HYDROGEOLOGY AND SIMULATION OF GROUNDWATER FLOW IN CEDAR VALLEY, UTAH COUNTY, UTAH

by J. Lucy Jordan and Walid W. Sabbah

SPECIAL STUDY 145
UTAH GEOLOGICAL SURVEY
a division of
UTAH DEPARTMENT OF NATURAL RESOURCES
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Cover photo: *Precipitation recharge in the Oquirrh Mountains is the primary source of recharge for Cedar Valley's basin-fill and bedrock aquifers. December 2004.*

ISBN: 978-1-55791-868-0

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UTAH DEPARTMENT OF NATURAL RESOURCES
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ABSTRACT

Development of new domestic water supplies driven by rapid population growth in and around Cedar Valley, Utah County, has prompted the need for a better understanding of the groundwater system in this north-central Utah valley. Water-level, aquifer-test, and water-quality data from this study, along with previously collected data, significantly improve our conceptual model of the Cedar Valley groundwater flow system and provide the framework for a two-layer, three-dimensional digital numerical model of the groundwater flow system.

Cedar Valley is an arid valley typical of the Basin and Range. We delineate four hydrogeologic units in the Cedar Valley study area, which includes Cedar Valley and parts of the surrounding mountain ranges and valleys: (1) an upper clay unit that covers the majority of the valley floor and confines the underlying aquifer, (2) a principal basin-fill aquifer, confined by the clay unit, contained generally in the upper 300 to 400 feet (90–120 m) of the interbedded basin-fill sediments underlying the clay unit, (3) fractured Paleozoic bedrock units combined into one bedrock aquifer, and (4) a small perched basin-fill aquifer at Cedar Pass.

Groundwater quality is generally good under much of the valley except in the southeast and in some wells in Mississippian-age bedrock. Aquifer lithology influences major ion water chemistry; wells in the principal basin-fill and Oquirrh Group bedrock (primarily sandstone and limestone) aquifers generally have the least dissolved solutes and a calcium-bicarbonate type water. Wells near Fairfield have the same recharge source as Fairfield Spring, as shown by their similar water chemistry, despite separation by more than 100 feet (30 m) of clay. From general chemistry, tritium, stable isotope, and carbon-14 water-chemistry data, we conclude that springs and wells on the western margin of the valley contain water that recharged the aquifer in the last 50 years. Wells in the north-central part of the valley contain the oldest water, believed to be a consequence of a long, deep flow path from the surrounding mountain upland. Many wells in the Cedar Pass area, regardless of well depth, contain some fraction of modern water, possibly an indicator that a component of modern recharge is reaching the wells in an otherwise old fractured bedrock flow system. The unique calcium-chloride type water and independent groundwater flow direction in the perched aquifer at Cedar Pass implicates the Traverse Mountains as a recharge source for this small, hydraulically separate aquifer.

The largest recharge source for the basin-fill aquifer is direct infiltration of precipitation in the Oquirrh Mountains and West Canyon Wash drainage basin, which supplies approximately 70% of the recharge to the Cedar Valley aquifer system. Other sources of recharge include precipitation on the East Tintic Mountains, Traverse Mountains, and valley floor; seepage from streams, canals, and the Sinks east of Fairfield; seepage of unused irrigation water; and seepage from septic tanks and wastewater treatment plants. We show that interbasin flow from Rush Valley, west of Cedar Valley, is negligible. Groundwater discharges from Cedar Valley via interbasin flow to northern Utah and Goshen Valleys, well pumping, spring discharge, evapotranspiration, and base flow to West Canyon Creek.

The volume of recharge entering the aquifer at its western margin is the most important control over long-term groundwater levels in the basin-fill aquifer. In turn, that potentiometric head controls Fairfield Spring discharge.

Groundwater in Cedar Valley generally flows from west to east through the upper few hundred feet of the basin-fill aquifer. A continuous clay unit, which is as much as 240 feet (73 m) thick, confines the basin-fill aquifer over much of the valley. Based on water-level and aquifer-test results, a north-south trending normal fault on the eastern margin of the valley is a conduit for fault-parallel groundwater flow and a barrier to groundwater flow across the fault. This fault directs groundwater flow around the Lake Mountains through bedrock at Cedar Pass to the north and Mosida Hills to the south. A wedge of Tertiary volcanic bedrock acts as a dam between water in the northern part of the basin-fill aquifer and the downgradient bedrock aquifer at Cedar Pass. Environmental isotopes demonstrate the existence of both deep groundwater flow paths, in which water may take thousands of years to

travel from the mountain tops to the basin fill, and relatively shallow flow paths, in which mountain recharge likely only takes a few tens of years to reach the basin-fill aquifer.

We created a two-layer, three-dimensional numerical groundwater flow model to simulate the groundwater flow system for Cedar Valley, focusing primarily on the unconsolidated basin-fill aquifer (layer 1) and its connection with the underlying, consolidated bedrock aquifer (layer 2), which receives the majority of recharge. A steady state model simulated conditions in 1969 and a transient model simulates the years 1970 to 2007. We calibrated the groundwater flow model using observed water levels at 24 wells and discharge measured at the one large basin-fill spring, Fairfield Spring. Model calibration was best in the central part of the valley, where water-level data were more closely spaced.

The simulated transient groundwater model flow budget showed a 39-year (1969–2007) average recharge to the Cedar Valley groundwater system of 25,600 acre-feet per year (acre-ft/yr) (31.6 hm^3/yr) and discharge of 25,200 acre-ft/yr (31.1 hm^3/yr). Over the 39 years simulated, our groundwater flow model allocated an average of 360 acre-ft/yr (0.44 hm^3/yr) to aquifer storage to balance recharge and discharge, a difference of about 1% in the overall water budget.

Most recharge (approximately 24,000 acre-ft/yr [29.6 hm^3/yr]) is in the form of precipitation on the Oquirrh and East Tintic Mountains, where the majority, 19,700 acre-ft/yr (24.3 hm^3/yr), becomes bedrock recharge to the basin-fill aquifer on the western side of the valley. The remaining 4300 acre-ft/yr (5.3 hm^3/yr) travels under the basin fill within bedrock to discharge to adjacent valleys or as bedrock well discharge. In addition to precipitation recharge through the mountain block, the basin fill receives approximately 1600 acre-ft/yr (2.0 hm^3/yr) of recharge on the valley floor, which is roughly 7% of its recharge.

Our model shows discharge to northern Utah and Goshen Valleys through Cedar Pass and Mosida Hills, respectively, averaged 14,900 acre-ft/yr (18.4 hm^3/yr) during the modeled period. About twice as much interbasin flow leaves Cedar Valley via Cedar Pass (10,200 acre-ft/yr [12.6 hm^3/yr]) compared to Mosida Hills (4700 acre-ft/yr [5.8 hm^3/yr]). Discharges from the groundwater system other than interbasin flow (14,900 acre-ft/yr [18.4 hm^3/yr]) are Fairfield Spring (3700 acre-ft/yr [4.6 hm^3/yr]), evapotranspiration (3000 acre-ft/yr [3.7 hm^3/yr]), and well pumping (2420 acre-ft/yr [3.00 hm^3/yr] from basin-fill wells and 1180 acre-ft/yr [1.46 hm^3/yr] from bedrock wells).

Groundwater flows through the basin-fill aquifer, entering as bedrock recharge from the west and discharging to the bedrock in the east, but not in equal proportions. On average, about 19,700 acre-ft/yr (24.3 hm^3/yr) flows into the basin-fill and 12,000 acre-ft/yr (14.8 hm^3/yr) flows out, which leaves 7700 acre-ft/yr (9.5 hm^3/yr) of net flow into the basin-fill aquifer. The net flow meets the discharge requirements of well withdrawal, evapotranspiration, and Fairfield Spring.

We modeled a variety of possible scenarios, including drought and increased pumping, 30 years into the future (from 2008 to 2037). If 2007 pumping (approximately 6500 acre-feet [8.0 hm^3/yr]) and average climatic conditions persist, the model predicts most areas of the basin-fill aquifer will experience as much as 15 feet (5 m) of drawdown from 2007 levels. In scenarios that include doubling the 2007 well extraction rates, our model predicts large areas of the valley will experience up to 50 feet (15 m) of drawdown.

INTRODUCTION

Description of the Study Area

The Cedar Valley study area encompasses 334 square miles (865 km^2) of northwest Utah County and small parts of Salt Lake and Tooele Counties (figure 1). It includes Cedar Valley and parts of the adjacent mountain ranges and valleys. Cedar Valley is a north-south trending valley surrounded by four mountain ranges. The highest of these is the Oquirrh Mountains to the northwest, where elevations range from approximately 5100 feet (1550 m) along the margins of the valley floor to 10,400 feet (3170 m). The lowest point in the valley is in the Sinks at approximately 4830 feet (1470 m) at the center of the closed surface-water drainage basin comprising the southern three quarters of the valley.

The valley floor (156 square miles or 400 km^2) has a semi-arid climate and receives an average of 13 to 16 inches (33–40 cm) of precipitation per year (PRISM Climate Group at Oregon State University, 2006). The southern Oquirrh Mountains receive up to 44 inches (112 cm) per year; the Lake and East Tintic Mountains receive up to 26 and 22 inches (66–56 cm) per year on average, respectively (PRISM Climate Group at Oregon State University, 2006). Most precipitation falls as winter snow or summer thunderstorms.

The Utah Division of Water Resources completed land-use classification surveys in Cedar Valley in 1988, 1995, 2002, and 2008 (Utah Division of Water Resources, 1993, 1995, 2003, 2009). A significant portion of the groundwater basin is unclassified in the surveys; these areas include mountainous terrain or unfenced, non-irrigated, or undeveloped land on the valley floor (figure 1). The Sinks, classified as riparian in the land-use surveys on figure 1, encompass roughly 1200 acres (490 ha) (Automated Geographic Reference Center, 2001). Of the roughly 71,000 acres (29,000 ha) classified in the 2008 survey, 90% are used for agriculture whereas urban land use is only 8% (figure 1), but urban use has been increasing. In the 1988, 1995, 2002, and 2008 land-use surveys, urban or residential-urban land use increased from 314 to 1046 to 4899

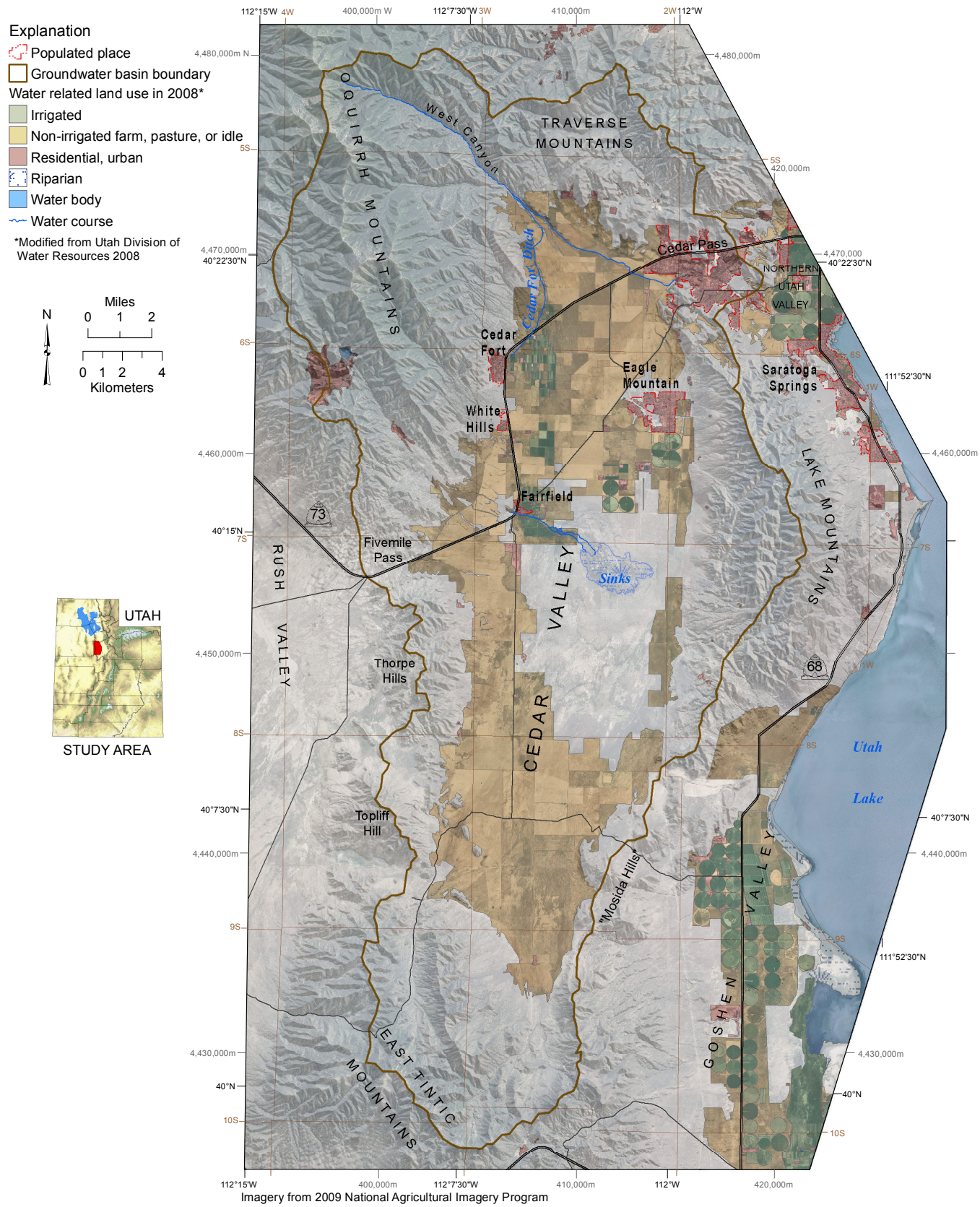


Figure 1. *Study area and water-related land use, Cedar Valley, Utah County, Utah.*

to 5890 acres (127 to 423 to 1983 to 2384 ha), respectively, an eighteen-fold increase (figure 2). Irrigated acreage decreased from 3983 acres (1612 ha) in 1988 to 2799 in 2008, a 30% decrease. (Sprinklers watered approximately 75% to 80% of the irrigated land in the 2000s; the remaining irrigated land was flood irrigated.) The 130% increase in the amount of dry farmed and pastured acreage is partly because the earlier surveys did not tally all the acres in that land-use category.

The dominant vegetation on approximately 35,500 acres (14,400 ha) of the valley floor, including most of the southern half of the valley, is greasewood (*Sarcobatus vermiculatus*), a phreatophyte; the northern half of the valley is dominated by sagebrush (*Artemisia* sp.) (approximately 28,900 acres [11,700 ha]) or cultivated crops (approximately 29,100 acres [11,800 ha]) (Automated Geographic Reference Center, 2001). Rabbitbrush (*Chrysothamnus* sp.) is another common phreatophyte in the greasewood-dominated area. The Sinks are mostly devoid of vegetation when not occupied by shallow ponds (Automated Geographic Reference Center, 2001). Mountain vegetation is dominated by Utah juniper (*Juniperus osteosperma*) and pinyon pine (*Pinus edulis*) and, in the highest elevations of the Oquirrh Mountains, oak (*Quercus* sp.), aspen (*Populus* sp.), Douglas fir (*Pseudotsuga menziesii*), and mountain mahogany (*Cercocarpus* sp.) (Automated Geographic Reference Center, 2001).

Cedar Valley is primarily a closed surface-water drainage basin except for the northern quarter of the valley, which drains east via West Canyon Wash and Tickville Gulch to Utah Lake through Cedar Pass (figure 3). Surface-water sources include West Canyon Creek, Fairfield Spring, three springs west of Cedar Fort (South, Tunnel, and Spring Creek Springs), and numerous small springs in the mountains. We calculated the annual peak discharge of West Canyon Creek, as measured at the mouth of the canyon at a U.S. Geological Survey gaging station, to be approximately 30 cubic feet per second (cfs) (850 L/s) but ranges from 5 to 110 cfs (140–3100 L/s). The annual peak usually occurs around May 20 but has been in August or September during 7 out of 31 years of record keeping; these late summer peaks are storm runoff and range from 9 to 1660 cfs (300–47,000 L/s) in magnitude. Low flow in January and February is approximately 0.5 to 0.6 cfs (14–17 L/s) (U.S. Geological Survey–Utah Water Science Center, 2006a). Flow from West Canyon Creek is almost completely diverted for irrigation during the irrigation season (G. Berry, Cedar Valley well owner, verbal communication, April 11, 2006). Surface flow in West Canyon Creek reaches Utah Lake only during years of greater-than-average spring runoff (D. Hale, Cedar Fort Irrigation Company, verbal communication, January 5, 2005; G. Berry, verbal communication, April 11, 2006).

The three springs west of Cedar Fort each discharge a few hundred gallons of water per minute (<0.5 cfs or 20 L/s) (Feltis, 1967; Utah Division of Water Rights, 2004a), although actual measurements are scarce. The spring water is used in and around Cedar Fort for culinary, residential, and agricultural purposes. Discharge at Fairfield Spring ranges from 1.2 to 9.7 cfs (34–270 L/s) (U.S. Geological Survey–Utah Water Science Center, 1970; Utah Division of Water Rights, 2004a; V. Carson, Fairfield Irrigation Company water master, written communication, August 23, 2004; Utah Division of Water Rights, 2006), and water that is not consumed by irrigation or evaporation runs to the Sinks, a seasonal, shallow, ponded, and marshy area at the low point of the closed basin (figure 1). Fairfield Spring discharge can and usually does flow to the Sinks during the non-irrigation season (October 21 to April 19) (V. Carson, verbal communication, April 11, 2006).

Purpose and Scope

Population growth within the study area has created pressure to develop new sources of drinking water. The Utah Division of Water Rights requested a study to define the current conditions of the hydrologic system and provide a tool to predict and understand the nature of possible future impacts to this system from changes in the nature and extent of water use in Cedar Valley. This report summarizes the results of the Utah Geological Survey's (UGS) comprehensive study of the hydrogeology and hydrogeochemistry of Cedar Valley and

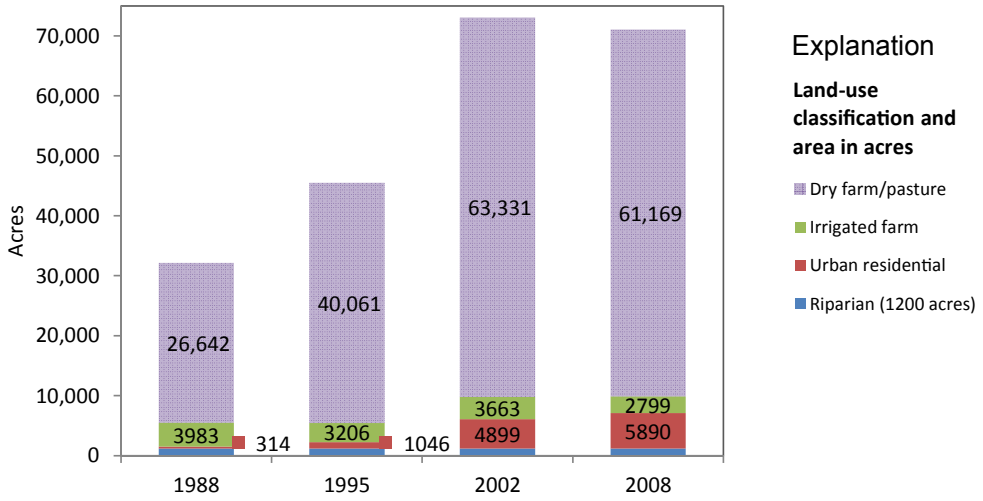


Figure 2. *Land-use classification in the Cedar Valley study area for years 1988, 1995, 2002, and 2008 showing a 30% decrease in irrigated acreage and an 18-fold increase in urban land use over the period.*

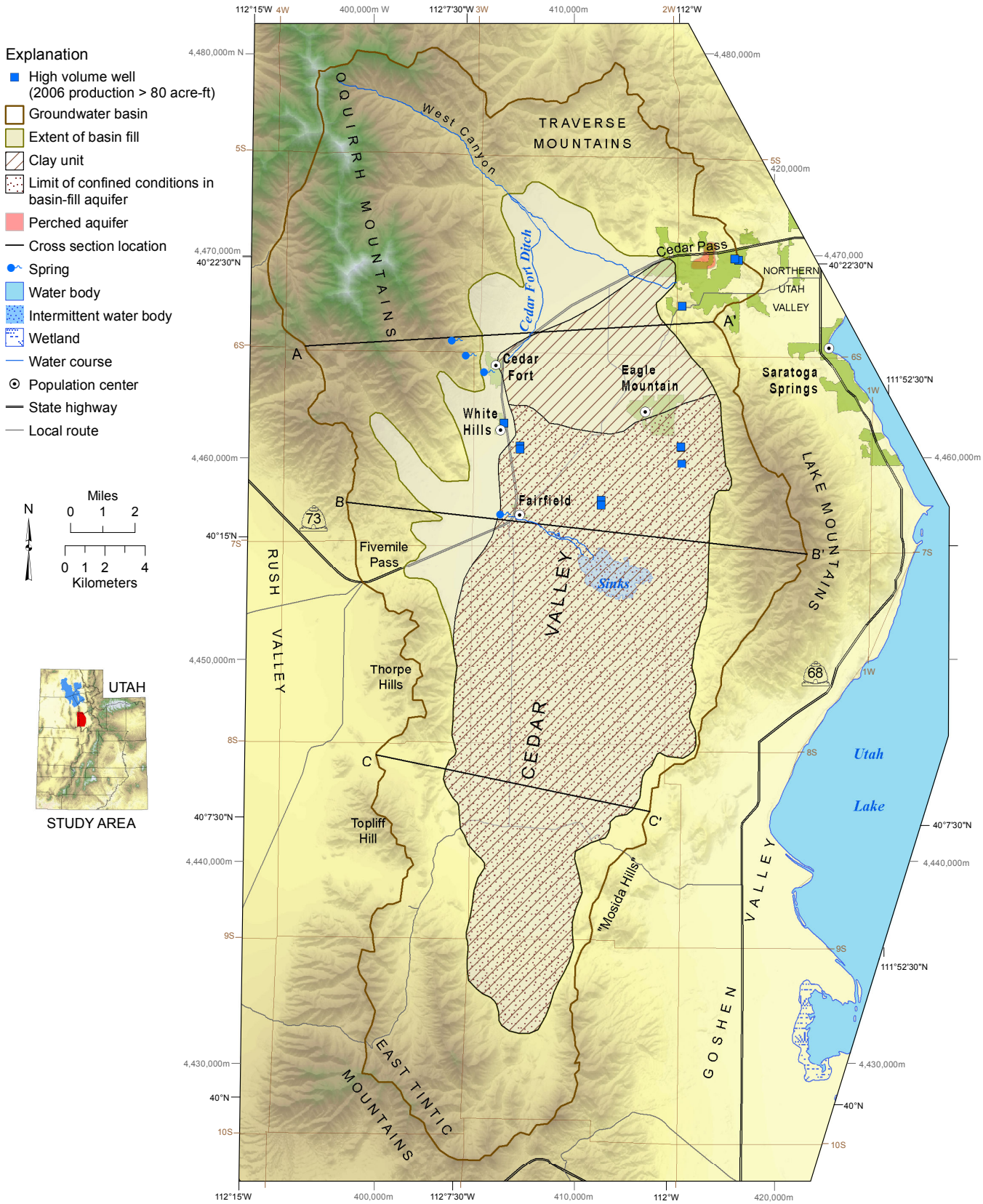


Figure 3. *Hydrogeologic features of Cedar Valley. Cross sections shown on figure 4.*

presents conceptual and numerical models of groundwater flow. We collected potentiometric (water-level) data, aquifer-test data, water-quality data including stable and radioactive isotope data, and seepage measurements for this study, and we compiled precipitation, surface-flow, and potentiometric data. Based on these data, we constructed a digital groundwater flow model using MODFLOW-2000 computer code (Harbaugh and others, 2000) to simulate steady-state groundwater flow conditions in the basin-fill aquifer in 1969 and transient conditions for the years 1970 to 2007. This report documents the data collected, the methods of data collection, our analysis of these data, our conceptual model of groundwater flow, and construction and results of the digital groundwater flow model developed for this study. Aquifer-test data and analysis are more fully documented in Jordan (2013).

Population Growth and Water Use

Cedar Valley is experiencing rapid population growth. From the 1940s until about 1993, the population of Cedar Valley was small and relatively stable (Demographic and Economic Analysis Section, 2006a). Population was concentrated in the two communities of Cedar Fort town and Fairfield; the estimated population of Cedar Fort town was 208 people in 1940 and 341 in 2000 (Demographic and Economic Analysis Section, 2006a). The community of Fairfield had an estimated 100 residents in 1959 (Larsen, 1960) and 135 in 2000 (Demographic and Economic Analysis Section, 2008b). Large-scale housing development began in the 1990s in three areas: Eagle Mountain "town center" (referring to the developed areas on the eastern side of the northern half of the valley), Cedar Pass (later incorporated under Eagle Mountain City), and White Hills (figure 1). Between 1994 and 2007 the population of the area now incorporated as Eagle Mountain City, which includes the town center and much of the residential development in the Cedar Pass area, grew from an estimated 31 people to 19,890 people (U.S. Census Bureau, 2000a, 2010). In that same time frame, the population of White Hills grew from an estimated 84 people to 418 (U.S. Census Bureau, 2000a, 2000b; Hansen, Allen & Luce, Inc., 2001; U.S. Census Bureau, 2010; inspection of 1993 aerial photograph). Between 1990 and 2007, the population of Cedar Valley as a whole, including the Cedar Pass area, grew from about 400 people to about 21,000 based on published data (U.S. Census Bureau, 2000a, 2000b; Utah Division of Water Rights, 2009a; U.S. Census Bureau, 2010), population estimates from other sources (Larsen, 1960; Hansen, Allen & Luce, Inc., 2001), inspection of aerial photographs, and field reconnaissance of unincorporated areas. In fact, Eagle Mountain City was listed as the second fastest growing city in Utah between 2000 and 2003 (Demographic and Economic Analysis Section, 2004). This population growth is almost entirely suburban in nature. Continued growth of 7% or more per year is expected over the next thirty years, resulting in an estimated combined population of Fairfield, Cedar Fort, and Eagle Mountain City of over 133,000 people by 2040 (Demographic and Economic Analysis Section, 2008a).

Water use in Cedar Valley has followed population growth and land-use changes. Between 1963 and 2007, well withdrawal ranged from 1300 to 10,500 acre-ft/yr (1.6–13.0 hm^3/yr). Over that time period, we have defined five periods characterized by water use.

1. Between 1963 and 1973, well withdrawal in Cedar Valley, almost entirely for irrigated agriculture, averaged approximately 2400 acre-ft/yr (3.0 hm^3/yr).
2. From 1974 to 1982, well withdrawals increased to an average of approximately 4000 acre-ft/yr (4.9 hm^3/yr) as four large irrigation wells on the western and eastern margins of the valley came online.
3. From 1983 to 1994, wells pumped an average of 2600 acre-ft/yr (3.2 hm^3/yr); much of the farmed land in the north-central part of the valley was not in production during this period, and the early part of this period was marked by very high precipitation, reducing the need for groundwater pumping for irrigation.
4. Well withdrawal averaged approximately 5200 acre-ft/yr (6.4 hm^3/yr) for the decade 1995 to 2005 due to increased groundwater extraction to supply housing development.
5. Well pumping approximately doubled from 2005 to 2007 as cities and towns met the needs of a rapidly expanding population. Pumping will likely continue to increase as the communities in Cedar Valley continue to grow.

Previous Work

Hugh Hurlow of UGS completed the most recent study of the hydrogeologic framework of Cedar Valley (Hurlow, 2004). Most of the area was geologically mapped or remapped by UGS geologists and others in the mid-2000s (Biek, 2004, 2005; Biek and others, 2005; Biek, 2006; Biek and others, 2009; Clark and others, 2009). The U.S. Geological Survey published a comprehensive hydrogeologic study in 1967 (Feltis), and student theses of Moulton (1951), Larsen (1960), and Floyd (1993) have focused on various aspects of the hydrogeology or geology of parts of Cedar Valley. We reviewed work in surrounding valleys by U.S. Geological Survey scientists, including Rush Valley (Hood and others, 1969); northern Utah Valley (Clark, 1984; Clark and Appel, 1985; Thiros, 2006; Cederberg and others, 2009; Gardner, 2009); Goshen Valley (Cordova, 1970; Dustin and Merritt, 1980; Stolp and others, 1993; Brooks and Stolp, 1995); Skull Valley (Hood and Waddell, 1968); and the regional carbonate aquifer (Prudic and others, 1995). Historical accounts and interviews with Cedar Valley landowners, city and town officials, and water-right holders were helpful in piecing together the water-use history of the valley (appendix A). Relevant consultants' hydrogeologic reports and other unpublished

data for Eagle Mountain City (Montgomery, 1995; Epic Engineering, 2001, 2004; Lang Exploratory Drilling, Salt Lake City, written communication, January 19, 2005), Cedar Fort Town (Montgomery Watson, Inc., 2000; ESI Engineering, Inc., 2003), and other organizations (Mower and Allred, 1997; EPW Engineering, Inc., 1999; Mayo and Associates LC, 2001; Harvest Irrigation Company, written communication, September 9, 2005) provided useful data.

Methods of Investigation

Investigative and field work for this study consisted of interviewing Cedar Valley residents and well owners to reconstruct historical water use (appendix A), reviewing approximately 450 well drillers' logs and associated water-rights information to compile a well information database (appendix B), running three downhole geophysical logs, collecting water-level data, sampling wells, performing aquifer tests, and conducting a canal seepage study. We measured water levels bi-monthly on 35 wells from October 2004 to August 2006 and on a quarterly basis thereafter on a subset of those wells through June 2009. We measured water levels in 50 wells in August 2006, including many private wells near Cedar Pass, in a one-time round of water levels, and we compiled water levels measured by cities, private well owners, and the U.S. Geological Survey from the 1940s through 2007. We sampled 45 wells and springs for general chemistry, trace metals, and environmental isotopes between February 2005 and April 2007. We compiled results for another 143 samples, including some duplicates of sites that we sampled. In all, 188 samples from 121 unique sites were considered in our analysis of water quality. We performed three multiple-well aquifer tests and two single-well aquifer tests and reviewed or reanalyzed seven aquifer-test data sets from private and municipal sources to estimate hydraulic conductivity, transmissivity, and storativity of the aquifers. We compiled specific capacity data from 95 wells in Cedar, Goshen, and northern Utah Valleys, 70 of which are within the Cedar Valley groundwater basin, to estimate hydraulic conductivity and transmissivity from specific-capacity data. We performed a seepage study on Cedar Fort ditch for the reach between the U.S. Geological Survey gaging station on West Canyon Creek at the mouth of West Canyon and the Cedar Fort Irrigation Company retention basin north of Cedar Fort. We estimated recharge as a percentage of precipitation dependent on elevation, volume of precipitation, and geologic material. We also estimated recharge from secondary sources, such as irrigation seepage, as a percentage of water applied to a given area.

We then used these field data and calculations to generate a conceptual water budget and conceptual model of groundwater flow, which we used to construct a digital groundwater flow model. The conceptual model is based on the spatial and temporal distribution of groundwater head and the direction of groundwater flow, hydrogeologic boundaries of the study area and aquifers, and hydrogeologic characteristics of the principal basin-fill aquifer and its relation to the underlying consolidated bedrock. We converted the conceptual model to a MODFLOW-2000 numerical model (McDonald and Harbaugh, 1988; Harbaugh and others, 2000; Hill and others, 2000). The basin-fill and underlying bedrock aquifers included in the digital groundwater flow model domain are within the larger study area and cover approximately 163 square miles (422 km^2). We calibrated the digital groundwater flow model for 1969 steady-state conditions and 1970 to 2007 transient conditions. The calibrated transient model simulates aquifer response to future hypothetical groundwater development and climatic scenarios.

Well Numbering System

We continue the convention used by Hurlow (2004) of assigning sequential well numbers to wells inventoried in the Cedar Valley study area. The 452 wells or boreholes were given a unique number between 1 and 1143. We assigned springs an ID number between 2001 and 2017, and we assigned UGS ID 3001 to the one surface water site that we included for water chemistry sampling, West Canyon Creek. In this report, we use mostly the UGS ID to identify wells or sites on maps or in discussion; however, the cadastral location [e.g., (C-6-2)17dcc-1] is used occasionally because it provides a more descriptive well ID that includes the section, township, and range location in the ID (figure B-1) and is the ID most commonly used by the U.S. Geological Survey. The UGS ID and cadastral location ID are cross refereneced to the Utah Division of Water Rights well identification number (WIN), the U.S. Geological Survey National Water Information Sytesm (NWIS) site number, and local well name in table B-2.

GEOLOGY

The structure and topography of Cedar Valley, a sediment-filled basin bounded by north-trending normal faults and surrounded by deformed Paleozoic rocks and Tertiary volcanic rocks, is typical of the Basin and Range Province (Hurlow, 2004). An inferred normal fault bounds the eastern side of the Oquirrh Mountains (Biek, 2004). Christiansen and others (2007) found evidence for high-angle normal faults on either side of the Lake Mountains.

The Cambrian to Pennsylvanian sedimentary rocks in the surrounding mountain ranges were deformed in the Sevier orogeny (Late Jurassic to earliest Tertiary time) into north- to northeast-striking folds (Bryant and Nichols, 1988; Allmendinger, 1992). Hurlow (2004, table 4) grouped the rock units into hydrogeologically similar aquifers and aquitards as shown on plate 1. The two bedrock units that have been developed most heavily for water in the past decade, particularly in the Cedar Pass area, are the Great Blue Limestone and the Oquirrh Group. The Mississippian Great Blue Limestone is a 2500-foot-thick (760 m) blue-gray fossiliferous limestone (Biek, 2005) that has a shale member in the middle. Two for-

mations in the Oquirrh Group have been the target of water development: (1) the Middle Pennsylvanian Butterfield Peaks Formation is 9070 feet (2760 m) thick in the Oquirrh Mountains and consists of orthoquartzite, calcareous sandstone, and sandy limestone, and (2) the Early Pennsylvanian West Canyon Limestone, which is approximately 1000 feet (300 m) thick (Biek, 2005). In the Cedar Pass area, Quaternary sediments partially conceal the bedrock, which is folded and faulted along a generally northwest axis as documented by recent geologic mapping (Biek, 2004, 2005; Biek and others, 2005) and supported by well logs. Wells at the northern end of the Lake Mountains are completed in fractured limestone and sandstone of the Oquirrh Group, mostly in West Canyon Limestone. Wells east of Cedar Pass in sections 15, 16, 17, 21, and 22, T. 5 S., R. 1 W., Salt Lake Base Line and Meridian (SLB&M) are completed in the older Great Blue Limestone. Between these two units lies the 1200- to 1400-foot-thick (370–430 m) Mississippian-aged Manning Canyon Shale, which typically acts as a barrier to groundwater flow and does not yield large quantities of water to wells.

