Lake Valley.

Shallow groundwater is either local in extent because it is perched on fine-grained materials or is laterally continuous and forms a more extensive aquifer. Perched groundwater can occur near the mountains where saturated discontinuous strata of sand and gravel are underlain by fine-grained material and lie above the regional water table. The shallow aquifer is typically present within the upper 50 ft of basin-fill deposits and therefore is vulnerable to contamination because of its proximity to human activities at the land surface. Low yields and poor quality (unacceptable for intended use) limit the use of shallow groundwater in Salt Lake Valley at the present time.

Water Budget

Recharge to and discharge from the basin-fill aquifer system in Salt Lake Valley has been estimated in studies by Hely and others (1971), Waddell and others (1987a), and Lambert (1995). Lambert used a steady-state numerical model to specify or compute an average annual recharge rate of about 317,000 acre-ft to the basin-fill groundwater system under modern conditions (table 1). Estimates of the total groundwater budget have decreased with each successive study. The amount of recharge to the groundwater system affects the amount of water that can be withdrawn from wells without affecting other types of discharge and places a greater emphasis on recharge that originates at the valley surface and therefore is vulnerable to contamination.

Although the amount of water that was recharged and discharged from the basin-fill aquifer before water development began in the valley is not known, estimates were made on the basis of the conceptual model of the system. Mountain-front recharge is estimated to have comprised about 70 percent of recharge to the basin-fill aquifer under predevelopment conditions and includes subsurface inflow from consolidated rocks in the adjacent mountains, underflow in channel fill at the mouths of canyons, and infiltration of streamflow and precipitation runoff near the mountain front (fig. 3). Information is not available to distinguish between water entering the basin-fill aquifer in the subsurface and precipitation runoff at the mountain front, but environmental tracers indicate that subsurface inflow from the mountain blocks may be a substantial component of recharge. Inflow from consolidated rock along the mountain front and from precipitation on the valley floor was specified at 142,000 and 67,000 acre-ft/yr, respectively, in the steady-state simulation by Lambert (1995, table 5), and these rates are assumed to be representative of predevelopment conditions.

Infiltration of excess irrigation water from croplands, lawns, and gardens, and seepage from canals became major sources of recharge to the groundwater system (about 27 percent of estimated average annual recharge) under modern conditions (Lambert, 1995, table 5; table 1). Groundwater discharge to the Jordan River and other streams (about 43 percent of estimated average annual discharge), withdrawals from wells (about 33 percent), and evapotranspiration (about 11 percent) are the main components of discharge under modern conditions. Groundwater discharge to the Jordan River and its tributaries and by evapotranspiration has been reduced from that under predevelopment conditions as a result of lowered groundwater levels caused by withdrawals from wells (table 1).

Recharge to the basin-fill aquifer as subsurface inflow from the mountain block on the east side of Salt Lake Valley is greater than that to the west side, primarily because the west face of the Wasatch Range receives greater amounts of precipitation than does the east side of the Oquirrh Mountains. Infiltration of precipitation in the primary recharge areas of the valley has likely decreased with time because of urban development and the installation of storm drains. Excess irrigation water applied to lawns and gardens is now a major source of infiltration to the basin-fill aquifer in the recharge areas, and much of this water is imported from outside the drainage basin. Losses from major canals diverting water from the Jordan River were estimated to be about 21,000 acre-ft/yr in the southwestern part of the valley (Lambert, 1996, p. 8) out of about 30,000 acre-ft/yr estimated valley wide (Lambert, 1995, table 5). Seepage losses from canals can recharge both the shallow and deeper parts of the basin-fill aquifer because the canals flow mainly through secondary recharge areas. Groundwater recharge has increased by almost one-third from that of predevelopment conditions, primarily due to the addition of canal seepage and excess irrigation water (table 1).

The recharge of excess irrigation water and canal losses has greatly modified the groundwater flow system in the southwestern part of Salt Lake Valley, where there was relatively little recharge prior to irrigation. Canals in this area transport water primarily from the Jordan River, resulting in water with higher concentrations of dissolved solids being recharged to the basin-fill aquifer. Stable isotope data indicate that the shallow unconfined aquifer (Thiros, 1995, p. 51; Thiros, 2003, p. 35) and parts of the deeper basin-fill aquifer (Thiros and Manning, 2004, p. 36) receive substantial recharge from water diverted for irrigation from the Jordan River.

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

[All values are in acre-feet per year and are rounded to the nearest thousand. Estimates of groundwater recharge and discharge under predevelopment and modern conditions were derived from Hely and others (1971); a steady-state numerical simulation of the basin-fill aquifer (Lambert, 1995); or were estimated as described in the footnotes. 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 3]

	Predevelopment conditions	Modern conditions	Change from predevelopment to modern conditions
Budget component		**Estimated recharge**	
Subsurface inflow from mountain blocks	[1]142,000	[1]142,000	0
Infiltration of precipitation on valley floor	[1]67,000	[1]67,000	0
Infiltration of streamflow and underflow in channel fill near mountain fronts	[2]18,000	[1]16,000	[3]-2,000
Underflow at Jordan Narrows	[1]2,000	[1]2,000	0
Infiltration of streamflow in valley	[1]1,000	[1]1,000	0
Canal seepage	0	[1]30,000	30,000
Infiltration of excess irrigation water	0	[1]47,000	47,000
Infiltration of excess irrigation water from lawns and gardens	0	[1]10,000	10,000
Infiltration from reservoirs	0	[1]2,000	2,000
Total recharge	**[4]230,000**	**317,000**	**87,000**
Budget component		**Estimated discharge**	
Discharge to streams	[5]145,000	[1]137,000	-8,000
Well withdrawals	0	[1]105,000	105,000
Evapotranspiration	[6]60,000	[1]36,000	-24,000
Discharge to springs	[1]19,000	[1]19,000	0
Discharge to drains	[7]5,000	[1]10,000	5,000
Subsurface outflow to Great Salt Lake	[1]1,000	[1]1,000	0
Discharge to canals	0	[1]9,000	9,000
Total discharge	**230,000**	**317,000**	**87,000**
Change in storage (total recharge minus total discharge)	0	0	0

[1] Estimates from steady-state numerical simulation of the basin-fill aquifer described by Lambert (1995).

[2] Hely and others (1971, p. 56) evaluated the relation of channel loss in Wasatch Range streams to runoff during 1964–68. They noted that the magnitude of losses changed with fluctuations in runoff and generally ranged from 8 to 16 percent of runoff. Recharge from streams and underflow in channel fill near the mountain fronts under predevelopment conditions was estimated to be 10 percent of an average streamflow of about 178,000 acre-feet per year for 1940–80 (Utah State Water Plan Coordinating Committee, 1997, p. 5-4).

[3] The change from predevelopment to modern conditions may be the result of the different methods used to estimate the component rather than an actual change over time.

[4] Hely and others (1971, p. 143) estimated that natural recharge was about 234,000 acre-feet per year.

