Hydrogeologic Setting and Ground-Water Flow Simulations of the Salt Lake Valley Regional Study Area, Utah

By Bernard J. Stolp

Section 2 of

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Hydrogeologic Setting and Ground-Water Flow Simulation of the Salt Lake Valley Regional Study Area, Utah

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Abstract

The transport of anthropogenic and natural contaminants to public-supply wells was evaluated in the Salt Lake Valley, Utah, as part of the U.S. Geological Survey National Water-Quality Assessment Program. The valley-fill aquifer in the Salt Lake Valley regional study area is representative of the Basin and Range basin-fill aquifers, is an important source of water for agricultural irrigation and public water supply, and is susceptible and vulnerable to contamination. An existing seven-layer, transient ground-water flow model of the Salt Lake Valley was converted to a steady-state model representative of average conditions for the period 1997–2001. The steady-state model and advective particle-tracking simulations were used to compute ground-water flow paths, areas contributing recharge, and traveltimes from recharge areas for 94 wells. Model results indicate recharge from the surrounding mountain block (43.8 percent of inflow) and precipitation plus irrigation (39.5 percent of inflow) provide the majority of ground-water inflow to the study area. Inflow from rivers and canals provides the remaining inflow. Ground-water discharge is primarily to wells (49.4 percent of outflow) and the Jordan River (28.3 percent of outflow) with the remainder of ground-water outflow going to evapotranspiration, springs, drains, and the Great Salt Lake. The model-computed areas contributing recharge reached to the edges of the modeled area indicating mountain-front and mountain-block recharge from the Wasatch Range on the east and the Oquirrh Mountains on the west contributes water to public-supply wells in the Salt Lake Valley study area. The simulated median traveltime for ground water to flow from its recharge point to a well ranged from 5 to 780 years. The longest traveltimes are associated with contributing areas for wells on the west side of Salt Lake Valley.

Introduction

The Salt Lake Valley regional study area for the transport of anthropogenic and natural contaminants to public-supply wells (TANC) study is on the western edge of the 37,500-km^2 Great Salt Lake Basins study unit of the U.S. Geological Survey National Water-Quality Assessment (NAWQA) program (fig. 2.1). The Salt Lake Valley is located west of the Wasatch Range (fig. 2.2) and is the metropolitan and industrial center of the State of Utah. Ground water exists in the unconsolidated and semiconsolidated basin-fill materials of the valley and is used extensively for water supply in and around Salt Lake City, Utah.

Purpose and Scope

The purpose of this Professional Paper section is to present the hydrogeologic setting of the Salt Lake Valley regional study area. The section also documents a steady-state regional ground-water flow model for the study area. Ground-water flow characteristics, pumping-well information, and water-quality data were compiled from existing data to develop a conceptual understanding of ground-water conditions in the study area. A seven-layer transient ground-water flow model of the Salt Lake Valley basin-fill aquifer was converted to a steady-state model to represent average conditions for the period from 1997 to 2001. The 5-year period 1997–2001 was selected for data compilation and modeling exercises for all TANC regional study areas to facilitate future comparisons between study areas. The steady-state ground-water flow model and associated particle tracking were used to simulate advective ground-water flow paths and to delineate areas contributing recharge to selected public-supply wells. Ground-water traveltimes from recharge to public-supply wells, oxidation-reduction (redox) conditions along flow paths, and presence of potential contaminant sources in areas contributing recharge were tabulated into a relational database described in Section 1 of this Professional Paper. This section provides the foundation for future ground-water susceptibility and vulnerability analyses of the study area and comparisons among regional aquifer systems.

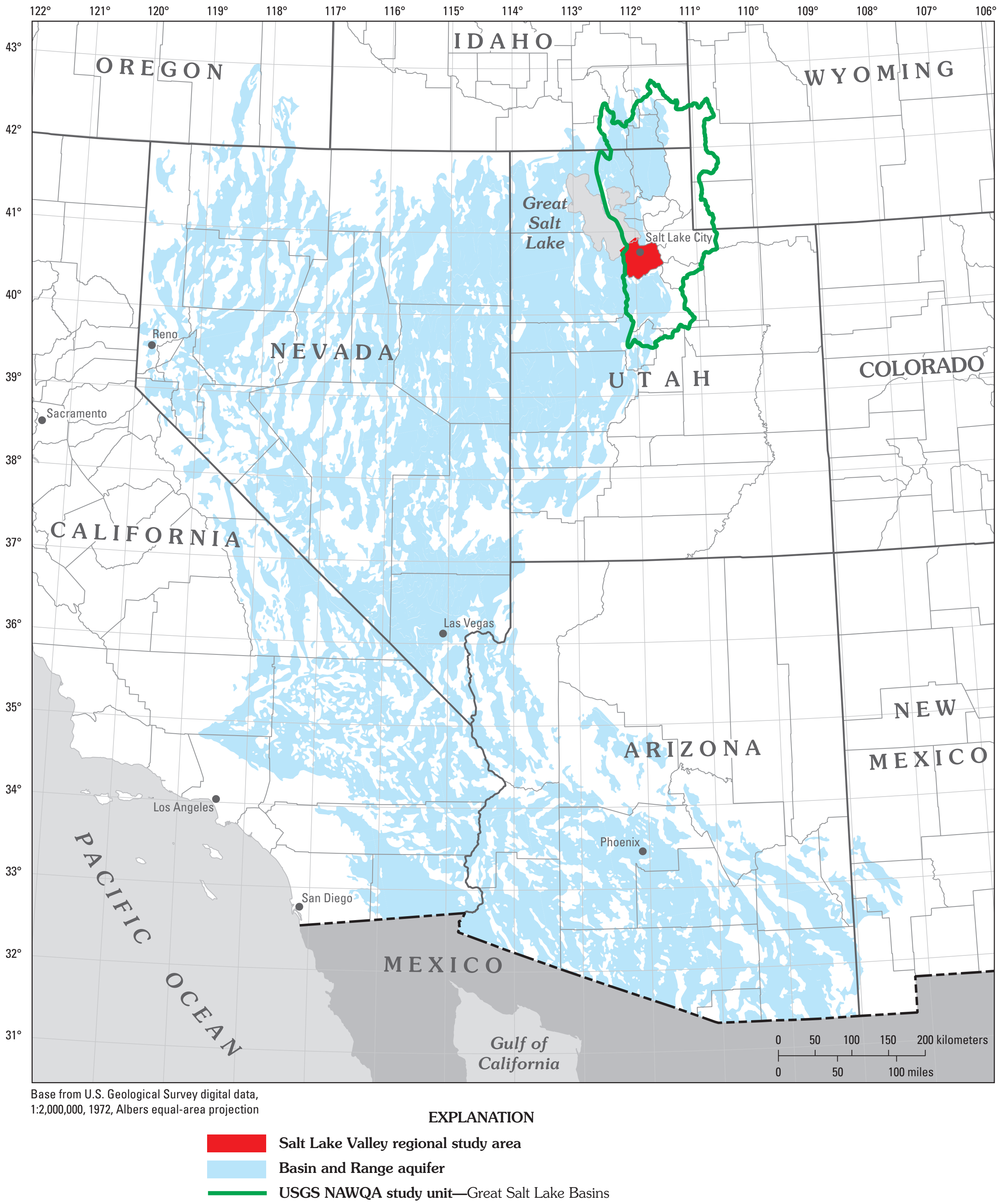


Figure 2.1. Location of the Salt Lake Valley regional study area within the Basin and Range basin-fill aquifers.

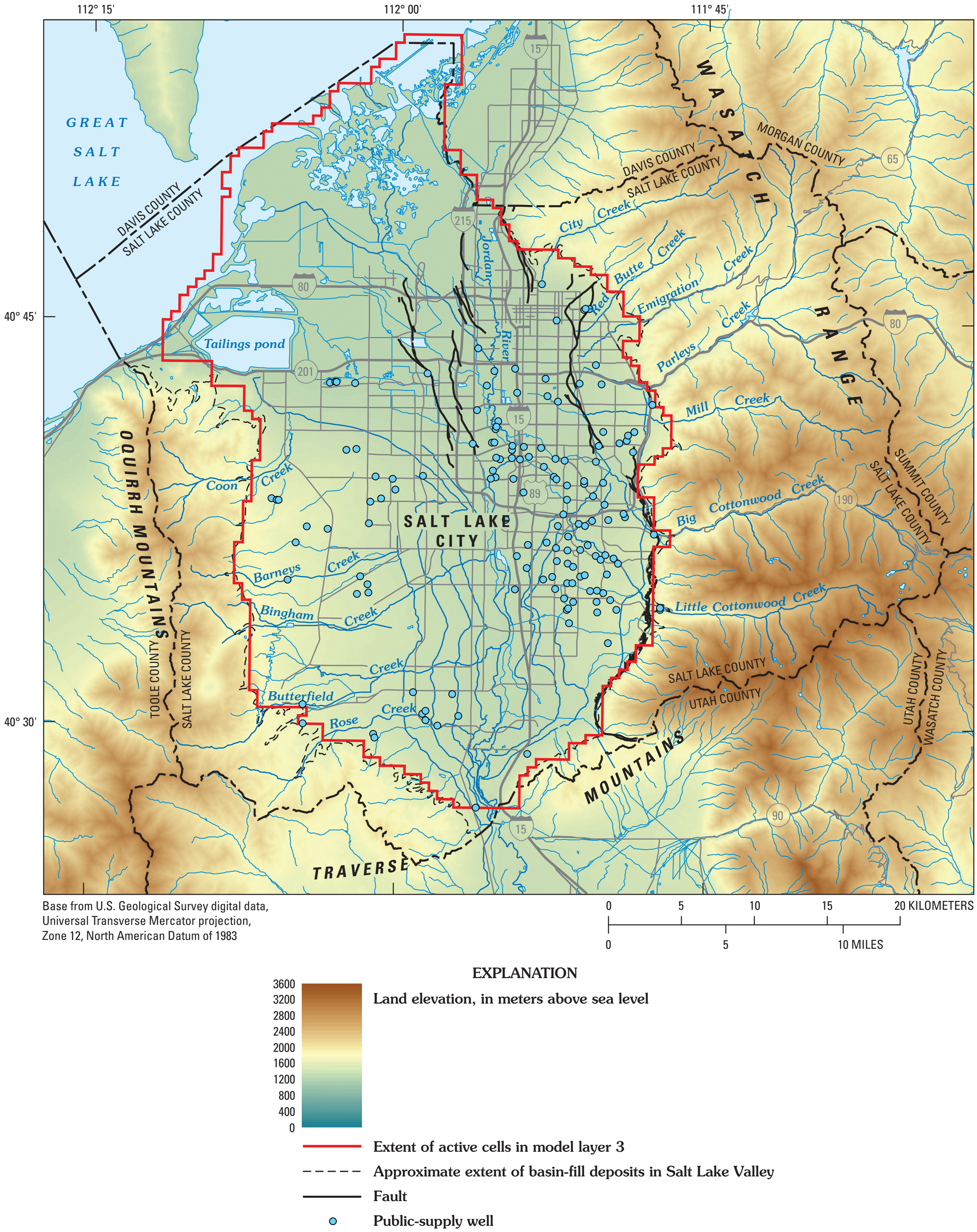


Figure 2.2. Topography, hydrologic features, and location of public-supply wells, Salt Lake Valley regional study area, Utah.