Clay is the predominant material in well logs in the center of the valley, but coarser grained intervals of mixed gravel, sand, and clay are also present. Sediment filling the deepest part of the Cedar Valley depositional basin may be Miocene- to Pliocene-aged Salt Lake Formation (Montgomery, 1995; Hurlow, 2004). At least four deep lake cycles have occurred in the Bonneville basin over the past 500,000 years in response to climate change (Oviatt and others, 1992; Balch and others, 2005). The lowest lake levels existed during dryer, interglacial cycles, whereas deep, freshwater lakes existed during colder, wetter glacial maxima, and saline and hypersaline lake conditions were common between these extremes (Balch and others, 2005). The large freshwater lakes occurring during deep lake cycles in the Bonneville basin were presumably present in Cedar Valley, and closed-basin lakes could have existed numerous times as a result of the same climatic factors controlling the lake cycles in the Bonneville basin. These lakes deposited the fine-grained sediment now found in the center of the valley (Morrison, 1991; Hurlow, 2004). Streams from the rising mountains deposited coarser grained and poorly sorted sediment along the valley margins in alluvial fans, which interfinger with the clay-rich lakebed sediments (Morrison, 1991; Hurlow, 2004).

Tertiary intrusive and extrusive rocks crop out in the Traverse Mountains, the East Tintic Mountains, and the "Mosida Hills" (the low hills between the southern end of the Lake Mountains and the East Tintic Mountains, including the area between Goshen Pass and Chimney Rock Pass). The volcanic rocks are present in the subsurface, as indicated by well logs. Gravity and magnetic surveys (Floyd, 1993) concluded that an extensive 100- to 200-foot-thick (30–60 m) tuff deposit may be buried in Cedar Valley. Christiansen and others (2007) interpreted the volcanic and tectonic history of the Soldiers Pass volcanic field located in Mosida Hills. Based on their work, volcanic rocks were erupting from a center in the Soldiers Pass area from 35 to 33 Ma (Oligocene epoch). The onset of extensional Basin and Range faulting occurred after these older ignimbrites and lavas erupted and at about the same time as the Miocene Mosida Basalt was erupting from a source also probably near Soldier Pass (Christiansen and others, 2007). Basin and Range faulting continued after the volcanic activity stopped (Christiansen and others, 2007), which means there are likely older Oligocene volcanic rocks and younger Miocene basalts in the Cedar Valley graben underlying the surface basin-fill deposits of southern Cedar Valley.

HYDROGEOLOGY

Groundwater in Cedar Valley occurs in both unconsolidated sedimentary aquifers and consolidated rock aquifers. Before the rapid population growth of the mid-1990s, most wells produced water from the basin-fill aquifer, but since the late 1990s, water suppliers and homeowners have successfully targeted the bedrock aquifer for new domestic and municipal supplies.

Hydrogeologic Units

We have delineated four important hydrogeologic units in the Cedar Valley groundwater system: (1) an upper clay unit, (2) the basin-fill aquifer, (3) the bedrock aquifer, and (4) a small perched basin-fill aquifer at Cedar Pass.

Clay Unit

A clay unit is as much as 240 feet (70 m) thick and is continuous across the valley except on the western and northern valley margins, where it interfingers with alluvial fans (figure 3, figure 4). Drillers' well logs and downhole geophysical logs indicate the clay unit is composed of clay and minor sandy clay and gravelly clay intervals, and covers approximately 80% (126 square miles [326 km^2]) of the surface of the basin fill. This unit confines the underlying basin-fill aquifer in some areas as shown on figure 3.

Basin-Fill Aquifer

The basin-fill aquifer occupies an area of 156 square miles (404 km^2) and is composed of fine-grained sediments in the valley center that grade into and are interbedded with coarser grained, poorly sorted, colluvial and alluvial-fan deposits on the valley margins (Hurlow, 2004). The aquifer is as much as 1900 feet (580 m) thick in the center of the valley and is overlain by the clay unit and underlain by bedrock (figure 3, figure 4). Cross sections shown on figure 4 are from profiles through an isopach map of the clay unit that we contoured using well-log data and an isopach map of the basin fill we modified from Hurlow (2004, plate 4) using data from recently drilled well logs. The fault locations are approximate and taken from Biek (2004) and Hurlow (2004, plates 1 and 2).

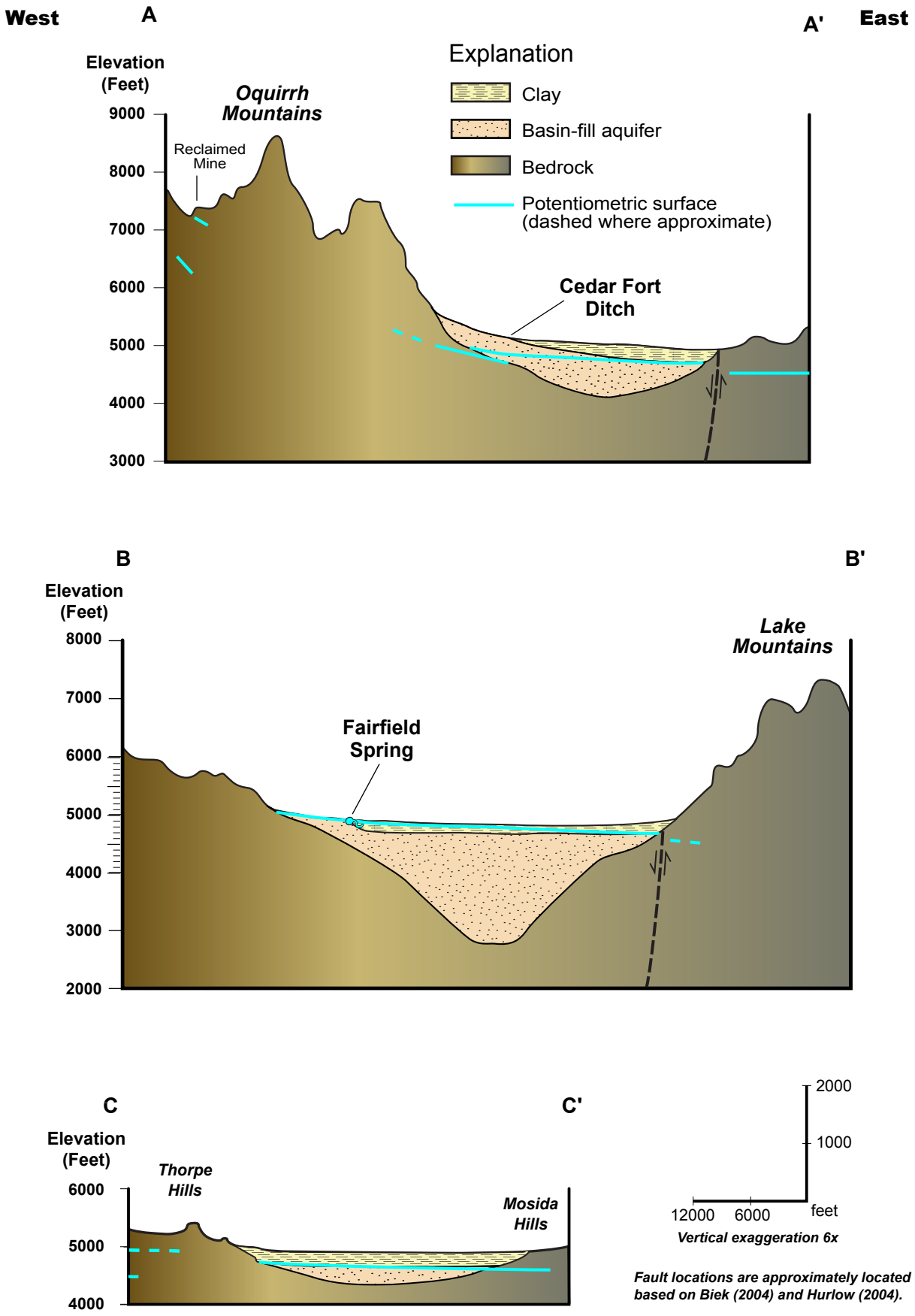


Figure 4. *Hydrostratigraphic cross sections, Cedar Valley, Utah County, Utah. See figure 3 for cross-sections locations.*

The potentiometric surface of the basin-fill aquifer is above ground level in the area around Fairfield and above the bottom of the overlying clay unit in the central and southern part of the aquifer, indicating confined aquifer conditions in approximately 70% of the aquifer. Water levels are below the top of the aquifer in its northern and western extents, creating unconfined conditions even where overlain by clay in the north (figure 3).

The Church of Jesus Christ of Latter-day Saints (LDS Church) drilled at least 18 large-diameter irrigation wells into the basin-fill aquifer in the late 1950s and 1960s. The wells penetrated to depths ranging from 455 to 2366 feet (139–721 m), and most were perforated quite deep (as deep as 1254 ft). Historically, a dozen or so large wells have produced water from the basin-fill aquifer, including some of the LDS Church wells, but by 2007 only six large-diameter wells and several dozen small-diameter wells, most screened shallower than 600 feet (180 m), were in production in the basin-fill aquifer. Many of the deep wells drilled in the valley center produced a large amount of sand and silt and later collapsed (appendix A; Larsen, 1960; Feltis, 1967). We conclude the reason for the poor production in the deep wells is a combination of the inherent low yield from fine-grained sediments and improper well design for fine-grained aquifers. Although the basin-fill aquifer is as much as 1900 feet (580 m) thick, the aquifer that effectively yields water to wells is only the upper 300 to 400 feet (90–120 m) of the interbedded basin-fill sediments underlying the clay unit.

Bedrock Aquifer

Approximately 178 square miles (460 km^2) of the groundwater basin area is bedrock or bedrock covered by a thin veneer of unconsolidated sediment. The bedrock aquifer is composed chiefly of folded, faulted, and fractured Paleozoic sedimentary rocks. Limestone and sandstone of the lower formations of the Pennsylvanian to Permian Oquirrh Group and Mississippian Great Blue Limestone are the main water-producing formations in Cedar Pass. The bedrock concealed under Quaternary sediments at Cedar Pass is folded and faulted along northwest axes (Biek, 2004, 2005; Biek and others, 2005). Large, northwest trending folds exposed in the Oquirrh Mountains deform the Paleozoic sedimentary rocks (plate 1) (Laes and others, 1998). Many small private wells near Cedar Fort are completed in Oquirrh Group bedrock, and the Great Blue Limestone has recently been tapped north of Cedar Fort.

Depth to bedrock in Cedar Valley is shallow (maximum depth to bedrock of approximately 2000 ft) (figure 4) relative to neighboring Utah Valley as shown by gravity modeling (Floyd, 1993; Hurlow, 2004) and one driller's log for a well in the center of the valley (section 15, T. 6 S., R. 2 W., SLB&M, UGS well ID 1122). The log records 30 feet (9 m) of blue shale and 276 feet (84 m) of hard, sharp, gray and brown limestone at the bottom of the 2366-foot-deep (721 m) hole. The quality of this log is probably better than some drillers' logs because this well was drilled as part of the LDS Church's water exploration in the 1960s under supervision of a hydrogeologist (G. Smith, Smith Farms, verbal communication, August 1, 2005), although there is no record that the geologist logged the hole.

Of the bedrock exposed in the study area, the Oquirrh Group West Canyon Limestone has the most number of wells, primarily because of the spatial distribution of population growth.

Older Paleozoic sedimentary rocks in the subsurface and exposed in the East Tintic Mountains may have similar hydrogeologic properties to those described above, but they have not been developed as groundwater sources. Large volumes of water in cavernous Cambrian-aged limestone were encountered in mines near Eureka, south of the study area in the East Tintic Mountains (Hall, 1949).

Volcanic bedrock in the Traverse Mountains and Mosida Hills area has not been extensively developed as a groundwater source. A few drill holes and wells through and in volcanic rocks in the study area indicate that the volcanic rocks may yield very little to moderate amounts of water.

In this study, we mostly discuss the water-bearing bedrock units as one "bedrock aquifer"; we also model the bedrock as one aquifer in the digital groundwater flow model. However, at least five small (mostly less than 2 square miles [5 km^2] in extent) areas have water levels in bedrock wells that are dissimilar to surrounding areas. As shown on our potentiometric map (plate 2) they are: (1) Tertiary bedrock west of Cedar Pass, (2) Paleozoic bedrock at Cedar Pass, (3) Paleozoic bedrock east of Cedar Pass in northern Utah Valley, (4) Paleozoic bedrock northwest of Cedar Fort, and (5) Paleozoic bedrock at Thorp and Topliff Hills. We contour water levels in each of these small aquifers separately from the main bedrock aquifer; however, groundwater in perched zones ultimately intersects faults or geologic contacts along which it may travel to the regional bedrock aquifer.

We treat less-permeable bedrock units (such as the Mississippian Manning Canyon Shale and Tertiary volcanic rocks) differently than aquifer units in our groundwater model by limiting recharge to them and assigning them lower hydraulic conductivity values.

The thickness of the bedrock aquifer across the study area is unknown due to the lack of deep well data in most areas; three deep, large-diameter wells located in Cedar Pass and north of Cedar Fort have producing intervals down to approximately 1300 feet (400 m) below surface. For modeling purposes, we have assumed the thinnest part of the bedrock aquifer is under the deepest part of the basin-fill aquifer, and here we model it to be approximately 800 feet (240 m) thick.

Perched Unconsolidated Aquifer

We identified a small perched aquifer at Cedar Pass (figure 3) by review of the well drillers' logs. The aquifer yields water to about 20 domestic wells in the NE1/4 of section 19 and SW1/4 of section 17, T. 5 S., R. 1 W., SLB&M. Drillers reported the lithology of the screened or perforated interval of wells in the perched aquifer mostly as unconsolidated materials, which we interpret to be unconsolidated Quaternary and semi-consolidated Tertiary Salt Lake Formation. Drillers completed the wells at shallower depths, generally less than 300 feet (90 m), than the 500+ feet- (150 m) deep wells in the bedrock to the west, south, and east of this area. The sediments are positioned in a graben bounded on the north and south by east-west trending normal faults. Water levels reported on drillers' logs from this area are generally less than 250 feet (76 m) to water, as compared to roughly 500 feet (150 m) to water in adjacent Paleozoic bedrock, and groundwater flows in a generally north to south direction in contrast to a generally west to east direction in the bedrock aquifer (plate 2). U.S. Geological Survey researchers modeling northern Utah Valley came to a similar but independent finding of this perched aquifer and structures surrounding it (Cederberg and others, 2009, p. 12).

Hydrogeologic Properties

Methods

We estimated aquifer properties by conducting aquifer tests, reviewing previously conducted aquifer-test results, using specific capacity data to estimate transmissivity, and, in the absence of field data, by using published values for similar aquifer materials.

We conducted five aquifer tests on wells in Cedar Valley and Cedar Pass. We completed three tests on basin-fill aquifer wells: (1) a multiple-well aquifer test lasting 69 days involving 12 observation wells and two closely-spaced, high-capacity irrigation wells pumping at a combined rate of between 1200 and 2800 gallons per minute (gpm) (76–180 L/s), (2) a single-well, 48-hour drawdown test on a well pumping 215 gpm (14 L/s), and (3) a single-well, 12-hour drawdown and recovery test on a domestic well pumping 31 gpm (2.0 L/s). We conducted aquifer tests on two production wells completed in the bedrock aquifer: (1) a multiple-well aquifer test on a municipal well pumping at a rate of 1950 gpm (123 L/s) during which we collected five months of drawdown data and one month of recovery data from four observation wells, and (2) a multiple-well drawdown test on a municipal well pumping at a rate of 2530 gpm (160 L/s) lasting 35 days with one observation well. We also reviewed or reanalyzed data sets from seven aquifer tests conducted previously by others on basin-fill or bedrock wells and estimated aquifer properties from 70 specific-capacity values calculated from drillers' logs. The locations of the pumping wells involved in the aquifer tests are shown on figure 5 as blue dots; red dots indicate wells for which we used specific capacity to estimate transmissivity. Important findings of the aquifer tests are summarized below, and complete details of the tests and data analysis are reported in Jordan (2013).

Our analysis of aquifer-test data employed computer-aided drawdown and recovery curve matching to unconfined-homogeneous, confined-homogeneous, and fractured aquifer solutions, whichever best matched the aquifer conditions of a particular test. Specific capacity (flow rate divided by drawdown) data were used in an iterative spreadsheet program to estimate the transmissivity and hydraulic conductivity of the aquifer based on the Cooper-Jacob (Cooper and Jacob, 1946) equation for transient radial flow to a well.

Aquifer Tests

We conducted a 69-day aquifer test on two irrigation wells at the edge of the confined basin-fill aquifer on the western side of Cedar Valley (southeast of White Hills on figure 5a) in 2005. Pumping created a drawdown cone elongated in the north-south direction, which is perpendicular to groundwater flow. Contrary to typical aquifer-test responses, wells upgradient drew down more than wells downgradient of the pumping wells. The elongated shape and upgradient direction of the drawdown cone is a reflection of the position of the coarse-grained alluvial-fan sediments along the edge of the confined aquifer (Jordan, 2013). The confined aquifer is elongated in the north-south direction, becomes unconfined to the west, and becomes finer grained and of lower transmissivity to the east toward the valley center, limiting the volume of aquifer available to transmit water to the pumping wells. The aquifer parameters estimated from the test data show a confined aquifer that has moderately high transmissivity (25,000 ft^2/d [2300 m^2/d]), hydraulic conductivity (60 ft/d [18 m/d]), and storage capacity (0.02). Seasonal pumping in 2005 did not affect the flow at Fairfield Springs.

We conducted a single-well, 48-hour drawdown test on a medium-diameter well in central Cedar Valley approximately six miles north of the Sinks (figure 5). The basin-fill aquifer, which is composed of silty clay at this location, has transmissivity (1000–1200 ft^2/d [93–110 m^2/d]) and hydraulic conductivity values (3.0–3.6 ft/d [0.9–1.1 m/d]) in the moderate range for unconsolidated sediments.

The third basin-fill aquifer test conducted for this study was a short, single-well test on a small diameter domestic well in Fairfield (figure 5). The hydraulic conductivity of the confined leaky aquifer sediments is approximately 2 ft/d (0.6 m/d) and the transmissivity is approximately 70 ft^2/d (6.5 m^2/d) at this location.

A six-month multiple-well drawdown and recovery test on a municipal well completed in fractured Butterfield Peaks Formation and West Canyon Limestone (part of the Oquirrh

Group) at the northern tip of the Lake Mountains (figure 5) produced an aquifer test indicative of a bounded anisotropic fractured-rock aquifer (Jordan, 2013). The cone of depression was shallow (drawdown of 10.40 feet [3.17 m] at an observation well 539 feet [164 m] away) but widespread (drawdown of 8.65 feet [2.64 m] at an observation well 4940 feet [1506 m] away) and elongated in the direction parallel to the axis of structural folding. The aquifer did not reach steady state after five months of pumping. In addition, monitoring well response showed that a perched volcanic rock aquifer northwest of the pumping well, identified on plate 2, is not hydraulically connected to the fractured Paleozoic aquifer, and is most likely acting as a barrier to groundwater flow.

Aquifer-test analysis for the Oquirrh Group aquifer test consisted of manual and automatic curve matching aided by computer software (Duffield, 2007) to dual-porosity fractured rock solutions for the pumping well and observation well closest to the pumping well, and radial flow solutions for observation wells too far removed to display characteristics of dual porosity. Derivative curve matching (Renard and others, 2009) confirmed that wellbore storage was affecting

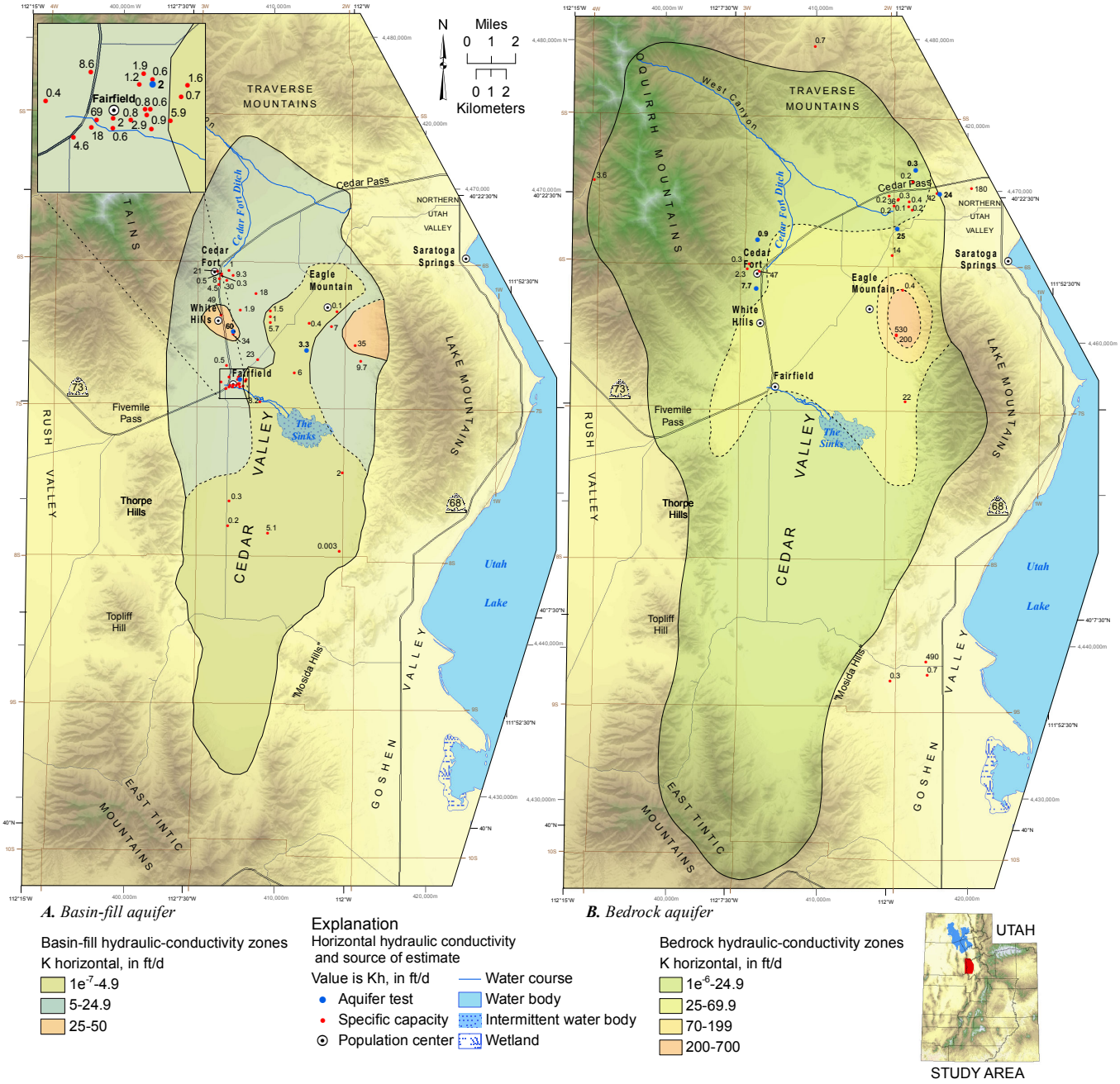


Figure 5. *Location of hydraulic conductivity estimates derived by aquifer tests and specific capacity data and hydraulic-conductivity zones for the basin-fill (A) and bedrock aquifers (B).*

the drawdown in two wells and supported the existence of linear flow close to the pumping well and no-flow aquifer boundaries distant from the well. Simple arithmetic methods (van Tonder and others, 2002; Heilweil and Hsieh, 2006) confirmed that the aquifer is anisotropic and that a flow-limiting aquifer boundary may be present approximately 4300 feet (1300 m) from the pumping well. Further experimentation, with positions of a no-flow boundary using image well theory and curve matching, provided aquifer parameters for a bounded aquifer, which likely are overestimates given that the boundaries likely are semi-permeable.

Table 1. *Aquifer parameter estimates for Cedar Valley aquifers.*

Aquifer		Transmissivity, in ft^2/d	Hydraulic conductivity, in ft/d	Storativity, unitless
Basin-fill[1]	Range	0.27 to 25,000	$2.6x10^{-3}$ to 69	0.02
	Geometric Mean	260	2.5	
Bedrock[2]	Range	4 to 120,000	0.1 to 530	0.007 to 0.02
	Geometric Mean	360	3.4	

[1] Basin-fill aquifer estimates are compiled from 3 aquifer tests and 45 specific capacity values. Storativity value is from one multiple-well aquifer test.

[2] Bedrock aquifer estimates are calculated from 6 aquifer tests and 22 specific capacity values. Storativity values are from two multiple-well aquifer tests.

The fractured rock aquifer in the Oquirrh Group has moderate to high transmissivity that is two to three times greater in the northwest to southeast direction to parallel to the axis of structural folding (11,000–16,000 ft^2/d [1000–1500 m^2/d]) as compared to perpendicular to folding (6,000 ft^2/d [600 m^2/d]). Average hydraulic conductivity is approximately 25 ft/d (7.6 m/d). The storage capacity of the aquifer is between 0.007 and 0.03. Linear flow near the pumping well and a wide drawdown cone characterize the aquifer. A volcanic rock wedge and/or a normal fault on the western side of the Lake Mountains, which restrict the flow from the Cedar Valley basin-fill aquifer to the west, limit the extent of the aquifer.

The last test we conducted was a 46-day multiple-well aquifer drawdown and recovery test on another municipal supply well located east of Cedar Pass (south of Highway 73 on figure 5). This well is completed in the Mississippian Great Blue Limestone aquifer, which is about 525 feet (160 m) thick at this location. The cone of depression did not encounter aquifer boundaries while pumping for 35 days at 2530 gpm (160 L/s), and maximum drawdown in an observation well 660 feet away (201 m) was 17.45 feet (5.32 m). The hydraulic conductivity of the fracture system is about 24 ft/d (7.3 m/d), which results in a transmissivity estimate of approximately 12,600 ft^2/d (1170 m^2/d). The storage capacity of the aquifer is 7 x 10^{-3}. This analysis did not evaluate the possible anisotropy of the aquifer, but did show that the Great Blue Limestone aquifer is moderately transmissive, confined, and at least extensive enough in this area to be unaffected by potential aquifer boundaries for at least one-month pumping periods.

We reviewed aquifer-test data collected by groundwater consultants obtained through the Utah Division of Drinking Water and private parties. We reanalyzed the tests where necessary and incorporated those results into our evaluation.

Aquifer transmissivity and storage capacity values estimated from the tests are summarized in table 1. Whereas the lower bound on hydraulic conductivity is similar for the basin-fill and bedrock aquifers, the bedrock aquifer has areas near faults or on fold axes where the hydraulic conductivity is an order of magnitude higher than any area in the basin-fill aquifer. Wells in the basin-fill aquifer located along the valley margins in coarser grained alluvial fans had the greatest hydraulic conductivity values, in contrast to lower values from wells in finer grained sediments nearer the center of the valley, which supports the conceptual model of the aquifer described by Feltis (1967) and Hurlow (2004). Not all wells located along faults, on fold axes, or in the alluvial fan are in zones of high hydraulic conductivity.

We defined zones of similar hydraulic conductivity (figure 5) by plotting hydraulic conductivity values from aquifer tests and specific capacity data (Jordan, 2013) and computer-generated contours of those values on maps of the basin-fill and bedrock aquifers. We refined the computer-generated contours using knowledge of aquifer lithology to smooth and simplify the values into three hydraulic-conductivity zones for the basin-fill aquifer and four hydraulic-conductivity zones for the bedrock aquifer. The highest hydraulic conductivity zone (200–700 ft/d [61–213 m/d]) is in the bedrock aquifer on the eastern side of the valley where two very productive wells are located (figure 5B). High hydraulic-conductivity zones in the basin-fill aquifer (20–50 ft/d [6–15 m/d]) are along the western and eastern margins of the basin-fill aquifer (figure 5A). The lowest hydraulic conductivity zone in the basin-fill aquifer ($1x10^{-6}$–4.9 ft/d [$3x10^{-7}$ –1.5 m/d]) is located in the southern arm of the valley and extends north through the center of the valley. We assigned the lowest hydraulic conductivity zone in the bedrock aquifer ($1x10^{-6}$ –24.9 ft/d [$3x10^{-7}$–7.6 m/d]) to areas where there was no evidence for higher hydraulic conductivity. We used these hydraulic-conductivity zones as the starting point for calibration of hydraulic conductivity values in the groundwater flow model.

Water-Level Trend Analysis

Water-level data include (1) water levels measured in 35 wells in Cedar Valley by the UGS approximately every two months from November 2004 to August 2006, (2) water-levels measured by the U.S. Geological Survey each March at approximately 25 of the same wells since the early 1960s and earlier at a few locations, (3) water levels measured by the UGS during a one-time round of water levels on 15 private wells in the Cedar Pass area in August 2006, (4) water levels reported on drillers' logs, and (5) miscellaneous water-level data obtained from cities, towns, and well owners. Appendix C is a compilation of these water-level data.

We analyzed water-level fluctuations in wells in Cedar Valley, Cedar Pass, and parts of Goshen, northern Utah, and Rush Valleys and compared them to annual precipitation data from National Weather Service weather stations in Fairfield, Lehi, and Saratoga Springs (National Oceanic and Atmospheric Administration Western Regional Climate Center, 2006) and well withdrawal in Cedar Valley (Jordan and Sabbah, 2007). We recognized four distinct water-level trends and grouped wells with similar trends together (figures 6 and 7). Water levels plotted on figure 7 were generally measured in March and, until the early 1990s, in September of each year; water levels that are much lower than the prevailing trend were measured immediately after pumping. Group A wells, located along the western Cedar Valley margin, experienced two episodes of rising water levels, one peaking at a historic high elevation around 1985 and the other peaking around 1999 (figure 7A). Group B wells are located in the middle of the valley, between (on a west to east line) group A and group C wells. Group B wells show two episodes of rising water levels similar in duration and magnitude to group A, but the peak water levels are offset two to four years later than group A, i.e., in 1987 to 1989 for the first peak and around 2001 for the second peak (figure 7B). Water levels in group C, located near and west of Eagle Mountain town center, generally rose until around 1986 and then remained relatively level thereafter (figure 7C). Water levels have been generally stable for the period of record in well group D (figure 7D) located in the southern part of Cedar Valley and Rush Valley.

Episodes of rising water levels in well group A correlate with periods of several years of higher than average precipitation in 1982–83 and 1998 (figure 7A, figure 8). Potentiometric head rose during these periods because additional water from precipitation went into storage in the groundwater system. Group A water levels peaked approximately two to three years after periods of above-average precipitation, indicating the wells are closer to the recharge source than wells in the other groups. Group A wells are located near the western valley-margin alluvial fans and Oquirrh Mountains bedrock block, where most precipitation falls and enters the basin-fill aquifer.

Water levels in group B wells also correlate to precipitation recharge, but the response is two to four years later than observed in group A wells, demonstrating the lag time for changes in aquifer storage from recharge to propagate from the margin to the interior of the valley. The response to higher than average precipitation in the late 1990s is smaller in magnitude or absent relative to group A. The delay is longer in wells farther downgradient, implicating the western alluvial fans or the western mountain block as recharge sources. Well 41 is located on the eastern valley margin (figure 6), far away from the primary recharge source of the Oquirrh Mountains and associated alluvial fans, but near an alluvial fan flanking the Lake Mountains and along the likely fault trace of the normal fault west of the Lake Mountains. A long response time of approximately nine years after above average precipitation in 1982–83 suggests the recharge to this well is not from precipitation falling on the Lake Mountains alluvial fans, but rather from a more distant source, mostly likely the Oquirrh Mountains.

Water-level peaks in group C wells are attenuated relative to groups A and B. The input of water to storage from the high precipitation years in the early 1980s and late 1990s that caused the peaks in groups A and B is the likely cause of the peaks in group C wells. Group C wells are located farther east and, accordingly, the delay for recharge to reach these wells is greater than four years and the magnitude of water-level change is less.

Group D wells in southern Cedar Valley and Rush Valley show no significant water-level changes because they are far removed from precipitation recharge sources. They also are confined by up to 200 feet (60 m) of clay, and there are no large production wells near these wells.

Pumping (figure 8) has a subordinate effect on long-term water-level trends relative to precipitation. Seasonal decline in water levels in pumped wells is evident when comparing water level measured during the spring and fall in wells in the 1960s, 1970s, and 2000s (figure 7B, figure 7C).

We measured 15 water levels in wells in Cedar Pass and along Lake Mountain Road in August 2006. Water levels were generally higher than the drillers' reported water levels measured after well completion (in 1996 or 1997 in most cases) by approximately 20 feet (6 m). Drillers' levels are sometimes measured before wells reach static conditions, which may explain why our 2006 levels were generally higher; however, the fact that the water levels we measured near the peak of the irrigation season were not lower than levels measured previously is a positive indicator that the aquifers were not in an overdraft situation at that time.