[5] Hely and others (1971, p. 84) estimated average annual groundwater discharge to the Jordan River from 1943–68 to be 154,000 acre-feet. About 147,000 acre-feet per year of the gross gain in river flow during this period is assumed to be from the confined part of the deeper aquifer because it is unaffected by seasonal changes (Hely and others, 1971, p. 136). The estimate used for groundwater discharge to the Jordan River under predevelopment conditions in this table is the residual amount needed to balance the other recharge and discharge components.

[6] Hely and others (1971, p. 179) estimated evapotranspiration from areas of natural and cultivated vegetation and from bare ground in 1964–68 at about 60,000 acre-feet per year. It is assumed here that natural vegetation would have grown in cultivated areas and discharged a similar amount of groundwater under predevelopment conditions.

[7] Hely and others (1971, p. 179) estimated groundwater discharge from the shallow part of the aquifer to drains in the northwestern part of the valley from measurements of low flows during water years 1964–68. It is assumed here that this shallow groundwater discharged under predevelopment conditions also.

This water is isotopically heavier because of evaporation. Richardson (1906, p. 41) reported that groundwater levels in the area downgradient from the Utah and Salt Lake Canal (completed in 1882) on the west side of Salt Lake Valley had risen as a result of canal seepage. Several wells in the area were reported to have water levels 30-65 ft nearer to the land surface then before the construction of the canal. Richardson stated that "… the quality of groundwater in the area has deteriorated in recent years, containing now much more alkali than formerly. So marked has this change been that surface wells are but little valued, and generally water for domestic use is obtained from deep wells." Recharge from excess irrigation water and canal seepage also affected water levels in the discharge area south-southeast of Salt Lake City that is traversed by Parleys, Mill, Big Cottonwood, and Little Cottonwood Creeks. Taylor and Leggette (1949, p. 23) noted local reports of increasing flow from artesian wells nearest to the recharge area soon after irrigation on higher altitude lands began.

Under present-day conditions, the groundwater system in Salt Lake Valley is greatly affected by withdrawals from wells, which has ranged from about 38,000 acre-ft in 1938 to 165,000 acre-ft in 1988. Withdrawals from wells are about one-third of the total estimated discharge from the modern groundwater system (table 1). Most of the pumping occurs on the east side of the valley because of higher yields and lower concentrations of dissolved solids. In some areas of the valley, groundwater is blended with water from other sources to improve its quality.

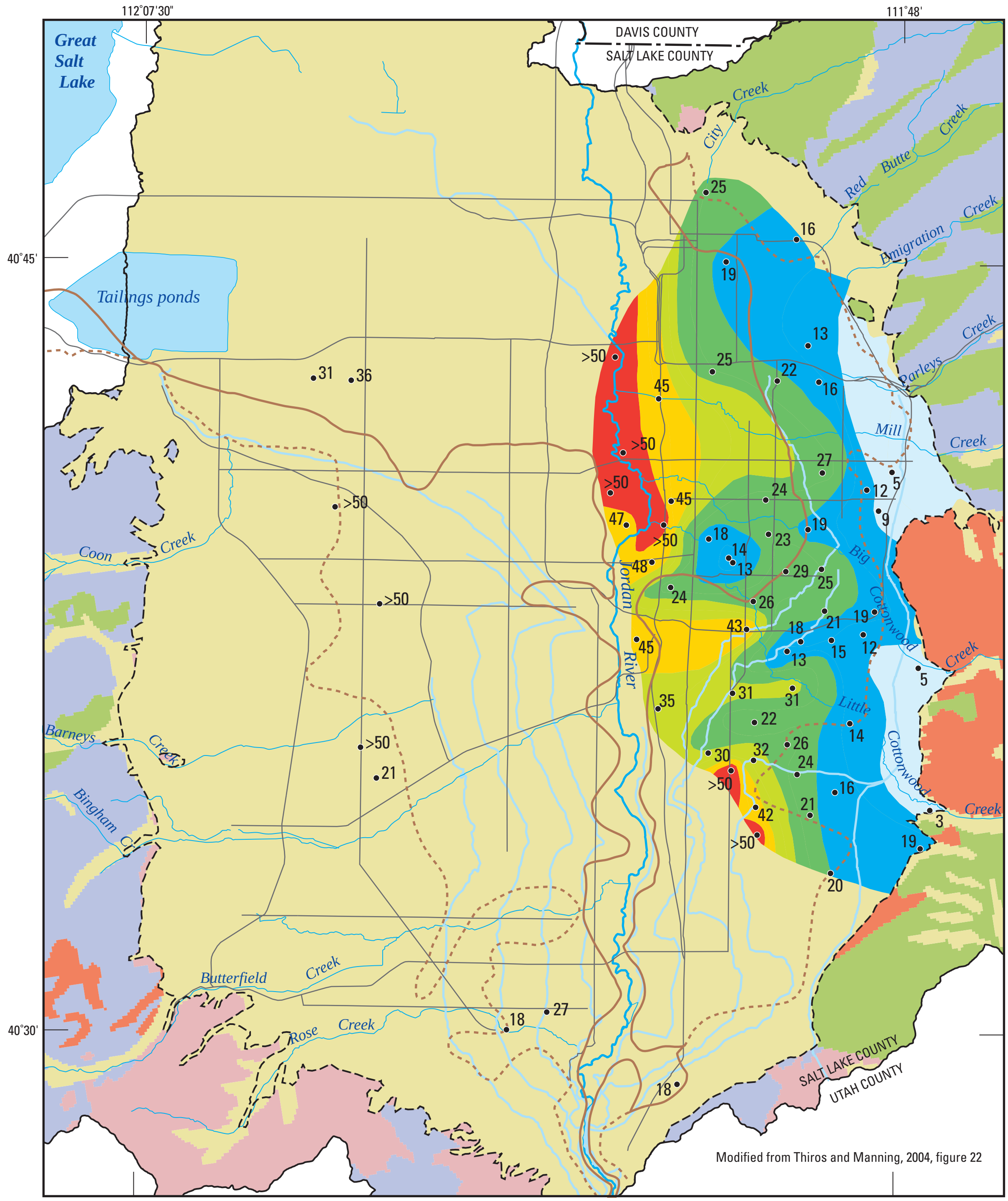
In 2000, utilized water rights and approved applications for rights show approximately 400,000 acre-ft/yr of potential groundwater withdrawal from the deeper basin-fill aquifer compared to an estimated "safe yield" of 165,000 acre-ft/yr (Robert Morgan, Utah Division of Water Rights, written commun., May 17, 2000, http://nrwrt1.nr.state.ut.us/meetinfo/m051700/slvplan.pdf). As a result, the Utah Division of Water Rights has implemented a groundwater management plan for the valley that provides guidelines on withdrawal limits in order to protect existing water rights and water quality.