Study Area Description

The Salt Lake Valley regional study area is located in the Basin and Range basin-fill aquifers, which are ranked fourth in total water use of the 62 principal aquifers in the United States (Maupin and Barber, 2005). The Salt Lake Valley regional study area is representative of the Basin and Range basin-fill aquifers (table 2.1) with ground water occurring in the basin-fill deposits of the valley.

Table 2.1. Summary of hydrogeologic and ground-water-quality characteristics for the Basin and Range basin-fill aquifers and the Salt Lake Valley regional study area, Utah.

[m, meters; cm/yr, centimeters per year; hm^3/yr; cubic hectometers per year; m^2/d, squared meters per day; m^3/d, cubic meters per day; m/d, meters per day; ET, evapotranspiration; mg/L, milligrams per liter]

Characteristic	Basin and Range basin-fill aquifers	Salt Lake Valley regional study area
	Geography	
Topography	Altitude ranges from about 46m at Yuma, Arizona to over 3,048 m at the crest of some mountain ranges (Robson and Banta, 1995).	Valley floor altitude slopes from 1,280 m near Great Salt Lake to about 1,580 m on the foothills of Wasatch and Oquirrh Mountains.
Climate	Arid to semi-arid climate. Precipitation ranges from 10 to 20 cm/yr in basins and 40 to 76 cm/yr in mountains (Robson and Banta, 1995).	Semi-arid climate. Precipitation in valley ranges from 30 cm/yr to almost 50 cm/yr. Precipitation exceeds 130 cm/yr in surrounding mountains.
Surface-water hydrology	Streams drain from surrounding mountains into basins. Basins generally slope toward a central depression with a main drainage that is dry most of the time. Many basins have playas in their lowest depressions. Ground-water discharge to streams can occur in basin depressions. (Planert and Williams, 1995)	Jordan River is the major stream in Salt Lake Valley with tributaries originating in the Wasatch Mountains. Diversions on Jordon River supply irrigation water. Small streams originating in Oquirrh Mountains infiltrate before reaching the Jordan River.
Land use	Undeveloped basins are unused, grazing, and rural residential. Developed basins are urban, suburban and agricultural.	Urban, suburban, rural residential, and agricultural.
Water use	Ground-water withdrawals from wells supply water for agricultural irrigation and municipal use. Population increases since the 1960's have increased the percentage of water being used for municipal supply.	Approximately 70 percent of total water use is from ground water and 30 percent from surface water. Total ground-water withdrawal estimated for 1997–2001 is about 500,000 m^3/d with 30 percent applied to household use and 70 percent applied to lawn and agricultural irrigation.
	Geology	
Surficial geology	Tertiary and Quaternary unconsolidated to moderately consolidated fluvial gravel, sand, silt and clay basin-fill deposits include alluvial fans, flood plain deposits, and playas. (Robson and Banta, 1995; Planert and Williams, 1995)	Tertiary and Quaternary unconsolidated fluvial basin-fill sediments consist of gravel, sand, silt, clay, tuff, and lava interbedded with lacustrine deposits of historical Lake Bonneville.
Bedrock geology	Mountains surrounding basins are composed of Paleozoic to Tertiary bedrock formations. Tertiary volcanic and metamorphic rocks are in general impermeable. Paleozoic and Mesozoic carbonate rocks are cavernous allowing inter-basin flow in some areas. (Robson and Banta, 1995; Planert and Williams, 1995)	Wasatch Mountains east of Salt Lake Valley are composed of Paleozoic and Precambrian quartzites and crystalline rocks. Oquirrh Mountains west of Salt Lake Valley are composed of Tertiary volcanic rocks and associated sulfide mineralization.

Table 2.1. Summary of hydrogeologic and ground-water-quality characteristics for the Basin and Range basin-fill aquifers and the Salt Lake Valley regional study area, Utah.—Continued

[m, meters; cm/yr, centimeters per year; hm^3/yr; cubic hectometers per year; m^2/d, squared meters per day; m^3/d, cubic meters per day; m/d, meters per day; ET, evapotranspiration; mg/L, milligrams per liter]

Characteristic	Basin and Range basin-fill aquifers	Salt Lake Valley regional study area
	Ground-water hydrology	
Aquifer conditions	Unconfined basin-fill aquifers surrounded by relatively impermeable bedrock mountains and foothills. Basin ground-water flow systems are generally isolated and not connected with other basins except in some locations where basins are hydraulically connected via cavernous carbonate bedrock.	Unconfined basin-fill aquifer along basin margins, which transitions to confined basin-fill aquifer under the central and northern parts of Salt Lake Valley because of the shallow confining layer. Confined aquifer is composed of interbedded clays, silts, sands, and gravels. Ground-water flow is from valley margins toward central and northern valley and upward toward discharge area along the Jordan River.
Hydraulic properties	Transmissivity ranges from less than 93 m^2/d to greater than 2,790 m^2/d. In general, alluvial fan deposits near basin margins are more conductive than flood plain and lacustrine deposits near basin centers. (Robson and Banta, 1995; Planert and Williams, 1995)	Transmissivity ranges from less than 930 m^2/d to more than 4,600 m^2/d (Lambert, 1995a). Horizontal hydraulic conductivity ranges from 3.05×10^{-4} to 19.8 m/d (Thiros, 1992). Vertical hydraulic conductivity ranges from 1.6×10^{-5} to 6.1×10^{-3} m/d (Thiros, 1992).
Ground-water budget	Recharge to basin fill deposits is from surface-water runoff in mountains where precipitation is highest. Ground-water discharges naturally as evapotranspiration (ET) to playas and stream channels in basin depressions. Ground-water withdrawal from wells is largest component of discharge from Basin and Range aquifers. (Robson and Banta, 1995)	Recharge to basin fill is from subsurface inflow from surrounding mountains, local precipitation, seepage from streams, and infiltration from irrigation. Discharge is to streams (Jordan River), wells, ET, springs, drains, and the Great Salt Lake.
	Ground-water quality	
	Water quality varies between basins. Dissolved solids can range from less than 500 mg/L to over 35,000 mg/L. Generally, low-dissolved solids, oxic water occurs near recharge areas of basin margins. High-dissolved solids anoxic water occurs with depth or near basin centers and playa lakes (Robson and Banta, 1995; Planert and Williams, 1995).	Dissolved solids are lowest along the eastern basin margins (200 to 500 mg/L) where calcium-bicarbonate type water dominates. Dissolved solids along the western margin ranges from 400 to 1,100 mg/L, and the water type is calcium-sulfate because mountains west of valley are volcanic rocks with sulfide mineralization. Dissolved solids concentrations increase and water type transitions to sodium-chloride from south to north in the valley. Water near valley margins is generally oxic with redox conditions transitioning to anoxic near the valley center.

Topography and Climate

The Salt Lake Valley is almost 1,300 km^2 in area, trends from south to north, and terminates on its northern end at the Great Salt Lake. The Wasatch Range bounds the valley on the east, and the Oquirrh and Traverse Mountains bound the valley on the west-southwest (fig. 2.2). The valley floor slopes gradually up from an elevation of 1,280 m near Great Salt Lake to about 1,580 m on the foothills of the Wasatch Range and Oquirrh and Traverse Mountains. Elevations in the Wasatch Range exceed 3,300 m. The Oquirrh and Traverse Mountains are not as extensive as the Wasatch Range, and the upper elevations are around 2,900 m.

The Salt Lake Valley is classified as semiarid, and average annual precipitation ranges from about 35 cm/yr in the northwest and central parts of Salt Lake Valley to about 60 cm/yr along the foothills of the Wasatch Range (Prism Group, Oregon State University, 2006). Precipitation in the surrounding mountain areas can exceed 130 cm/yr and occurs mainly as snowfall during the winter months. March and April are the wettest months of the year. Average daytime temperatures range from 33.6°C in July to 3.1°C in January.

Surface-Water Hydrology

The major stream in the Salt Lake Valley is the Jordan River (fig. 2.2), which flows north along the axis of the valley and discharges to the Great Salt Lake. Flow in the Jordan River is diverted through seven major canals as it enters the south end of Salt Lake Valley to feed an extensive surface-water irrigation system. The Jordan River has seven major tributaries, all of which originate in the Wasatch Range. Several small streams originate in the Oquirrh and Traverse Mountains but none reach the Jordan River.

Land Use

Land in the Salt Lake Valley was historically used for agriculture, which included grazing, orchards, dry farming, and irrigated cultivation. As population grew and commercial activities increased, agricultural lands have slowly converted to residential and commercial use. The population in Salt Lake Valley more than doubled between 1963 and 2001. As of 2002, land use in the valley is categorized as 39 percent residential, 29 percent commercial/industrial, 21 percent water/riparian/idle, and 11 percent agricultural (Utah Department of Natural Resources, 2003).

Water Use

Most water use in the Salt Lake Valley in 2000 was for domestic purposes. An estimated 30 percent of the domestic water supply goes toward household uses, and about 70 percent of the domestic water supply is used for lawn watering. About 70 percent of the domestic water supply is from surface water, and the remaining 30 percent comes from public-supply wells located throughout the valley (Lawrence Spangler, U.S. Geological Survey, written commun., September 2005) (fig. 2.2).

Conceptual Understanding of the Ground-Water System

The hydrogeology of the Salt Lake Valley has been closely scrutinized since the middle of the 20th century (Marine and Price, 1964; Hely and others, 1971; Waddell and others, 1987; Thiros, 1992 and 1995; and Lambert, 1995a). Those discussions, particularly Lambert (1995a), are paraphrased and summarized in the following sections.

Geology

The ground-water system underlying the Salt Lake Valley exists in unconsolidated and semiconsolidated basin-fill material. The source of basin fill is the surrounding mountains. The depositional basin was created by a downward rotation of the consolidated-rock base of the valley relative to the Wasatch Range. The thickness of the unconsolidated basin fill averages about 600 m and in some places exceeds 1,200 m.

The basin-fill material consists mostly of Tertiary- and Quaternary-age clay, silt, sand, gravel, tuff, and lava. The depositional history of these sediments is extremely complex (Marine and Price, 1964). In the late Pleistocene (10,000 to 25,000 years ago), changes in regional climate and topography created conditions that led to numerous cycles of inundation and subsequent desiccation of the Salt Lake Valley by a series of ancient lakes. The most extensive and recent ancient lake was Lake Bonneville. As the valley filled with water, lacustrine and deltaic depositional mechanisms dominated. As lakes dried, these sediments were reworked and redeposited by stream erosion. Previously inundated areas were eroded and received stream-channel and flood-plain deposits. Alluvial fans formed along the mountain fronts at canyon mouths; glacial and mud-rock flow deposits also were laid down at the valley margins. As lakes reappeared and filled the valley, lacustrine deposition again predominated. These cyclic changes in the depositional environment resulted in the interlayered lacustrine, alluvial, and glacial sediments that compose the basin fill. Generally, coarse-grained sediments are common near the mountains, and finer grained sediments are dominant in the low-lying areas in the central and northern parts of the valley.