Overall, water levels in 2007 were not lower than they had been historically. No evidence of large-scale overdraft of the aquifers is apparent through 2007, even though withdrawals had more than doubled in the preceding decade (figure 8). Most wells shown in figure 7 are relatively far from the areas of increased pumping southeast of Eagle Mountain town

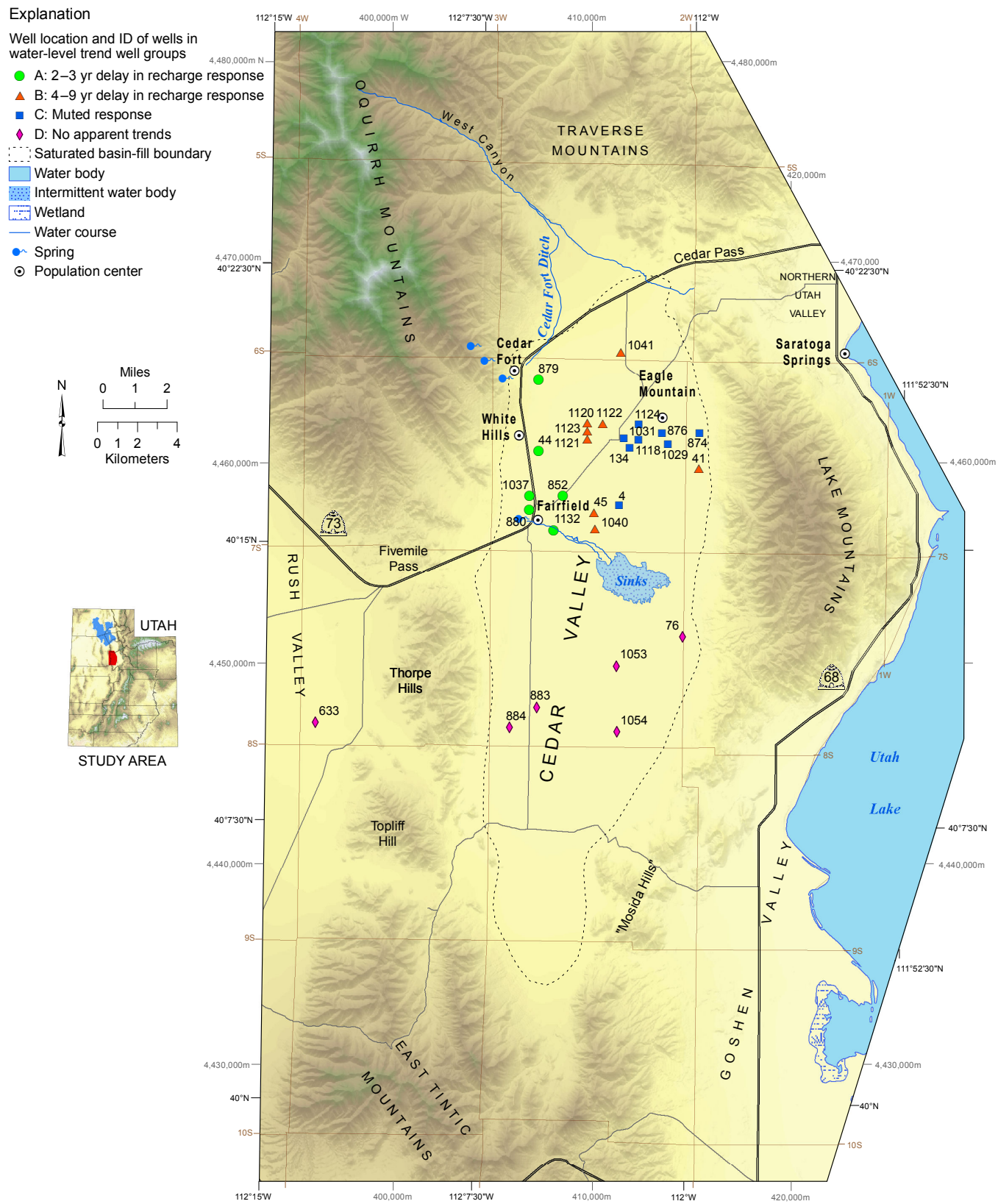


Figure 6. *Wells grouped by water-level trends in the Cedar Valley study area. The locations of wells having similar trends in water levels over time help us to understand the response of the basin-fill aquifer to recharge. Water-level trends are shown on figure 7.*

center and at Cedar Pass; therefore, water-level decline in response to increased pumping may not have affected the wells yet. Recent water-level declines in wells 41 (figure 7B) and 874 (figure 7C), both located southeast of Eagle Mountain town center (figure 6), are greater than declines observed in other wells in their respective groups and may represent a response to increased pumping.

Fairfield Spring and Irrigation Well Withdrawal

Fairfield Spring is on the western side of the town of Fairfield, near the contact of Manning Canyon alluvial-fan deposits and the clay unit (figure 9). Spring flow results when groundwater flowing eastward in permeable alluvial-fan sediments is forced to the surface as it encounters less permeable lakebed sediments and may be focused at the spring by a pre-existing topographic low and/or a gravel-filled alluvial channel (Hurlow, 2004). Historically, discharge has ranged from 1.2 to 9.7 cfs (34–270 L/s) from 1962 to 2005 (figure 10), but no records are available from 1971 to 1986, in which there were seven consecutive higher-than-average precipitation water years in the early to mid 1980s. Most years show some seasonal variation in flow whereby spring-time flow is usually 1.5 to 2 cfs (43–57 L/s) higher than fall-time flow.

Two large irrigation wells were drilled two miles north-northeast of Fairfield Spring (figure 9) in 1961 and 1962. During a legal battle in the early 1960s, pumping the wells was shown to decrease the flow of Fairfield Spring (Utah County District Court, 1965). That a hydraulic connection exists between Fairfield Spring and the White irrigation wells is an accepted fact (Utah County District Court, 1965; Feltis, 1967; Hurlow, 2004), but no clear physical explanation has been given for the connection. Hurlow (2004) conducted a seismic-

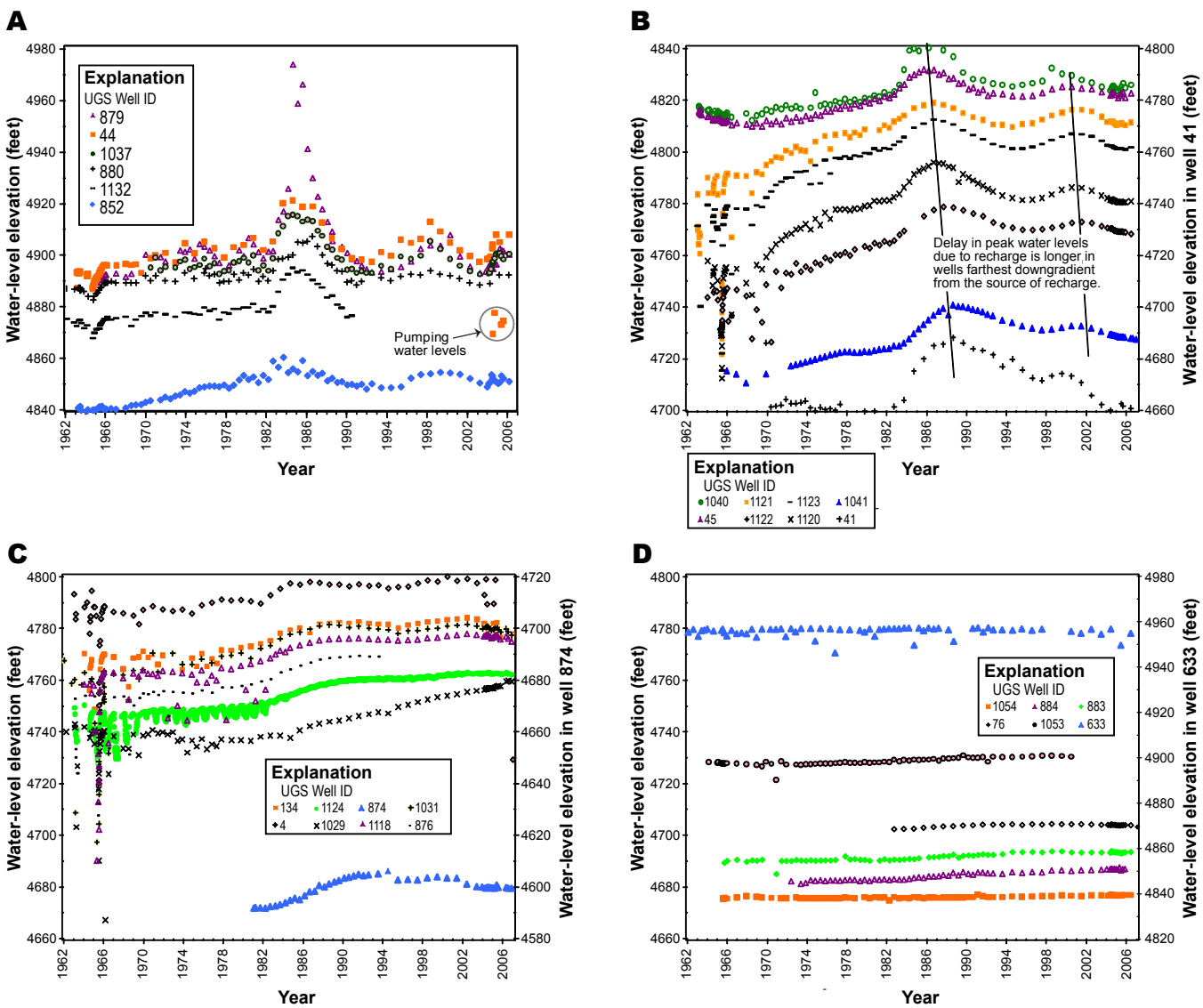


Figure 7. Water-level elevation fluctuation in well groups A through D, Cedar Valley study area. Well groupings are shown on figure 6. Time delay is greater and water-level response to precipitation is less as distance from the recharge zone increases.

refraction survey to investigate the possibility that a concealed fault might explain the connection between the wells and the spring, but found no evidence for such a fault. Hurlow (2004) suggested that an aquifer test in this area would improve our understanding of the connection between the wells and the spring. The UGS conducted such an aquifer test in 2005, and the results, along with analysis of more recent spring-flow data, well water levels, precipitation, and pumping data, reveal that the relationship between spring discharge and pumping is not as straightforward as the court decision states (Jordan and Sabbah, 2007).

Figure 10A shows the data that led to the decision in the 1965 court case between Fairfield Spring water users and

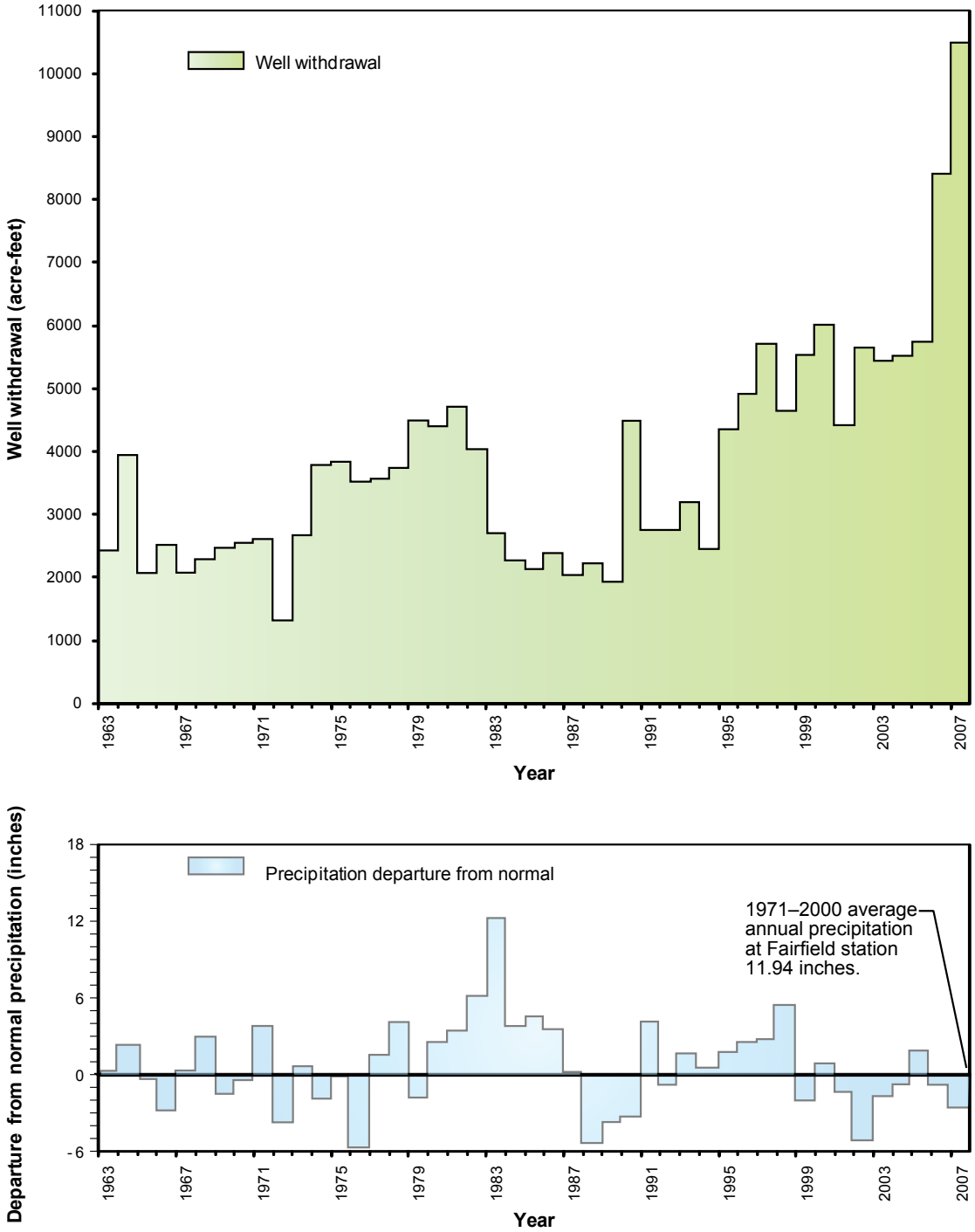


Figure 8. *Annual well withdrawal and precipitation departure from normal, Cedar Valley, Utah County, Utah. Pumping volume is affected by groundwater development for agriculture (1974–1982), higher than average precipitation (1983–1985), fewer acres farmed (1986–1994), and population increase (1994–2008).*

well owner M. Kenneth White. Spring discharge in 1962, 1964, 1969, and 1970 is inversely related to pumping at the White irrigation wells; pumping seems to create a "drawdown curve" in spring discharge. Higher total pumping for years 1962 and 1964 coincides with decreased total spring discharge for those years. However, data collected after the court's decision indicate that pumping may not always negatively affect spring discharge (figure 10B). Looking at specific time periods in more recent history shown on figure 10B, we note that spring flow is relatively low and consistent from 1991 through 1995 while pumping more than doubled in two of those years. We also note that there is no apparent relationship of spring discharge to annualized well pumpage between 1991 and 2000; in 1991 through 1995, the total pumping was considerably lower on average than during the period 1996 through 2000, yet spring discharge was lower in 1991 through 1996 and higher in 1996 through 2000, converse to what is expected if pumping adversely affects spring discharge. Finally, figure 10B shows that spring discharge did not increase even though the White wells pumped very little in 2003 and 2004, and in 2005, spring discharge increased greatly even though the White wells pumped a moderate amount, suggesting a correlation to greater than average precipitation but not to pumping. If increased pumping decreases spring discharge, we would expect a negative correlation between the two, but we actually find a low positive correlation coefficient (0.36) between combined annual pumping at the White wells and annualized spring discharge, consistent with no adverse effect of pumping on discharge.

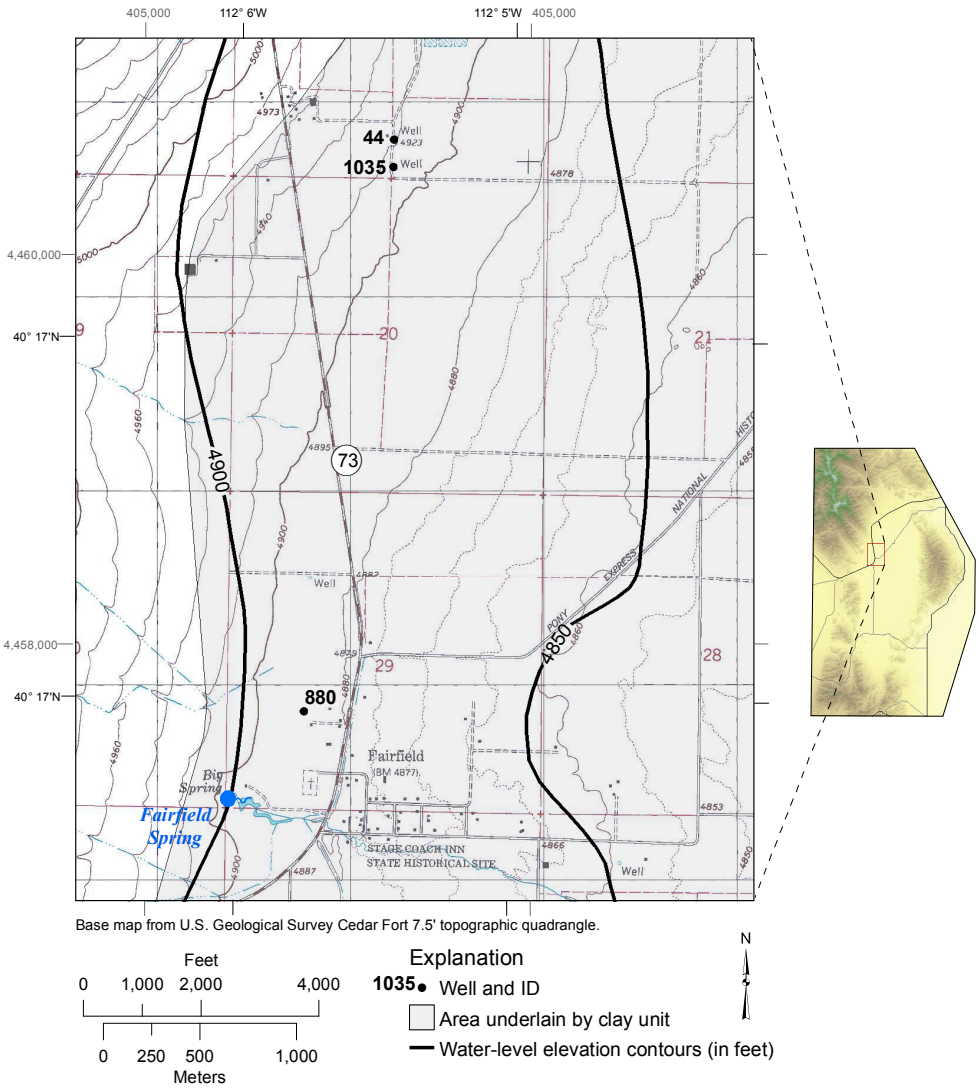


Figure 9. *Fairfield Spring and White irrigation well area, showing water-elevation contours, Cedar Valley, Utah County, Utah.*

Therefore, other environmental factors must control Fairfield Spring discharge variability. Available data indicate no correlation (correlation coefficient of 0.01) between total annual precipitation at the Fairfield weather station and spring discharge in a given year, but show slightly better correlation (correlation coefficient of 0.39) between precipitation and discharge two years later. An even stronger correlation exists between the potentiometric head in wells in the basin-fill aquifer and spring discharge (figure 11). Water levels shown on figure 11 were measured in the north White irrigation well and domestic well 880 (figure 9). The irrigation well is screened in the confined basin-fill aquifer between 4754 and 4337 feet (1449–1322 m) elevation and below 147 feet (45 m) of the clay confining unit; well 880 is open to the same aquifer from 4809 to 4669 feet (1466–1423 m) elevation and below approximately 110 feet (34 m) of the clay. Other wells in the western part of the basin-fill aquifer have similar well completions and exhibit similar water-level trends (figure 7A). The correlation coefficient between water levels measured in the irrigation well and Fairfield Spring discharge measured within 47 days of the water-level measurement is 0.91 and between well 880 water level and spring discharge is 0.94, suggesting that there is a hydraulic connection between the spring, at 4896 feet (1492 m) elevation, and the

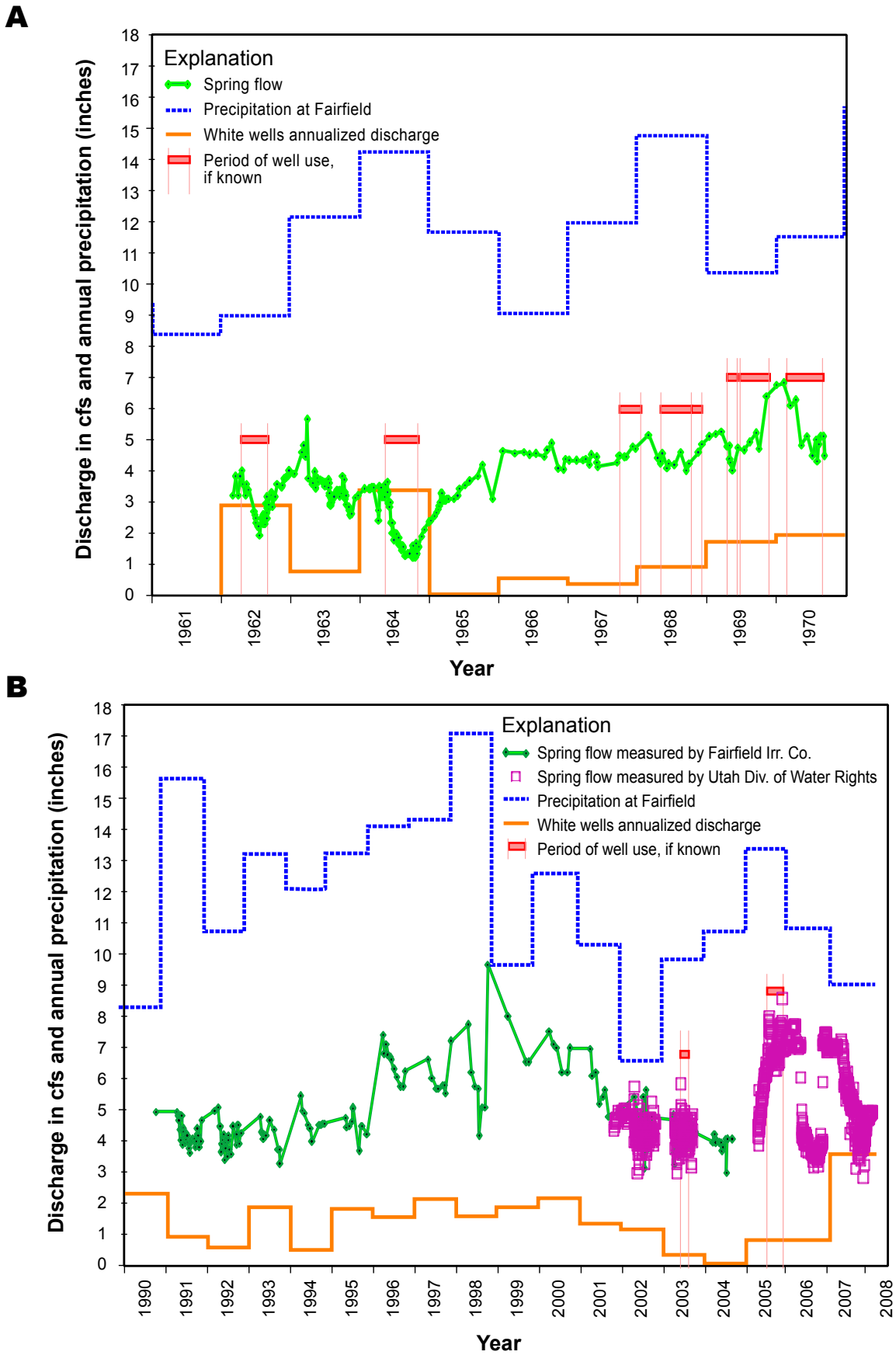


Figure 10. *Fairfield Spring discharge, White irrigation wells production, and annual precipitation during years 1961 to 1970 (A) and 1990 to 2006 (B). Pumping at the White wells only negatively affects spring flow if pumping averages higher than about 2.8 cfs (79 L/s).*

confined aquifer, at elevations between 4809 and 4337 feet (1466–1322 m). Such a connection could exist if either the confining unit is absent at the spring, as could be the case if the spring is located at the western edge of the confining unit, or the continuity of the clay confining unit is interrupted by coarser grained sediments, which provide a conduit for groundwater to reach the surface. Hurlow's (2004) proposed buried alluvial channel hosting the spring could provide a coarse-grained conduit to the west where the aquifer is unconfined. From these data, we conclude that spring discharge is a function of the potentiometric head in the aquifer, which is influenced mostly by the amount of recharge to the groundwater from infiltration of precipitation on the alluvial fan or in the Oquirrh Mountains, and less by pumping.

Urbano and others (2006) investigated the interactions between a groundwater flow system and streams that cross the transition zone where unconfined aquifers become confined, similar to the hydrogeologic setting at Fairfield Spring. They demonstrated that a decrease in stream flow just downgradient of the point the stream crossed the edge of the confining unit was induced by pumping in the underlying confined aquifer. Pumping in the confined aquifer lowered the water table at the edge of the confining unit, which then decreased groundwater discharge to the stream channel and decreased stream flow accordingly. The lower water table allowed recharge that otherwise would have flowed laterally to the edge of the confining unit and then into the stream channel, to be captured by the underlying confined aquifer. Urbano and others (2006) modeled three geologic settings for the section of the stream experiencing the changes in stream flow: (1) lying directly above the edge of the confining unit, (2) in a finger of coarser grained sediment connected with the unconfined, upgradient aquifer, and (3) at a breach in the confining unit. All three are possible settings for Fairfield Spring.

The causes of variations in stream flow demonstrated by Urbano and others (2006) are similar to the causes of variations in Fairfield Spring discharge, as a closer look at potentiometric head demonstrates. The potentiometric head in the aquifer was already low in the late 1950s and early 1960s before the White wells were drilled, as shown by water level in well 880 (figure 11). Annual precipitation at the Fairfield weather station had been below average every year except

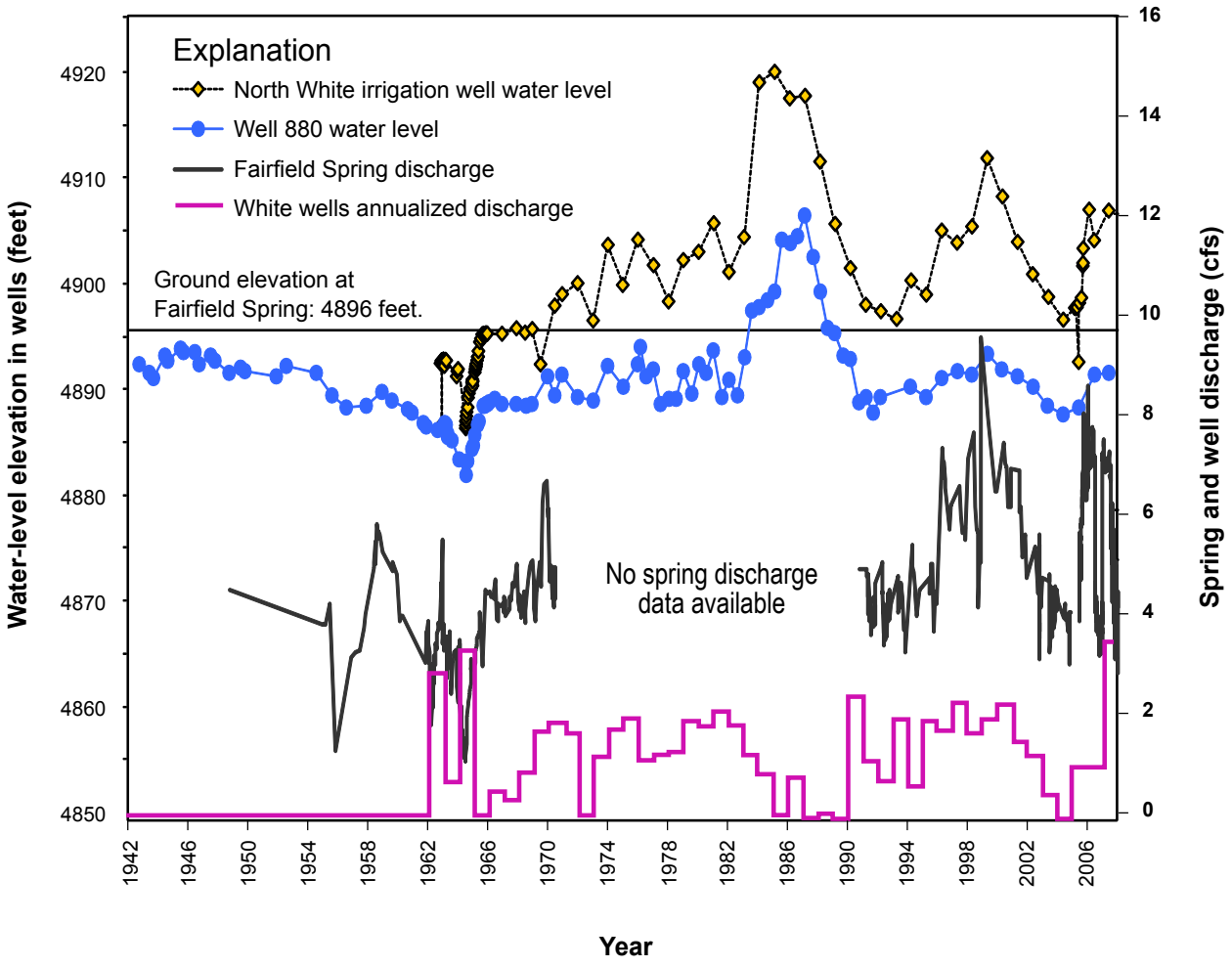


Figure 11. Relationship of Fairfield Spring discharge and White well pumping to water-level fluctuation in wells. Spring flow depends primarily on the potentiometric head in the aquifer, and pumping does not always influence spring flow.

one from 1952 to 1962 (NOAA Western Regional Climate Center, 2006). Production from the White wells in 1962 and 1964 further lowered the head in the aquifer below the level needed to sustain the spring discharge of 4.10 cfs (116 L/s) entitled to Fairfield Spring water-right holders. Potentiometric head decline due to pumping at the White wells may have exacerbated subsequent periods of below-adequate spring discharge, but available data do not clearly indicate this relationship (figure 11).

Potentiometric-head changes in the confined part of the basin-fill aquifer and the resulting changes in Fairfield Spring discharge can occur a great distance from the source inducing the change (i.e., the White irrigation wells) because the radius of influence of a well in a confined aquifer is much larger than in an unconfined aquifer having similar transmissivity. This is because the water must be produced from storage in a confined aquifer, not from draining sediments as in an unconfined aquifer (Fetter, 1988, p. 445). During the UGS aquifer test at the White wells in 2005, we observed water-level response up to 1.4 miles parallel to gradient and upgradient from the pumping wells, but not downgradient (east) (Jordan, 2013). This response is caused by the lower transmissivity of the aquifer to the east, which forces the pumping well to acquire water from an area elongated in the north-south direction along and west of the edge of the confining unit. This coarser grained part of the basin-fill aquifer pinches out to the west against the bedrock of the Oquirrh Mountains. Flow did not decline at Fairfield Spring during the aquifer test; instead, flow increased as part of a trend in response to above average precipitation in 2004 and 2005 that caused potentiometric head in the aquifer to rise (figure 7A, figure 11). Recharge to the aquifer was sufficient to supply the wells and the spring with adequate water.

We agree with previous conclusions (Utah County District Court, 1965; Feltis, 1967; Hurlow, 2004) that Fairfield Spring and the White irrigation wells are drawing from the same principal basin-fill aquifer and that a hydraulic connection exists, but by examining 20 years of additional data that were not available in 1965, we conclude that spring flow is not always negatively affected by pumping at White irrigation wells. Spring flow depends primarily on the potentiometric head in the confined aquifer, which is controlled primarily by recharge to the aquifer. The conditions for direct influence of pumping at the White wells on Fairfield Spring discharge are met only when storage in the aquifer is depleted, which allows the radius of influence of the wells to reach the aquifer at the spring and decrease the potentiometric head at the spring, thereby decreasing spring discharge. Historically, storage, manifested as water levels in wells, has been depleted by extended periods of lower than average precipitation and by pumping greater than approximately 2000 acre-ft/yr (3.2 hm^3/yr) from the White irrigation wells as happened in 1962 and 1964. Projections based on the groundwater flow model support these conclusions, and are discussed along with the other projection results in the numerical modeling section of this report.

HYDROGEOCHEMISTRY

We studied the chemical composition of the groundwater in Cedar Valley to better understand sources of groundwater recharge and groundwater flow patterns. We used general chemistry, radiocarbon and tritium dating, stable isotopes of hydrogen and oxygen, and potentiometric data to evaluate groundwater recharge sources and residence time of groundwater in the aquifers.

Methods

Field Methods and Data Compliation

We collected 45 water samples from 37 wells, 7 springs, and 1 stream in Cedar Valley, Cedar Pass, and Goshen Valley in 2004 through 2007 (figure 12). Following published guidelines for water sampling methods (Barcelona and others, 1985; Yeskis and Zavala, 2002; U.S. Geological Survey, variously dated), wells were purged of at least three well volumes before temperature, pH, and conductivity were determined in the field using a Hydrolab Quanta multiparameter meter. We filtered samples for major cations and trace elements in the field through a disposable 0.45 µm filter using a portable peristaltic pump. We collected 45 water samples for general chemistry analysis in laboratory-provided and preserved bottles and transported them on ice or refrigerated them until delivery to the laboratory. We collected 42 water samples for isotopic analysis in new clear plastic bottles (42 ^{18}O and ^{2}H samples), amber glass bottles (37 samples for ^{3}H), or laboratory-provided five-gallon plastic containers (13 samples for C isotopes). No preservation or filtering was performed other than eliminating head space in the container and sealing the caps securely with electrical tape to prevent interaction with the modern atmosphere. We decontaminated the peristaltic pump tubing and multiparameter probes by triple rinsing with distilled water after sample collection.