Groundwater Movement

The potentiometric surface for the basin-fill aquifer indicates that groundwater generally moves from recharge areas near the mountain fronts toward the Jordan River and Great Salt Lake (fig. 4). Groundwater moves downward in the primary and secondary recharge areas from the land surface to the shallow unconfined aquifer (where it exists) and then to the deeper basin-fill aquifer. Groundwater moves upward in the discharge area through the confined aquifer, into and through overlying confining layers, and into the shallow unconfined aquifer, where it can discharge to the Jordan River, to drains, or by evapotranspiration or seepage to Great Salt Lake, which is minor. The steeper slope of the potentiometric surface on the west side of the valley indicates less recharge and lower transmissivities due to thinner saturated deposits or less permeable material when compared to the less steep surface on the east side. Faults within and bounding the basin-fill deposits may affect the hydraulic gradient and groundwater movement, and water from wells near faults in the northwestern part of the valley generally is warmer than water more distant from faults, indicating movement from greater depths. Most measured water levels in the deepest parts of the basin-fill aquifer have declined from spring 1975 to spring 2005 (Burden and others, 2005, fig. 14), with the largest decline of about 53 ft in a well in the southeastern part of the valley. This is an area with large withdrawals for public supply because of high yields and good water quality from the wells.

An approximate recharge rate was derived for the southeastern part of Salt Lake Valley from the mouth of Mill Creek Canyon southward to about 2 mi south of the mouth of Little Cottonwood Canyon. The typical age gradient of about 7.5 years/mi (along the groundwater flow path) in this area corresponds to an average linear groundwater flow velocity of 1.9 ft/d (Thiros and Manning, 2004, p. 54). Assuming a porosity of 0.2 (20 percent), an average saturated thickness of 330 ft (generally ranges from 150 to 500 ft), and a north-south cross-section length of 10 mi, the approximate recharge rate for the southeastern part of the valley is about 55,000 acre-ft/yr. Results of age dating using chlorofluorocarbons indicate an average groundwater flow velocity of between 1.4 and 1.8 ft/d in the southwestern part of the valley (Kennecott Utah Copper, 1998, p. 3-18).

Apparent tritium/helium-3 ages determined for water from 64 public-supply wells completed in the basin-fill aquifer in Salt Lake Valley range from 3 years to more than 50 years (Thiros and Manning, 2004, fig. 22) (fig. 5). See Section 1 of this report for a discussion of groundwater age and environmental tracers. Because public-supply wells generally have long open (screened or perforated) intervals (typically 150-500 ft), the samples likely contain mixtures of water with different ages. Water recharged before large amounts of tritium were introduced into the atmosphere by nuclear testing in the early 1950s is considered to be pre-bomb water. Interpreted-age categories were determined from the initial tritium concentration for each sample (measured tritium plus measured tritiogenic helium-3) and its relation to that of local precipitation at the apparent time of recharge (Thiros and Manning, 2004, fig. 21). Water sampled from the public-supply wells was divided into dominantly pre-bomb, modern or a mixture of pre-bomb and modern, or dominantly modern interpreted-age categories.



Base from U.S. Geological Survey digital line graph data, 1979, 1980,
Universal Transverse Mercator projection, Zone 12

0 2 4 Miles
0 2 4 Kilometers

EXPLANATION

Apparent tritium/helium-3 age in years

- Less than 10
- 10 to 20
- 20 to 30
- 30 to 40
- 40 to 50
- Greater than 50

Geology

- Carbonate rocks
- Metamorphic or intrusive igneous rocks
- Sedimentary-dominated rocks
- Volcanic rocks
- Basin-fill sediments

Boundary between secondary recharge and discharge areas

Boundary between primary and secondary recharge areas

Approximate boundary of basin-fill sediments

Study area boundary

Canal

18• **Public-supply well**—Number is apparent age of water in years; >, greater than

Figure 5. Distribution of apparent tritium/helium-3 ages for water sampled from the deeper basin-fill aquifer in Salt Lake Valley, Utah, 2000–01.

Tritium concentrations in water sampled from the shallow part of the basin-fill aquifer in secondary recharge areas within Salt Lake Valley indicate that most or all of the water was recently recharged from the land surface with little or no mixing with older groundwater. The apparent tritium/helium-3 age for water sampled from 24 monitoring wells ranged from 1 year or less to 38 years (Thiros, 2003, table 5). Water from most of the monitoring wells was contaminated with chlorofluorocarbons, which also indicates that the water has been in contact with human-derived compounds at the land surface.

Ages of groundwater in the primary and secondary recharge areas are generally younger on the east side of the valley than on the west side (Thiros and Manning, 2004, fig. 24), indicating that recharge rates are generally greater on the east side. Groundwater on the east side of the valley generally becomes older with distance from the mountain front, the oldest water being that in the discharge area. On the west side of Salt Lake Valley, the median apparent age of water from wells in the secondary recharge and discharge areas is younger than that of water from wells in the primary recharge area. This age difference is probably affected by the primary recharge area on the west side of the valley being upgradient from two major components of recharge in the area under modern conditions: losses from canals and infiltration from irrigated fields.

Effects of Natural and Human Factors on Groundwater Quality

The occurrence and concentrations of contaminants in water within the basin-fill aquifer system in Salt Lake Valley are influenced by the locations and sources of recharge, the vertical hydraulic gradient, and aquifer properties. Water that enters the basin-fill aquifer in the valley (valley recharge) is more susceptible to transporting man-made chemicals than is subsurface inflow from the adjacent mountains (mountain-block recharge) and surface flow at the mountain front and in major mountain streams. Seepage of excess water from irrigated crops, lawns, gardens, parks, and golf courses; and from leaking canals, water distribution pipes, sewer lines, storm drains, and retention basins are modern-day sources of groundwater recharge in many parts of the valley.

Data were collected as part of three National Water-Quality Assessment (NAWQA) Program studies in Salt Lake Valley to characterize and determine the effects of natural and human factors on groundwater quality. A study to evaluate the occurrence and distribution of natural and human-related chemical constituents and organic compounds in shallow groundwater underlying recently developed (post-1963) residential and commercial areas in the valley was done in 1999 (Thiros, 2003). Thirty monitoring wells were installed and sampled in areas where there was a downward gradient between the shallow and deeper aquifers. Although the aquifers are separated by layers of fine-grained deposits, there is potential for water in these wells to move deeper to parts of the basin-fill aquifer used for public supply. The occurrence and distribution of natural and human-related compounds in groundwater used for drinking and public supply in Salt Lake Valley were evaluated by analyzing water-quality data collected from 31 public-supply wells in 2001 (Thiros and Manning, 2004). An additional 19 wells completed in the primary and secondary recharge areas, mostly used for domestic and public supply, also were sampled to characterize water quality in the deeper basin-fill aquifer in the valley.

General Water-Quality Characteristics and Natural Factors

The inorganic chemical composition of groundwater largely depends on its recharge source, the type of rocks and associated minerals it has contacted, and how long the water has been in contact with the aquifer material. Generally, the most mineralized groundwater is in the northwestern part of the valley near the Great Salt Lake. This area is at the downgradient end of the overall Salt Lake Valley groundwater flow path, and on the basis of stable isotope data (Thiros, 1995, p. 51), the water is possibly thousands of years old. Stable isotope data also indicate that evaporation is not a factor contributing to mineralization of the deeper aquifer; sulfate-reducing conditions and the presence of sodium and chloride ions in pore water left from the desiccation of paleolakes contribute to chemical processes that result in a sodium-chloride-type groundwater. Dissolved-solids concentrations in groundwater from this part of the valley are generally greater than 1,000 mg/L (fig. 6).