The consolidated rock of the Wasatch Range consists mainly of Precambrian and Paleozoic quartzites, tillites, and carbonates. Where the range borders the southeastern Salt Lake Valley, the consolidated rock is Tertiary-age quartz monzonite. The Oquirrh and Traverse Mountains consist of Paleozoic-age quartzite and limestone. Volcanism occurred during the Oligocene Period and resulted in sulfide mineralization.

Ground-Water Occurrence and Flow

A generalized conceptual model of the saturated basin-fill material consists of (1) a confined aquifer underlying the central and northern parts of the Salt Lake Valley that transitions to unconfined conditions along the margins of the valley (hereinafter called the basin-fill aquifer), (2) a shallow confining layer that overlies the basin-fill aquifer in the center of the valley, and (3) shallow, unconfined ground water above the shallow confining layer (fig. 2.3). The basin-fill aquifer is composed of interbedded clay, silt, sand, and gravel and exists within the discontinuous and interconnected lenses of sand and gravel. The confining layer is composed of finer grained, lower permeability materials than the underlying basin-fill aquifer. The top of the shallow confining layer generally lies within 30 m of land surface. Along the margins of the valley, the higher energy depositional environment deposited coarse-grained sediment, and the ground-water system in these areas is conceptualized as a single, deeper unconfined aquifer without vertical stratification. Ground water is withdrawn from wells completed in both the confined basin-fill aquifer beneath the shallow confining layer and the unconfined basin-fill aquifer near the margins of the valley.

The Salt Lake Valley basin-fill aquifer exists primarily in the Quaternary-age basin-fill material that ranges from 0 to 600 m thick. Quaternary-age material generally overlies relatively impermeable, semiconsolidated sediments of Tertiary and pre-Tertiary age (Arnow and others, 1970, p. D257). In scattered areas, the Tertiary-age basin fill is more permeable and yields small amounts of ground water to wells. Where the Tertiary-age sediments yield water, they are considered part of the basin-fill aquifer.

Ground water flows laterally from the primary recharge areas at the valley margins to the center and northern parts of the valley (fig. 2.4). An upward gradient is established between the confined aquifer and the unconfined aquifer as water moves laterally beneath the confining layer. In the central part of the valley, ground water flows upward in the confined aquifer, through the overlying confining layer and into the shallow unconfined aquifer. From the shallow unconfined aquifer, water discharges primarily into the Jordan River, to drains, and is used by riparian vegetation, or evaporates at land surface. Ground water along the valley margins is generally 30

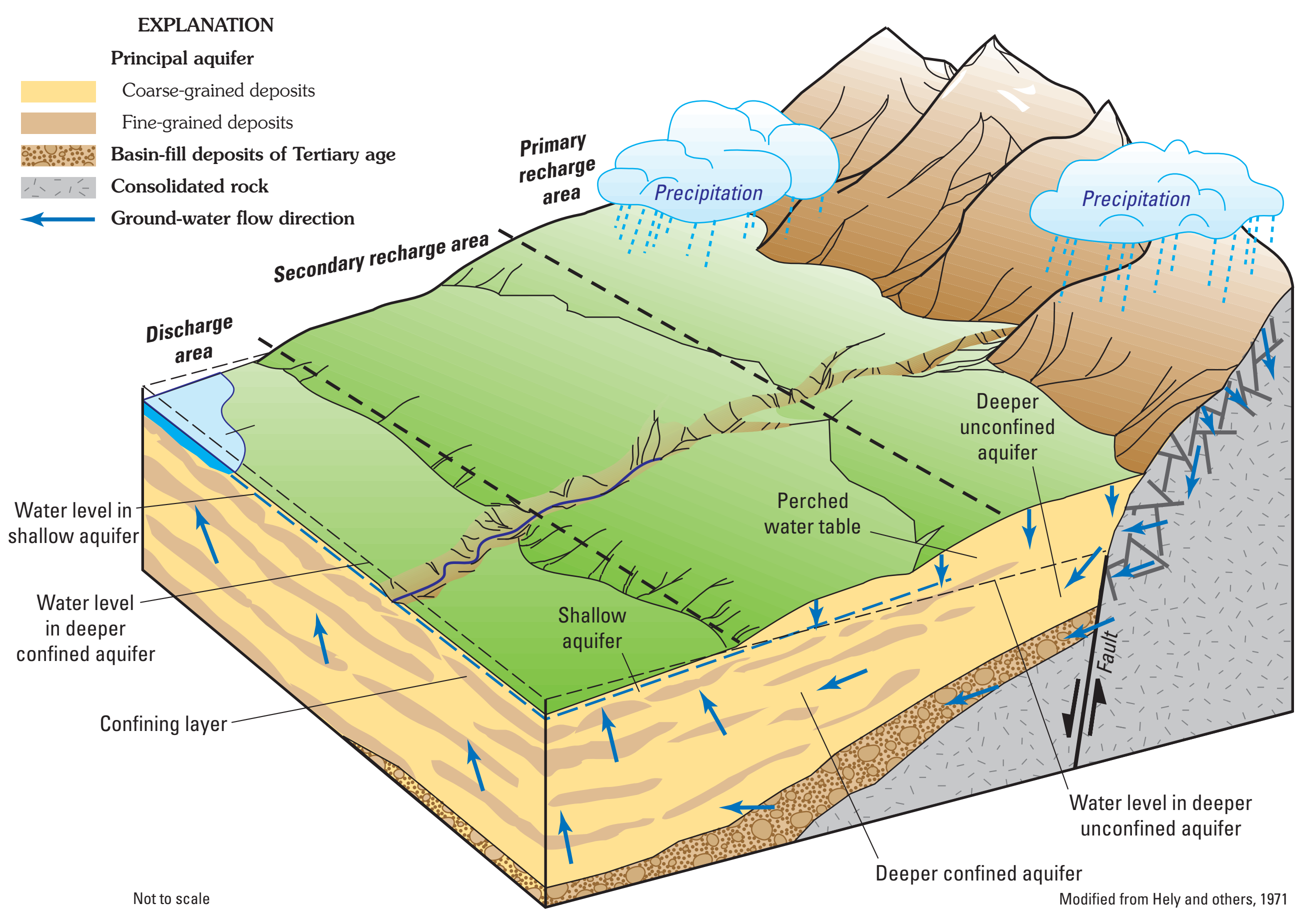
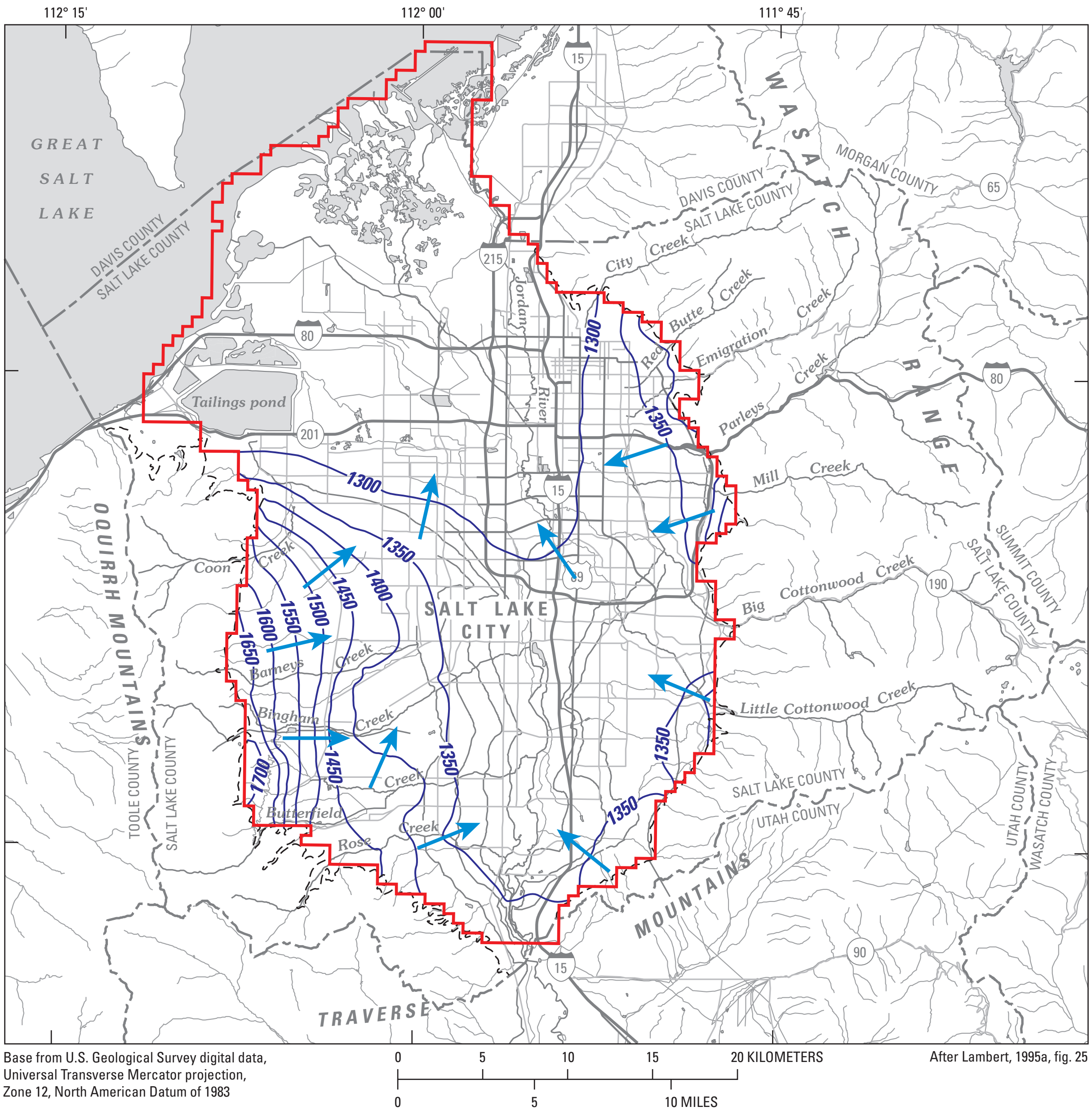


Figure 2.3. Basin-fill ground-water flow system, Salt Lake Valley regional study area, Utah.



EXPLANATION

— 1350 — **Potentiometric contour**—Model-computed line of equal steady-state potentiometric surface, in meters. Contour interval is 50 meters. Datum is sea level

Approximate direction of horizontal ground-water flow

Extent of active cells in model layer 3

Approximate extent of basin-fill deposits in Salt Lake Valley

Figure 2.4. Elevation of model-computed basin-fill aquifer potentiometric surface for 1997–2001 average conditions, Salt Lake Valley regional study area, Utah.

to 100 m below land surface. In the central and northern areas, water levels are usually 3 to 6 m below land surface.