We combined our water sample analyses with 139 analyses from several other sources including (1) samples collected in 2001 by the Utah Department of Agriculture and Food (UDAF) (Quilter and Sanderson, 2002) and reported in Hurlow (2004), (2) the National Water Information System (NWIS) database maintained by the U.S. Geological Survey (U.S. Geological Survey–Utah Water Science Center, 2006b), (3) published (Feltis, 1967) and unpublished (Dames & Moore, 1976; Montgomery, 1995) reports, (4) the Utah Department of Environmental Quality, Division of Water Quality (Utah Department of Environmental Quality, 2006), (5) the Utah Department of Environmental Quality, Division of Drinking Water (Utah Division of Drinking Water, 2005), (6) written communication from consultants and cities (J.S. Brown, consultant to Barrick Resources Mercur Mine, written communication, March 21, 2005; M. Sovine, Eagle Mountain City water service manager, written communication, April 1, 2005), and (7) a private well owner. We compiled and examined a total of 184 samples from 119 in-

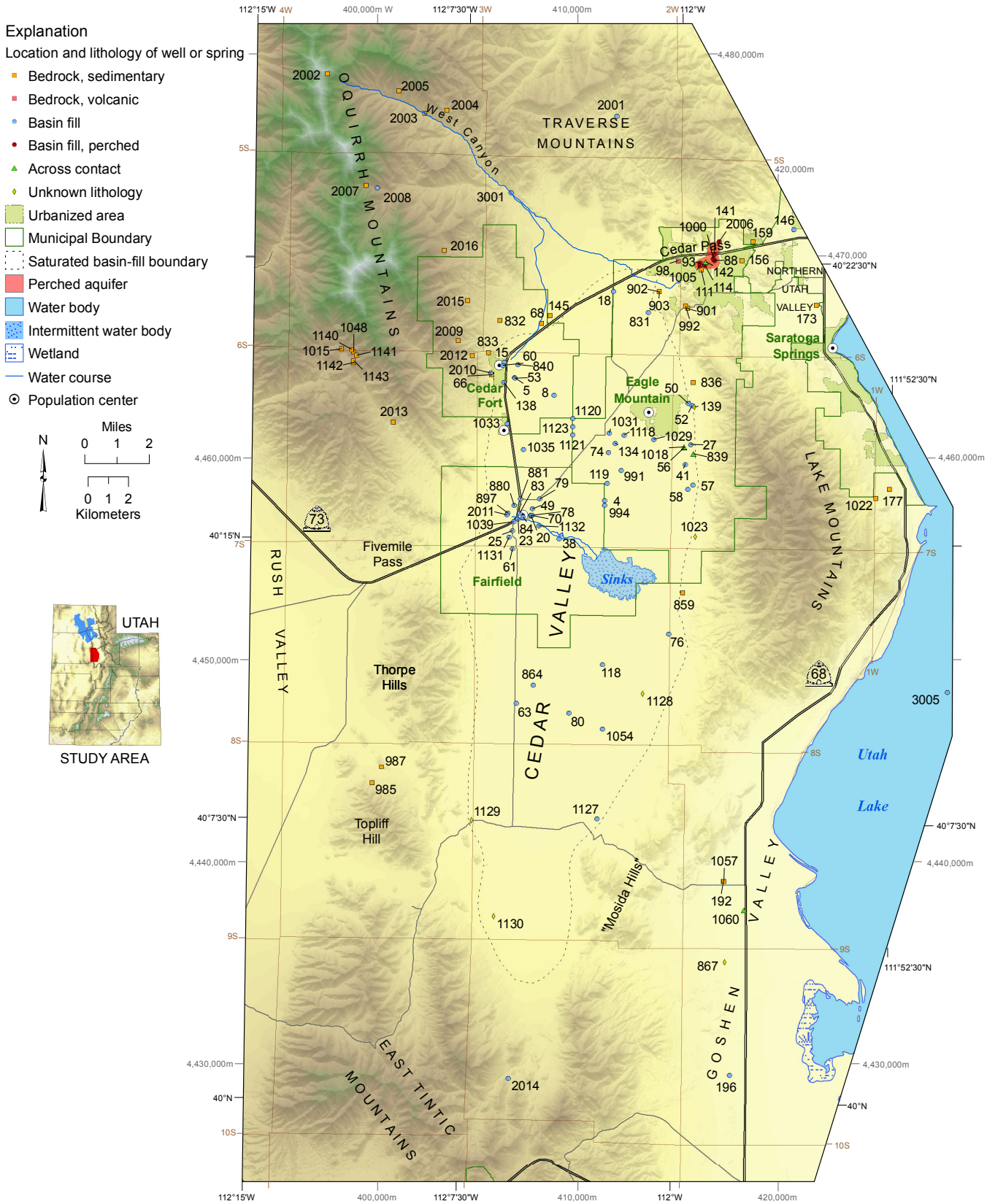


Figure 12. Well, spring, and surface water locations having water-chemistry information in the Cedar Valley study area.

dividual sites. The number and type of samples are tabulated in appendix D, table D-1.

Some data from sources 2, 3, 4, and 5 listed above were collected before 1996. These older samples are the only representative sample available from 30 of 119 sample sites because either the wells are currently not accessible or the site is outside Cedar Valley, and we use the data for general comparison purposes only. Of these 30 sites, six samples were collected in 1965 or 1966 from wells 134, 1031, 1118, 1120, 1121, and 1123 located in the basin-fill aquifer in the center of the valley near an area where one well has shown a change in water quality since that time (discussed in the section Water-Quality Changes Over Time); therefore, concentrations in these six wells were considered approximate values to account for possible water-quality changes in the area since 1966.

Despite the moderate changes in water quality over time at three of twelve sites for which time-series data are available, the water quality in Cedar Valley as a whole has not changed enough to warrant discarding water-quality data from sites where the only sample available is from the 1960s. We used these older data to broadly characterize water-quality types in different areas of the valley and show a progression from one water-quality type to another, and these conclusions would not likely change given the type and magnitude of changes detailed in Water-Quality Changes Over Time below.

Analytical Methods

The State of Utah Public Health Laboratory (UPHL) analyzed samples collected for this study for major and minor general chemistry constituents. The Laboratory of Hydrogeochemistry–Brigham Young University (BYU) Department of Geological Sciences analyzed samples for environmental isotopes (tritium [^{3}H], carbon-14 [^{14}C], stable isotope ratios of oxygen-18 to oxygen-16 [$^{18}O/^{16}O$], deuterium to hydrogen [$^{2}H/^{1}H$], and carbon-13 to carbon-12 [$^{13}C/^{12}C$]). Chemistry results compiled from other sources usually included a general chemistry suite of pH and electrical conductivity measured in the field and major ions of calcium, magnesium, sodium, bicarbonate, chloride, and sulfate analyzed at various commercial and research laboratories. Analytical results for major ions, minor ions, and isotopes are compiled in appendix D, tables D-2, D-3, and D-4, respectively.

General chemistry: Samples collected by UGS and UDAF were analyzed for constituents using standard analytical methods listed in appendix D, table D-5. Total dissolved solids (TDS) in mg/L was calculated by UDAF by multiplying field-measured electrical conductivity in microSiemens per centimeter (µS/cm) by 0.6, an empirical relationship based on field-measured electrical conductivity to laboratory-measured TDS in samples collected in Utah. We analyzed the relation of field-measured electrical conductivity to lab-measured TDS in 76 Cedar Valley samples reported by sources other than UDAF, and concluded that the empirical relationship used by UDAF to calculate TDS produced an error from the measured TDS of -21% to +15%; therefore, the TDS values for samples from UDAF reported in table D-2 should be considered approximate values within a range of approximately ±20%. Analytical methods were not always available for results acquired from sources other than UGS or UDAF, but analyses were generally performed at commercial water-testing laboratories or at university or governmental research laboratories, which use standard test methods.

Constituents in UDAF samples are reported as total concentrations. For all other samples, constituents are reported as total concentrations for all except aluminum, arsenic, barium, cadmium, chromium, cobalt, copper, iron, lead, lithium, mercury, manganese, molybdenum, nickel, selenium, silver, vanadium, and zinc, which are dissolved concentrations.

Stable isotopes of oxygen, hydrogen, and carbon: Stable isotope concentrations of oxygen, hydrogen, and carbon are commonly expressed in delta notation ($\delta^{18}O$, $\delta^{2}H$, and $\delta^{13}C$) as the difference between the ratio of the concentrations of the heavy isotope to the lighter isotope in the sample and that ratio in a standard, relative to the ratio in the standard. The units are permil (‰), and the standard is Vienna Standard Mean Oceanic Water (VSMOW) for hydrogen and oxygen and the Pee Dee Formation Belemnite (PDB) for carbon.

Stable isotope ratios of oxygen, hydrogen, and carbon, $\delta^{18}O$, $\delta^{2}H$, and $\delta^{13}C$, were analyzed at the Laboratory of Hydrogeochemistry–BYU Department of Geological Sciences with an isotope ratio mass spectrometer. More details and references for the analytical methods used at the BYU Laboratory of Hydrogeochemistry are provided in appendix D.

Carbon-14: Radiocarbon (^{14}C) age determination calculations are based on the amount of radioactive carbon remaining in the sample. Carbon isotopes present in the carbon compounds in the sample can be affected by reactions with plants, soil gas, mineral carbonate, and organic matter (Clark and Fritz, 1997; Kazemi and others, 2006). Fossil fuel burning and atmospheric testing of nuclear weapons also alters the carbon-14 content in young water samples (Kazemi and others, 2006). Dr. Alan Mayo at BYU calculated the radiocarbon ages for our water samples using methods described by Pearson and Hanshaw (1970) or Fontes and Garnier (1979) in Clark and Fritz (1997). The starting gas and mineral $\delta^{13}C$ values used were consistent with groundwater flow though carbonate rocks in arid environments. Although these algebraic-formula based geochemical models may not accurately represent the full hydrogeologic system in the study area (Zhu and Murphy, 2000), the age determinations calculated using them are good indicators of the approximate age of the waters in the system. In one study (Plummer and Sprinkle, 2001), these algebraic methods produced groundwater ages several thousand years younger than the uncorrected age determination and a

few thousand years older than those determined using more complicated Netpath (Plummer and others, 1994) computer modeling (Kazemi and others, 2006).

Samples for ^{14}C were processed at the Laboratory of Hydrogeochemistry–BYU to concentrate the carbon before analysis by conventional liquid scintillation counter. More details and references for the analytical methods are provided in appendix D.

Tritium: Tritium (^{3}H) is a radioactive isotope of hydrogen. Tritium concentrations are measured in tritium units (T.U.). Our samples for ^{3}H concentration were distilled and electrolytically enriched at the Laboratory of Hydrogeochemistry–BYU before analysis by ultra low-level liquid scintillation counter. More details and references for the analytical methods are provided in appendix D.

Water Temperature Deviation Above Normal

Shallow groundwater, in the absence of another heat source, should equilibrate to approximately the annual normal mean air temperature in a region. Deep groundwater wells naturally will have warmer temperature water than shallow wells because the water is heated geothermally, and water temperature should be relative to well depth. To demonstrate warm groundwater occurrence in the study area, we calculated the expected temperature range of the well water using the average geothermal gradient in the area and the depth of the midpoint of the screened or open interval. We calculated the midpoint of the open interval as the average of the depth to the bottom and the depth to the top of the screen, perforated interval, or open section of hole. The geothermal gradient in this area is probably in the range of 25 to 45°C (45–81°F) per kilometer of depth (Henrickson, 2000; Blackett, 2004). We used the difference, calculated in degrees warmer than the temperature expected from a geothermal gradient of 45°C (81°F) per kilometer, to indicate the warmer-than-expected areas. Limitations of this method that may produce erroneous calculated temperature differences are (1) the water collected in a sample is generally produced from the most productive strata surrounding the well screen or open interval, which may not be the same depth as the midpoint of the screen interval, (2) in wells having multiple screened intervals, we did not weight the calculation of the depth to the midpoint of the screen interval more heavily toward the more open intervals, (3) the geothermal gradient from Blackett (2004) is not based on wells in Cedar Valley, and (4) water temperature of the sample may be affected by the sampling method.

Quality Control

We collected two sample duplicates for quality assurance of UGS-collected samples (appendix D, table D-6). Analyses were within 10% relative standard deviation for all parameters except selenium, silica, and turbidity, which were at 125%, 100%, and 87% relative standard deviation, respectively. The poor reproducibility of selenium and silica is concerning because selenium is a drinking water contaminant and silica is a major ion that can indicate the nature of water-aquifer matrix interactions. The error for the stable and radioactive isotopes is an absolute value for each analysis and is presented with the results of those analyses in table D-4. Four sample duplicates sent to the U.S. Geological Survey Stable Isotope Laboratory in Denver confirm that stable isotope results reported by the U.S. Geological Survey are comparable to the analyses performed for this study.

Of the 189 samples represented in tables D-2, D-3, and D-4, 165 samples had reported concentrations for the major ions, which allowed us to check that the water sample was electroneutral, a good general indicator of the quality of the sampling and laboratory procedures. All but one of the 165 samples were electroneutral to within plus or minus 10%. The analysis of water sampled in 1976 from well 177, is electropositive by 34%, which indicates that one or more of the ion concentrations are reported incorrectly or there is another anion in substantial concentration that was not analyzed. This sample contained moderately high TDS (1650 mg/L) and the highest arsenic, calcium, and sodium concentrations of any sample represented. Large concentrations of some ions interfere with the analysis of other anions. Also, this sample was analyzed as a part of a reconnaissance study, so quality control was not a primary concern to the investigators. We included the sample in our water quality analysis of Cedar Valley and surrounding area because of its unusual chemistry and the well's location on the eastern side of the Lake Mountains, where water-quality data are scarce.

Results

Water-Quality Changes Over Time

We assessed water-quality changes over time by comparing two or more samples from the same site collected more than 10 years apart (figure 13); twelve sites met this condition. Water quality was determined to be significantly different over time if: (1) individual samples were separated by a difference of more than 20% on any axis on a Piper diagram, and (2) the concentration of any parameter in the last sample, within a measurement error of 10%, was not within 10% of the concentration in the first sample. Using these criteria, three sites showed significant changes in water quality over the period of sampling.

Well 4, located in the center of the valley and drawing from the basin-fill aquifer, had the most significant deterioration in water quality between 1965 and 2001 as indicated by increasing concentrations of several major ions in the 15 samples during that time (figure 13), most notably chloride, magnesium, and calcium. Worsening water quality in the center of the valley may reflect anthropogenic effects of agriculture or dust and

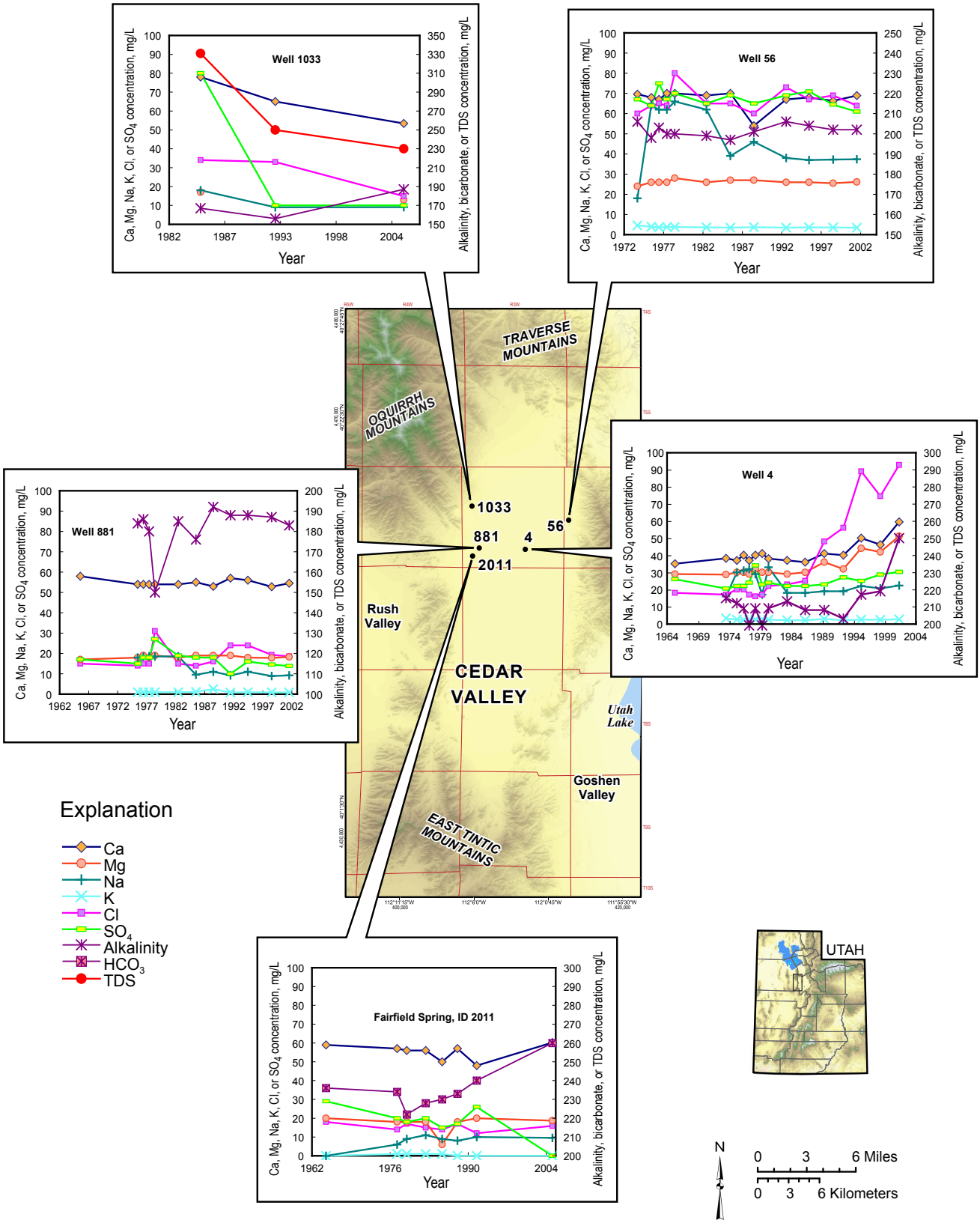


Figure 13. *Major ion concentrations over time in selected wells. Cause of water-quality variation over time was not investigated in this study, but may be due to changing land uses or increased proportion of pumped water from strata that have poor groundwater quality. Water-quality data are presented in table D-2.*

ice control on roads, or it may be caused by an increase in the proportion of pumped water that comes from clay layers after the coarser grained layers have been depleted. Clay-rich aquifer units typically have increased dissolved solids due to longer residence times (Hem, 1992).

A well at the western edge of the basin-fill aquifer, White Hills culinary well (well number 1033), showed significantly improving water quality (figure 13). Another site on the western side of Cedar Valley, South Spring near Cedar Fort town (site number 2010), showed a change in water quality between 1965 and 2005, although with only two sample results available, changes are difficult to verify. The cause of these water-quality changes is unknown.

General Chemistry

Spatial distribution of the total-dissolved-solids (TDS) concentration, an indication of general water quality, in Cedar Valley and surrounding area is shown in figure 14. Several of the springs and West Canyon Creek, sources of recharge to the aquifer system, contain very low TDS water, generally below 300 mg/L. A smaller number of wells and springs in the Oquirrh Mountains show the influence of lithology in their higher TDS concentrations. For example, wells in confining units in the Mercur mining district (the cluster of wells in the Oquirrh Mountains several miles west of Cedar Fort) and a small spring northwest of Cedar Fort (Crafts Spring, ID 2015, TDS 1110 mg/L) issuing along a geologic contact between limestone and shale have higher TDS concentrations. Many of the wells completed in the basin-fill aquifer contain water having TDS concentrations less than 400 mg/L. Groundwater underlying irrigated areas near Cedar Fort has concentrations of up to 982 mg/L TDS and several of the wells sampled in Fairfield contain water with TDS concentrations in the 500 to 750 mg/L range. TDS concentrations in groundwater increase in the southeast part of Cedar Valley where concentrations as high as 2020 mg/L were measured. Several of the wells in the southeast part of the valley shown on figure 14 are currently dry or not in use. The perched unconsolidated aquifer at Cedar Pass contains water having TDS concentrations ranging from 804 to 2252 mg/L.

Water chemistry type varies throughout the study area as illustrated by Stiff diagrams (figure 15), which show the proportions of major ion species in the most recent complete water sample analysis. Calcium and bicarbonate ions dominate waters in the northwest part of the valley, including springs (ID numbers 2000–2017), West Canyon Creek (ID 3001), and wells in both bedrock and basin fill (figure 15). By contrast, sodium or magnesium and chloride or sulfate dominate the water chemistry in the southeastern portion of the valley.

We use Piper diagrams to illustrate the relative abundance of major ions in a sample. The Piper diagram may also illustrate the correlation between the dissolved solids and major ion concentrations by scaling the symbol representing a sample in the upper diamond proportional to the sample's TDS concentration. Figure 16 shows that greater dissolved solids in samples is a result of more sodium, potassium, chloride, and/or sulfate in the water, and not necessarily more calcium and bicarbonate.

The U.S. Environmental Protection primary drinking water standard for arsenic is 10 micrograms per liter (µg/L) (U.S. Environmental Protection Agency, 2010). Groundwater in the southeast part of Cedar Valley, Goshen Valley, and parts of northern Utah Valley contains arsenic above these levels (figure 17, table D-3). Arsenic is found naturally in volcanic gases, certain ores, and in geothermal waters (Hem, 1992). It is used as a wood preservative, and in paints, dyes, metals, drugs, soaps, semi-conductors, and certain fertilizers and pesticides; it may be released to the environment by natural weathering of geologic formations, mining, smelting, coal burning, agricultural runoff, and concentrated animal feeding operations (Hem, 1992; U.S. Environmental Protection Agency, 2007). A point source of arsenic on the valley floor is unlikely because its distribution is widespread, it occurs in wells completed in all rock types, and it is found in the confined aquifer under more than 100 feet (30 m) of clay.

The U.S. Environmental Protection Agency primary drinking water standard for nitrate is 10 mg/L (U.S. Environmental Protection Agency, 2010). Two areas have multiple wells showing elevated nitrate concentration (table D-2)—near Cedar Fort and in the perched aquifer at Cedar Pass (figure 18). Nitrate concentration in groundwater near Cedar Fort ranged from 1 to 10 mg/L, and six of the 11 wells sampled for nitrate in the Cedar Fort area had concentrations over 3.9 mg/L. Six of the seven wells sampled in the perched aquifer had concentrations around 5 mg/L. Nitrate is found naturally in some geologic formations and as a pollutant from agricultural fertilizer, livestock feedlots, explosives, paper mills, and septic systems (Hem, 1992; U.S. Environmental Protection Agency, 2006).

Warm Water Occurrences

Areas that have hot or warm groundwater at shallow depths may indicate a heat source, such as a pluton, or a conduit for groundwater flow that allows heated water to flow to the near-surface more quickly than through the surrounding rock. The difference between sample temperature and the temperature expected at the depth of the midpoint of the well's open interval based on the average geothermal gradient in the area (25 to 45°C [45–81°F] per kilometer of depth, [Blackett, 2004]) is shown on figure 19. Four areas have groundwater that is warmer than it would be if the geothermal gradient was 45°C (81°F) per kilometer: (1) north of Cedar Fort along the projection of the Long Ridge anticline, (2) east of Eagle Mountain town center along the concealed trace of a normal fault, (3) east of Cedar Pass in bedrock wells in faulted rock terrain,

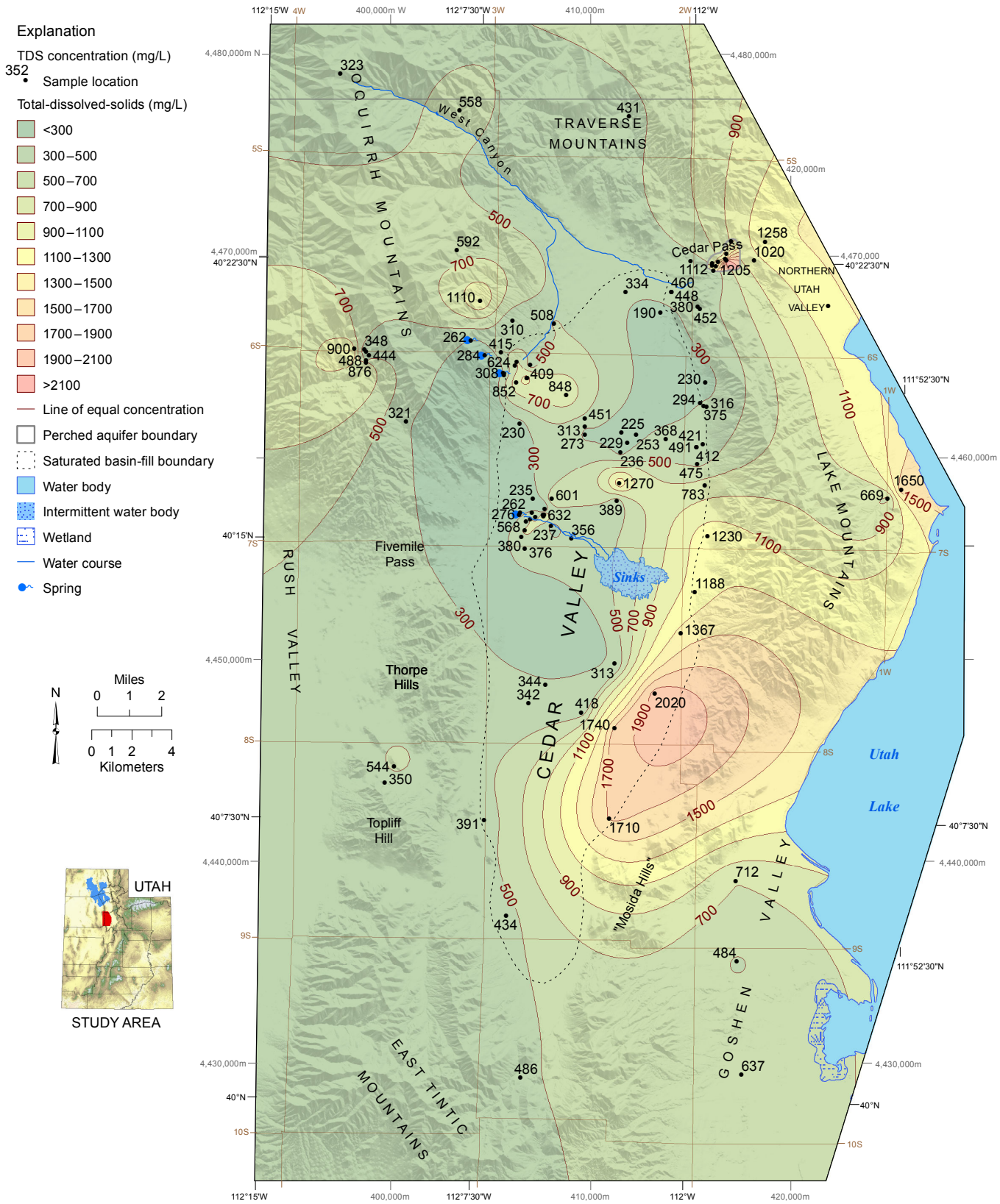


Figure 14. *Total dissolved solids (TDS) concentration in springs and groundwater in the Cedar Valley study area contoured separately for the principal and perched aquifers. Higher TDS is generally associated with reactive geologic formations or irrigated agriculture. Water-quality data are presented in table D-2. Well IDs are shown on figure 12.*

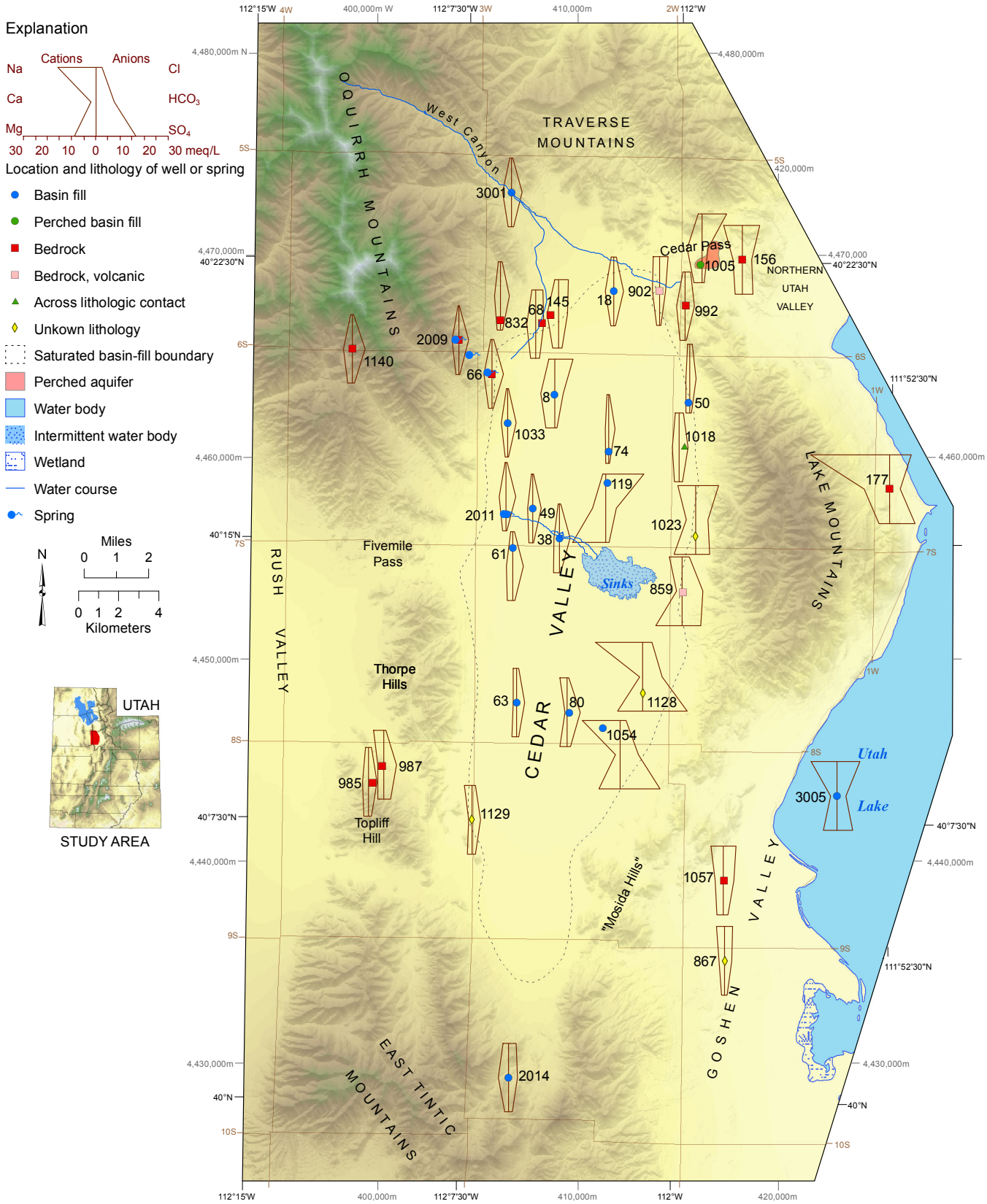


Figure 15. *Stiff diagrams for selected wells, springs, and surface waters in the Cedar Valley study area. Most of the basin fill contains good-quality calcium-bicarbonate type water. Water-quality data are presented in table D-2. Number corresponds to well ID, see table B-1.*

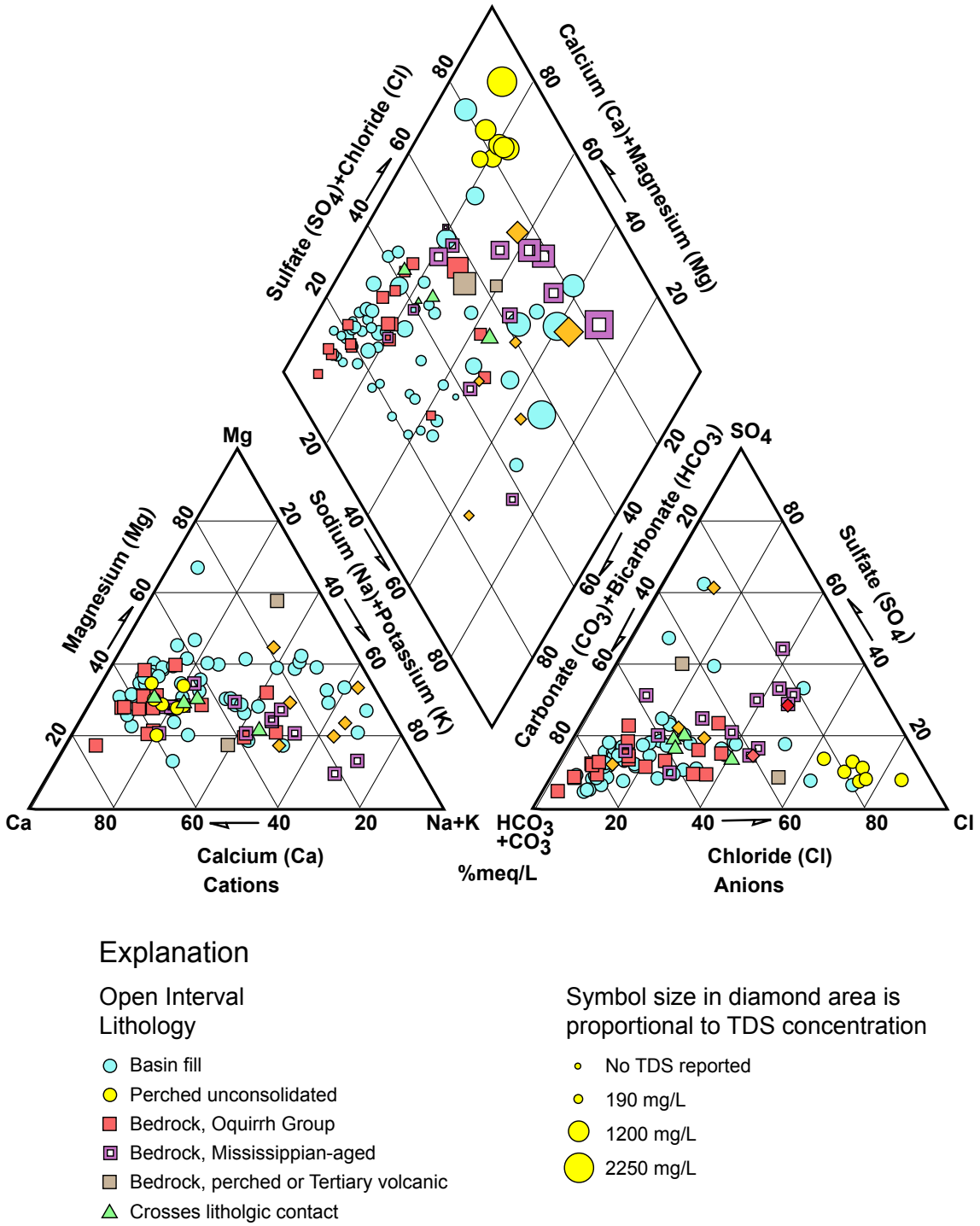


Figure 16. *Major ion composition of representative samples from all sampled wells, springs, and surface waters in the Cedar Valley study area. Higher dissolved solids concentrations are the result of more Na, K, Cl, and SO_4. The perched unconsolidated aquifer at Cedar Pass stands out as having Ca-Cl type water. Water-quality data are presented in table D-2.*