Groundwater in the northeastern part of the valley generally has more dissolved sulfate relative to bicarbonate than water in upgradient areas and from local mountain-front streams. Dissolved-solids concentrations there are greater than 500 mg/L (fig. 6), primarily as a result of the contact of the water with easily eroded Triassic-age shale and mudstone in the mountain block and in the basin-fill deposits in the area.

Basin-fill deposits in the southeastern part of the valley are derived from rocks such as quartzite and quartz monzonite, which are more resistant to weathering and include less easily soluble material than the rocks further north. The groundwater in this area is predominantly a calcium-bicarbonate type, similar to that of water in local mountain-front streams, and concentrations of dissolved solids are generally less than 500 mg/L (fig. 6). A relatively large area of groundwater with concentrations of dissolved solids less than 250 mg/L extends northwestward from the mountain front toward the Jordan River following regional flow paths. Age-dating of this water indicates that it moves rapidly through coarse-grained deposits near the mountain front (Thiros and Manning, 2004, fig. 23).

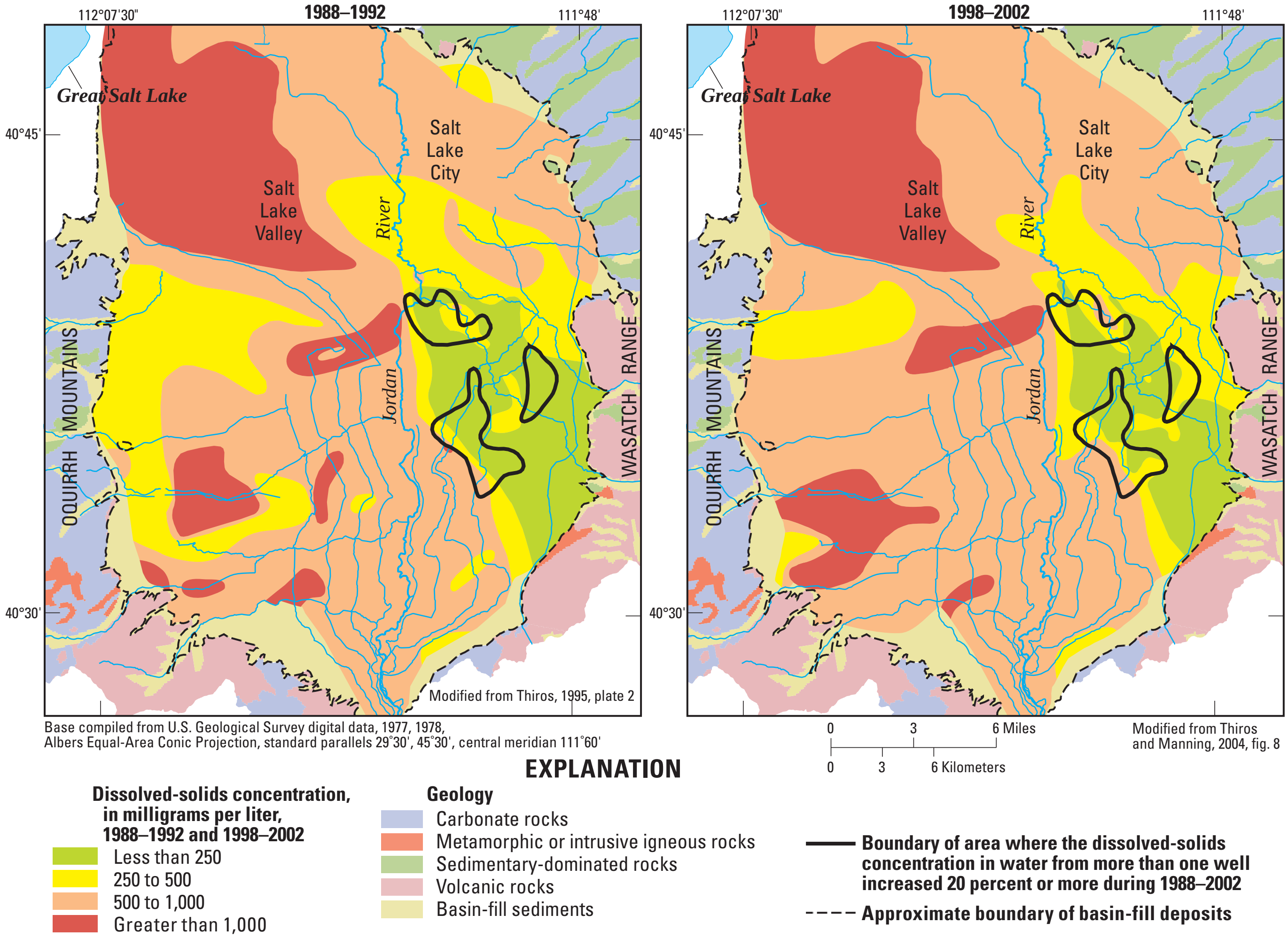


Figure 6. Dissolved-solids concentration in water sampled from parts of the deeper basin-fill aquifer in Salt Lake Valley, Utah, in 1988–92 and 1998–2002.

Groundwater quality in the southwestern part of Salt Lake Valley, Utah, is influenced by reactions between the basin-fill deposits derived from rocks of the Oquirrh Mountains and the different types of water recharged in the area. The Oquirrh Mountains are composed primarily of carbonate rocks that locally have undergone sulfide mineralization. Prior to development in the valley, the main source of recharge to the basin-fill aquifer was subsurface inflow from the mountain block along with seepage from the mountain-front streams and infiltration of precipitation on the valley floor. Geochemical reactions between the basin-fill deposits and the naturally recharged water probably resulted in groundwater with dissolved-solids concentrations less than 1,000 mg/L. Under modern conditions, canal seepage and infiltration of excess irrigation water have contributed to higher concentrations of dissolved solids (greater than 1,000 mg/L) in some areas in this part of the valley (fig. 6). Infiltration of mine drainage and wastewater (most seepage from mining related sources was stopped in 1992) has resulted in an area with high concentrations of sulfate in groundwater downgradient from the Bingham Canyon mining operations (Waddell and others, 1987b, p. 16).

Concentrations of dissolved oxygen in groundwater sampled as part of the NAWQA studies ranged from 0.3 to 11.6 mg/L, and pH ranged from 6.8 to 8.0 standard units. Dissolved-oxygen concentrations in pre-bomb era water from the deeper part of the aquifer in the discharge area indicate reducing conditions; otherwise, groundwater in the valley is generally oxic (contains dissolved oxygen).