Aquifer Hydraulic Properties

Hydraulic properties of aquifer materials were determined using a number of standard techniques that include (1) ground-water gradients and discharge, (2) slug tests, (3) laboratory testing of core samples, (4) aquifer tests, and (5) specific-capacity data. Generally, these methods test only small intervals and volumes of the aquifer, and quantification commonly produces results that vary over several orders of magnitude. This range of aquifer hydraulic properties is not surprising and reflects the complex depositional history of the Salt Lake Valley.

Horizontal hydraulic conductivity for the shallow unconfined aquifer is estimated to range from 9.1×10^{-4} to 19.8 m/d (Thiros, 1995), and horizontal hydraulic conductivity for the confining layer is estimated to range from 1.2×10^{-4} to 0.7 m/d (S.A. Thiros, U.S. Geological Survey, written commun., 1993). Vertical hydraulic conductivity of the shallow confining layer ranges from 1.6×10^{-5} to 0.3 m/d (Hely and others, 1971; Waddell and others, 1987; Thiros, 1992; Thiros, 1995). Transmissivity of the basin-fill aquifer is estimated to range from less than 930 to more than 4,600 m^2/d (Lambert, 1995a). Hydraulic conductivity, which equals transmissivity divided by saturated thickness of the aquifer, was given an upper limit of 70 m/d on the basis of reported hydrologic properties for aquifers of the Basin and Range Province (Bedinger and others, 1986). Vertical hydraulic conductivity of the basin-fill aquifer is estimated to range from 0.003 to 1.5 m/d (Lambert, 1995a, p. 17 and fig. 8).

Storage-coefficient values in confined zones of the Salt Lake Valley are estimated to range from 1×10^{-3} to less than 1×10^{-4} (Hely and others, 1971). The range of probable storage-coefficient values for confined zones of the basin-fill aquifer was assumed also to apply to the storage-coefficient value of the shallow confining layer. Hely and others (1971) estimated that specific yield of the shallow unconfined aquifer ranges from 0.10 to 0.20 and that specific yield of unconfined basin-fill aquifer near the basin margins has an upper limit of 0.3.

Water Budget

Recharge to the ground-water system in the Salt Lake Valley is primarily from (1) subsurface inflow from consolidated rock at the margins of the valley; (2) infiltration of precipitation on the valley floor; (3) seepage from streams and canals; and (4) infiltration from commercial crop fields, lawns, and gardens. Discharge occurs to (1) streams and canals, (2) pumping and flowing wells, (3) evapotranspiration, (4) springs, (5) drains, and (5) Great Salt Lake. Recharge and discharge quantities were originally estimated by Hely and others (1971) for conditions during 1964 through 1968. Since then, components of the water budget have been reevaluated because of additional data collection and interpretation (Herbert and others, 1985; Waddell and others, 1987; Lambert, 1995a). The conceptual water budget presented here is a combination of previously estimated water budgets and scaling of water-budget components determined from the 1969–91 transient ground-water flow model calibration (Lambert, 1995a, p. 21) to 1997–2001 conditions on the basis of precipitation and streamflow ratios. Given the various timeframes, the complexity of the ground-water system, and the density of available data, individual components of the budget are probably only accurate to within +/– 25 percent. Conceding these limitations, the conceptual budget described here is presented as a 1997–2001 average and is considered a steady-state portrayal because ground-water pumping rates and climatic conditions were relatively stable for the time period.

Recharge

The movement of ground water from the fractures, joints, and pore space of the mountain block into the adjacent basin fill (mountain-block recharge) recharges the aquifer at an estimated rate of approximately 402,000 m^3/d for 1997–2001. This rate was computed using a long-term average water balance for the mountains and measured hydraulic gradients at the margins of the valley. It is scaled to 1997–2001 conditions by using the ratio of 1997–2001 average Wasatch Range precipitation to the long-term average Wasatch Range precipitation. Inflow is distributed along the mountain front on the basis of the inferred relative permeability of the different consolidated rock units (Hely and others, 1971, table 21; Waddell and others, 1987, table 1).

Recharge from infiltration of precipitation on the valley floor was estimated to be about 257,000 m^3/d for 1997–2001. The 1997–2001 recharge rate is scaled from a long-term estimate by using the ratio of average 1997–2001 precipitation rate to the long-term precipitation rate in the Salt Lake Valley. The long-term estimate was derived by subtracting the sum of surface runoff and precipitation consumed by evapotranspiration from the total precipitation falling on the valley (Hely and others, 1971, table 21; Waddell and others, 1987, table 1; Lambert, 1995a, table 5).

Mountain-front recharge occurs where mountain streams enter the Salt Lake Valley and lose surface water to the coarser grained basin-fill material at the canyon mouths. Ground water moving laterally through the channel fill beneath the streams (underflow) also contributes recharge to adjoining basin-fill material at canyon mouths. In addition, recharge from underflow occurs where the Jordan River enters the southern end of the Salt Lake Valley. On the basis of data collected by Hely and others (1971, p. 123 and table 5) and modifications by Lambert (1995a, table 5), the annual recharge rate from streams and underflow for 1997–2001 is estimated to be about 60,800 m^3/d. Surface-water seepage losses were established from data collected at multiple streamflow-gaging stations on individual streams. Estimates of underflow were determined using Darcy's law. In addition to streams, there is also seepage from the major irrigation canals in the valley. On the basis of gain/loss measurements made in 1983 (Herbert and others, 1985), recharge from the canals is estimated at about 94,500 m^3/d. Total recharge from streams and canals is estimated as 155,300 m^3/d.

Infiltration from agricultural irrigation return flow during 1997–2001 was estimated to be about 108,000 m^3/d on the basis of historical estimates (Hely and others, 1971, p. 126) and modifications by Lambert (1995a, p. 37). Infiltration from irrigation of lawns and gardens is estimated to be about 33,700 m^3/d (Lambert, 1995a, p. 33). Historical estimates (Hely and others, 1971) assumed recharge rates that were about 30 percent of the applied irrigation water and were based on generalized field-application efficiency rates and a series of site-specific farm studies. The more recent recharge estimates are close to 15 percent of the applied irrigation water (Lambert, 1995a).

Discharge

The largest component of natural discharge from the aquifer system in the Salt Lake Valley is seepage to the Jordan River and the lower reaches of its principal tributaries. Based on records from an extensive streamflow-gaging network, Hely and others (1971, p. 83 and 136) estimated annual ground-water discharge from the confined part of the basin-fill aquifer to the Jordan River and its tributaries to be 500,000 m^3/d. The average rate of ground-water discharge to canals in the valley is estimated as 33,700 m^3/d and is based on gain/loss measurements made by Herbert and others (1985) and adjusted to average climatic conditions by Waddell and others (1987, p. 27). The relation between the aquifer and streams/canals in the central parts of the valley has been fairly stable over time, and the previous analysis of discharge is likely a reasonable estimate of discharge for 1997–2001.

Ground water is withdrawn from wells in the Salt Lake Valley for the purposes of public supply, irrigation, industrial, and domestic/stock uses. The average withdrawal for all these purposes for 1997–2001 is estimated as 500,000 m^3/d for the Salt Lake Valley regional study area. Withdrawals for public-supply, irrigation, and industrial uses is estimated as about 399,000 m^3/d and is based on annual withdrawal compilations made by the U.S. Geological Survey. The remaining withdrawals, 101,000 m^3/d, are from thousands of small domestic and stock wells scattered throughout the valley and were estimated by Hely and others (1971, p. 140) for the period 1964–68. The domestic/stock withdrawal estimate for 1964-1968 also was used for the period 1997–2001 because it was beyond the scope of this study to inventory all domestic and stock wells in the valley. Some verification of the domestic/stock withdrawals was made in 1992 by examining the number of recorded water rights for domestic and stock uses (Utah Department of Natural Resources, Division of Water Rights, written commun., 1992) and results indicate that the 1964–68 estimate is reasonable for 1997–2001.

Initial estimates of evapotranspiration in the Salt Lake Valley were based on the assumption that evapotranspiration occurred in areas where the average depth to ground water is less than 5 m (Hely and others, 1971, p. 179). To determine an evapotranspiration rate, the area of shallow ground water was divided into five major land categories: bare ground, cultivated land, urban land, waterfowl-management land, and areas of phreatophytes. The phreatophyte area was further subdivided by plant group. Each land category and plant group was assigned a maximum evapotranspiration rate (Hely and others, 1971, p. 179; Blaney and Criddle, 1962). The multiplication of area and rate (adjusted to compensate for an average depth to ground water) resulted in an evapotranspiration rate of 203,000 m^3/d for 1964–1968. Revised evapotranspiration estimates made initially by Waddell and others (1987, p. 29), and later by Lambert (1995a, p. 36), resulted in evapotranspiration rates about 40 percent less than that presumed by Hely and others (1971). The revised evapotranspiration estimates were made by simulating ground-water flow in the valley-fill aquifer of Salt Lake Valley and matching model-computed and measured water levels for the shallow unconfined portion of the aquifer. On the basis of the last stress period of the transient calibration by Lambert (1995a, p. 37), which incorporates land-use changes in Salt Lake Valley from 1968 to 1991, the average evapotranspiration rate estimated for 1997–2001 is 109,000 m^3/d.

Discharge to springs in the Salt Lake Valley from the basin-fill aquifer was originally estimated by Hely and others (1971) on the basis of springflow water-rights records. For the present modeling study, the 1964–1968 estimates of Hely and others (1971) are used to estimate a spring discharge rate of about 64,110 m^3/d for 1997–2001. The estimate assumes springflows have been relatively stable over time because the springs are located near the valley margins and are generally not affected by pumping.

Ground-water discharge from the shallow unconfined aquifer to surface drains is known to occur near the Great Salt Lake and to buried storm drains in Salt Lake City. Data are available to quantify flow to the surface drains near the Great Salt Lake, and a rate of 17,000 m^3/d was estimated by Hely and others (1971 p. 136). The discharge rate to buried drains in the Salt Lake City area is not known. However, a steady discharge to and from storm drains has been observed by the employees of the Salt Lake City Department of Public Utilities (Charles H. Call, Jr., oral commun., 1992) and is assumed by them to be seepage from shallow ground water. Lambert (1995a) simulated 33,700 m^3/d of discharge to surface and buried drains during steady-state simulation, and for lack of additional information, this is the rate assumed for 1997–2001.

Ground-water discharge to Great Salt Lake has been calculated by applying Darcy's law along an arbitrary line parallel to and near the shore of Great Salt Lake (Mower, 1968, p. D71; Hely and others, 1971, p. 136; and Waddell and others, 1987, p. 29). The average discharge rate from previous computations is about 11,800 m^3/d, and this same rate is assumed for 1997–2001. Discharge to the Great Salt Lake is less than 1 percent of the Salt Lake Valley water budget.