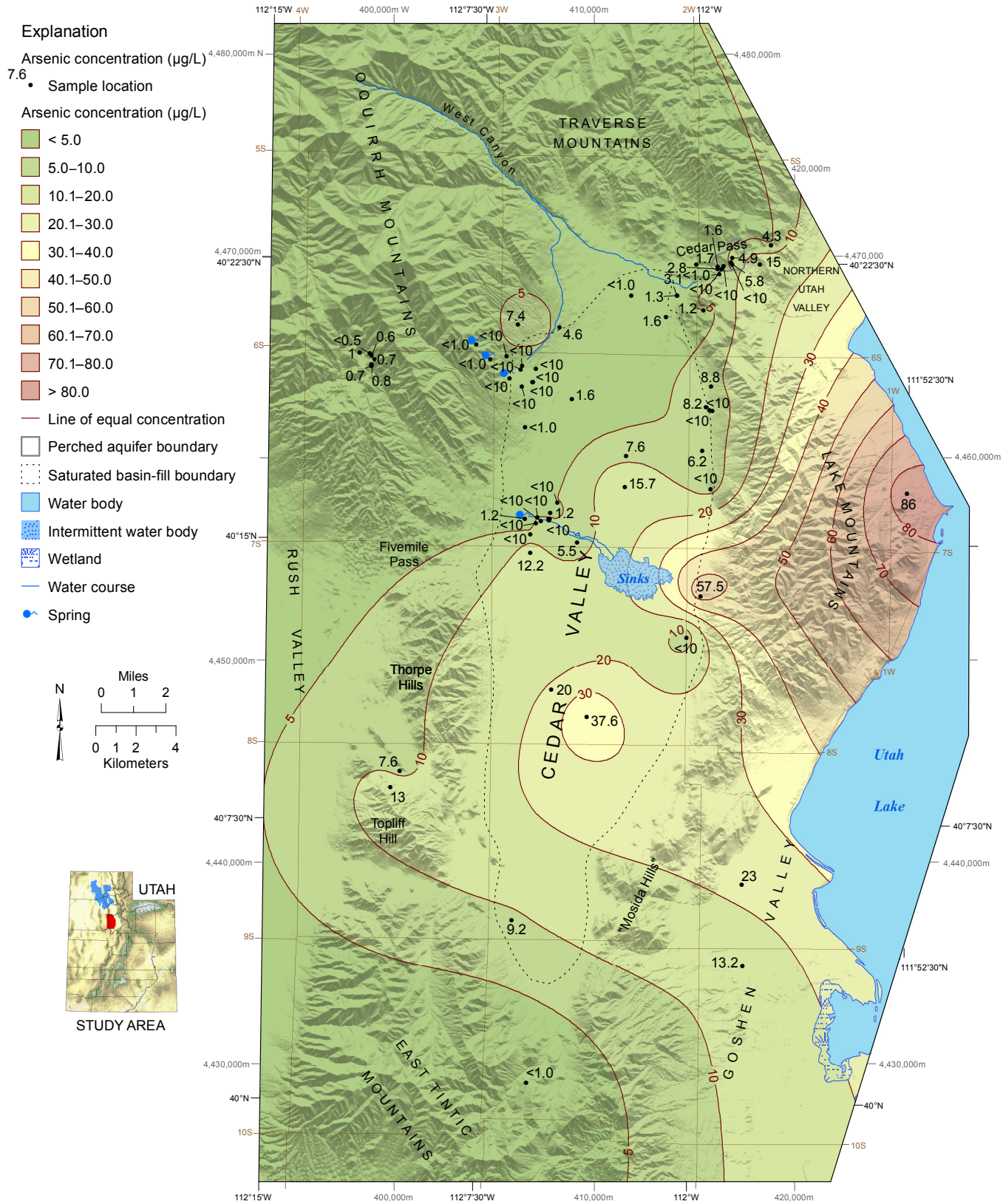


Figure 17. *Arsenic concentration in springs and groundwater in the Cedar Valley study area contoured separately for the principal and perched aquifers. Some areas contain arsenic greater than the primary drinking water standard (10 µg/L), but a point source of the pollutant is unlikely. Water-quality data are presented in table D-3. Well IDs are shown on figure 12.*

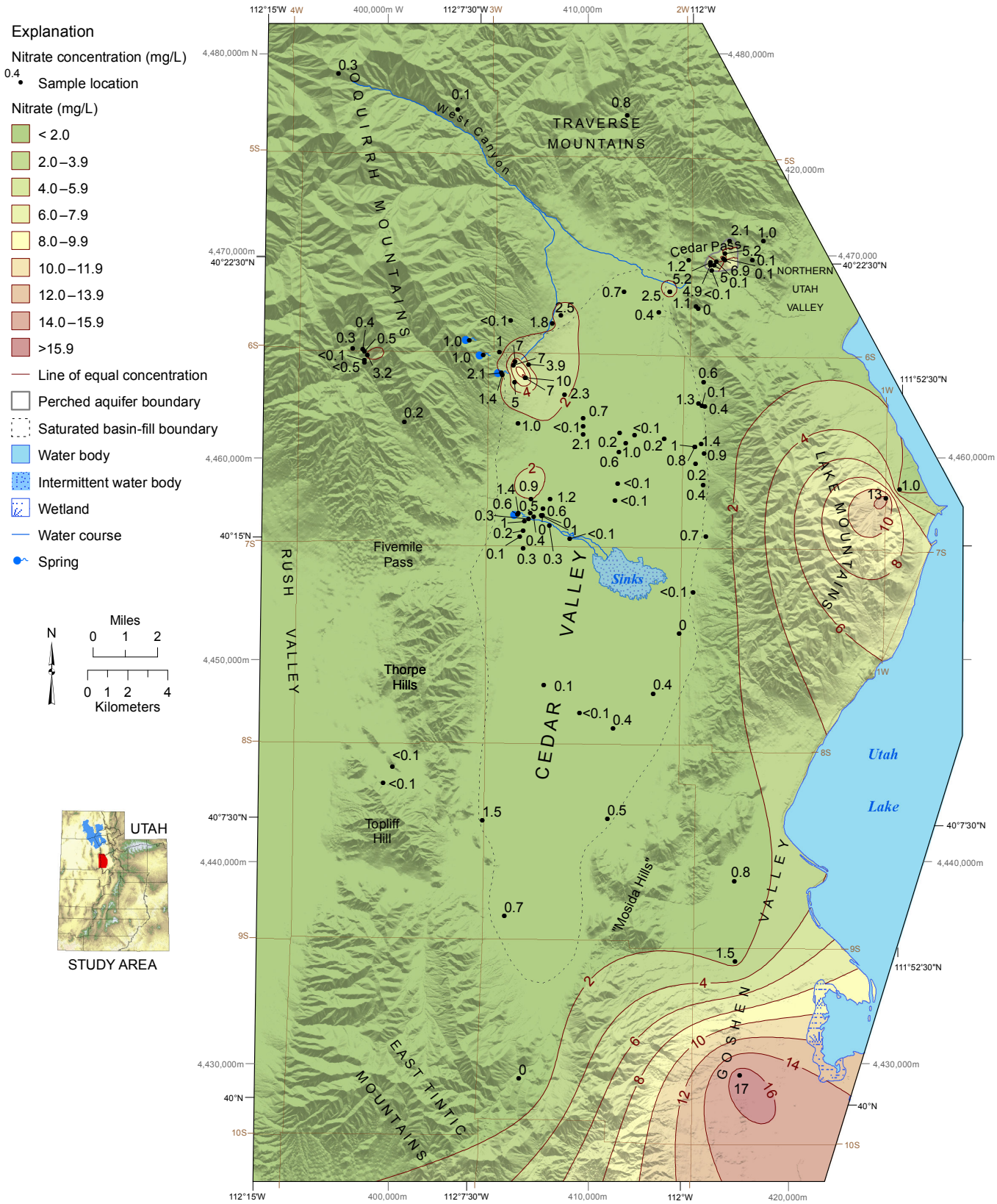


Figure 18. *Nitrate concentration in springs and groundwater in the Cedar Valley study area contoured separately for the principal and perched aquifers. Elevated nitrate may be associated with agriculture and septic-tank use. Water-quality data are presented in table D-2. Well IDs are shown on figure 12.*

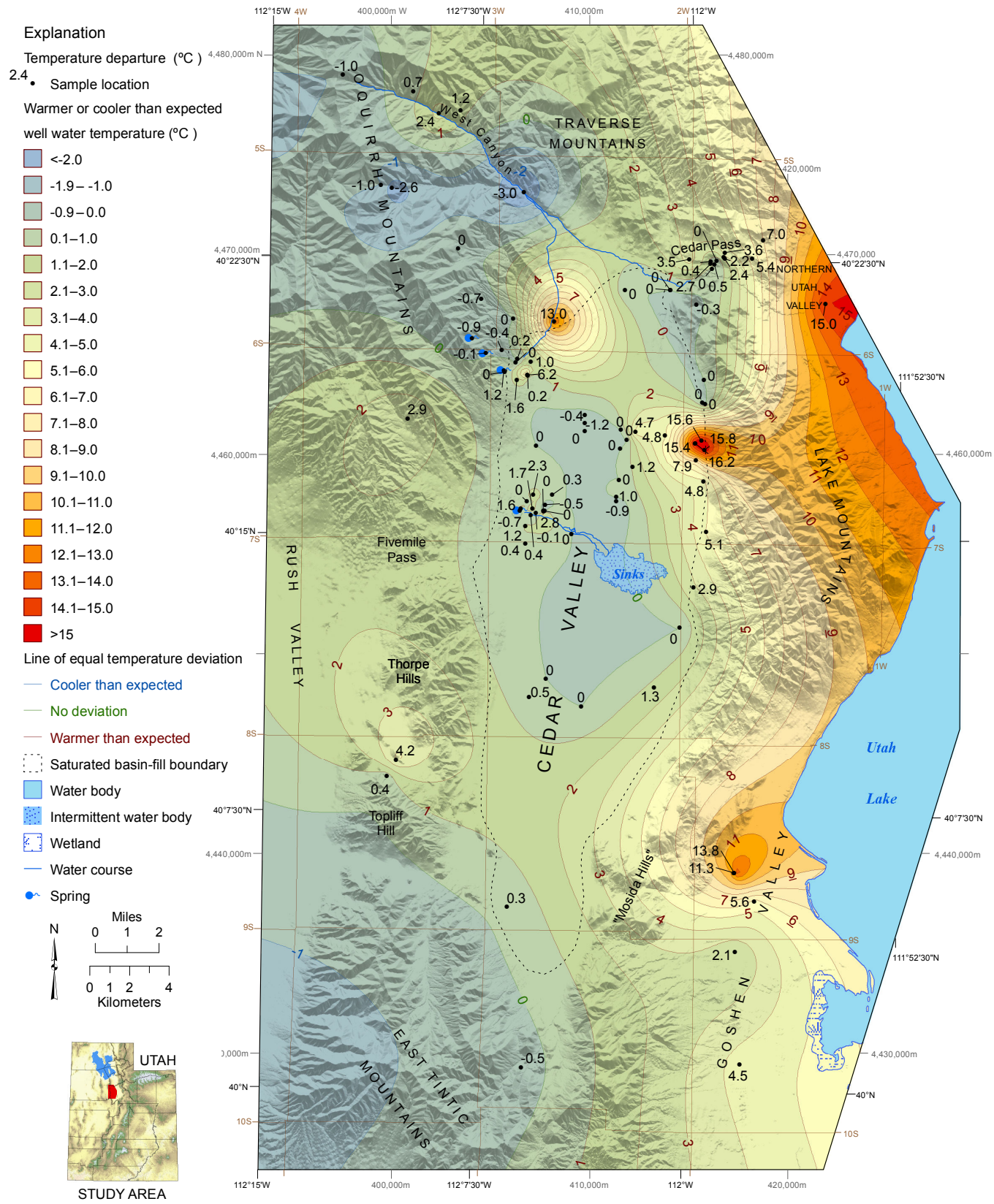


Figure 19. Deviation from expected well water temperature based on well depth and normal geothermal gradient in the Cedar Valley study area. Warm water in wells is an indicator of higher than average permeability that allows geothermally heated water to rise to the near surface. Temperature data are presented in table D-2. Well IDs are shown on figure 12.

and (4) in Goshen Valley. The area east of Eagle Mountain town center has the most elevated groundwater temperature, having four wells less than 540 feet (165 m) deep in which water temperatures range from 23.5 to 29.1°C (74.3–84.4°F).

Stable Isotopes of Oxygen and Hydrogen

Heavy isotopes of oxygen and hydrogen (^{18}O and ^{2}H) are present in small quantities in the water molecule. Meteorological processes affect the concentration of these isotopes in water and impart a characteristic fingerprint of the water's origin in the hydrologic system. The observed differences in concentration correlating to seasons, altitude, latitude, distance from the ocean, and paleoclimates are primarily caused by the effect of temperature on isotopic fractionation between water phases (Clark and Fritz, 1997, p. 47). Isotopically depleted waters are found in cold regions of the earth (both high latitude and high altitude regions), and enriched waters are found in warm regions (Clark and Fritz, 1997). Since most groundwater originates as precipitation, these differences can be used to identify the origin of groundwater.

Over Cedar Valley and the surrounding mountain ranges, continental effects on precipitation are small, and the important causes of differences in the stable isotope concentration in precipitation are the temperature of the precipitation, the history and origin of the precipitation, and whether it evaporates before it recharges the groundwater. While the isotopic concentration of precipitation in individual storms can vary widely from storm to storm and between seasons, mixing of recharge from individual storms in the groundwater system averages the isotopic concentration in groundwater (Clark and Fritz, 1997; Manning and Solomon, 2004; Harvey, 2005; Gammons and others, 2006). However, the difference between isotopic concentrations in high elevation precipitation versus low elevation precipitation is preserved, and this is the basis for most stable isotope studies in mountainous terrain (e.g., Mayo and Loucks, 1995; Thiros, 1995; Brouste and others, 1997; Heilweil and others, 2000; Larson and others, 2000; Parry and others, 2000; Manning and Solomon, 2004; Thiros and Manning, 2004; Gammons and others, 2006). The colder temperature precipitation at high altitude has an isotopically depleted or "light" signature (referring to the relative abundance of lower molecular-weight isotopes) than warmer, low elevation precipitation (Blasch and Bryson, 2007). Therefore, recharge to groundwater at high elevation will have depleted (more negative) oxygen-18/oxygen-16 and deuterium/hydrogen concentration ratios as compared to precipitation that falls at lower elevation (Clark and Fritz, 1997).

Evaporation and high temperature water-rock interactions may impart a distinctive signature to groundwater in Cedar Valley. Because evaporation fractionates the heavy isotopes into the liquid phase (Clark and Fritz, 1997) groundwater recharge that has been subject to evaporation will have an enriched or less negative value. Water-rock interactions in geothermal systems above 100°C (212°F) shift the $\delta^{18}O$ value in a positive direction but do not affect the $\delta^{2}H$ values (Clark and Fritz, 1997, p. 250).

The concentration ratios of oxygen and hydrogen isotopes for 43 wells, seven springs, and one surface-water sample in and around Cedar Valley are reported in table D-4. Values for well waters range between -17.62 and -15.51‰ for $\delta^{18}O$ and -135.9 and -118.6‰ for $\delta^{2}H$, with the exception of wells 859 and 985, which have enriched isotopic signatures. Reported $\delta^{18}O$ and $\delta^{2}H$ values from spring water ranged from -16.68 to -15.21 and -124.9 to -115.9, respectively. We sampled West Canyon Creek shortly after a spring thunderstorm when the creek was swollen with runoff, and consequently, the values are heavily influenced by the isotopic composition of precipitation falling during that particular storm event.

We did not sample precipitation on the high elevations (7000 to 10,400 ft [2000–3200 m]) of the primary recharge area for the Cedar Valley aquifer system, the southern Oquirrh Mountains. Groundwater in the central Oquirrh Mountains and the Wasatch Range can be a proxy to estimate the approximate range of stable isotope values in recharge water in the Oquirrh Mountains. Stream flow and groundwater baseflow to streams has been used as a proxy for precipitation (Kendall and Coplen, 2001; Manning and Solomon, 2004) because groundwater serves as an integrator of highly variable precipitation. Oquirrh Mountain precipitation and baseflow should have similar isotopic concentrations to the Wasatch Range because they are only approximately 30 miles (~50 km) apart and both ranges receive the majority of their precipitation from similar sources. However, the Oquirrh Mountains are not as high as the Wasatch Range, and therefore we should expect Oquirrh Mountains precipitation to be slightly less depleted (have a more negative value) than that in the Wasatch Range.

Butterfield Creek drains the Oquirrh Mountains on the northern side of the drainage divide between Cedar Valley and Salt Lake Valley. Thiros (1995) sampled the stream at its mouth approximately 9 miles (15 km) northeast of the highest elevations in the southern Oquirrh Mountains during baseflow and obtained isotope ratios of -16.45‰ $\delta^{18}O$ and -123.0‰ $\delta^{2}H$. Isotope ratios in streams at baseflow conditions draining the western Wasatch Range are between -17.15 and -16.00‰ $\delta^{18}O$ and -128.0 and -118.0‰ $\delta^{2}H$ (Thiros, 1995). Because the $\delta^{2}H$ and $\delta^{18}O$ values of the Oquirrh Mountain baseflow sample collected by Thiros (1995) on lower Butterfield Creek most likely represent integrated groundwater baseflow of the drainage basin, we assume the higher elevation groundwater recharge would be slightly more depleted (have slightly more negative values).

Mayo and Loucks (1995) sampled shallow groundwater from springs and mines in the central Wasatch Range at elevations between 6000 and 10,000 feet (1800–3000 m). Results for all but one anomalous sample (Manning and Solomon, 2004)

range from -18.0 to -15.5‰ $\delta^{18}O$ and -140 to -122‰ $\delta^{2}H$; mean values are -16.5‰ and -130‰ for $\delta^{18}O$ and $\delta^{2}H$, respectively. The waters sampled in their study (Mayo and Loucks, 1995) are from higher elevation, on average, than the elevation of the majority of the Cedar Valley recharge area in the Oquirrh Mountains, and therefore Oquirrh Mountain recharge would be expected to have slightly heavier isotopic signature than the average isotopic composition of the Wasatch waters reported in Mayo and Loucks (1995). Using the data presented in Thiros (1995) and Mayo and Loucks (1995), we estimate that precipitation-based recharge in the high elevations of the southern Oquirrh Mountains may average between -16.8‰ and -16.3‰ $\delta^{18}O$ and -129‰ and -125‰ $\delta^{2}H$. The East Tintic Mountains are not as high as the Oquirrh Mountains and therefore recharge would be more enriched in heavy isotopes than the Oquirrh Mountains but more depleted than valley precipitation.

The relationship of $\delta^{2}H$ to $\delta^{18}O$ for all water samples is plotted on figure 20. Most samples plot near the global meteoric water line (GMWL), and there are no discernible groupings by aquifer lithology. Two samples depart significantly from the GMWL: well 859 and well 985. Well 859, located east of the Sinks on our maps of $\delta^{2}H$ and $\delta^{18}O$ isoconcentration contours (figures 21 and 22), stands out as having heavier isotope concentrations of -107.1‰ $\delta^{2}H$ and -12.47‰ $\delta^{18}O$ as compared to the majority of our water samples. Well 985, located on the surface drainage boundary between Rush and Cedar Valleys, is enriched in ^{18}O (-7.7‰ $\delta^{18}O$). Aside from these two wells, isoconcentration contours of $\delta^{2}H$ and $\delta^{18}O$ (figures 21 and 22) show similar patterns of isotopically heavier groundwater in springs in the lower elevations of the Oquirrh Mountains and wells on the western side of the valley and lighter groundwater in the middle of Cedar Valley, particularly in the northeastern and southern areas of the valley. The likely isotopic values in Oquirrh Mountain recharge plot near the middle of the range of values seen in our samples.

Tritium and Carbon-14 Dating

Tritium (^{3}H) is a radioactive isotope of hydrogen found naturally in very small quantities in the atmosphere. Tritium concentration in the atmosphere, and thus in precipitation, increased by several orders of magnitude during above-ground testing of large nuclear weapons between 1951 and 1980 (Clark and Fritz, 1997, p. 174). The highest levels of tritium released to the atmosphere were between 1952 and 1962, causing tritium concentrations in precipitation to peak in 1963. Concentrations in precipitation are now largely back to natural levels as the tritium decays to helium-3, but the "bomb" tritium was incorporated into groundwater systems through recharge after 1951. Tritium concentrations in groundwater decrease due to radioactive decay and mixing with un-tritiated groundwater. Because of the 12.43-year half-life and groundwater mixing, precipitation that had significant levels of "bomb" tritium when it recharged the aquifer may now have a similar tritium concentration as recent precipitation. To quantitatively date groundwater using tritium, long-term monitoring, information about recharge and mixing zones, and tritium concentrations in precipitation are needed. In this study, as in other studies (e.g., Mayo and Loucks, 1995; Thiros, 1995; Mahlknecht and others, 2006), detectible levels of tritium in groundwater sampled in 2004 and 2005 are interpreted to indicate the water has some component of modern (post-1951) recharge; whereas levels below the detection limit indicate the water entered the groundwater system before 1951.

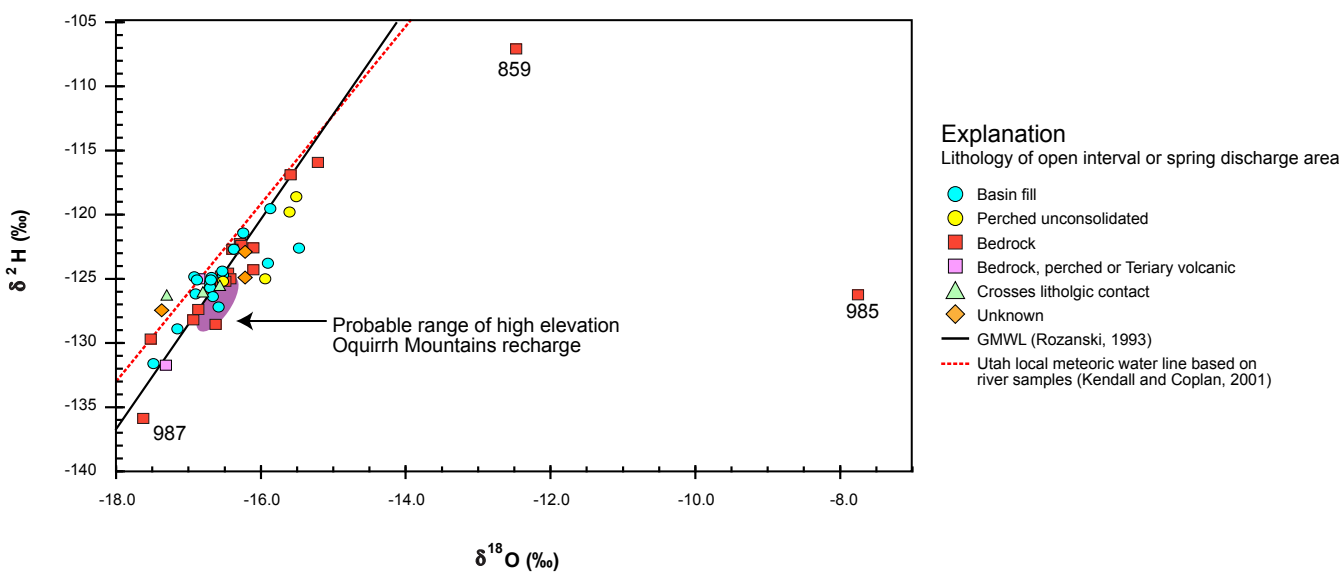


Figure 20. *Stable-isotope ratios of hydrogen versus oxygen in groundwater and springs in the Cedar Valley study area. Most samples plot along the meteoric water line except those labeled and discussed in the text. Water-quality data are presented in table D-4. Number corresponds to well ID, see table B-1.*

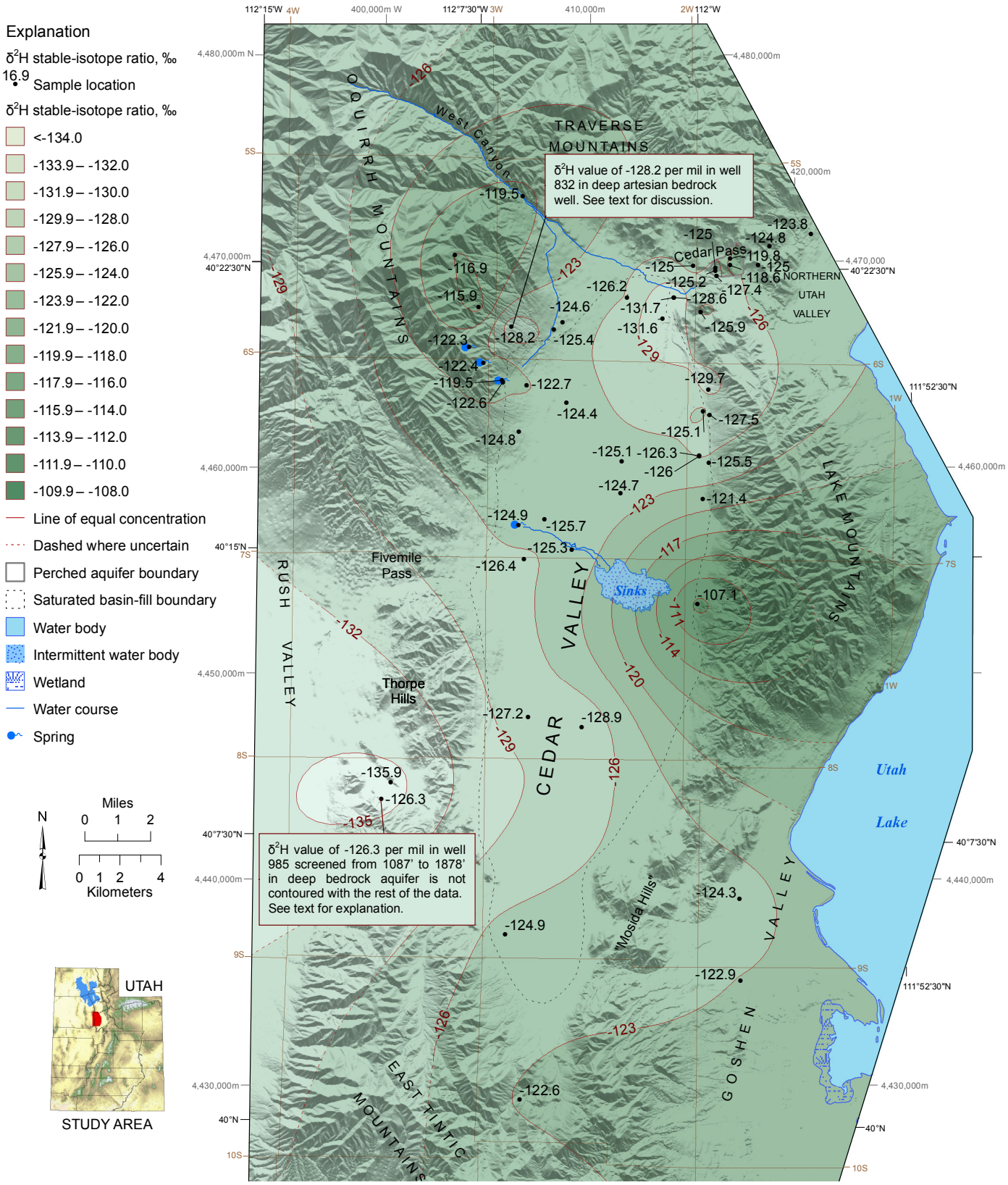


Figure 21. *Stable-isotope ratios of δ²H in groundwater, springs, and surface water in the Cedar Valley study area contoured separately for the principal and perched aquifers. The most depleted water is in the north central part of the valley, suggesting a long flow path from high elevations or recharge in a colder climate. Water-quality data are presented in table D-4. Well IDs are shown on figure 12.*

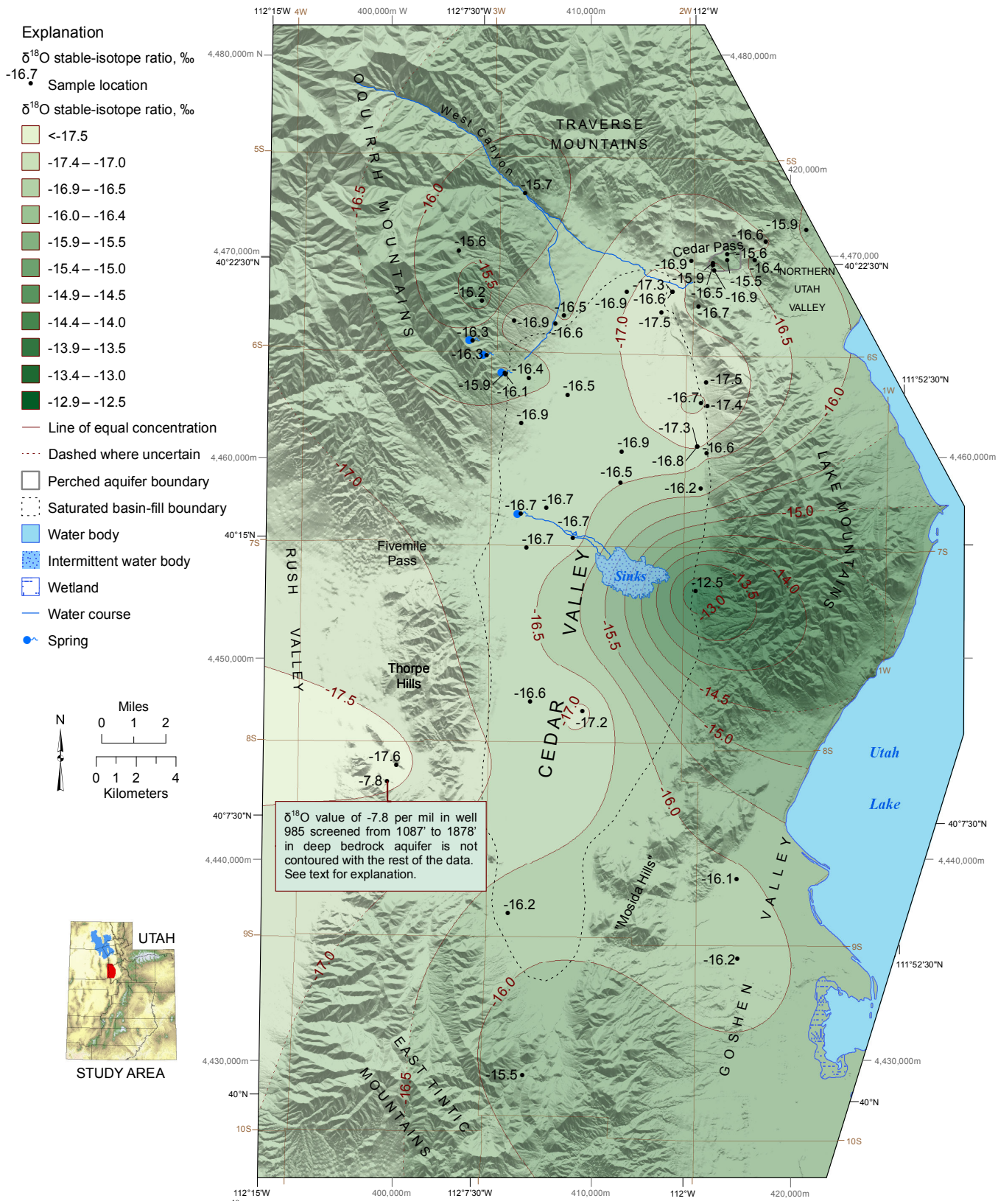


Figure 22. Stable-isotope ratios of $\delta^{18}O$ in groundwater, springs, and surface water in the Cedar Valley study area contoured separately for the principal and perched aquifers. The most depleted water is in the north central part of the valley, suggesting a long flow path from high elevations or recharge in a colder climate. Water-quality data are presented in table D-4. Well IDs are shown on figure 12.

The tritium concentration in samples collected in 2003 through 2007 from wells in and around Cedar Valley ranged from <0.2 to 5.7 T.U. (table D-4). Springs and surface water contained <0.2 to 7.9 T.U. tritium. We found higher concentrations of tritium on the western side of the valley (figure 23). The three bedrock springs in the Oquirrh Mountains and South Spring near Cedar Fort contained some of the highest tritium values analyzed in this study (4.7 to 7.9 T.U. in sample IDs 2009, 2012, 2016, and 2010, table D-4). Fairfield Spring, which is approximately 3 miles from the Oquirrh Mountains and hydraulically connected to the confined basin-fill aquifer, contained 1.3 T.U. of tritium (ID 2011, table D-4). Greeley Spring, in the East Tintic Mountains, did not contain tritium at detectible levels (ID 2014, table D-4). We detected higher concentrations of tritium in water from basin-fill and bedrock wells on the western side of the valley than wells in the central, southern, or eastern portion of the study area. Some wells in the Cedar Pass area completed in the Oquirrh Group and Mississippian bedrock aquifers contained tritium (0.7–2.5 T.U.), and two of the three wells analyzed for tritium in the perched unconsolidated aquifer at Cedar Pass had low levels of tritium (0.2–0.4 T.U.) (figure 23).

We analyzed a small number of wells for radiocarbon dating (table D-4). We selected wells based on the likelihood that they may have water old enough to date with this method; that is, we did not sample springs and shallow wells near the recharge area. Sample results ranged from 3.7 to 56.4 percent modern carbon (pmC), and the $\delta^{13}C$ ratio ranged from -9.2 to -3.5‰ (table D-4). The average carbon-14 age of the water in the wells sampled ranged from 2000 to 18,000 years old (table D-4, figure 24). Bedrock wells on the eastern side of the valley contained the oldest water. Wells in the southern arm of the valley contained old water, and both relatively young and old dates were determined for waters from Cedar Pass. The geologic setting is key to understanding these results and integrating them with other data collected for this study, as discussed below.

Discussion

Perched Aquifer

The water chemistry of samples from wells completed in the unconsolidated perched aquifer at Cedar Pass (well IDs 88, 93, 114, 141, 1000, and 1005, table D-2) is strongly dominated by calcium and chloride ions (figure 16). A water sample from a very small spring north of Cedar Pass (ID 2006, table D-2) reported by Feltis (1967) shows the same calcium-chloride type water as the perched wells. This spring issued from alluvium, but volcanic bedrock, Manning Canyon Shale, and Great Blue Limestone crop out within one half mile of the spring's location. Two possible mechanisms for producing calcium-chloride type water are cation exchange reactions in groundwater in long term contact with shale or clay (Hem, 1992) or saline water interaction with basalt (Ingebritsen and others, 2006). The only well in the area of the perched aquifer that does not have calcium-chloride type water, well ID 142, was drilled deeper, had a deeper water level, and likely is completed in the Tertiary Salt Lake Formation based on a geologist's description of cuttings from a well 120 feet (37 m) away (Utah Division of Water Rights, 2008).

All four samples for oxygen and hydrogen isotopes from perched aquifer wells had slightly less depleted stable isotope ratios ($\delta^{18}O$ -125.2‰ to -118.6‰, average -122.2‰, $\delta^{2}H$ -16.52‰ to -15.51‰, average -15.89‰) as a group than the seven Paleozoic bedrock samples in the Cedar Pass area ($\delta^{18}O$ -128.6‰ to -124.8‰, average -126.0‰, $\delta^{2}H$ -16.86‰ to -16.42‰, average -16.64‰). This suggests that the recharge area for the perched aquifer received warmer precipitation and possibly was at a lower elevation than the recharge area for the surrounding Paleozoic aquifer. Three wells sampled for isotopes in the perched aquifer had traces of tritium (up to 0.4 T.U.) and the ^{14}C age was less than approximately 1000 years.