Concentrations of dissolved arsenic in groundwater sampled as part of the NAWQA studies ranged from 0.4 to 23 µg/L, with a median value of 2.0 µg/L, in the deeper part of the basin-fill aquifer, and from less than 1.0 to 19.6 µg/L, with a median of 7.3 µg/L, in the shallower part. The drinking-water standard for arsenic is 10 µg/L (U.S. Environmental Protection Agency, 2008). Arsenic concentrations in water from wells in most of the western part of the valley generally were higher than in groundwater from other areas (Thiros and Manning, 2004, fig. 9). Human-related factors in addition to natural factors may be affecting arsenic concentrations in this area. More arsenic-bearing minerals associated with the sulfide-mineralized zone in the Oquirrh Mountains may be present in the fine-grained basin-fill deposits coupled with less recharge available to transport arsenic through the system. Groundwater sampled from near the water table that contained arsenic at concentrations greater than 10 µg/L may be affected by dissolved organic carbon and oxygen present in recharge water from excess irrigation and canal losses. This source of recharge may have mobilized arsenic from the aquifer material through the dissolution of pyrite or by desorption from iron oxides bound to the basin-fill sediments in the western part of the valley. The proximity of faults, and the potential for geothermal water from deep sources to move into the basin-fill deposits also is a potential factor in the elevated concentrations of arsenic in groundwater in some areas.

Concentrations of dissolved uranium in groundwater sampled as part of the NAWQA studies ranged from 0.04 to 15.1 µg/L in the deeper part of the basin-fill aquifer and from less than 1.0 to 93 µg/L in the shallower part, with a composite median value of 4.9 µg/L. The drinking-water standard for uranium is 30 µg/L (U.S. Environmental Protection Agency, 2008). Uranium is soluble under oxic conditions and is concentrated in the sediment in reducing environments as a result of mineral precipitation. The highest concentrations of dissolved uranium were measured in water from wells in the southeastern part of the valley and may result from proximity to uranium-rich intrusive rocks in the Wasatch Range coupled with oxic conditions. Uranium ore processed from 1951 to 1964 at a site in the central part of the valley and its mill tailings were a source of contamination to the basin-fill aquifer (Waddell and others, 1987b, p. 29). Withdrawals from wells in the area are small, so that the naturally upward hydraulic gradient is not affected. A reversal in the gradient could allow contaminated shallow water to move downward to the deeper confined part of the aquifer.

Potential Effects of Human Factors

Agricultural and urban development in the Salt Lake Valley has brought additional sources and processes of recharge to and discharge from the basin-fill aquifer system, which together have acted to accelerate the movement of water from the land surface to parts of the system. This results in the aquifer being more susceptible to activities at the land surface and more vulnerable to contaminants if their sources are present in the valley.

Comparison of analyses of groundwater from the deeper basin-fill aquifer in the valley sampled during 1988–92 and again during 1998–2002 shows a reduction (during the latter period) in the extent of the area with dissolved-solids concentrations of less than 500 mg/L (fig. 6). Dissolved-solids concentrations increased more than 20 percent in some areas near the Jordan River and on the east side of the valley between the two periods (Thiros and Manning, 2004, p. 22). Withdrawals from wells may have caused the vertical and(or) lateral groundwater flow gradients to change, which could allow water with higher concentrations of dissolved solids from the shallow aquifer or from other parts of the deeper aquifer, both from the west and from greater depths, to reach the wells in these areas.

A long-term trend of increasing concentration of dissolved solids, mainly in the form of chloride, approximately corresponds with rising water levels through time at a flowing well in the northeastern part of the valley (fig. 7). Most valley wells show a declining water-level trend over time (Burden and others, 2005, fig. 10) that is related to groundwater pumping. Although in a discharge area, this well is near urbanized recharge areas. New sources of water and contaminants used in the recharge area likely have moved downgradient along the groundwater flow path to this well on the basis of the occurrence of human-related compounds in water from the well and a modern tritium/helium-3 determined age. Waddell and others (1987b, p. 11) suggested that a possible cause for the increase in chloride is the storage and use of road salt in recharge areas along the east side of the valley.

Although nitrate can occur naturally in groundwater, concentrations greater than an estimated background level of about 2 mg/L are generally thought to be related to human activities (Thiros and Manning, 2004, p. 24). Nitrate (as nitrogen) concentrations in water sampled from 26 of the 30 monitoring wells (87 percent) completed in the shallow aquifer in residential/commercial land-use areas were greater than 2 mg/L, indicating a likely human influence. Concentrations ranged from less than 0.05 to 13.3 mg/L with a median value of 6.85 mg/L. The drinking-water standard for nitrate is 10 mg/L (U.S. Environmental Protection Agency, 2008). Nitrate (as nitrogen) concentrations in water from 12 of the 31 public-supply wells sampled for the drinking-water study (39 percent) also were greater than 2 mg/L. The source of nitrate at concentrations above the background level may be the application of fertilizers, other agricultural activities, and leaking or improperly functioning septic systems and sewer pipes in the valley.

Pesticides and (or) VOCs were detected, mostly at very low concentrations, in water from 23 of the 31 public-supply wells sampled for the drinking-water study (Thiros and Manning, 2004). Produced and used exclusively by humans, pesticides and VOCs are known as human-related compounds. Although the measured concentrations of these compounds are not a health concern, their widespread occurrence indicates the presence of water young enough to be affected by human activity in much of the deeper basin-fill aquifer in Salt Lake Valley. Detection of these compounds in water from a well indicates the possibility that water with higher concentrations may enter the well in the future.

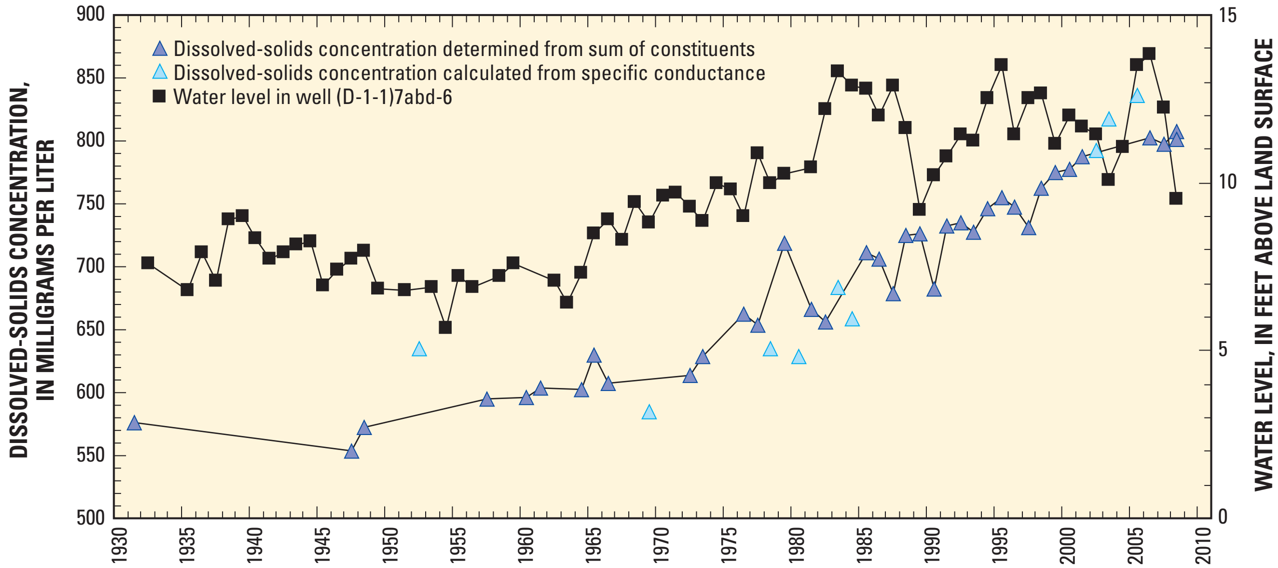


Figure 7. Relation of dissolved-solids concentration to water levels in a flowing well in the northeastern part of Salt Lake Valley, Utah.