Ground-Water Quality

General ground-water quality in the Salt Lake Valley has identifiable trends along east- west and south-north transects. Dissolved-solids concentrations in ground water are lowest along the margins of the valley where most recharge occurs. Along the eastern margin, dissolved-solids concentrations typically range from 200 to 500 mg/L, and the dominant ions are calcium and bicarbonate. On the western margin, dissolved-solids concentrations are in the range of 400 to 1,100 mg/L, and the dominant ions are calcium, magnesium, and sulfate. The difference in water quality between the eastern and western parts of the valley can be explained by rock type in the recharge source area. Recharge on the eastern valley margin originates in the Wasatch Range, which is predominantly composed of crystalline rock and quartzites, and recharge on the western valley margin originates in the Oquirrh and Traverse mountains, which are predominantly composed of Tertiary-age volcanic rocks and associated sulfide mineralization.

Dissolved-solids concentrations increase and the dominant ions become sodium and chloride as ground water flows from south to north in the Salt Lake Valley. As ground-water residence time increases from south to north, there is more time for ground water to interact with the basin-fill materials and dissolved-solids concentrations increase. Vertically, the best quality water is at intermediate depths within the basin-fill aquifer. Water in the shallow unconfined aquifer and deeper in the basin-fill aquifer have the highest dissolved-solids concentrations.

Oxidation-reduction zones within the Salt Lake Valley (fig. 2.5) have been conceptualized on the basis of recharge and discharge areas using existing water-quality data. The basin-fill aquifer is spatially divided into three areas with respect to recharge/discharge processes (Anderson and others, 1994): (1) the primary recharge area, (2) the secondary recharge area, and (3) the discharge area. These areas are delineated on the basis of lithology reported on drillers' logs and vertical hydraulic-gradient information.

The primary recharge area exists along the valley margins where coarse-grained sediments dominate the basin fill and the vertical hydraulic gradient is downward. Fresh oxygenated water recharges the aquifer in these areas, and ground water is assumed oxygen reducing (oxic). The secondary recharge area occurs where layers of fine-grained sediment are present, but the vertical gradient is still downward. The secondary recharge area is adjacent to and downgradient from the primary recharge area, although a small amount of recharge from land surface does occur. Because ground water in the secondary recharge area has a longer residence time than that in the primary recharge area, the secondary recharge area is conceptualized as a transition zone between oxic and iron-reducing (anoxic) conditions. The discharge zone is defined by extensive fine-grained layering within the aquifer and vertically upward gradients. No recharge occurs in the discharge zone and ground water in these areas has experienced the longest travel and residence times, so it is assumed that all dissolved oxygen has been consumed and ground water is iron-reducing in the discharge zone.

Ground-Water Flow Simulations

The modular ground-water flow simulation code MODFLOW-2000 (Harbaugh and others, 2000) was used to simulate a steady-state condition based on the annual average conditions for the 5-year period from 1997 through 2001. A previously calibrated transient model, which was constructed and calibrated to 1968 steady-state and 1969–91 transient-state conditions by Lambert (1995a), was used by this study to simulate a steady-state stress period representing 1997–2001 average conditions. This study modified specified-flux terms of the Lambert (1995a) model defining (1) inflow from consolidated rock, (2) infiltration of precipitation, (3) inflow from streams, and (4) discharge to pumping wells to reflect 1997–2001 average values. Aquifer parameters of hydraulic conductivity and transmissivity were not recalibrated by this modeling exercise. The steady-state model is considered a reasonable approximation of ground-water flow conditions for 1997–2001 because ground-water pumping rates and climatic conditions were relatively stable for the time period.

Modeled Area and Spatial Discretization

The model grid covers 1,152 km^2 of the Salt Lake Valley and is subdivided into 94 rows, 62 columns (fig. 2.6) and 7 layers. Each model cell represents 0.32 km^2 of surface area. The shallow unconfined aquifer is represented by model layer 1, and the shallow confining layer is represented by model layer 2. The thicknesses of model layers 1 and 2 vary spatially and roughly represent the estimated depth and thickness of the shallow unconfined aquifer and the underlying shallow confining layer, respectively. Layers 1 and 2 are both simulated as convertible between confined and unconfined conditions depending on the elevation of hydraulic head computed by the model. The basin-fill aquifer is simulated by model layers 3 through 7. Layer 3 defines the areal extent of the model domain and is simulated as convertible between confined and unconfined conditions. Model layers 4 to 7 represent deep sediments of the basin-fill aquifer and are simulated as confined. Model layers 3 to 5 are each 46 m thick, and model layer 6 is 61 m thick. Model layer 7 ranges in thickness from 61 m to more than 460 m. The term "vertical column," as used in this report, is the set of model cells with the same row and column index.

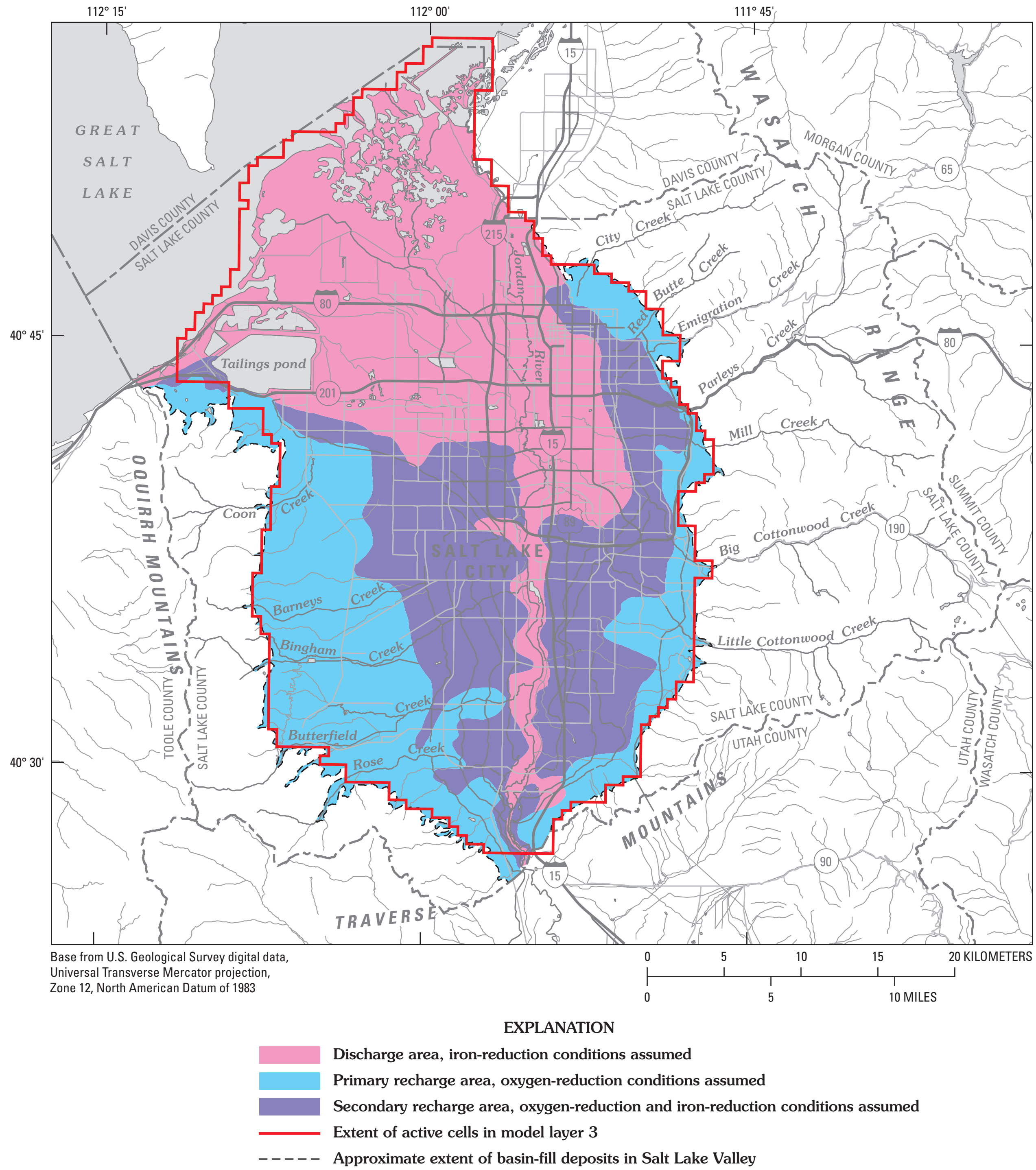
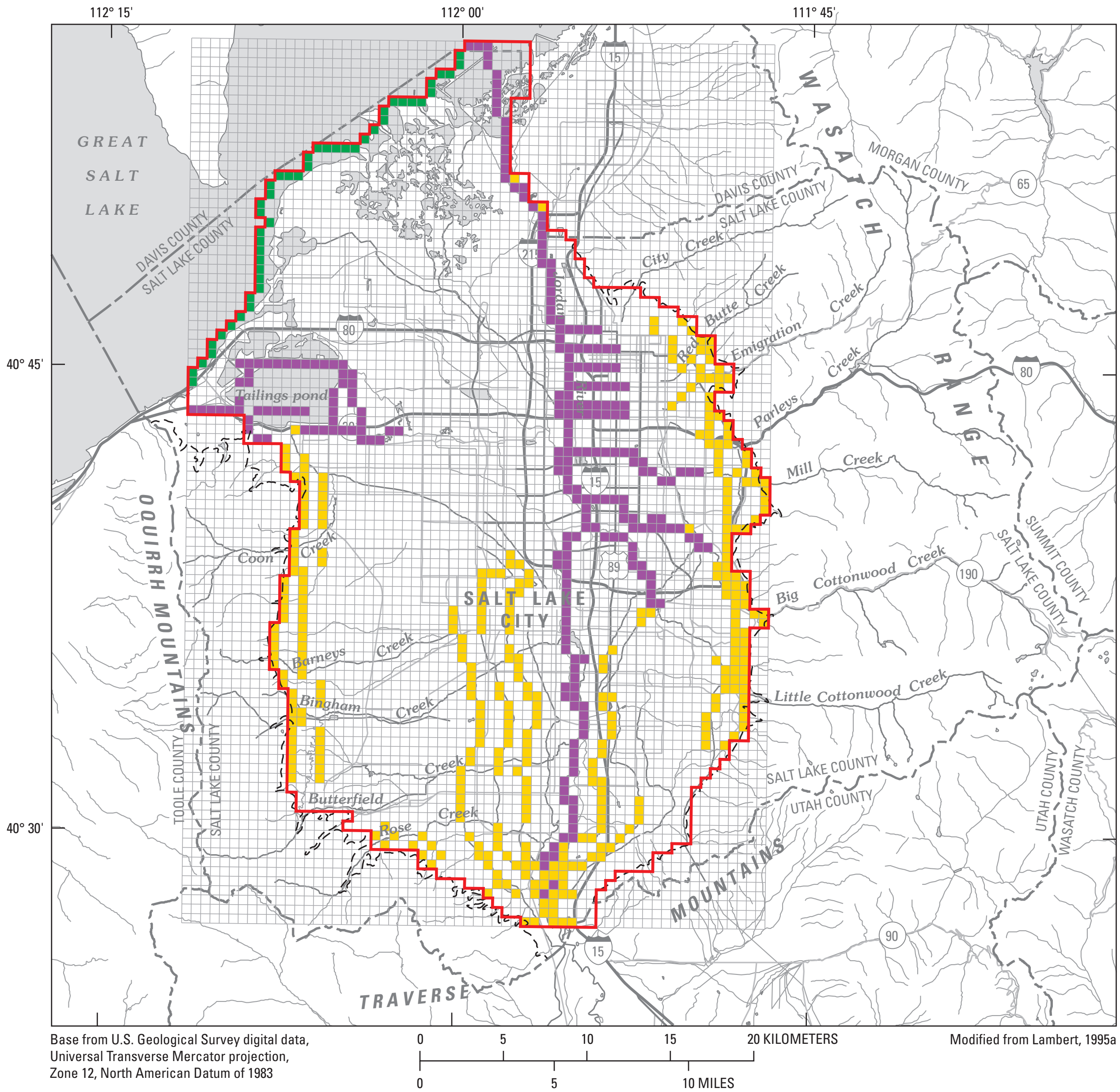


Figure 2.5. Generalized oxidation-reduction classification zones, Salt Lake Valley regional study area, Utah.