The similar water quality between every water sample from the perched aquifer and the spring, the slightly more enriched isotope ratios, the young age of the water, and the direction of perched groundwater flow inferred from the potentiometric surface (plate 2) indicate that the source of the groundwater recharge for the perched aquifer is the nearby low-elevation Traverse Mountains to the north.

Spatial Water-Chemistry Trends and Implications for Flow Regime

The relatively low TDS concentration (figure 14) and dominance of calcium and bicarbonate ions (figure 15) in springs and wells in the northwest quarter of the valley (excluding those influenced by shale geology as noted earlier) reflect carbonate rock weathering in an arid climate as a result of precipitation recharging the aquifer through carbonate rocks in the Oquirrh Mountains. The relative abundance of tritium in wells and springs on the western side of Cedar Valley compared to wells in the central, southern, or eastern portion of the study area (figure 23) suggests the recharge source is nearer to the western wells and springs, that is, the Oquirrh Mountains. Tritium concentrations in the spring water indicate that the average time for recharge to each spring is probably less than 50 years. The mountain springs have higher tritium than the lower springs indicating an even shorter travel time. The fact that Greeley Spring (ID 2014), at the southern end of the valley in the East Tintic Mountains, did not contain tritium, and the presence of iron-oxide deposits at the spring, produced when groundwater from a reducing environment comes in contact with oxygen, may indicate that the water travels a longer distance in the subsurface at this location.

The chemistry of water from wells in the Fairfield area is similar to the water chemistry of Fairfield Spring (figure 25), and tritium is present in both the spring water and the well

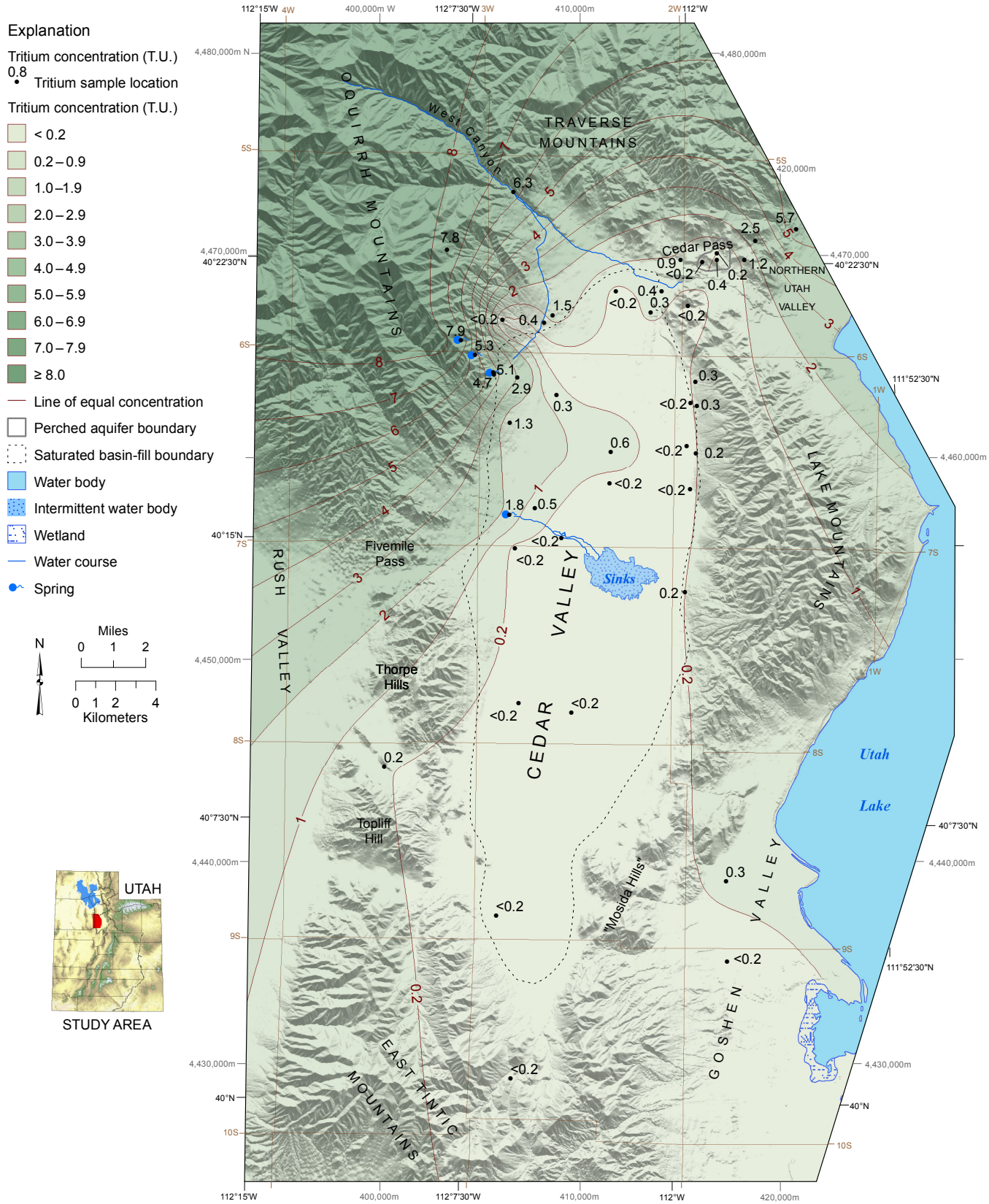


Figure 23. *Tritium concentration in the Cedar Valley study area contoured separately for the principal and perched aquifers. The highest tritium concentrations are observed in western springs and wells and to a lesser extent in the Cedar Pass area, suggesting modern recharge to these areas. Water-quality data are presented in table D-4. Well IDs are shown on figure 12.*

analyzed for tritium in Fairfield (figure 23). These similarities lead us to conclude that, even though the wells in Fairfield are completed beneath a 100-foot-thick (30 m) confining unit, the source of water to the wells is the same source supplying the spring.

Groundwater underlying irrigated areas near Cedar Fort has higher total dissolved solids concentrations (up to 982 mg/L TDS) than the springs and West Canyon Creek water used to irrigate them (235 to 305 mg/L), and generally higher TDS than the water in the basin-fill aquifer in the northern part of the valley (figure 14). Nitrate is also present in higher concentrations in groundwater near Cedar Fort than in the surrounding basin fill (figure 18). The elevated TDS and nitrate in groundwater near Cedar Fort may result from seepage of unused irrigation water from fertilized fields, septic tanks,

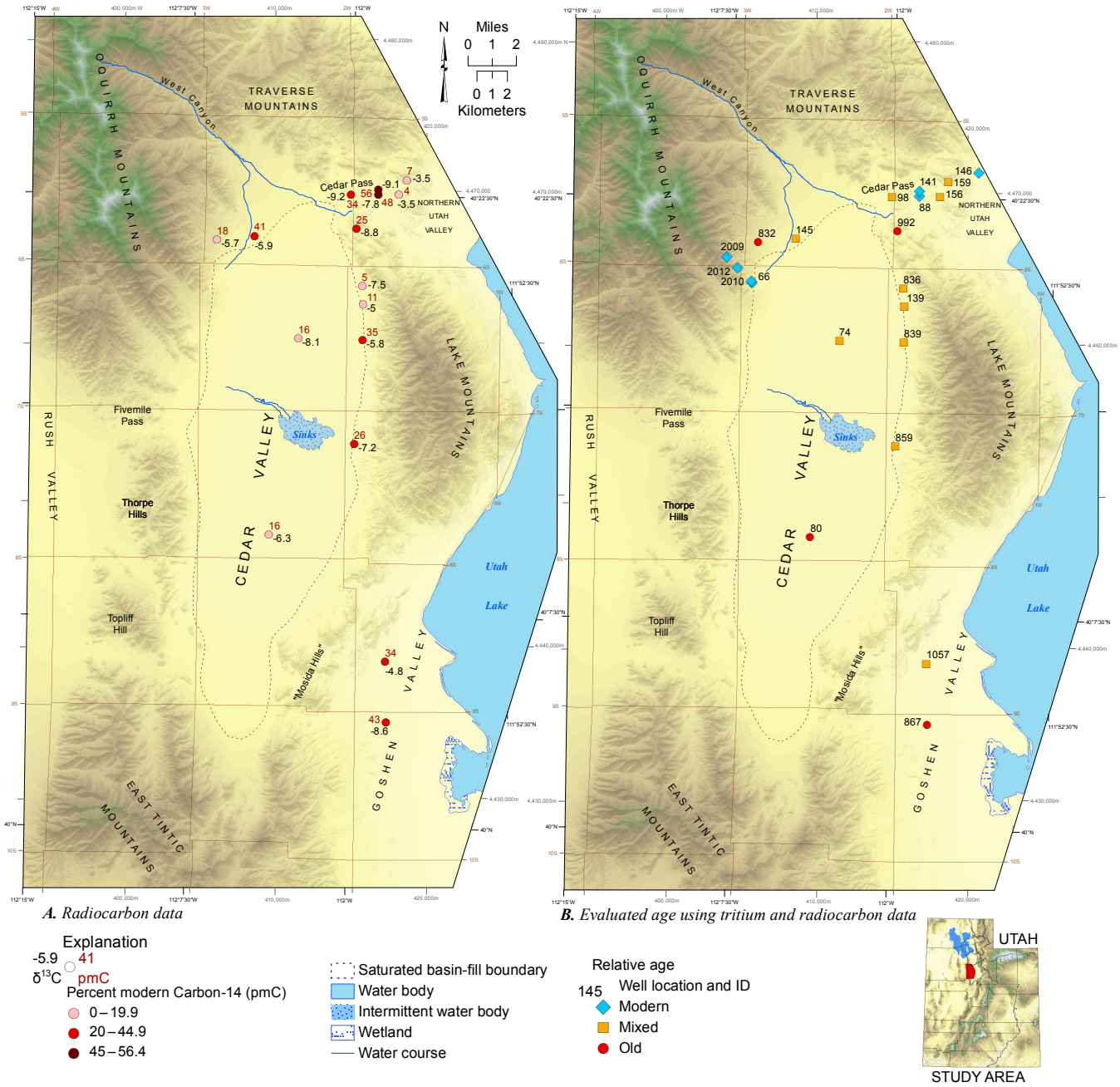


Figure 24. *Radiocarbon data distribution (A) and general groundwater age (B) evaluated using tritium and radiocarbon analyses. Modern or young waters are found only in the western springs and in Cedar Pass; mixed modern and old waters are found throughout the study area; waters with no modern component are limited to a few deep or confined aquifer wells. Combined with stable isotope data, these data suggest shorter recharge pathways on the western alluvial fan and longer recharge pathways to the interior of the valley. Groundwater having mixed modern and old water indicates that wells may derive water from different geologic units having different recharge sources and/or travel times. Water-quality data are presented in table D-4. Number corresponds to well ID, see table B-1.*

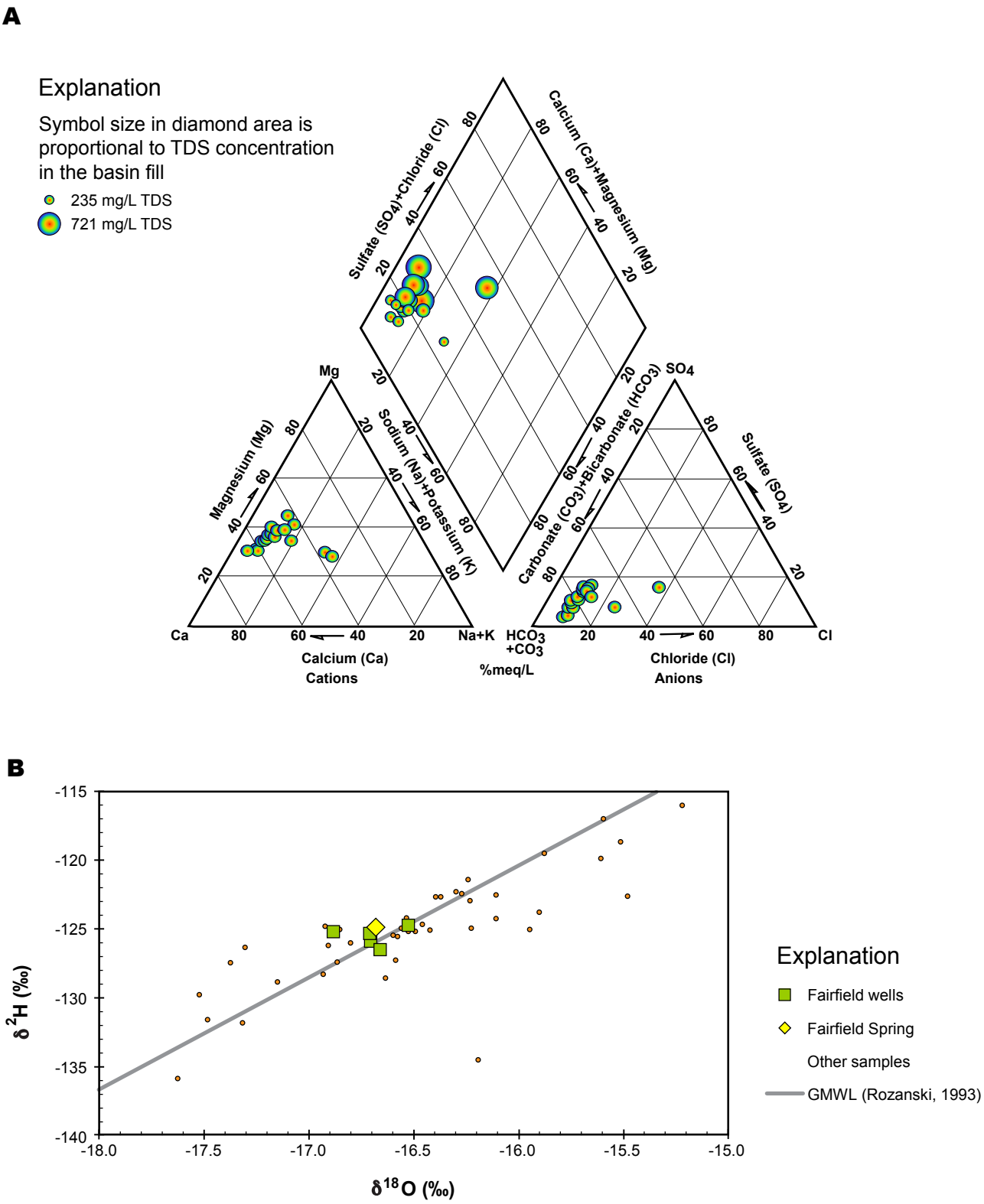


Figure 25. Chemical composition of water in the Fairfield area. Major ion composition of wells in the Fairfield area (A) and stable-isotopes ratios of hydrogen versus oxygen for Fairfield samples as compared to all samples (B). Water from wells in and near Fairfield has similar major ion and stable isotope composition to Fairfield Spring, suggesting one source, despite separation by a 100-foot-thick (30 m) clay layer. Water-quality data are presented in tables D-2 and D-4.

and/or livestock pens, which has been shown to be higher in dissolved solids and nitrate than the surrounding groundwater in other central Utah valleys (Wallace and others, 2002; Wallace, 2010).

Nitrate concentrations in the perched aquifer at Cedar Pass were around 5 mg/L, whereas the upgradient spring, which has very similar water quality to the wells, had a nitrate concentration of only 2.1 mg/L. Although concentrations around 5 mg/L are not a health concern (the maximum contaminant level allowed for nitrate in Utah drinking water is 10 mg/L), we are curious about the source of the elevated nitrate compared to other samples collected for this study. Before residential development of the area starting in 1996, there were a few small dry-farmed fields to which nitrogen fertilizer may have been applied. Although unlikely, the nitrogen may have leached through the 150- to 230-foot-thick (46–70 m) vadose zone to the water table. Possible more recent anthropogenic sources include septic tanks and small numbers of livestock on the 2- to 5-acre (1–2 ha) residential lots in this area. Weathering and leaching of volcanic and evaporative sedimentary deposits are two natural geologic sources of nitrogen (Lowe and Wallace, 2001) possibly present in the unconsolidated sediments making up the perched aquifer. Traces of tritium in the water suggest a travel time for at least some of the water in the perched aquifer of years or tens of years, which excludes neither natural nor anthropogenic sources for the nitrogen. Our data are inconclusive as to the source of nitrate in the perched aquifer at Cedar Pass.

The major ion water chemistry in the Cedar Pass area depends on the aquifer lithology from which each well derives its water. Wells screened, perforated, or open to the principal basin-fill and Oquirrh Group bedrock aquifers (e.g., wells 18 and 992 on figure 15 and most of the blue and red symbols on figure 16) yield water with TDS less than 500 mg/L that is dominated by calcium and bicarbonate ions. The perched unconsolidated aquifer (e.g., well 1005) yields calcium-chloride type water of up to 2250 TDS. Wells in the Great Blue Limestone aquifer (e.g., well 156) also have higher TDS but their waters are sodium and chloride dominated.

The influence of bedrock aquifer lithology on water quality is apparent throughout the study area. Samples from wells and springs that produce water from the Oquirrh Group sandstones and limestones had low-TDS water (average TDS concentration in 24 samples was 445 mg/L) dominated by calcium and bicarbonate ions (figure 26). We noted only two exceptions to this pattern: a well completed in a shaly unit within the Oquirrh Group had higher TDS and sodium-chloride type water, and a spring on the West Canyon Limestone/Manning Canyon Shale contact had a TDS concentration of 1110 mg/L. Conversely, wells or springs known or suspected to produce water from the Mississippian formations or Tertiary volcanic bedrock are dominated by ions other than calcium and bicarbonate and generally have higher TDS concentrations (average TDS concentration in 11 samples from Mississippian-aged rock was 906 mg/L and average TDS concentration in two samples from volcanic bedrock was 824 mg/L). Only one exception to this pattern was found in well 832 [(C-5-2)30dcc-1], an artesian well drilled in 2004 approximately 2 miles (3 km) north of Cedar Fort town. The lithologic log indicates the well is completed in limestone underlying Manning Canyon Shale, which is the Great Blue Limestone in a normal geologic section. The chemistry, however, suggests the well is completed in the Oquirrh Group bedrock. There may be concealed geologic structures that position Oquirrh Group bedrock below Manning Canyon Shale, or the unit marked as Manning Canyon Shale on the driller's log may be a shale within the Oquirrh Group.

Well 832, north of Cedar Fort, and two wells located 1 to 2 miles (1.6–3 km) east of well 832 (figure 12) illustrate the importance of looking at the relationship between the geology and spatial arrangement of wells and the chemical differences between them. The general chemical composition of well 832 is consistent with a source in the Oquirrh Group bedrock units, whereas wells 145 [(C-5-2)28ccb-1] and 68 [(C-5-2)32aab-1], located 1 to 2 miles (1.6–3 km) east of 832 have major ion chemistry consistent with wells completed in Mississippian formations (figure 26). The wells also differ in isotope signature; well 832 has more depleted stable isotope values (-128.2‰ δ^2H, -16.93‰ δ^{18}O) (figures 21 and 22), lower pmC (18 pmC), and older relative age (figure 24) than wells 68 (-125.4‰ δ^2H, -16.59‰ δ^{18}O) and 145 (-124.6‰ δ^2H, -16.45‰ δ^{18}O, 41 pmC). The chemical differences can be explained by examining the depth and geologic setting of the wells. Well 832 is a deep artesian well drilled through a confining shale unit and screened in limestone between 818 and 1280 feet (249–390 m) below land surface; wells 145 and 68 are screened in limestone in the top 150 feet (46 m) of saturation. Water that recharged the aquifer at high elevations through Oquirrh Group bedrock in Pole Canyon and followed a deep flow path to well 832 would produce the Oquirrh Group chemical signature, depleted isotope signature, and older relative age in 832; whereas wells 68 and 145 may be intercepting water that recharged on Mississippian-aged strata at lower elevations in West Canyon. The younger relative age of water in well 145 also supports a more local recharge source as compared to well 832.

Wells 68 and 145 produce warm water (23.5°C [74.3°F]) (figure 19) and are located along the projected axis of the Long Ridge anticline and possibly near a concealed normal fault (Biek, 2004). The isotopic signature of the water from wells 68 and 145 (absence of a δ^{18}O shift) does not indicate a geothermal origin. One explanation as to why the water is warm if it is not from a geothermal source is that the relatively local recharge has circulated through the fractured, anticlinal axis to depths great enough to heat it before it follows a pathway along a fault to the wells. Whatever the lithology and structural setting of the wells, well 832 and the two wells east of it do not appear to share the same recharge source because of the different recharge elevation shown by the oxygen and hydrogen

isotopes, the difference in temperature and relative age, and the difference in major ion composition.

Water in the southeast part of the valley has higher TDS concentrations than the other areas of the valley. Floyd (1993) found evidence for widespread buried volcanic rocks in the southern arm of the valley, as the driller's log shows for well ID 859 [(C-7-1)7bda-1]. Geologists have identified volcanic rocks overlying Paleozoic bedrock and underlying basin fill on the western and northeastern sides of the valley in at least three drill holes [wells (C-5-2)24cdd-2, (C-6-2)7ccc-1, and (C-5-2)24aab-1]. Christiansen and others (2007) studied the rocks in the Soldiers Pass area (referred to in this paper as Mosida Hills) and concluded that potassium-rich Paleogene volcanic rocks exposed in Mosida Hills likely had a local source. The nature and timing of the eruptions provides the source for the volcanic rocks suspected by Floyd (1993). Mahlknecht and others (2006) and Johannesson and others (1997) showed the influence of volcanic rock type on the chemical characteristics of recharge water. In these studies, rhyolitic and an-

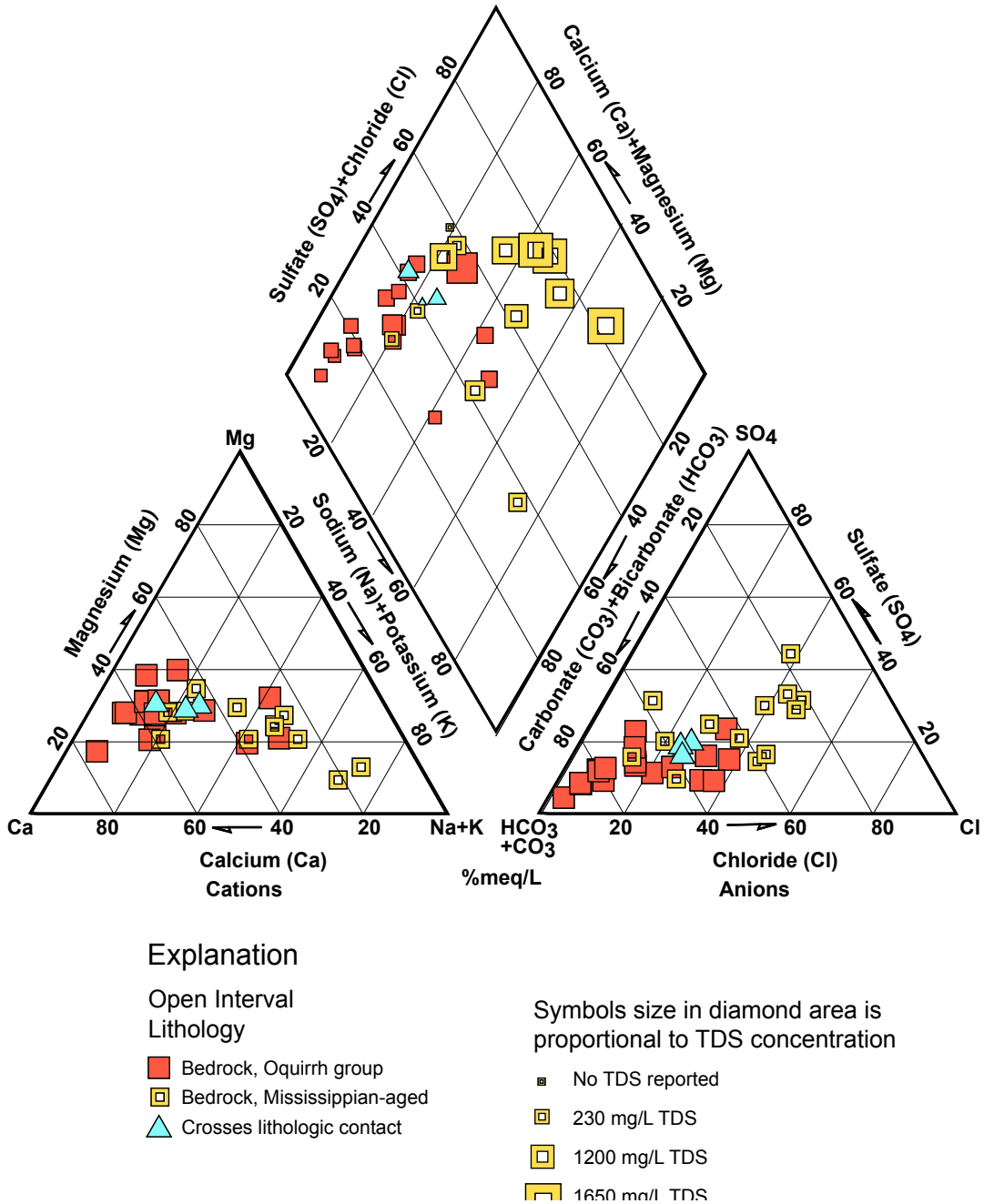


Figure 26. *Chemical composition of bedrock aquifer water samples in the Cedar Valley study area. The difference between Oquirrh Group bedrock (Ca-HCO_3 type) and Mississippian bedrock (richer in Na and Cl or SO_4) is evident. Water-quality data are presented in table D-2.*

desitic rocks produced sodium-bicarbonate or sodium-potassium-bicarbonate type water. Some of the volcanic rocks at Mosida Hills are enriched in soluble elements such as barium, lead, and potassium (Christiansen and others, 2007), and we hypothesize that these volcanic rocks have imparted sodium and potassium to the groundwater.

Johannesson and others (1997) hypothesized that calcium-bicarbonate type water from the Paleozoic carbonate-rock aquifer in Nevada had picked up sulfate from gypsum deposits and sodium from felsic volcanic rocks along the flow path. Playas were probably present intermittently in the Cedar Valley closed basin during the late Pleistocene and early Holocene (Currey, 1990; Hurlow, 2004), and may have left salt and gypsum deposits in the subsurface of the southern arm of Cedar Valley. Evaporite deposits may also form subaqueously from deep lakes undergoing rapid brine concentration due to drying climate, as indicated in core samples of Great Salt Lake sediments (Balch and others, 2005). Probable evaporite deposits and volcanic rocks in the subsurface are likely sources of the much higher concentrations of dissolved constituents in the southern arm of the valley (figure 15).

The water type in wells sampled in Goshen Valley is dissimilar to water upgradient in the southern arm of Cedar Valley (figure 15). The presence of some tritium and more modern carbon (figures 23 and 24) in Goshen Valley water as compared to southern Cedar Valley water suggests that, although potentiometric data indicate groundwater flows from Cedar Valley to Goshen Valley, at least a portion of the water in Goshen Valley likely has a source other than interbasin flow through Mosida Hills. The warm water occurrence in the Goshen Valley wells (figure 19) has been attributed to deep circulation of meteoric water along permeable fault zones (Cordova, 1970; Goode, 1978). Fault zones are also implicated in warm groundwater movement in mines in the nearby East Tintic Mountains (Hamaker and Harris, 2007). Water in Goshen Valley may be a mixture of water that wells up from the carbonate bedrock and water from the Cedar Valley basin fill passing through the Soldiers Pass volcanic rock complex. We performed theoretical mixing calculations using various waters sampled in this study, but water similar to that found in Goshen Valley was not a product of any two existing waters using conservative, i.e. non-reactive, mixing. Interaction between Cedar Valley groundwater and the aquifer matrix along the flow path to Goshen Valley is likely, and there may be other types of water or sources of solutes in Goshen Valley or Mosida Hills that we did not sample.

Environmental Isotopes and Implications for Recharge Source and Residence Time

Isoconcentration contours of δ^2H and δ^{18}O (figures 21 and 22) show similar patterns of isotopically enriched groundwater in springs and wells in the lower elevations of the Oquirrh Mountains and isotopically depleted groundwater in the middle of Cedar Valley, particularly in the northeast and southwest areas of the valley. One well on the eastern side of the valley has water enriched in heavy isotopes of both oxygen and hydrogen, and another well on the border between Rush Valley and Cedar Valley is greatly enriched in oxygen-18. The percent modern carbon content of the water does not regularly decrease with distance from the recharge source as one might expect (figure 24); to explain the distribution of the data, we must interpret the results in three dimensions while taking into consideration the geologic setting of each well. The following sections discuss conclusions about the groundwater flow system drawn from these patterns.

Springs: Five mountain spring samples collected for this study (site IDs 2009, 2012, 2014, 2015, and 2016) issue from bedrock in the lower elevations of the Oquirrh and East Tintic Mountains between elevations of 5720 and 6960 feet (1740–2120 m) and have isotopic ratios between -16.29‰ and -15.21‰ δ^{18}O and -122.6‰ and -115.9‰ δ^2H. These values are enriched in heavier isotopes as compared to precipitation that falls at higher elevations in local mountains, which supports a theory of a local, middle elevation recharge area for each mountain spring.

Small springs such as Greeley (ID 2014), Crafts (ID 2015), and Fourmile (ID 2016) have enriched isotopic signatures compared to larger Fairfield (ID 2011) and South (ID 2010) Springs (figures 21 and 22). Their small flow suggests a small, local catchment area, around the elevation of these springs at roughly 5800 feet (1770 m), 6000 feet (1830 m), and 7000 feet (2130 m). The larger springs discharge at lower elevations around 4900 to 5200 feet (1490–1580 m); if the catchment area for the larger springs is also local, the isotopic signature should be more enriched than that of the small springs above them, but we observe the opposite trend. The larger springs have more depleted isotopic signatures, suggesting their recharge areas may encompass higher elevations where more isotopically depleted precipitation falls. A larger recharge area is also consistent with the larger discharge at South and Fairfield Springs. The higher elevation mountain springs also have higher tritium concentrations than the lower, larger springs consistent with local, small catchments in which travel time is short for the mountain springs (figure 23).

Wells: Most of the wells in the northern half of Cedar Valley have values of δ^2H ranging from -126.4‰ to -124.4‰ and δ^{18}O ranging from -16.92‰ to -16.52‰. These values are more depleted than those of the springs and wells located upgradient that we suspect represent low elevation mountain recharge, as discussed above. This suggests the water in the majority of the principal basin-fill aquifer has a component that fell as precipitation higher than approximately 7000 feet (2100 m), infiltrated to bedrock in the Oquirrh Mountains, and traveled through the bedrock to enter the basin-fill aquifer at depth. The mid-range values found in wells completed in the confined aquifer along the western margin of the valley are evidence that wells here have a comparatively lower eleva-

tion recharge area. Therefore, the water in the north-central portion of the valley is most likely a mixture of the western margin recharge and deep bedrock recharge.

Some of the most depleted isotope values sampled in this study (δ^2H values less than -126‰ and δ^{18}O values less than 17.0‰, figures 21 and 22, respectively) occur in wells along the northeast margin of the valley. These depleted isotope values, along with old ^{14}C groundwater age (figure 24, wells 139 and 836 in table D-4) and very low level or absence of tritium in these wells (figure 23), indicate water in this area may have been recharged as precipitation during a cooler glacial climate and/or as the highest elevation recharge, as on the Oquirrh Mountains during past glacial periods. Paleoclimate research suggests a colder and wetter glacial period ended approximately 15 thousand years ago with the onset of a drying and shrinking Lake Bonneville (Balch and others, 2005). Later, warmer tropical moisture falling in summer may have dominated the northern Great Basin around 11 thousand years ago (Currey, 1990); as recently as two to three thousand years ago, the northern Great Basin may have been somewhat colder and wetter than it is today (Currey, 1990).

By comparing figures 21 and 22 to figure 23 and figure 24, we see that the oldest water roughly correlates to the isotopically depleted water, suggesting that this water is from recharge during the last glacial cycle when Lake Bonneville occupied the valley. Well 139 [(C-6-1)7dba- 2], completed in the bedrock aquifer on the eastern side of Cedar Valley, fits into this group (δ^2H -127.5‰, δ^{18}O 17.37‰, ^{14}C age 18,000 years), while nearby confined basin-fill well 50 [(C-6-1)7dbb- 1] has isotope values similar to the values in the main part of the Cedar Valley basin-fill aquifer (δ^2H -125.1‰, δ^{18}O -16.69‰). The southwest area of the valley also has wells having depleted isotope values and old water. Long travel times are consistent with the fine-grained sediments and low production capacity of wells in the southern part of the valley.

Wells in the Paleozoic bedrock in the Cedar Pass area have depleted stable isotope values (δ^2H -128.6 to -124.8‰, δ^{18}O -16.86 to -16.42‰) relative to wells in the perched aquifer above them, and similar values to the main part of the Cedar Valley basin-fill aquifer. The Cedar Pass bedrock wells contained up to 1.2 T.U. tritium and had low to moderate percentages of modern carbon (figure 23 and figure 24A). These data suggest there may be a component of modern recharge in an otherwise quite old fractured bedrock flow system (mixed relative age, figure 24B), which receives its recharge from precipitation in the Oquirrh Mountains.

Well 859 is located southeast of the Sinks (figure 12) and is completed in Tertiary volcanic bedrock. The major ion chemistry is dominated by magnesium, bicarbonate, and sulfate, the sample had a TDS concentration of 1188 mg/L (figure 15), and it is greatly enriched in deuterium and oxygen-18 (-107.1‰ δ^2H, -12.47‰ δ^{18}O) (figures 21 and 22). Water from Fairfield Spring flows to the Sinks, where it may pond for months before evaporating or seeping into the ground. After undergoing evaporation, the residual water left in the Sinks as a source of recharge to the groundwater would be enriched in heavy isotopes (Clark and Fritz, 1997) and concentrated in dissolved solids. Groundwater potentiometric contours show a slight mound around the Sinks, indicating groundwater recharge. The direction of groundwater flow is east and southeast from the Sinks toward well 859 (plate 2). The isotope chemistry and local hydrology of well 859 are consistent with the Sinks being a source of recharge to the well; however, the major-ion chemistry of well 859 (table D-2) is not simply a concentration of Fairfield Spring water. Chemical changes of the water during impoundment in the Sinks or interaction with playa sediments or volcanic bedrock before the water reaches the well screen has changed the dissolved constituent ratio from that of Fairfield Spring water. Detectible tritium in the water and relatively little modern carbon may indicate that this well produces water from strata containing both recent recharge and much older water.