At least one pesticide or pesticide degradation product was detected in water from 28 of the 30 monitoring wells completed in the shallow aquifer in residential/commercial land-use areas. The herbicide atrazine and its degradation product deethylatrazine were the most frequently detected pesticides in the NAWQA land-use and drinking-water studies (Thiros, 2003, p. 26, and Thiros and Manning, 2004, p. 27), detected in samples from 23 and 21 of the 30 monitoring wells, respectively, and in 7 and 10 of the 31 public-supply wells, respectively. Atrazine is a restricted-use pesticide that is used primarily on corn and along roads, railroads, other right-of-ways, utility substations, and industrial lots to control weeds and undesired vegetation. It is not intended for household use. The high detection frequency of atrazine in shallow groundwater in residential areas on the west side of the valley may be the result of its application in formerly agricultural or industrial areas that have been converted to residential uses, or the herbicide was applied to agricultural or industrial land upgradient from the residential areas and was transported to these areas in groundwater.

Eleven of the 85 VOCs for which water samples collected for the drinking-water study were analyzed were detected in one or more of the samples. The most frequently detected VOCs were chloroform (54.8 percent of the samples), bromodichloromethane (35.5 percent), and 1,1,1-trichloroethane (19.4 percent). These compounds, along with tetrachloroethylene (PCE, a solvent), also were the most frequently detected VOCs in shallow groundwater in the valley. Chloroform and bromodichloromethane are byproducts of chlorinated groundwater and surface water that has reacted with organic material in the water and aquifer material. Widespread occurrence of these compounds in both shallow and deeper basin-fill aquifers is likely a result of recharge of chlorinated public-supply water used to irrigate lawns and gardens in residential areas of Salt Lake Valley.

Leaking underground gasoline storage tanks commonly are a source of shallow groundwater contamination from the VOCs benzene, toluene, ethylbenzene, and xylene (BTEX compounds). These gasoline-derived compounds typically were not detected in water samples from the shallow aquifer monitoring wells or the public-supply wells in the valley. Natural attenuation enhanced by oxygen-rich (oxic) conditions likely removes most of the BTEX compounds before they reach the deeper aquifer.

Drinking-water study wells in which low levels of VOCs (mainly chloroform) and pesticides (mainly atrazine and (or) its degradation products) were measured at concentrations greater than laboratory or minimum reporting levels (LRLs or MRLs) are shown in figure 8. Also shown are wells that contain water with nitrate concentrations greater than an estimated background level of 2 mg/L. Wells with water that contain human-related compounds above reporting levels and (or) nitrate concentrations above 2 mg/L are referred to as “affected wells.” Wells that meet these criteria thus have a reasonably high level of susceptibility to receive water that has been affected by human activities. Eighteen of the 31 public-supply wells (58 percent) sampled for the drinking-water study are considered affected wells.

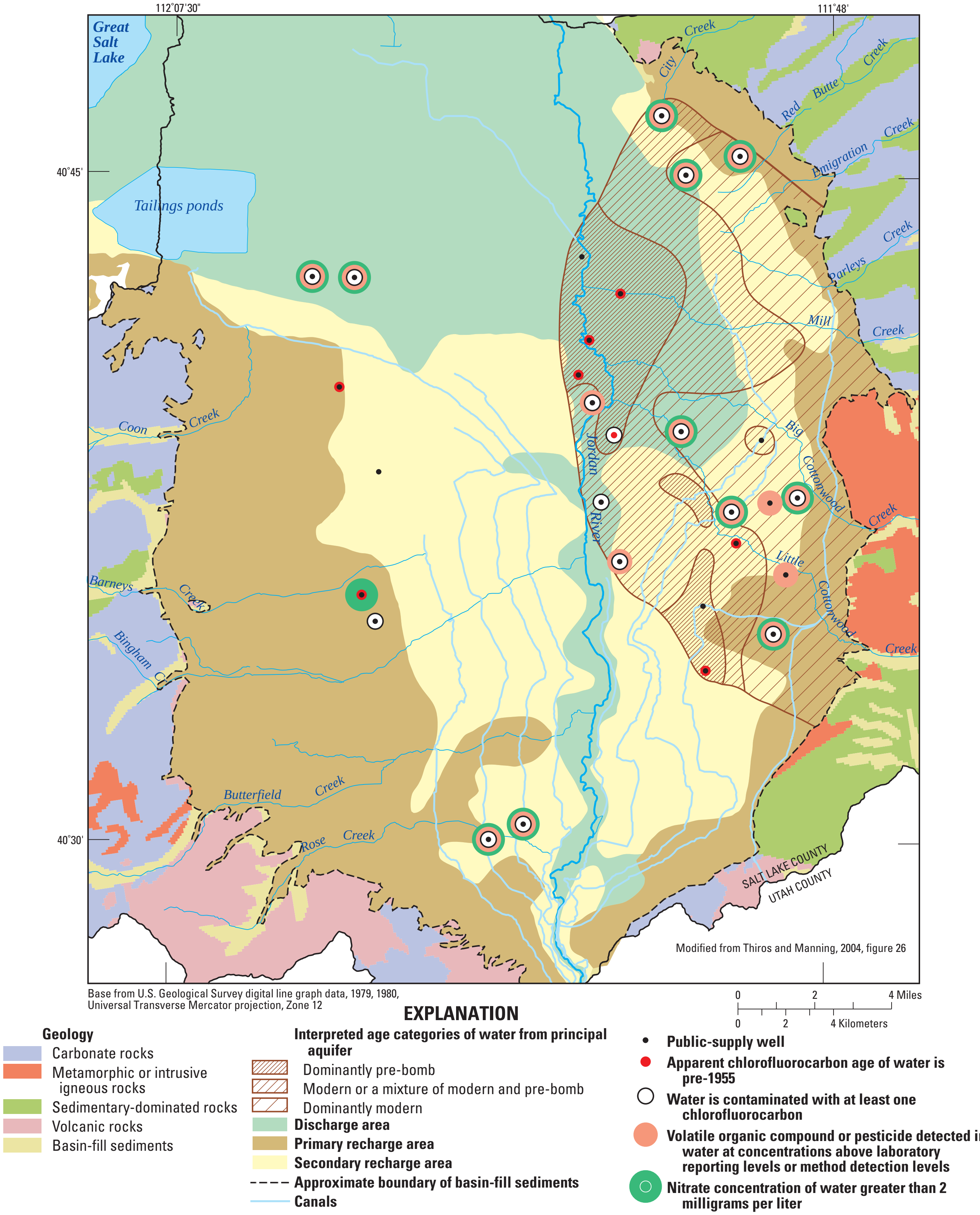


Figure 8. Interpreted-age category, chlorofluorocarbon, human-related compounds, and nitrate information for water sampled from 31 public-supply wells in Salt Lake Valley, Utah, 2001.