EXPLANATION

Head-dependent flux—Used to simulate surface-water/ground-water interaction along streams, mountain-block recharge from the Oquirrh Mountains, and ground-water discharge to drains and springs

Specified-flux boundary—Used to simulate mountain-block recharge, surface-water/ground-water interaction along streams and canals, and discharge from springs

Constant-head cells along Great Salt Lake

Model grid

Extent of active cells in model layer 3

Approximate extent of basin-fill deposits in Salt Lake Valley

Figure 2.6. Ground-water flow model grid and selected boundary conditions, Salt Lake Valley regional study area, Utah.

Boundary Conditions and Model Stresses

Boundary conditions assigned to the numerical solution are mathematical equations that represent flow at surface boundaries and internal sources and sinks. Boundary types and the specified amounts of recharge and discharge were assigned to reflect the conceptual analysis of the ground-water flow system (table 2.2). Four distinct boundary types are used to simulate recharge, discharge, and the spatial extent of the Salt Lake Valley ground-water system. They are (1) no flow, (2) specified flux, (3) head-dependent flux, and (4) constant head. A no-flow boundary simulates an impermeable hydrologic boundary. Unless specifically noted, the horizontal and vertical extent of the model domain is set by no-flow boundaries. A specified-flux boundary allows a specified rate of flow across a boundary as a function of location and time. A head-dependent boundary allows the flow rate across the boundary surface to change in response to changes in water level in the aquifer adjacent to the boundary. Constant-head boundaries fix the water level in a cell, and flows to or from adjacent cells are computed on the basis of that water level.

No-flow boundaries are assigned at the base of the modeled area. The base corresponds to the contact between consolidated rock of pre-Tertiary age and basin-fill material or to a depth within the basin fill below which sediments were assumed not to contribute substantially to the basin-fill ground-water flow system. The northern border of the modeled area approximates a flow line and was treated as a no-flow boundary.

Recharge

Mountain-block recharge from the consolidated rock of the Wasatch Range and the Oquirrh Mountains is simulated using specified-flux cells with the MODFLOW Well package placed at the lateral edges of the model domain in layers 3 or 4 (Lambert, 1995a, fig. 9; fig. 6). Some mountain-block recharge occurs at the northern end of the Oquirrh Mountains, and that portion is simulated using MODFLOW General-head cells (Lambert, 1995a, fig. 15). The amount of specified flow from mountain-block recharge, which is the conceptualized amount minus the Oquirrh Mountains inflow, is set at 401,918 m^3/d (table 2.2).

Recharge from precipitation on the valley floor is simulated as a specified flux using the MODFLOW Recharge package over the entire modeled area except in areas of dense commercial and residential development (Lambert, 1995a). In dense commercial and residential areas, it is assumed that precipitation was collected as runoff in drain systems and routed directly to surface-water bodies. The total simulated amount of precipitation recharge (256,712 m^3/d) is adjusted from the conceptualized amount of precipitation recharge (257,000 m^3/d) to account for the dense commercial and residential area. The MODFLOW Recharge package applies recharge to the uppermost active cells in a vertical column of cells. The total recharge is spatially distributed across the model grid on the basis of mean annual precipitation isohyets (Hely and others, 1971).

Specified-flux cells using the MODFLOW Recharge package also are used to simulate mountain-front recharge from streams at and near where they enter the Salt Lake Valley from the mountains (Lambert, 1995a, fig. 12) and underflow recharge through stream-channel fill where the Jordan River enters the Salt Lake Valley. The boundaries are placed in the uppermost active cell of the model grid that corresponds to the location of the stream. This recharge encompasses the major streams that flow out of the Wasatch Range. Simulated recharge from the streams draining the Wasatch Range is 54,000 m^3/d, and lateral subsurface flow associated with the Jordan River is set at 6,850 m^3/d. Recharge from the five canals that traverse the west and east sides of the valley is simulated using the MODFLOW Well package to specify flux. Ground-water recharge from canals is simulated approximately 94,500 m^3/d.

Recharge from irrigation of fields, lawns, and gardens is simulated as a specified flux using the MODFLOW Recharge package. The cells where the recharge is applied correspond either to irrigated land use or residential land use (lawns and gardens). Recharge was distributed on the basis of the percentage of cell area that represents irrigated fields or residential land and the irrigation recharge is added to the precipitation recharge. The recharge amount for commercial fields is about 108,200 m^3/d (19.5 cm/yr), and for residential areas the rate is about 33,700 m^3/d (5.5 cm/yr) (Lambert, 1995a, p. 33 and 42).

Discharge

Discharge to streams is simulated as head-dependent boundaries using the MODFLOW River package along the length of the Jordan River and the lower reaches of three of the Wasatch Range streams (Lambert, 1995a, fig. 15; fig. 6). The boundary cells are in model layer 1 and follow the course of the streams. Riverbed altitude and length were determined from 1:24,000 U.S. Geological Survey topographic maps. Riverbed width and thickness were not measured; it was assumed that the riverbed thickness is one tenth of the riverbed width. Hydraulic conductivities of the riverbed range from 0.03 to 3.0 m/d and were determined during model calibration (Lambert, 1995a).

Discharge to canals is simulated as a specified flux using the MODFLOW Well package for four of the major canals in the Salt Lake Valley where ground-water discharge has been measured (Herbert and others, 1985). The boundaries are in the uppermost active cell of the vertical columns that correspond to the canal locations (Lambert, 1995a, fig. 12).

Public-supply, irrigation, and industrial wells that withdrew more than 170 m^3/d for the period 1997–2001 are simulated in the ground-water flow model. The wells are simulated as specified-flux cells using the MODFLOW Well package located in model cells corresponding to actual well locations.

Discharge is disseminated vertically to the appropriate model layer on the basis of well depth and the depth of well-casing perforations (Lambert, 1995a, p. 27). All simulated wells withdraw water from model layers 3 to 7. The discharge quantity associated with individual wells is based on annual-withdrawal data reported by the water user and compiled by the U.S. Geological Survey and the Utah Division of Water Rights. The steady-state model simulates the average withdrawals for 1997–2001, and the total simulated withdrawal in the model is 398,630 m^3/d.

The model also simulates withdrawals from domestic and stock wells. These small-diameter wells are represented as specified-flux cells using the MODFLOW Well package in model layer 3. Areal distribution of withdrawal was determined from individual locations recorded by the Utah Department of Natural Resources, Division of Water Rights (Lambert, 1995a, p. 28). Simulated withdrawals from domestic and stock wells are 101,370 m^3/d.

Evapotranspiration (ET) is simulated as head-dependent flux boundaries using the MODFLOW ET package. The boundary is placed at cells in model layer 1 that correspond to the areas of shallow ground water in the Salt Lake Valley (Lambert, 1995a, fig. 15). The extinction-depth value assigned to the boundary is 4.6 m (Lambert, 1995a). As a generalization, the presence of phreatophytes is limited to areas of the valley where the water table is within 4.6 m of land surface. To capture the variability in water use by different plant species, the evapotranspiration area was subdivided into five major land-use categories. Each category is assigned a maximum evapotranspiration rate. The rate was adjusted to a finalized value during model calibration by Lambert (1995a, p. 36).

Six major freshwater springs exist in the Salt Lake Valley, and they are simulated as specified-flux boundaries using the MODFLOW Well package. The boundaries are assigned to model layer 3 and correspond to the locations of the springs (Lambert, 1995a, fig. 12). Total specified spring discharge is 64,110 m^3/d.

Surface drains near Great Salt Lake and buried drains beneath commercial and residential areas in Salt Lake City are simulated using MODFLOW Drain cells placed in model layer 1 at the location of actual drains. Drain altitudes were specified to be 3.0 m less than land-surface altitude. Drain conductance was not measured, and initial values were arbitrarily selected. Drain conductance was adjusted during model calibration by Lambert (1995a, p. 36) to simulate a conceptually reasonable amount of ground-water discharge (23,562 m^3/d).

The hydrologic connection between the basin-fill aquifers and Great Salt Lake is simulated with a constant-head boundary (fig. 2.6). The boundary is in model layer 1 along the northwestern border of the model domain at cells that represent the shore of Great Salt Lake (Lambert, 1995a, fig. 15). The water level assigned to the constant-head boundary is 1,280 m, which is the approximate average historical water level of the lake.

Table 2.2. Model-computed water budget for 1997–2001 average conditions, Salt Lake Valley regional study area, Utah.

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

Water-budget component	Specified flow (m^3/d)	Computed flow (m^3/d)	Total flow (m^3/d)	Percentage of inflow or outflow
Model inflow (recharge)				
Mountain-block recharge	401,918	40,548	442,466	43.8
Precipitation	256,712		256,712	25.4
Irrigation return flow	141,918		141,918	14.1
Mountain-front recharge, rivers, and canals	155,342	13,425	168,767	16.7
TOTAL INFLOW			**1,009,863**	**100**
Model outflow (discharge)				
Jordan River		287,123	287,123	28.3
Wells				
Public supply, irrigation, and industrial	398,630		398,630	39.4
Domestic and stock	101,370		101,370	10.0
Evapotranspiration		104,658	104,658	10.3
Springs and drains	64,110	23,562	87,671	8.7
Canals	30,411		30,411	3.0
Great Salt Lake		3,288	3,288	0.3
TOTAL OUTFLOW			**1,013,151**	**100**

Model Calibration and Sensitivity

The model used to simulate the average conditions for 1997–2001 was calibrated to 1968 steady-state and 1969–91 transient conditions by Lambert (1995a). The model was calibrated by manually adjusting calibration variables (primarily transmissivity) within a prescribed range until a reasonable match between model-computed and observed conditions was achieved. A complete discussion of the calibration process is given in Lambert (1995a). Final values of transmissivity assigned to the basin-fill aquifer by Lambert (1995a) are shown in figure 2.7 and represent the sum of transmissivity values for the basin-fill aquifer (model layers 3 to 7). Calibrated aquifer hydraulic properties presented by Lambert (1995a) were not altered during the present modeling exercise.