Well 985, on the border between Rush and Cedar Valleys near Tenmile Pass and Topliff Hill, is completed in a deep, hydrologically isolated bedrock aquifer in the Mississippian Humbug and Deseret Formations (plate 2). The oxygen-18 shift away from the GMWL (figure 20) is evidence for water-rock interaction above approximately 100°C (212°F) (Clark and Fritz, 1997, p. 250). Although the stable isotope signature suggests a geothermal origin for this water, the water temperature was not elevated higher than expected for a well of this depth (figure 19), suggesting that the travel time and/or distance is long enough to allow the water to equilibrate to ambient temperature.

Thermal waters: Wells yielding elevated temperature water (greater than 5°C [9°F] elevated, figure 19) have a narrow range of isotope values (-126.3 to 124.3‰ δ^2H and -17.30 to 16.41‰ δ^{18}O) near the middle of the range found throughout the study area and have indications of mixed modern and old water (figure 24). The similarity of isotope values suggests that the thermal water may be an integration of water throughout the basin. A possible flow path that could lead to the observed temperature and isotope signature is one in which water recharges in the mountains and follows a deep flow path where it is heated before traveling up along geologic structures to wells. Mixing of old and modern water suggested by the isotope signature is likely during transport of old, deep water to the near surface in a fractured bedrock flow system. Because mixing would affect heat loss, the old deep groundwater would necessarily need to be warmer than observed in warm water wells. With no mixing, groundwater would have had to travel to depths of between 1500 and 2700 feet (450–800 m) (based on a geothermal gradient between 45º and 25ºC [81–45°F] per km of depth) to be heated to the temperature observed in wells; mixing with cooler modern water would require a deeper flow path or one through an area where the geothermal gradient is greater than 45°C (81°F) per kilometer.

WATER BUDGET AND CONCEPTUAL MODEL OF GROUNDWATER FLOW

Table 2 lists the sources of recharge and discharge to the Cedar Valley hydrologic system and the values we estimated for each. We used these values, or a subset of them in the case of springs and wells that are included in the groundwater flow model domain, as starting values in the digital groundwater flow model. A discussion of each source or sink and the methods we used to calculate our estimates follows. Supporting calculations and annual values are provided in appendices E (recharge) and F (discharge).

Table 2. *Cedar Valley conceptual model initial water budget estimates for 1969 to 2004 or 2007.*

Budget component	Range[1]	Average	Years estimated [2]
RECHARGE	acre-ft/yr	acre-ft/yr	
Precipitation recharge on mountains	14,000–43,500	25,500	1969–2007
Precipitation infiltration on valley floor [3]	0–16,900	4500	1969–2007
Unused irrigation seepage	550–1500	1100	1969–2004
West Canyon Creek seepage	70–1600	800	1969–2004
Cedar Fort Ditch seepage	40–600	300	1969–2004
Fairfield Sinks seepage	200–400	200	1969–2004
Septic tank and wastewater seepage	30–130	40	1969–2004
Subsurface inflow from Rush Valley	0	0	1969–2004
Total recharge[4,5]	**15,000–64,100**	**32,100**	
DISCHARGE	acre-ft/yr	acre-ft/yr	
Subsurface outflow to Cedar Pass	7700–14,600	12,000	1969–2007
Subsurface outflow to Mosida Hills	2300–4400	4000	1969–2007
Well withdrawal, all wells [6]	1300–10,500	4000	1969–2007
Fairfield Spring	2900–6300	3800	1969–2007
Evapotranspiration from groundwater	1700–4000	3200	1969–2004
All other springs	1000–2200	1000	1969–2004
Base flow to West Canyon Creek	200–1800	900	1969–2004
Total discharge[5]	**26,000–36,300**	**28,900**	
	Average Difference[5]	3700	

[1] See appendices E, F, and G for annual values.

[2] Detailed calculations for all recharge and discharge sources were done for 1969 to 2004. Additional calculations for 2005-2007 were done on the largest or most important flow components when we extended the model's time domain.

[3] Precipitation recharge estimate for the conceptual model water budget is the geology-refined Maxey-Eakin estimate of recharge from precipitation minus estimates of indirect recharge, i.e. seepage source estimates.

[4] Total recharge is the geology-refined Maxey-Eakin estimate of recharge from precipitation to the four recharge areas contributing to the groundwater system.

[5] Average values are the average of annual values for each budget component, whereas the average total recharge and discharge values are the average of the annual sum of recharge or discharge components, and therefore, the ranges and averages for total recharge and discharge may not be the sum of the range and average values for each component.

[6] Includes all wells in the groundwater basin, including wells outside the digital groundwater flow model domain in the Cedar Pass area, that discharged an additional several thousand acre-ft/yr starting in about 2005, as discussed in the text.

Recharge

Recharge to the Cedar Valley groundwater system, in order of decreasing average volume, is from (1) direct infiltration of precipitation, (2) seepage from streams and canals, (3) seepage of unused irrigation water, including water in the Sinks, (4) seepage from septic tanks and wastewater treatment plants, and (5) possibly minor subsurface flow from adjacent Rush Valley (Hood and others, 1969) (figure 27). Tables E-1 through E-3 contain compiled data for each of the sources. We discuss methods for calculating recharge estimates for the conceptual model are below and have tabulated the pertinent points in table E-4.

Precipitation

Feltis (1967) estimated recharge to the Cedar Valley basin-fill aquifer from precipitation to be 24,000 acre-ft/yr (30 hm^3/yr) using precipitation data from 1931 through 1960. We updated this recharge estimate using a method similar to that used by Feltis and precipitation records for the transient groundwater flow model simulation period, 1970 to 2007. We estimated recharge from precipitation for the Cedar Valley aquifer system using three basic steps: (1) we obtained the spatial distribution of annual precipitation for each year from published precipitation data, (2) we estimated the annual recharge for each year in Cedar Valley using a percentage of precipitation, which varies spatially depending on land surface elevation, according to a method described by Maxey and Eakin (1949), and (3) we refined the resulting recharge based on geologic outcrop characteristics.

First, we obtained PRISM (Parameter-elevation Regressions on Independent Slopes Model) precipitation data for the study area (PRISM Climate Group at Oregon State University, 2006). PRISM is a precipitation model that incorporates point data, a digital elevation model, and other climatic components such as rain shadows, coastal effects, and temperature inversions to produce continuous, digital grid estimates of monthly, yearly, and event-based climatic parameters. PRISM data sets are available on the PRISM Climate Group website (http://prism.oregonstate.edu/). The online PRISM precipitation data for the United States has a grid cell resolution of 800 meters by 800 meters (2625 ft x 2625 ft). Overlaying the precipitation grid onto our study area resulted in 74 precipitation zones, each with an estimated precipitation rate.

We classified Cedar Valley into eight precipitation/recharge regions based on the spatial distribution of precipitation and

recharge in the study area (figure 28). We overlaid these eight regions onto the 74 precipitation zones created from the PRISM dataset, which produced 114 new precipitation zones (figure 29). We estimated the total precipitation in each zone for each year from 1969 to 2007 from the annual PRISM data and averaged the data for the 39-year period (figure 29).

Our second step involved estimating the recharge from precipitation using the Maxey-Eakin method, which was developed for 13 watersheds in east-central Nevada (Maxey and Eakin, 1949). Others have applied the Maxey-Eakin method, with some modification, to estimate recharge in valleys near Cedar Valley (Hood and Waddell, 1968; Hood and others, 1969; Razem and Steiger, 1981; Lambert and Stolp, 1999) and most of the valleys in the Great Basin (Harrill and Prudic, 1998; Nichols, 2000). Avon and Durbin (1994) evaluated the Maxey-Eakin method and compared it to recharge estimates made using the chloride-mass balance method, groundwater flow models, deuterium ratios, and water budgets and concluded that recharge estimates using the Maxey-Eakin method are reasonably good.

The Maxey-Eakin method (Maxey and Eakin, 1949) is based on the assumption that areas having higher precipitation result in more groundwater recharge than areas having lower precipitation. In each zone of equal precipitation, a fraction of that precipitation, termed the recharge efficiency, is assumed to recharge the groundwater system. The recharge efficiency is higher for zones of higher precipitation, which usually coincide with higher elevation. In the Cedar Valley study area, we used the recharge efficiencies developed by Maxey and Eakin (1949) to initially estimate the water available as recharge in each zone of precipitation (table 3). We assigned the appropriate recharge efficiency value to the 114 precipitation zones and then multiplied the value by the precipitation rate for each zone to estimate the annual recharge from precipitation for each zone for each year from 1969 to 2007 and averaged for all 39 years (figure 30).

Step 3 addressed the fact that geologic properties of the rocks or sediments receiving precipitation are not factored into the Maxey-Eakin method (Maxey and Eakin, 1949). To account for differences in recharge rates due to geologic conditions, we introduce a factor we term the "geologic outcrop sensitivity to recharge" based on the relative permeability of each type of outcrop (table 3). We determined this factor, which ranged from 0.1 to 1, using information from our aquifer tests, published values of hydraulic conductivity for various rock and sediment types, and the degree of weathering and surface fracturing, if noted on geologic maps and sources. We then applied the factor to the corresponding outcrop (figure 31) on Hurlow's (2004) geologic map of the study area. Hood and Waddell (1968) modified the Maxey-Eakin

Table 3. *Recharge efficiency values for a geology-refined Maxey-Eakin recharge estimate based on precipitation zones and sensitivity of geologic outcrop to recharge for Cedar Valley.*

Annual precipitation (inches)	Recharge efficiency
0–8	0.00
8–12	0.03 (3%)
12–15	0.07 (7%)
15–20	0.15 (15%)
>20	0.25 (25%)

Geologic outcrop type	Sensitivity to recharge
Younger alluvial fans	1 (100%)
Oquirrh Group, Great Blue Limestone, fractured Cambrian carbonates	0.75 (75%)
Volcanic rock	0.75 (75%)
Middle Paleozoic carbonate aquifer, other older sedimentary bedrock	0.5 (50%)
Older alluvial fans	0.25 (25%)
Tertiary sediments	0.25 (25%)
Laucustrine sediments	0.1 (10%)
Manning Canyon Shale, other aquitards	0.1 (10%)

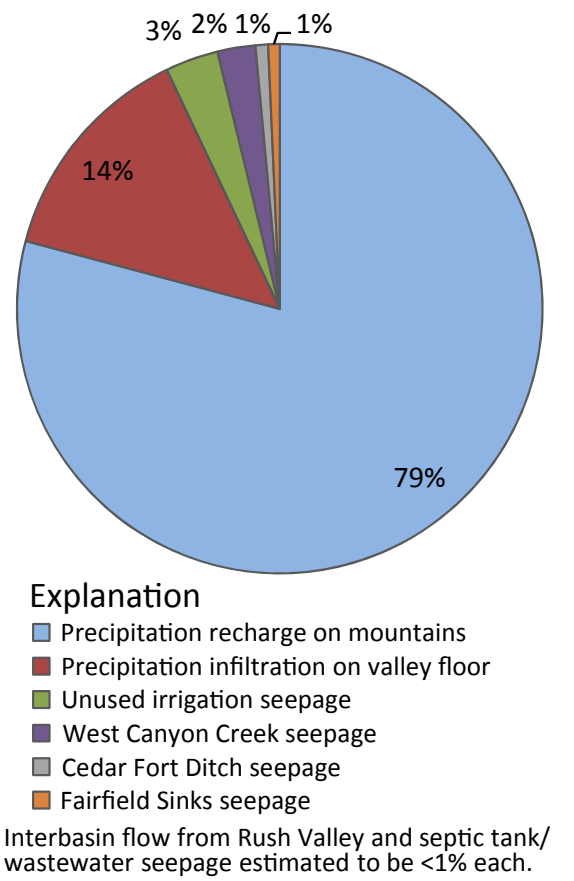


Figure 27. *Contribution to Cedar Valley recharge from various sources estimated for conceptual model (average values 1969 to 2007).*

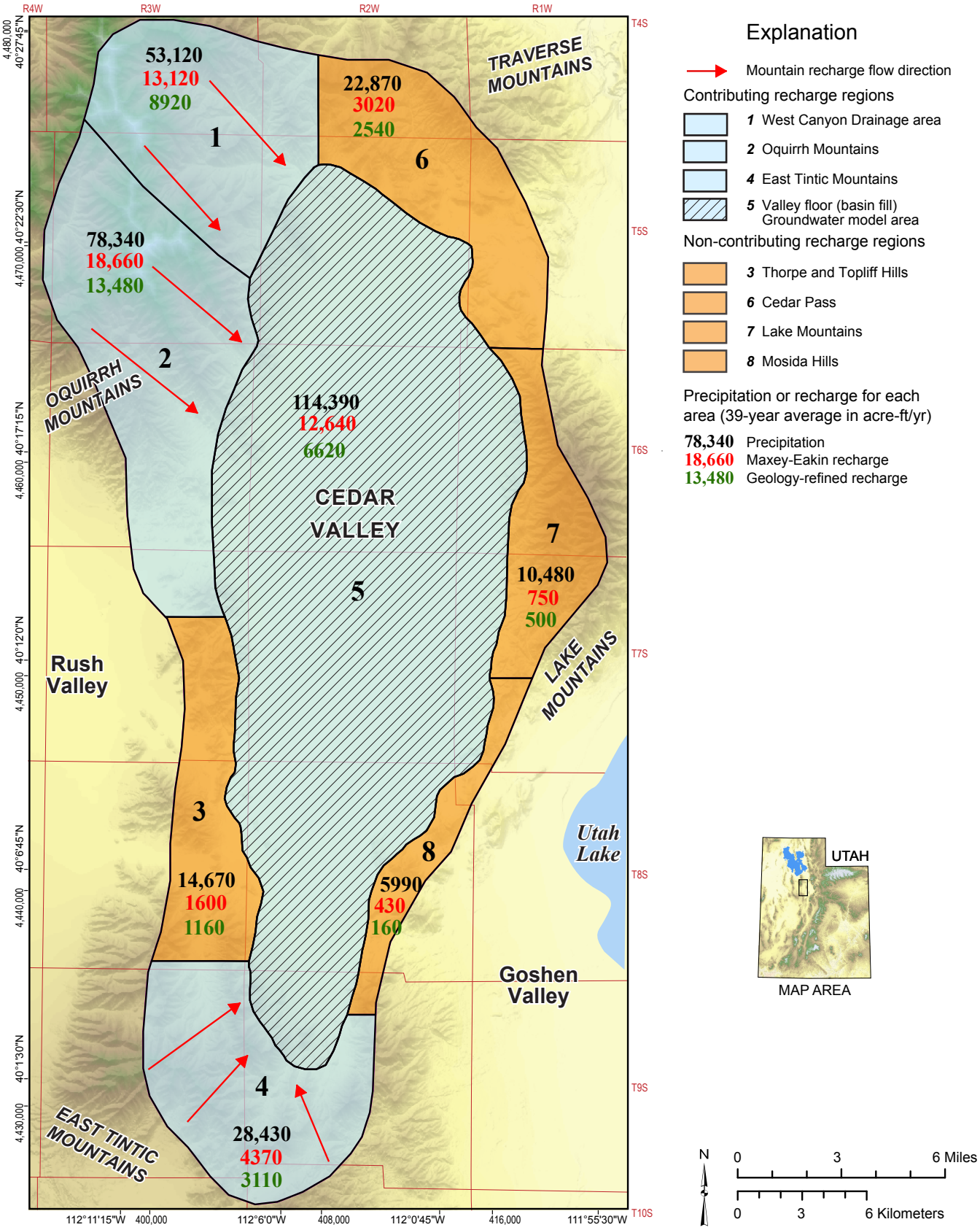


Figure 28. *Groundwater flow model area and recharge regions. Values in each region represent 39-year average precipitation, Maxey-Eakin recharge, and geology-refined recharge by region.*

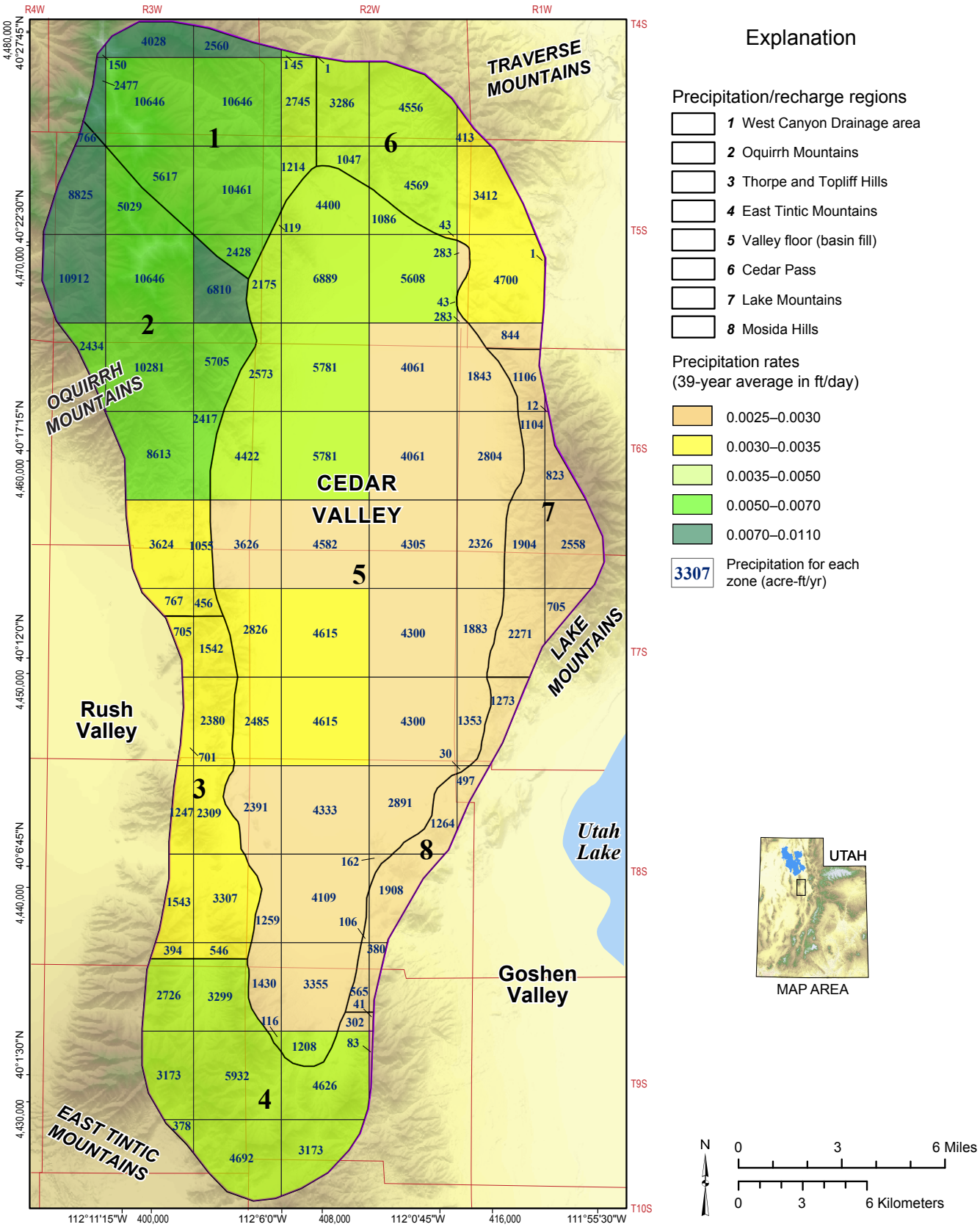


Figure 29. Thirty-nine-year average estimated annual precipitation from PRISM data by recharge zone. The total 39-year average estimated annual precipitation for all zones is 328,000 acre-ft/yr.

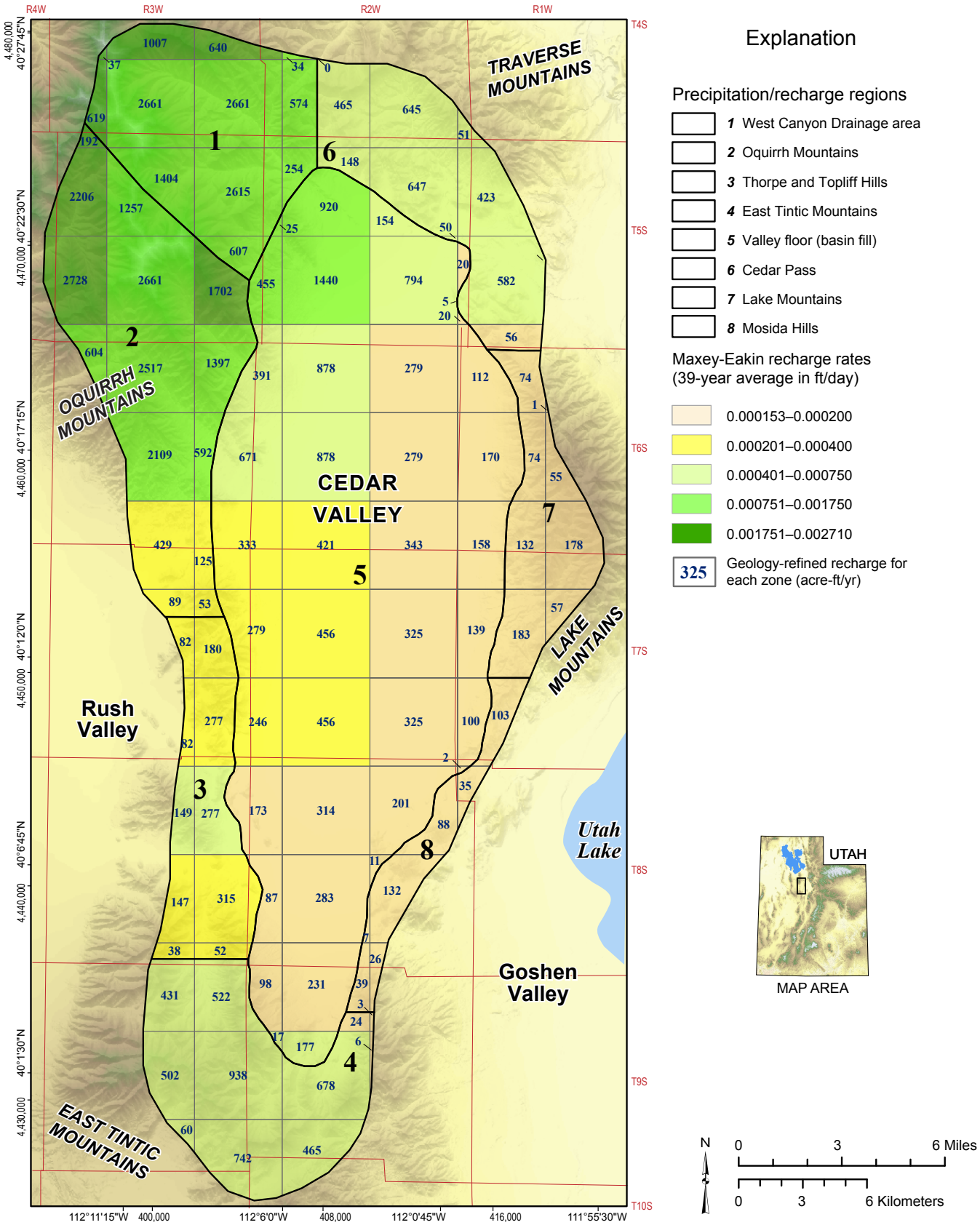


Figure 30. *Thirty-nine-year average estimated annual Maxey-Eakin recharge by recharge zone. The total 39-year average estimated annual Maxey-Eakin recharge for all zones is 54,600 acre-ft/yr.*

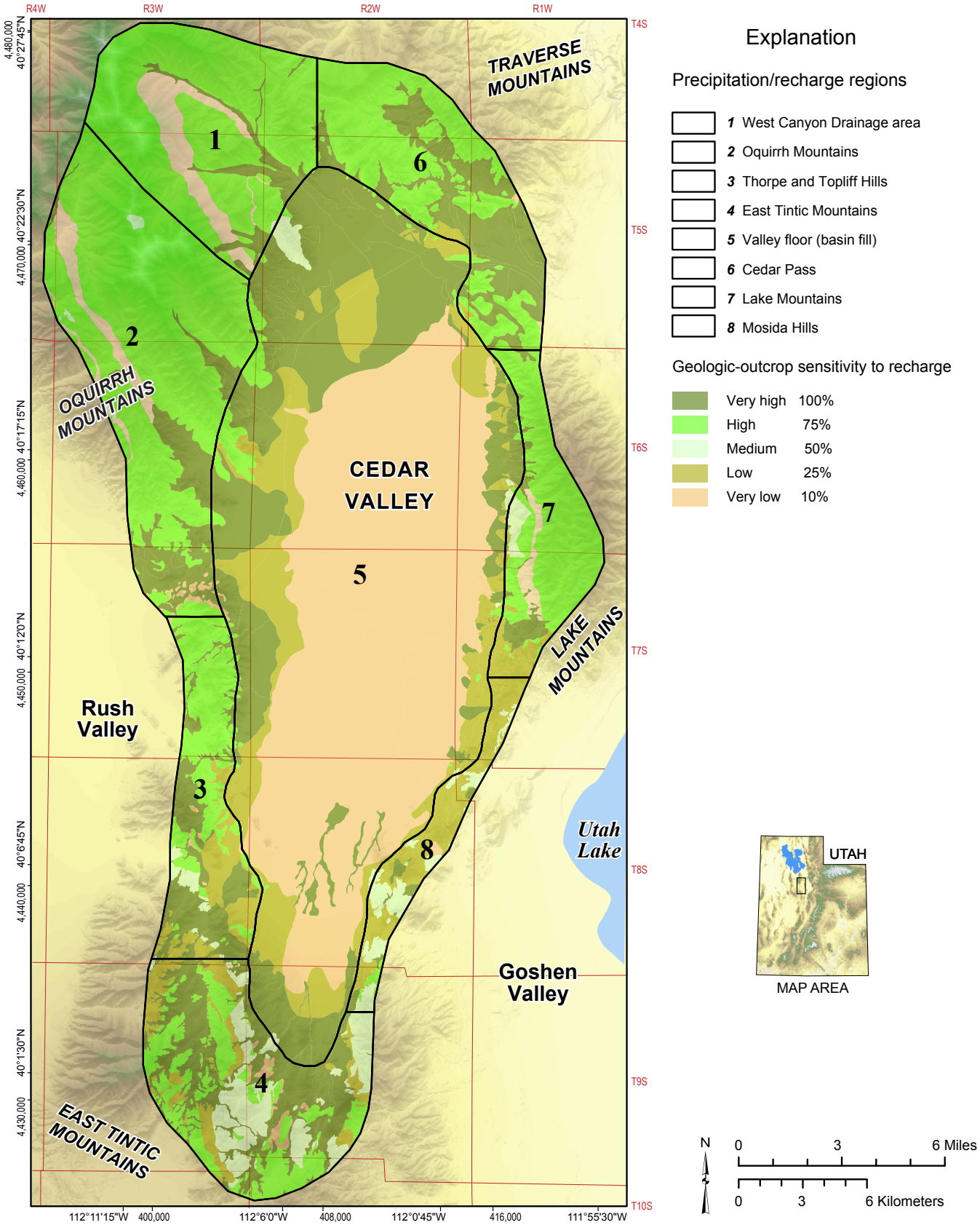


Figure 31. Geologic outcrop sensitivity to recharge in Cedar Valley.

recharge efficiencies in a similar way for Skull Valley, Utah, which has similar bedrock units as Cedar Valley.

We overlaid the Maxey-Eakin estimated recharge volumes for the 114 recharge zones (figure 30) with the geologic outcrop sensitivity to recharge classification map (figure 31). We multiplied the Maxey-Eakin recharge estimate by the geologic outcrop sensitivity to recharge factor for each intersecting polygon to yield an estimate of the geology-refined Maxey-Eakin recharge from precipitation (figure 32). The relationship between precipitation, Maxey-Eakin recharge estimate, and geology-refined Maxey-Eakin recharge estimate is summarized with respect to recharge region (figure 28, table E-1) and time (figure 33, table E-1).

We determined that four of the eight precipitation and recharge regions initially defined in the hydrologic basin are outside the hydrogeologic basin modeled for this study for several reasons. Groundwater flow direction (perpendicular to the potentiometric contours shown on plate 2) in the Cedar Pass recharge region (area 6 on figures 28 through 32) is either roughly parallel to the flow direction in the basin-fill aquifer in the northeast part of the valley or is downgradient from the basin-fill aquifer; therefore, recharge from precipitation on this part of the Traverse Mountains is not included in the groundwater flow model. Recharge from precipitation falling on the Lake Mountains (area 7 on figures 28 through 32), as suggested by Hurlow (2004, p. 24) and Feltis (1967), probably does not enter the basin-fill groundwater system. A syncline trending north to south along the axis of the Lake Mountains (plate 1) includes up to 1100 feet (335 m) of low permeability Manning Canyon Shale (Biek, 2004; Biek and others, 2009), which probably directs the estimated average annual recharge of 500 acre-ft/yr (0.6 hm^3/yr) along its axis north to Cedar Pass or south to Mosida Hills. Potentiometric data support this conclusion as discussed in the Conceptual Model of Groundwater Flow section below. Recharge through Mosida Hills (area 8 on figures 28 through 32) was not included because it occurs downgradient of the basin-fill aquifer. Potentiometric and stable isotope water-chemistry data suggest recharge in the Topliff Hill and Thorpe Hills region (area 3 on figures 28 through 32) may not recharge the basin-fill aquifer of Cedar Valley, as discussed in the sections on Interbasin Flow from Rush Valley and Environmental Isotopes and Implications for Recharge Source and Residence Time. The combined recharge from all four of the non-contributing recharge regions, Cedar Pass (7%), Lake Mountains (1%), Mosida Hills (<1%), and Topliff and Thorpe Hills (3%), is about 12% of the total recharge that we estimate from precipitation falling on the Cedar Valley hydrologic basin. Had the small amount of recharge in any or all of these four regions been included in the groundwater flow model, results likely would not vary significantly from those presented later in this report, as we demonstrate in the sensitivity analysis.

The estimated annual precipitation over the Cedar Valley hydrologic basin ranges from 202,000 acre-feet (249 hm^3) in 1988 to 535,000 acre-feet (660 hm^3) in 1983 and has a 39-year average of 328,000 acre-feet (405 hm^3) (figure 33). Precipitation on the four areas that contribute recharge to the groundwater flow model area ranged from 172,000 acre-ft/yr (212 hm^3) to 443,000 acre-ft/yr (547 hm^3) and averaged 274,000 acre-ft/yr (338 hm^3/yr) over the 39 years modeled. The total recharge to the hydrologic basin is between 15,500 and 80,500 acre-ft/yr (19.1–99.3 hm^3/yr) and averages 36,500 acre-ft/yr (45.0 hm^3/yr). Recharge estimates over those four areas contributing recharge to the groundwater flow model area, which are the recharge values we used as starting input in the groundwater flow model, range from 15,000 to 64,100 acre-ft/yr (18.5–79.1 hm^3/yr) and average 32,100 acre-ft/yr (39.6 hm^3/yr) (table E-1).

The primary recharge source for the aquifers in Cedar Valley in our conceptual flow model is precipitation infiltration and runoff from the Oquirrh Mountains. On average, while only approximately 40% of the precipitation over the hydrologic basin falls on the Oquirrh Mountains and West Canyon drainage areas, recharge through them accounts for 61% of the total recharge to the hydrologic basin, or almost 70% of the recharge to the groundwater flow model area. The valley floor and surrounding alluvial fans and the East Tintic Mountains contribute, on average, approximately 20% and 10% of recharge to the model area, respectively.

Flint and others (2004) developed a basin characterization model to estimate recharge in the Great Basin. This model uses a water balance approach to estimate potential recharge and runoff, and takes into account elevation, geology, soils, vegetation, precipitation, and temperature. For Cedar Valley, the potential in-place recharge, i.e., recharge of precipitation on the location it fell, averaged 16,000 acre-ft/yr (19.7 hm^3/yr). The potential runoff was 12,100 acre-ft/yr (14.9 hm^3/yr), but only between 10% and 90% of the runoff becomes recharge. Adding the in-place recharge and either 10% or 90% of potential runoff, the total potential recharge for Cedar Valley using the model of Flint and others (2004) would average 17,200 acre-ft/yr (21.2 hm^3/yr) or 26,900 acre-ft/yr (33.2 hm^3/yr). These estimates are lower than we estimated using the modified Maxey-Eakin method.

Indirect Sources

The value of recharge we estimated by using a modified Maxey-Eakin method represents all recharge to groundwater from precipitation, both via direct infiltration and by indirect seepage during movement or use of runoff (Avon and Durbin, 1994; Nichols, 2000). Indirect seepage includes contributions of unused irrigation water applied to agricultural lands, lawns, and gardens, including seepage from the intermittent Sinks; contributions from West Canyon Creek as it crosses an alluvial fan; seepage from the Cedar Fort Ditch irrigation canal; seepage from septic-tank soil absorption systems; and seepage from land application of wastewater treatment plant efflu-

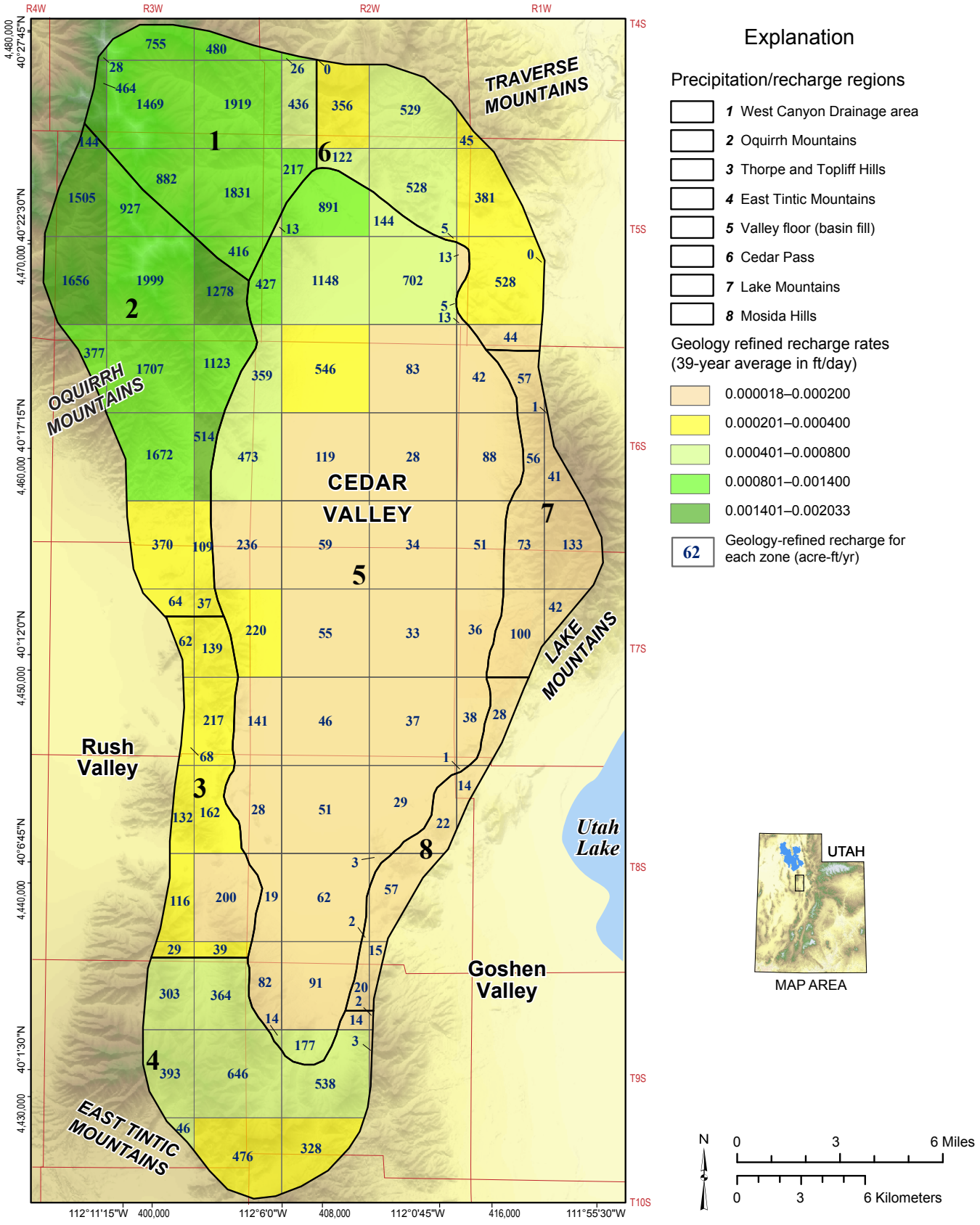


Figure 32. Thirty-nine-year average estimated annual geology-refined Maxey-Eakin recharge by recharge zone. The total 39-year average estimated annual geology-refined Maxey-Eakin recharge for all zones is 36,500 acre-ft/yr.

ent. Because we distributed recharge spatially in the groundwater flow model domain according to the Maxey-Eakin precipitation zones and geologic outcrops, we needed to quantify where our recharge may be over- or underestimating recharge from indirect runoff sources, which we did not input directly in the model.