The presence of human-related compounds and elevated concentrations of nitrate in the deeper basin-fill aquifer is strongly correlated with the distribution of interpreted-age categories (fig. 8). Nearly all of the affected wells (17 of 18) have either dominantly modern water (generally water less than 20 years old) or a mixture of modern and pre-bomb era waters (Thiros and Manning, 2004, p. 63). Most of the unaffected wells (10 of 13) contain dominantly pre-bomb era water and thus contain little modern water. All of the wells (10 of 10) with dominantly modern water were affected while only 1 of the 11 wells with dominantly pre-bomb era water was affected. These results indicate that most of the modern groundwater in Salt Lake Valley contains human-related compounds at concentrations above reporting levels and (or) has nitrate concentrations greater than the estimated background level of 2 mg/L, and that pre-bomb era water generally is free of these human effects.

The relation between chloroform and atrazine and prometon in water from the shallow aquifer monitoring wells, although not statistically significant, was opposite for the two herbicides. The three highest concentrations of chloroform detected corresponded to three of the four highest concentrations of prometon, likely because of the presence of both of these compounds in residential areas (Thiros, 2003, p. 42). Prometon is registered for use by homeowners to control vegetation. Relatively low concentrations of chloroform corresponded to the four highest concentrations of atrazine and its degradation products; this may be a result of atrazine use on agricultural or nonirrigated industrial and vacant land.

The number of human-related compounds detected in water sampled from the drinking-water study public-supply wells is inversely correlated with the apparent tritium/helium-3 age. This dataset includes concentrations that are considered estimates because they are less than the reporting limit for the analytical method and therefore have a greater relative uncertainty, but have met the identification critera for the compound. Human-related compounds were not detected in water with an apparent age older than 50 years, with one exception. Concentrations of nitrate in water from the 31 sampled public-supply wells is correlated with many factors. Generally, nitrate concentration in water from the sampled wells increased as the depth to the top of the well’s open interval became shallower; as the delta oxygen-18 ratio became heavier (more evaporated); as the apparent age of the water became younger; and as the number of human-related compounds detected in water per well increased (Thiros and Manning, 2004, p. 65). On the basis of these correlations, the concentration of nitrate in water from many of the public-supply wells is related to the occurrence of modern valley recharge, which has the potential of being influenced by human activity.

Water-quality data for 80 wells sampled in Salt Lake Valley as part of the NAWQA studies were separated into 8 classes of wells and compared to hydrogeology, water use, and land use (table 2). The well classes represent major components of the conceptual groundwater flow system: the shallow aquifer in the secondary recharge area divided into east and west sides of the valley, the deeper aquifer in the primary and secondary recharge areas divided into east and west sides of the valley, and the deeper aquifer in the discharge area divided into pre-bomb era and modern or mixed-age groundwater.

Groundwater sampled from the shallow basin-fill aquifer on the east side of the valley (class A) is recharged mainly by seepage from mountain-front streams, from canals originating at the Jordan River, and from the infiltration of imported surface water and pumped groundwater used for public supply. The major source of recharge to the shallow aquifer on the west side of the valley (class B) is seepage from canals and fields irrigated with water from the Jordan River. Water from class A (east side) wells had lower median concentrations of dissolved solids, nitrate, and arsenic than did water from the class B (west side) wells. Although most of the class B wells are in residential areas, the detection of agricultural or industrial use pesticides in all of the wells likely indicates groundwater movement from upgradient areas.

Water samples from wells in the unconfined aquifer in primary recharge areas generally had modern or a mixture of modern and pre-bomb era ages, and VOCs were detected in samples from many of the wells. The greatest median depth to water was in wells in the primary recharge area on the east side of the valley (class C), but the surrounding land use is mostly urban, and the groundwater is dominantly modern. VOCs were detected in water from all five wells sampled in this class. Pesticides or VOCs were detected at a higher frequency and median concentrations of nitrate were higher in Class C wells than in wells in the primary recharge area on the west side of the valley(class D), which includes undeveloped range, agricultural, and urban land. Nine of the 10 class D wells are west (upgradient) of any irrigation canal and therefore are not subject to recharge derived from that source. The thicker unsaturated zones in the primary recharge areas (where class C and D wells are located) lessen the susceptibility of the aquifer to the movement of contaminants from the land surface, but the presence of contaminant sources associated with urban land use increases the aquifer’s vulnerability to contamination.

Wells completed in the deeper aquifer in secondary recharge areas of the valley (classes E and F) had shallower median depths to water than did wells in the primary recharge areas (classes C and D), and contained water of modern or mixed age. Water from wells in the secondary recharge area on the east side of the valley (class E) had lower

Table 2. Summary of physical and water-quality characteristics for eight classes of wells sampled in Salt Lake Valley, Utah.

[per mil, parts per thousand; TU, tritium units; mg/L, milligrams per liter; µg/L, micrograms per liter; %, percent; pesticide and volatile organic compound (VOC) detections include estimated values below the laboratory reporting level]

Well class	A	B	C	D	E	F	G	H
Number of wells	11	19	5	10	15	9	5	6
Part of basin-fill aquifer	Shallow	Shallow	Deeper	Deeper	Deeper	Deeper	Deeper	Deeper
Recharge or discharge area	Secondary recharge area	Secondary recharge area	Primary recharge area	Primary recharge area	Secondary recharge area	Secondary recharge area	Discharge area	Discharge area
Aquifer confinement	Unconfined	Unconfined	Unconfined	Unconfined	Confined	Confined	Confined	Confined
Head gradient	Downward	Downward	Downward	Downward	Downward	Downward	Upward	Generally upward
General location	East side of valley	West side of valley	East side of valley	West side of valley	East side of valley	West side of valley	Near the Jordan River	East and west sides of valley and near the Jordan River
Interpreted age category of water	Dominantly modern	Dominantly modern	Dominantly modern	Dominantly pre-bomb era with some modern or mixed age	Modern or mixed age	Modern or mixed age	Dominantly pre-bomb era	Modern or mixed age
Land use	Mostly urban areas	Mostly urban areas	Mostly urban areas	Mostly agricultural areas	Mostly urban areas	Urban and agricultural areas	Urban and industrial areas	Mostly urban areas
Dominant sources of water used for irrigation of crops, lawns, and gardens in area	Mountain-front streams, Jordan River, groundwater	Jordan River	Mountain-front streams, groundwater	Groundwater	Mountain-front streams, Jordan River, groundwater	Jordan River	Jordan River	Mountain-front streams, Jordan River, groundwater
Physical characteristics								
Median well depth, feet	73.5	67.5	510	306	544	440	935	318
Median depth to top of well screen, feet	62.5	57	266	208	265	290	395	115
Median depth to water, feet	58.7	49.7	194	162	136	105	5	1
Median deuterium concentration, per mil	[1]-112.9	-102.1	-117.0	-118.6	-120.4	-111.2	-124.2	-113.5
Median tritium concentration, TU	12.4	12.3	21.3	1.0	7.6	10.7	0.2	11.7
Water-quality characteristics								
Median pH, standard units	7.3	7.3	7.1	7.2	7.5	7.4	7.7	7.4
Median dissolved-oxygen concentration, mg/L	5.3	5.3	7.4	7.9	[1]5.8	[1]5.6	0.5	4.8
Median dissolved-solids concentration, mg/L	414	1,300	562	696	316	615	345	675
Median nitrate concentration, mg/L	4.45	7.05	3.34	2.96	1.21	3.06	0.04	3.14
Median arsenic concentration, µg/L	1.1	11.7	0.9	[1]5	0.5	5	1.9	1.5
Number of different pesticides detected	14	10	2	3	3	4	0	3
Number of pesticide detections	23	100	5	5	4	11	0	7
Percentage of wells where pesticides were detected	82%	100%	60%	30%	20%	56%	0%	83%
Number of different VOCs detected	13	18	12	4	7	8	0	5
Number of VOC detections	42	73	22	10	[2]25	[1,3]12	0	12
Percentage of wells where VOCs were detected	91%	95%	100%	67%	80%	67%	0%	100%