As part of the model calibration by Lambert (1995a), a sensitivity analysis was done to determine the response of the model to changes in selected parameters. Calibration parameters were independently adjusted and the effects of these adjustments on simulated water levels and flow rates were noted. Generally, the calibrated model is more sensitive to decreasing parameter values than to increasing values. Specifically, the model is most sensitive to decreasing horizontal hydraulic conductivity in model layer 1; decreasing conductivity caused substantial increases in water levels in model layer 1. The model is relatively insensitive to (1) increasing vertical leakance within model layers 1 to 3, (2) decreasing or increasing vertical leakance within model layers 3 to 7, and (3) increasing riverbed conductance (Lambert, 1995a).

Model-Computed Hydraulic Heads

The ability of the ground-water flow model to simulate the 1997–2001 average conditions was judged by comparing model-computed and measured water levels at 45 wells for the same time period. Measured levels are an average of the February, March, and April 1997–2001 available water-level data for the well. The overall goodness of fit of the model to the observation data was evaluated using summary measures and graphical analyses. The root-mean-squared error (RMSE), the range of head and residuals, the standard deviation, and the standard-mean error of the residuals (SME) were used to evaluate the model calibration. The RMSE is a measure of the variance of the residuals and was calculated as:

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

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

The SME was calculated as:

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

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

A simple method of assessing model fit is to plot the model-computed hydraulic head values against the measured observations. For a perfect fit, all points should fall on the 1:1 diagonal line. Figure 2.8 shows the locations of water-level measurements and the spatial distribution of head residuals and indicates a random spatial distribution of the residuals. A plot of the model-computed heads against the measured hydraulic heads for the Salt Lake Valley regional ground-water flow model (fig. 2.9) indicates reasonable model fit. The mean residual for the entire model is 3.91 m, and residuals range from –18.3 m to 38.4 m. The RMSE for the entire model is 10.7 m, which is about 6 percent of the 183-m range of head observations in the model, and the head residuals appear to be randomly distributed at all values of measured head (fig. 2.10). The standard deviation of the residuals is 10.1 m, and the SME is 1.58 m. The results of these comparisons indicate a reasonable match between model-computed and measured water levels for 1997–2001 average conditions.

Model-Computed Water Budget

The model-computed water budget for 1997–2001 average conditions in the Salt Lake Valley regional study area is presented in table 2.2. Many of the water-budget components simulated by the model were specified values and some components were computed by the model. Mountain-block recharge (43.8 percent of inflow) and recharge from precipitation and irrigation (39.5 percent of inflow) were the primary sources of recharge to the basin-fill aquifer. Recharge from mountain-front recharge, streams, and canals provided the remaining 16.7 percent of ground-water inflow. Discharge to wells (49.4 percent of outflow) and to the Jordan River (28.3 percent of outflow) were the primary ground-water outflows from the Salt Lake Valley. Model-computed ground-water discharge to the Jordan River was less than the conceptual model estimate, but, in general, the model-computed water budget is in reasonable agreement with the conceptual estimates of flow discussed in the Water Budget section of this chapter.

Simulation of Areas Contributing Recharge to Wells

The steady-state regional flow model was used to estimate areas contributing recharge and zones of contribution for 94 wells in the Salt Lake Valley using the MODPATH (Pollock, 1994) particle-tracking post processor and methods outlined in Section 1 of this Professional Paper. The model-computed areas contributing recharge represent advective ground-water flow and do not account for mechanical dispersion. Advection-dispersion transport simulations would likely yield larger areas contributing recharge than advective particle-tracking simulations because the effects of dispersion caused by aquifer heterogeneity would be included.

Along with flux output from the models, the MODPATH simulations require effective porosity values to calculate ground-water flow velocities. An effective porosity value of 0.4 was assigned to model layers 1 and 2, and an effective porosity value of 0.3 was assigned to model layers 3 to 7 based on estimates from Lambert (1995b, p. 21).

The simulated contributing areas can be summarized as long and narrow and truncating at specified-flux boundaries at the edges of the model domain (fig. 2.11). This summarization holds true regardless of the pumping rate at individual wells. The shape of the contributing areas is controlled mainly by the recharge being simulated primarily along the edges of the model domain, which is a direct reflection of the conceptualization of the ground-water system. Truncation of contributing areas at model boundaries indicates mountain-front and mountain-block recharge from the Wasatch Range and Oquirrh Mountains is contributing water to public-supply wells in the Salt Lake Valley.

The simulated median traveltime for water to move from its recharge point to a well ranges from 5 to 780 years based on particle-tracking estimates from MODPATH. The longest traveltimes are associated with contributing areas for wells on the west side of the Salt Lake Valley.

Limitations and Appropriate Use of the Model

The ground-water flow model for the Salt Lake Valley regional study area was designed to evaluate the water budget for 1997–2001 and to delineate areas contributing recharge to public-supply wells. Sources of error in the model may include the steady-state flow assumption and errors in the conceptual model of the system, hydraulic properties, and boundary conditions.

The assumption of steady-state conditions for the Salt Lake Valley regional model is reasonable for the time period of study because sources of recharge and discharge were relatively stable from 1997 to 2001. However, model calibration parameters were taken from an existing model and were not specifically calibrated to match water levels and flow rates during 1997-2001. Further calibration for transient conditions may be needed to accurately represent temporal changes in the system.

Measured water levels, historical water-level changes, and simulated discharge to the Jordan River were not accurately simulated in all areas of the model domain. However, a reasonable match was obtained between simulated and measured hydrologic conditions for the study area.

Sensitivity analysis indicates that increasing vertical hydraulic conductivity relative to calibrated estimates within reasonable limits does not substantially affect model results. Vertical gradients and flows simulated in the model are controlled, in part, by the vertical hydraulic conductivity incorporated in model input. The uncertainty of the final estimates of vertical hydraulic conductivity of the basin fill (and thus, vertical leakance between model layers) should be noted when evaluating simulation results.

The simulation of mountain-block recharge to the basin-fill aquifer is greatly simplified. In the physical system, flow from the consolidated-rock aquifer to the basin-fill aquifer is controlled by the difference in water level between the two aquifers. The head-dependent nature of flow between the two aquifers is not accounted for in the model other than at the northern end of the Oquirrh Mountains. Large declines in basin-fill hydraulic heads near the margins of the valley may increase inflow from consolidated rock, and because the model represents mountain-block recharge using constant-flux boundaries, changes in mountain-block flux resulting from drawdown in the basin fill are not simulated.

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

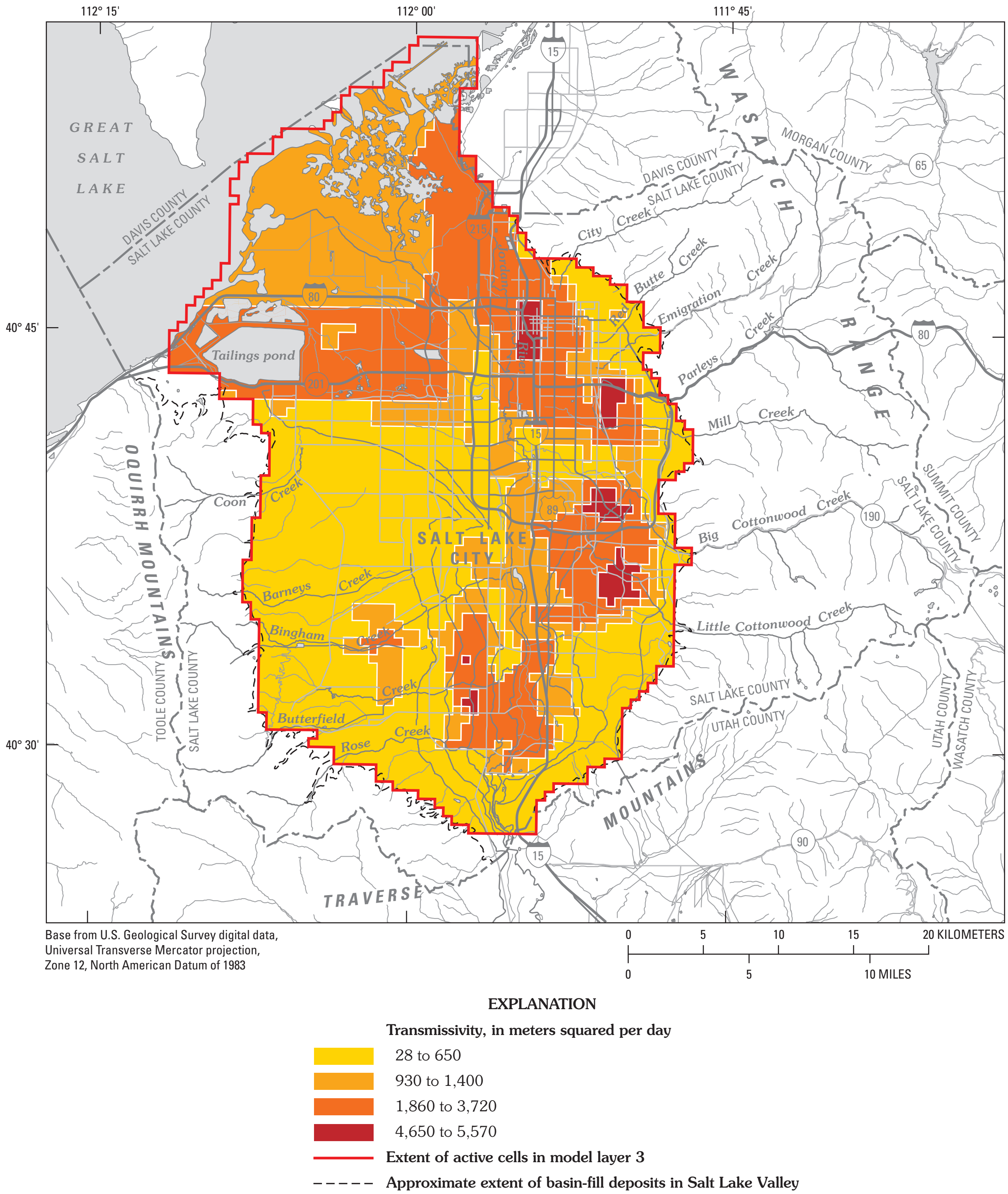


Figure 2.7. Distribution of basin-fill aquifer transmissivity for the calibrated ground-water flow model, Salt Lake Valley regional study area, Utah.

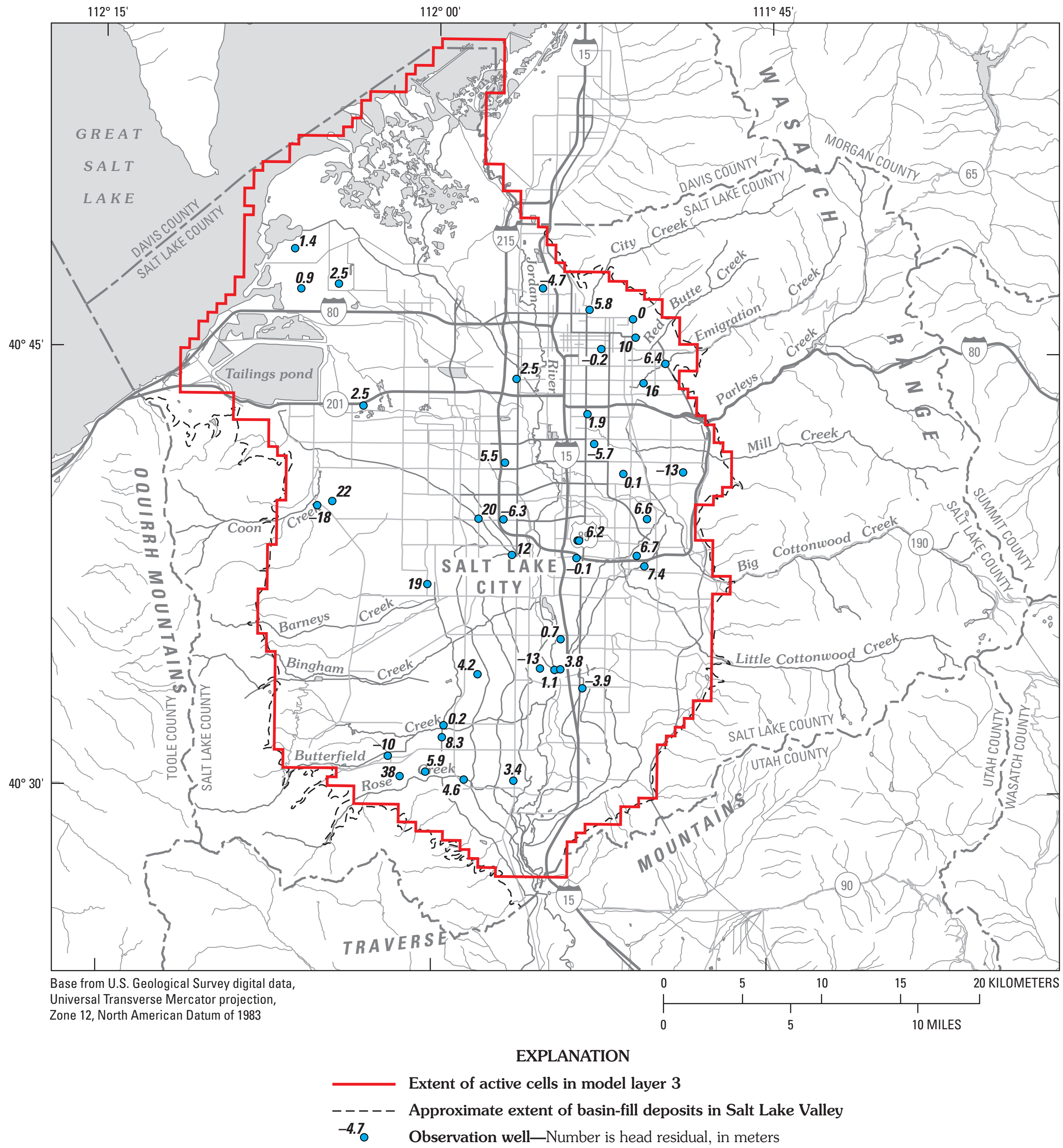


Figure 2.8. Water-level observation well locations and head residuals, Salt Lake Valley regional study area, Utah.

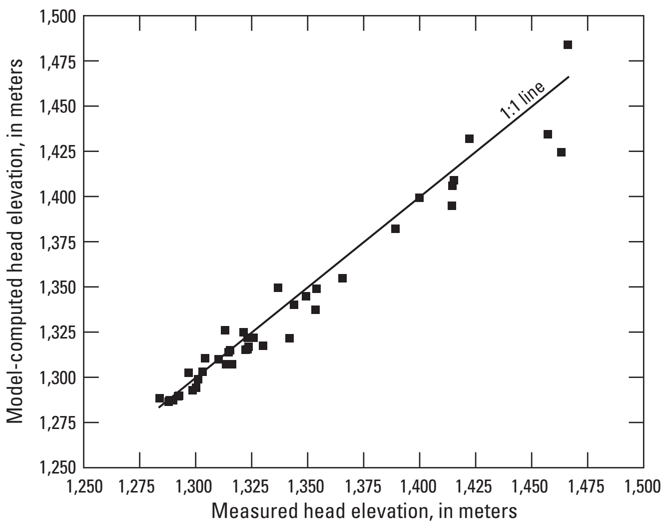


Figure 2.9. Relation between model-computed and measured hydraulic head, Salt Lake Valley regional study area, Utah.

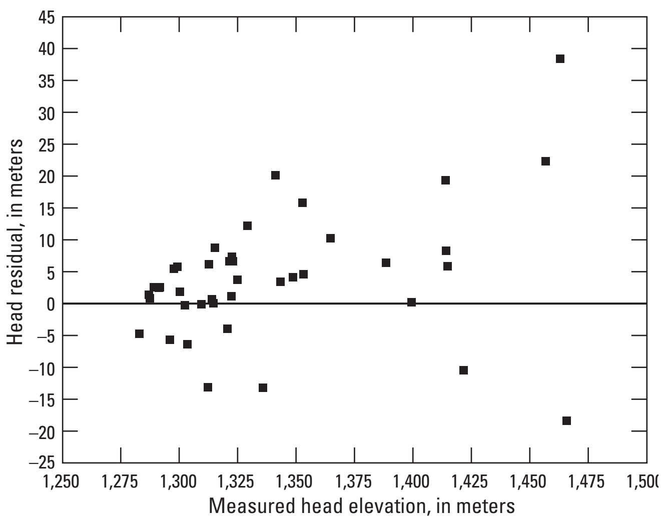
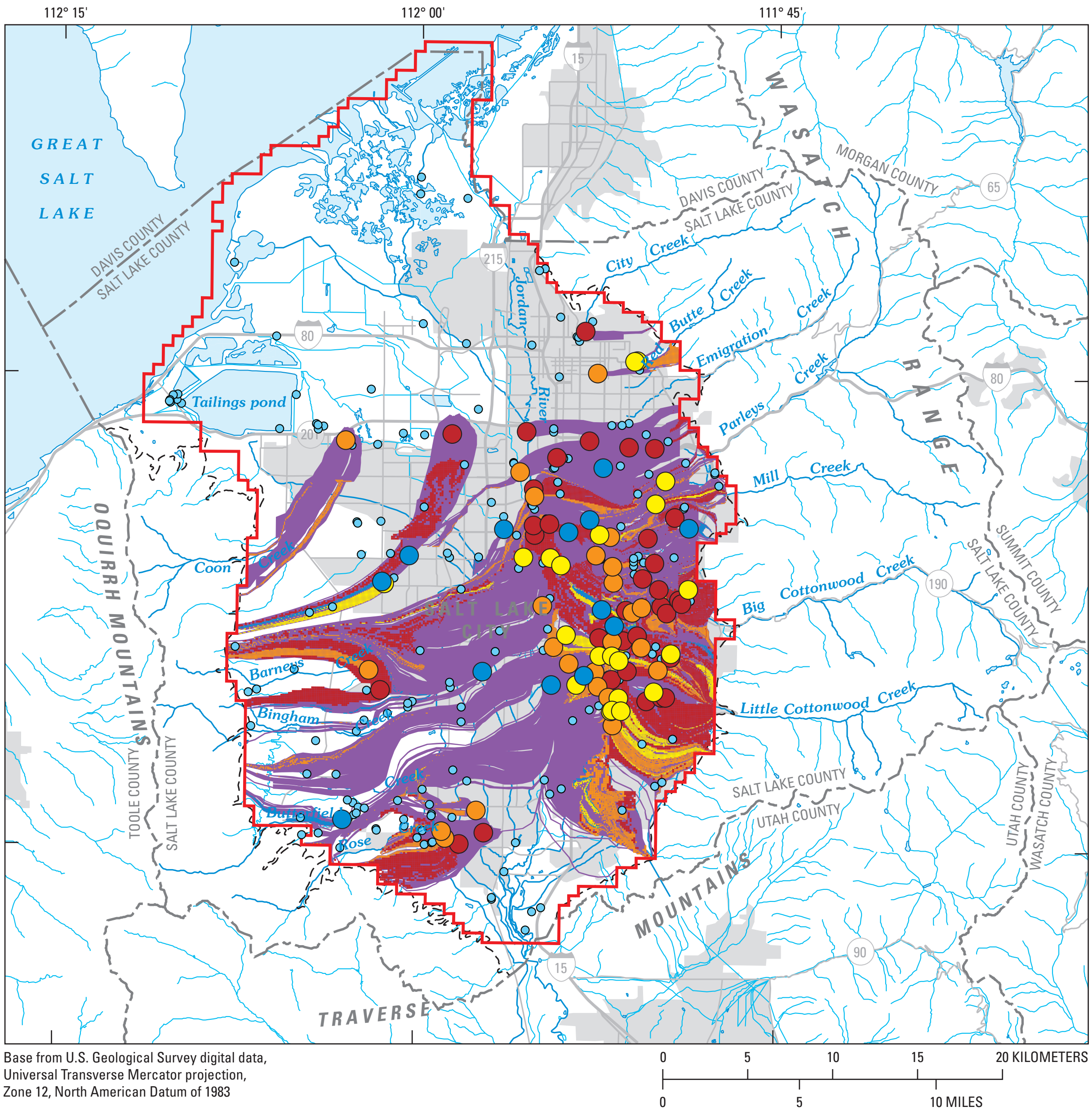


Figure 2.10. Relation between head residual and measured hydraulic head, Salt Lake Valley regional study area, Utah.

The Salt Lake Valley regional ground-water-flow model uses previously calibrated aquifer properties and boundary conditions and provides a reasonable representation of average ground-water flow conditions for 1997–2000. The model is suitable for evaluating regional water budgets and ground-water flow paths in the study area for the time period of interest but may not be suitable for long-term predictive simulations. This regional model provides a useful tool to evaluate aquifer vulnerability at a regional scale, to facilitate comparisons of ground-water traveltime between regional aquifer systems, and to guide future detailed investigations in the study area.



EXPLANATION

Area contributing recharge
- First quartile of pumping (highest 25 percent of pumping rates)
- Second quartile (50 to 75 percent of maximum pumping rate)
- Third quartile (25 to 50 percent of maximum pumping rate)
- Fourth quartile (lowest 25 percent of pumping rates)

Pathlines

Extent of active cells in model layer 3

Urban area

Approximate extent of basin-fill deposits in Salt Lake Valley

Wells with model-computed contributing areas
- First quartile
- Second quartile
- Third quartile
- Fourth quartile

Other wells

Figure 2.11. Model-computed areas contributing recharge to public-supply wells, Salt Lake Valley regional study area, Utah.

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