[1] One well in this classification was not sampled for this constituent or constituent group.
[2] Two samples in this classification were analyzed for a smaller set of compounds.
[3] One sample in this classification was analyzed for a smaller set of compounds.

median concentrations of dissolved solids and nitrate and a lower frequency of pesticide or VOC detections compared to upgradient wells in the unconfined part of the aquifer (class C). This is likely due to fine-grained beds impeding the downward flow of water in the aquifer in the secondary recharge area. Water from wells completed in the deeper aquifer in the secondary recharge area on the west side of the valley (class F) had more frequent pesticide detections and an isotopically heavier median concentration of deuterium, indicating that it has undergone some evaporation, than water from wells in classes D and E. The area of class F wells includes the last large parcels of agricultural land in the valley and receives a significant amount of recharge from water diverted from the Jordan River for irrigation.

Water samples from deeper wells in the discharge area that were composed predominantly of pre-bomb era water (class G) had no pesticide or VOC detections and a very low median concentration of nitrate. Although the wells in class G are generally surrounded by urban or industrial land, they have the deepest median depth to the top of the well screen (open interval) and are in areas with a dominantly upward hydraulic gradient. Water from three of the five wells had dissolved oxygen concentrations equal to or less than 0.5 mg/L, indicative of reducing conditions. In contrast, wells completed in the deeper aquifer in a discharge area, but with modern or mixed age water (class H), had higher median concentrations of dissolved solids and nitrate and pesticides and VOCs were frequently detected. This indicates that class H wells produce a component of water recharged in the valley. The median depth to the top of the interval open to the aquifer in class H wells was the shallowest of the well classes representing the deeper basin-fill aquifer in the valley. These wells were probably completed in the upper part of the confined aquifer because of the artesian conditions present when they were drilled. Changes in the vertical hydraulic gradient at and in the area of class H wells have likely occurred as a result of pumping, so that some water recharged at the land surface has moved downward past the confining layers and into the deeper aquifer.

Summary

Changes in land use and water use in Salt Lake Valley, Utah have affected groundwater quality through changes in the sources, amount, and quality of water that recharges the basin-fill aquifer system. Water that enters the aquifer in the valley (basin or valley recharge) is more susceptible to receiving man-made chemicals than is both surface flow and subsurface inflow from the adjacent mountains. Seepage of excess water from irrigated cropland, lawns, gardens, parks, and golf courses; and from leaking canals, water distribution pipes, sewer lines, storm drains, and retention basins are now sources of recharge to the basin-fill aquifer. The diversion of water from Jordan River/Utah Lake to the east side of the valley began in 1882. Water from the Jordan River is acceptable for irrigation, but not for potable uses because of turbidity and mineral content. Surface water from local streams draining the Wasatch Range and imported from outside of the local drainage basin provided about 70 percent of the public supply in 2000. This water is chlorinated and distributed for use across the valley. Groundwater withdrawal from wells in 2000 was about 28 percent of the total used for public supply.

The basin-fill deposits in the valley consist of unconsolidated to semiconsolidated Tertiary-age deposits overlain by unconsolidated Quaternary-age deposits. The groundwater system in the valley includes a shallow aquifer that is separated from a deeper aquifer by discontinuous layers or lenses of fine-grained sediment. The deeper basin-fill aquifer consists of an unconfined part near the mountain fronts that becomes confined toward the center of the valley. Groundwater discharges in areas where there is an upward gradient from the confined part of the deeper aquifer to the overlying shallow aquifer, generally in the center of the valley along the Jordan River and in the topographically lowest parts of the valley. Both the confined and unconfined parts of the aquifer are important sources of drinking water for Salt Lake Valley.

Under predevelopment conditions, recharge occurred along the mountain fronts and from the infiltration of precipitation. Mountain-front recharge is estimated to have comprised more than 70 percent of recharge to the basin-fill aquifer system under predevelopment conditions, and includes subsurface inflow from consolidated rocks in the adjacent mountains (mountain-block recharge) and seepage from major streams and precipitation runoff near the mountain front. Under modern conditions, infiltration of excess irrigation water from croplands, lawns, and gardens, and seepage from canals became major sources of recharge to the groundwater system (about 27 percent of estimated average annual recharge). Groundwater recharge has increased by almost one-third from that of predevelopment conditions, primarily due to the addition of canal seepage and excess irrigation water.

The inorganic chemical composition of groundwater depends largely on its recharge source, the type of rocks and associated minerals it has contacted, and how long the water has been in contact with the aquifer material. Major factors related to the occurrence of contaminants within the basin-fill aquifer include the locations and sources of recharge, vertical direction of groundwater movement, and aquifer properties. Water that enters the basin-fill aquifer in the valley (valley or basin recharge) is more susceptible to receiving man-made chemicals than is subsurface inflow from the adjacent mountains (mountain-block recharge). Widespread occurrence of chloroform and bromodichloromethane in both the shallow and deeper basin-fill aquifers is likely a result of recharge of chlorinated public-supply water used to irrigate lawns and gardens in residential areas of Salt Lake Valley.

The presence of human-related compounds and elevated concentrations of nitrate in the deeper basin-fill aquifer is strongly correlated with the distribution of interpreted-age categories. Nearly all of the public-supply wells where a VOC or pesticide was detected or where the nitrate concentration was greater than 2 mg/L, have either dominantly modern water (water less than 20 years old) or a mixture of modern and pre-bomb era (pre-1950) waters. With one exception, human-related compounds were not detected in groundwater with an apparent age of older than 50 years.

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