Below, we discuss the methods and estimates of recharge we derived for each of the indirect sources (applied irrigation, stream and ditch seepage, surface-water seepage, and wastewater seepage). Together, we estimate indirect sources average approximately 2300 acre-ft/yr (2.8 hm^3/yr), which is only approximately 7% of total recharge (table 2, figure 27).

Applied irrigation: We estimated recharge to the groundwater table from unconsumed irrigation water (table 2, table E-3). There are four main sources of irrigation water in Cedar Valley: (1) Cedar Fort Ditch (water from West Canyon Creek), (2) three springs west of Cedar Fort (Tunnel, North Spring Creek, and South Springs), (3) Fairfield Spring, and (4) wells. We identified 23 areas of similar soil type and management practices irrigated by these sources using aerial photographs from 1993, 1997, 2004, and 2006 and historical reports. We multiplied the volume of water supplied by each source each year to each area by a recharge efficiency, or the fraction of supplied water that becomes recharge, to calculate the volume of recharge to the groundwater system over that area. The irrigated areas and the volume calculations are shown on figure E-1 and table E-3, respectively.

Volumes from each source were obtained from well production records or estimates (see Discharge section below), measured or estimated spring discharge, or estimates based on water rights for that source. For Cedar Fort Ditch, we estimated flow on a monthly basis as the remainder of the discharge from West Canyon Creek diverted to the ditch minus seepage (1% to 15% depending on the time of year, see Streams and irrigation ditch seepage discussion below) minus 5% loss to evaporation.

Many property owners in Cedar Fort and Fairfield and owners of the larger lots in Cedar Pass have private domestic wells. We assumed two-thirds of the volume of the water right associated with each private well was used for outdoor watering based on the ratio of indoor residential to outdoor residential water use in Cedar Fort and White Hills in a 2003 municipal

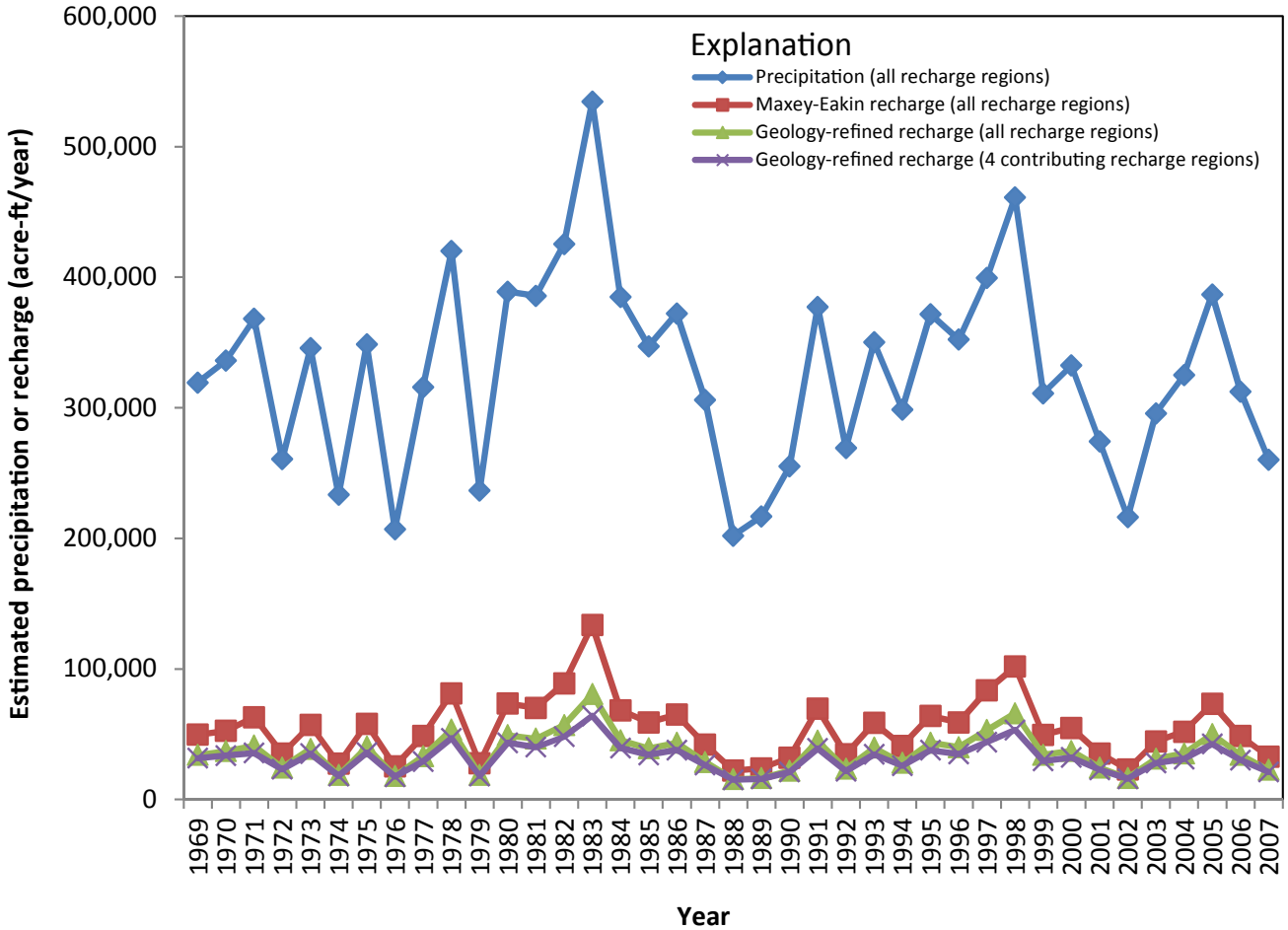


Figure 33. *Cedar Valley groundwater basin total estimated annual precipitation, Maxey-Eakin recharge estimated from precipitation, and the net estimated geology-refined Maxey-Eakin recharge volumes for 1969 to 2007.*

and industrial water use study for this area (Utah Division of Water Resources, 2004).

The water from some sources may have multiple uses. For example, Eagle Mountain Municipal Well #1 (UGS ID 1018) was exclusively an irrigation well until 1995; since then the water has also been piped to Eagle Mountain and the Cedar Pass area for residential and commercial use. We split the discharge from these multi-use wells based on historical data and information from well operators.

Once we estimated the volume applied to each area, we applied a recharge efficiency to each irrigated area based on the soil type and irrigation method (table E-3). We used recharge efficiency values between 5% and 30% based on values used in other groundwater modeling exercises in Tooele Valley (25%) (Lambert and Stolp, 1999), Salt Lake Valley (17% to 30%) (Hely, 1971; Lambert, 1995), Cache Valley (15% to 65%) (Kariya and others, 1994), Sanpete Valley (25%) (Wilberg and Heilweil, 1995), Juab Valley (10% for sprinklers and 30% for flood for a range of 18% to 27% of all irrigation water) (Thiros and others, 1996), Goshen Valley (1% to 30%) (Cordova, 1970; Brooks and Stolp, 1995), and Panguitch Valley (0% to 24%) (Thiros and Brothers, 1993). Areas underlain by coarse-grained alluvial fans (U.S. Soil Conservation Service, 1980; U.S. Department of Agriculture, Natural Resources Conservation Service, 2007) were assigned a recharge efficiency of 25% to 30%, whereas areas underlain by fine-grained lacustrine sediments were assigned recharge efficiencies of 5% to 10%. Flood irrigation usually results in more recharge from unconsumed irrigation water than sprinkler irrigation (Thiros and Brothers, 1993; Susong, 1995), so we assigned recharge efficiencies of 20% to 30% to areas where flood irrigation is or was the dominant irrigation method versus 5% to 10% where sprinkler-irrigation dominates (appendix A).

Estimates of recharge to the groundwater table from unconsumed irrigation water average 1100 acre-ft/yr (1.4 hm^3/yr) and range from 550 to 1500 acre-ft/yr (0.68–1.9 hm^3/yr) (table 2, table E-3). The three areas having the most unused irrigation water seepage are areas irrigated by the Cedar Fort Ditch, springs and private wells around Cedar Fort, and Fairfield Spring. Overall, the amount of recharge from unused irrigation is only about 3% of the total estimated recharge to the groundwater system.

Streams and irrigation ditch: West Canyon Creek is a gaining stream in the Oquirrh Mountains and a losing stream on the alluvial fan in the northwest corner of the valley (Feltis, 1967). Most of the stream flow is diverted into Cedar Fort Ditch during the irrigation season at a point just downstream from the U.S. Geological Survey gaging station at the mouth of West Canyon. A portion of the water in the ditch is subsequently diverted into a pipe installed in 1975 at a point approximately 3200 feet (980 m) downstream from the diversion of the stream. The pipe and the ditch convey West Canyon Creek water to a retention pond/settling basin located 3 miles (5 km) northeast of Cedar Fort. From the pond, water travels via open channels to the fields east of Cedar Fort, where it is applied by flood and sprinkler irrigation methods. We reconstructed the history of ditch usage, pipe installation, and changes in irrigation practices (appendix A) based on interviews with members of Cedar Fort Irrigation Company and local farmers, and examination of Utah Division of Water Rights records.

UGS conducted a seepage study on Cedar Fort Ditch during the 2006 irrigation season. We measured flow on three occasions using a Swoffer model 3000 open-channel velocity meter at up to 10 locations in the ditch between the U.S. Geological Survey stream gaging station at the mouth of West Canyon Creek and the first diversion into smaller irrigation ditches downgradient of the retention pond (figure 34). The seepage measured in June 2006 was approximately 3.1 cfs (88 L/s) or approximately 19% of the flow at the mouth of the canyon (table 4). In July, seepage was less than 0.1 cfs (3 L/s) or approximately 1% of the flow at the mouth of the canyon, and in September, seepage was negligible. Seepage was so much larger in June because the water level in the ditch was higher and water was running the entire length of the ditch, whereas in July and September, only the section of ditch upstream from the pipe contained running water, and the water was shallower than in June.

We calculated recharge to the aquifer via seepage from West Canyon Creek and Cedar Fort Ditch (table E-2) in two steps. First, we split the average monthly discharge at the mouth of West Canyon Creek (U.S. Geological Survey–Utah Water Science Center, 2006a) between Cedar Fort Ditch during the irrigation season (April 20 to October 20) and the natural channel of West Canyon Wash for the rest of the year. Cedar Fort Irrigation Company diverts their full water right of 40 cfs (1100 L/s) to the ditch during the irrigation season except during extremely muddy runoff events (D. Hale, Cedar Fort Irrigation Company, verbal communication, January 5, 2005; G. Berry, Cedar Valley well owner, verbal communication, April 11, 2006). We assumed that when the total monthly discharge at the point of diversion was greater than 1190 acre-feet (1.47 hm^3), a discharge event greater than 40 cfs (1100 L/s) had occurred, and we therefore allotted the discharge in excess of 1190 acre-feet (1.47 hm^3) in that month to West Canyon Wash. Also, we assumed 10% of the monthly discharge each May would have been routed down the wash by Cedar Fort Irrigation Company personnel to prevent sediment-laden runoff or storm-event water from entering the irrigation system. No discharge data were available for West Canyon Creek for the years 1976 through 1986 so we estimated the discharge based on a correlation with the precipitation at Fairfield for the years we had data.

Second, we calculated how much of the flow in each channel may contribute to the groundwater as seepage. In the winter months, we assumed all flow in West Canyon Wash recharges

the groundwater table because the stream channel is composed of highly porous cobbles and gravel and because temperatures are cool and plants are growing less; therefore, evaporation and transpiration are low. Thiros and others (1996) made a similar assumption in Juab Valley in central Utah. In the summer months, we assumed that 50% of any flow released to the wash is recharged and the rest is lost to evapotranspiration. We assumed a higher fraction of seepage compared to seepage estimates made on stream and canals in other Utah groundwater studies (Cordova, 1970; Clark and Appel, 1985; Lambert, 1995) because flow is released to the creek during storm events and vegetation has less chance to use the stormwater than streams or canals in constant flow.

Of the fraction of monthly flow estimated to be diverted to Cedar Fort Ditch, 15% was estimated to end up as seepage and recharge, which is based on our 2006 seepage study and agrees with seepage studies in other Utah valleys (Cordova and Subitzky, 1965; Cruff, 1980; Thiros and Brothers, 1993) and estimates made for other Utah groundwater models (Cordova, 1970; Clark and Appel, 1985; Lambert, 1995), which range from 10% to 30%. Since the pipeline was installed in 1975, water has been preferentially routed into the pipe from the ditch starting in July when the water carries less sediment and when the flow is less than 12 cfs (340 L/s) (D. Hale, Cedar Fort Irrigation Company, verbal communication, May 31, 2006; G. Berry, Cedar Valley well owner, verbal communication, April 11, 2006). For the months of July, August, September, and October for years 1975 to 2004, we calculated seepage as 1% of the estimated flow in the ditch, based on the results of our seepage study. Using this method, we calculate that the volume of water recharged to the aquifer via seepage from West Canyon Creek and Cedar Fort Ditch is between 70 and 1600 acre-ft/yr (0.09–2.0 hm^3/yr) and 40 and 600 acre-ft/yr (0.05–0.7 hm^3/yr), respectively (table 2, table E-2). The large variability in the ranges is due to the large variability of discharge in West Canyon Creek. Together, West Canyon Creek and Cedar Fort Ditch seepage is on average approximately 3% of the total recharge (table 2, table E-3).

The Sinks: The centers of many Utah basins are groundwater discharge areas (Anderson and others, 1994; Snyder and Lowe, 1998a, 1998b; Thomas and Lowe, 2007). Cedar Valley is different from most Utah valleys in that the Sinks (also known as Fairfield Sinks) appear to be a source of recharge to

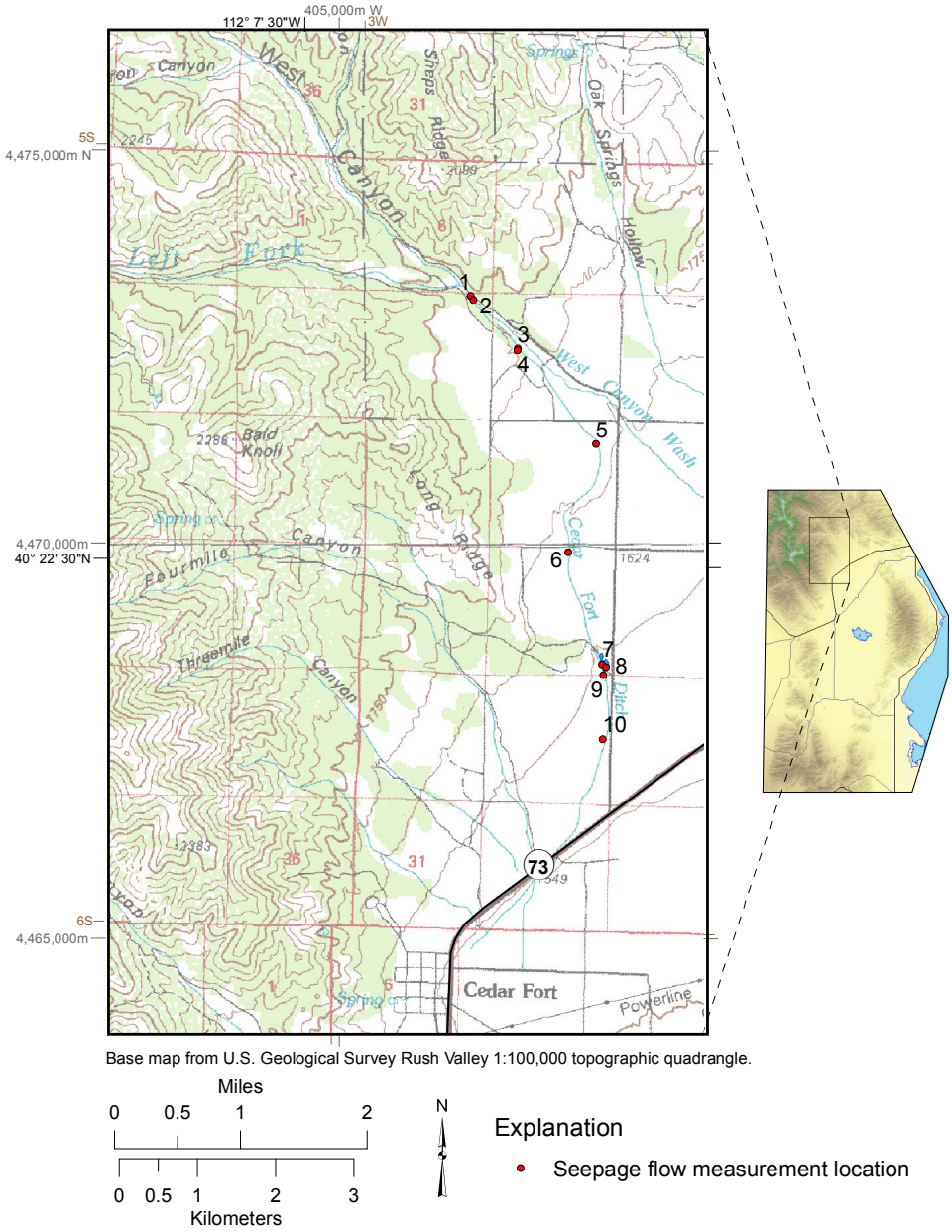


Figure 34. *Cedar Fort Ditch seepage study flow measurement locations. U.S. Geological Survey gaging station located at seepage flow measurement location 1. West Canyon Creek can be diverted into Cedar Fort Ditch between locations 1 and 2. Ditch flow is diverted into a buried pipe between locations 3 and 4. A retention pond is located between locations 7/8 and 9. See text for further discussion.*

Table 4. *2006 discharge and seepage loss from segments of Cedar Fort irrigation ditch.*

	Map ID (see fig. 34)	Flow measurement location	June 2 flow	June 2 loss from segment[1]	July 17 flow	July 17 loss from segment[1]	Sept. 1 flow
			cfs	cfs	cfs	cfs	cfs
Segment 1	1	In stream at USGS gaging station (not on weir)	16.5	0.8	4.6	0.1	2.0
	2	Flume below diversion from stream	15.7		4.2		2.0
	3	Above diversion into pipe	15.7		4.5		0
Segment 2	4	Weir/dam below pipe diversion	13.2	1.8	0	0.0	0
	5	Near abandoned concrete buildings	13.5		0		0
	6	Location where road crosses ditch	13.4		0		0
	7	Flume at inlet to pond	11.4		0		0
	8	Stream in middle of pond	NA		4.3		2.0
Segment 3	9	Outlet from pond (controlled)	6.2	0.5	0	0.0	0
	10	Immediately above 1st diversion for irrigation	5.8		0		0
		Water loss as percentage of flow at mouth of West Canyon		19%		1%	

[1] Water loss calculated as the difference between like measurements. For Segment 1, the difference is between flow measurements in the natural channel at measurement locations 1 and 3. For Segment 2, the difference is between measurements in a concrete-lined channel at locations 4 and 7. For Segment 3, the difference is between natural channel measurements at locations 9 and 10.

the groundwater system, as shown by isotope geochemistry (see Environmental Isotopes and Implications for Recharge Source and Residence Time above) and a downward head gradient as shown by a slight mound in the potentiometric contours near the Sinks (plate 2). We estimated seepage from the Sinks the same way we estimated recharge from unconsumed irrigation water. From April 20 to October 20, most, but not all, of the flow from Fairfield Spring and one flowing artesian well (UGS well ID 1039) is used around Fairfield (appendix A) so we assumed that 60% of the annual flow goes to the Sinks. We assumed that 10% of this volume, or 200 to 400 acre-feet (0.3–0.5 hm^3) depending on the year, becomes groundwater recharge (table E-3). Recharge from the Sinks accounts for only 1% of total recharge.

Wastewater treatment systems: Because of the small number of homes in the study area that are on septic systems, we suspected that the estimated seepage from septic tanks and wastewater treatment facilities would be a small component of groundwater recharge. However, because large areas of the valley have no sewer systems, and because the total water budget for the valley is not large in comparison with other Utah basins' water budgets, each recharge component in Cedar Valley is potentially important to the overall groundwater budget.

We quantified the volume of recharge from septic tanks to the groundwater system in one of two ways. In areas where population estimates were the best available data (Cedar Fort town and Fairfield before 1993) we multiplied the population by 95% of per capita residential indoor water use. Many studies (e.g., Lowe and others, 2000; Lowe and Wallace, 2001; Rosen and others, 2006; Bishop and others, 2007) consider 100% of indoor water use in homes with septic systems to be discharged from the system; we chose to allow for 5% consumptive use. We obtained population estimates for the study period from various historical and recent sources (Larsen, 1960; Demographic and Economic Analysis Section, 1991; U.S. Census Bureau, 2000b; Demographic and Economic Analysis Section, 2000; Hansen, Allen & Luce, Inc., 2001; Demographic and Economic Analysis Section, 2001; Utah Valley Economic Development Association, 2002; Utah Division of Water Resources, 2004, Demographic and Economic Analysis Section 2006a, 2006b, 2006c) and per capita residential indoor use from Hansen, Allen & Luce, Inc. (2001) and Utah Division of Water Resources (2004). For areas where the number of septic systems was known (J. Harris, Eagle Mountain City water service manager, written communication, April 19, 2006) or could be estimated from aerial photographs taken in 1993, 1997, 2003, 2004, and 2005, we estimated seepage by taking the number of tanks in each area multiplied by the number of people per household (U.S. Census Bureau, 2000b, 2000c; Hansen, Allen & Luce, Inc., 2001; Utah Division of Water Resources, 2004) multiplied by the per capita residential indoor water use (Hansen, Allen & Luce, Inc., 2001; Utah Division of Water Resources, 2004) multiplied by 95%. For

both methods, where no data existed for a particular year, the values were interpolated between years for which data were available.

The homes in White Hills are on a community sewage system consisting of five acres of open, clay-lined ponds (K. Jackson, White Hills Water Company, verbal communication, April 11, 2006; V. Carson, Fairfield Irrigation Company water master, verbal communication, April 11, 2006) built to Utah Department of Environmental Quality standards to minimize leakage. By rule, the ponds must not leak more than 36 acre-ft/yr (0.04 hm^3/yr) (Utah Division of Water Quality, 2008); however, because the system has much larger capacity than is currently used (K. White, White Hills Water Co., verbal communication, January 20, 2005), the ponds are often dry, and we assumed no groundwater recharge from them. Eagle Mountain town center sewage is treated at the wastewater treatment plant south of town in section 24, T. 6 S., R. 2 W., SLB&M. The plant began disposal of the some of the treated effluent on the land west of the treatment plant in 2004 (J. Harris, Eagle Mountain City water service manager, written communication, April 19, 2006). We assumed 25% of the water applied to the land recharges the groundwater, based on soil type and flood irrigation values from other groundwater studies (Thiros and Brothers, 1993; Susong, 1995). A treatment plant outside the study area services the more densely populated areas of Cedar Pass.

Although seepage from septic tanks and wastewater treatment facilities grew from an estimated 30 acre-ft/yr (0.04 hm^3/yr) in 1969 to 140 acre-ft/yr (0.17 hm^3/yr) in 2004 as population grew, the values are very small compared to other water budget components (table 2).

Interbasin Flow from Rush Valley

The potentiometric gradient in the eastern part of Rush Valley is toward Cedar Valley (Hood and others, 1969) (plate 2), and the water level in the basin-fill sediments of Rush Valley is roughly 200 feet (60 m) higher than water level in the basin fill of Cedar Valley. Based on these data and a Darcy's flow calculation, Hood and others (1969) estimated that approximately 5000 acre-ft/yr (6.2 hm^3/yr) of water may flow from Rush to Cedar Valleys. Hood and others' (1969) estimate was based on discharge through a cross-sectional area 15 miles (24 km) long by 400 feet (120 m) thick.

Since the 1969 study, three wells have been drilled near the surface drainage divide between Rush and Cedar Valleys in the Tenmile Pass area between Thorpe Hills and Topliff Hill. Two of the wells, located in sections 5 and 9, T. 8 S., R. 3 W., SLB&M, are completed in the Humbug Formation and Deseret Limestone and have static water-level elevation of just over 4500 feet (1380 m) (wells 985 and 986, plate 2), which is similar to a water level reported in 1907 from a bedrock well (well 634) in section 6. One of the newer wells (986) was drilled using the air rotary drilling method, which allows the driller to detect significant amounts of water in the strata being drilled; no water was encountered above the Humbug Formation in this well (J.D. Files, Cascade Water Resources, verbal communication, October 30, 2007). As discussed in the section Environmental Isotopes and Implications for Recharge Source and Residence Time above, the unusual stable isotope signature from one of the wells suggests a geothermal origin for this water. The third new well (ID 987), located in section 3, T. 8 S., R. 3 W., SLB&M, is completed in the middle and lower Great Blue Limestone. It had a static water level roughly 445 feet (136 m) higher than the other wells and on par with the water level in eastern Rush Valley basin fill. From these data, we conclude that there are two aquifers present beneath the Topliff Hill area, an upper aquifer in the Great Blue Limestone that could be a thin conduit for groundwater flow from Rush Valley basin fill to Cedar Valley basin fill, and a deep aquifer in older Paleozoic rocks (Humbug and Deseret Formations), which is hydrologically isolated from the higher aquifer. Furthermore, Mississippian Manning Canyon Shale lies in the subsurface beneath Thorpe Hills in a syncline having a northwest-southeast axis (plate 1). Based on the new well evidence supporting only a thin conduit for groundwater flow from Rush Valley to Cedar Valley under Topliff Hill, and the presence of flow-inhibiting shale under much of the rest of the divide, we conclude that the cross-sectional area used by Hood and others (1969) to calculate interbasin flow was too large, and therefore their estimate of interbasin flow was too large. We suspect that interbasin flow is close to zero.

Discharge

Discharge from the Cedar Valley groundwater system in order of decreasing average volume is by (1) interbasin flow from Cedar Valley to northern Utah and Goshen Valleys, (2) well pumping, (3) spring discharge, primarily from four medium to large springs, (4) evapotranspiration and, (5) base flow to West Canyon Creek (table 2, figure 35). Tables F-1 through F-3 contain compiled data for selected discharge components. We discuss methods for calculating discharge estimates for the conceptual model below and have tabulated the pertinent points in table E-4.

Interbasin Flow to Northern Utah and Goshen Valleys

Water-level elevations in Cedar Pass and Goshen Valley wells are generally 100 to 200 feet (30–60 m) lower than the elevations in the eastern Cedar Valley basin-fill wells (except in the perched aquifer, which are approximately 50 to 150 feet [15–46 m] higher than in eastern Cedar Valley basin-fill wells), indicating that Cedar Pass and Goshen Valley are downgradient of Cedar Valley. Water-level contours for the Cedar Valley basin-fill aquifer (plate 2) show an easterly groundwater gradient indicative of interbasin flow toward northern Utah Valley and Goshen Valley. Feltis (1967) used Darcy's equa-

tion and water balance calculations to estimate that between 10,000 and 19,000 acre-ft/yr (12–23 hm^3/yr) of water may be discharging from the Cedar Valley basin-fill aquifer eastward via interbasin flow to northern Utah and Goshen Valleys. To quantify the volume of interbasin flow from the Cedar Valley basin-fill aquifer to northern Utah and Goshen Valleys for use as approximate targets in the groundwater model, we divided Feltis's estimate into northeasterly and southeasterly flow along a mid-valley groundwater divide shown on his potentiometric map. Seventy-seven percent of Feltis's original cross sectional area contributed to the northeasterly flow segment and the remaining area made up the southeasterly flow. We multiplied these fractions by Feltis's estimate to determine an estimated 7700 to 14,600 acre-ft/yr (9.5–18.1 hm^3/yr) may flow to northern Utah Valley and between 2300 and 4400 acre-ft/yr (2.9–5.4 hm^3/yr) may flow to Goshen Valley. Feltis's estimates were for water exiting the basin fill and do not include bedrock flow beneath the basin fill. They were made before new, very productive wells yielded information about the highly conductive nature of the fractured bedrock aquifer in Cedar Pass and Mosida Hills.

Clark and Appel (1985) estimated that subsurface flow from the northern Lake Mountains bedrock block plus bedrock flow under Cedar Pass to northern Utah Valley was 8200 acre-ft/yr (10 hm^3/yr), which is within the range we derive from Feltis's (1967) work. Additionally, we extrapolated estimates made by Brooks and Stolp (1995) to estimate that approximately 2400 acre-ft/yr (3.0 hm^3/yr) may be leaving Cedar Valley as interbasin flow to Goshen Valley, which is also within Feltis's estimate. More recently, Gardner (2009) modeled groundwater flow in northern Utah Valley. His results, while not focused on the Cedar Pass area, showed subsurface inflow from Cedar Valley through the Cedar Pass area to be approximately 8800 to 9800 acre-ft/yr (11–12 hm^3/yr).

As approximate values in our conceptual model water budget and starting target values for constructing the groundwater flow model, we chose values at the upper end of the ranges of previous estimates to accommodate an unknown volume of bedrock underflow. We estimated that an average of approximately 12,000 acre-ft/yr (15 hm^3/yr) may be exiting the Cedar Valley groundwater system as interbasin flow under Cedar Pass and 4000 acre-ft/yr (5 hm^3/yr) may exit under Mosida Hills. Combined, we estimated that subsurface discharge may account for approximately 55% of the discharge from the groundwater system.

Wells

We estimated well withdrawal for all wells, including private domestic wells, large irrigation wells, and public supply wells, for the years 1963 to 2007. Discharge varied from an estimated 1300 to 10,500 acre-ft/yr (1.6–13.0 hm^3/yr) and averaged 4000 acre-ft/yr (5 hm^3/yr) (table 2, tables F-2 and F-3). The U.S. Geological Survey–Utah Water Science Center estimated irrigation well discharge from power-use records. We compiled well discharge records from public water suppliers' reports to the Utah Division of Water Rights (2009b) and water use information compiled by the Utah Division of Water Resources (Hansen, Allen & Luce, Inc., 2001). In some cases, these data sources conflicted with other data sources (Feltis, 1967; U.S. Geological Survey–Utah Water Science Center, 2006b), in which case we interpolated or used information from interviews with long-time residents of Cedar Valley to reconstruct the pumping history of each well.

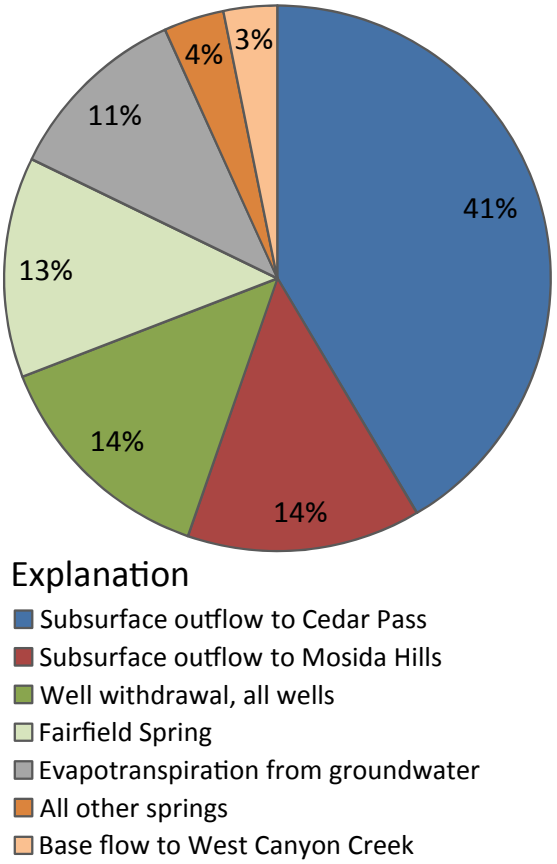


Figure 35. *Contribution to Cedar Valley discharge from various sources estimated for conceptual model (average values 1969–2007).*

Amount and type of irrigation, population growth, and precipitation all affect well withdrawal in Cedar Valley. As more large irrigation wells came online on the edges of the valley in the 1970s, production from large wells increased (figure 36), and higher-than-normal precipitation in the 1980s corresponds to a decrease in well pumping. The variability in the subtotal for pumpage from the western alluvial fans (western valley and Fairfield on figure 36) results partially from pumping restrictions on the White irrigation wells (well IDs 44 and 1035), from which extraction is limited by a court order when the discharge at Fairfield Spring is less than 4.10 cfs (116 L/s) (Utah County District Court, 1965). New public supply wells near Cedar Pass show an increasing trend in production in 2001 to 2007 (figure 36).

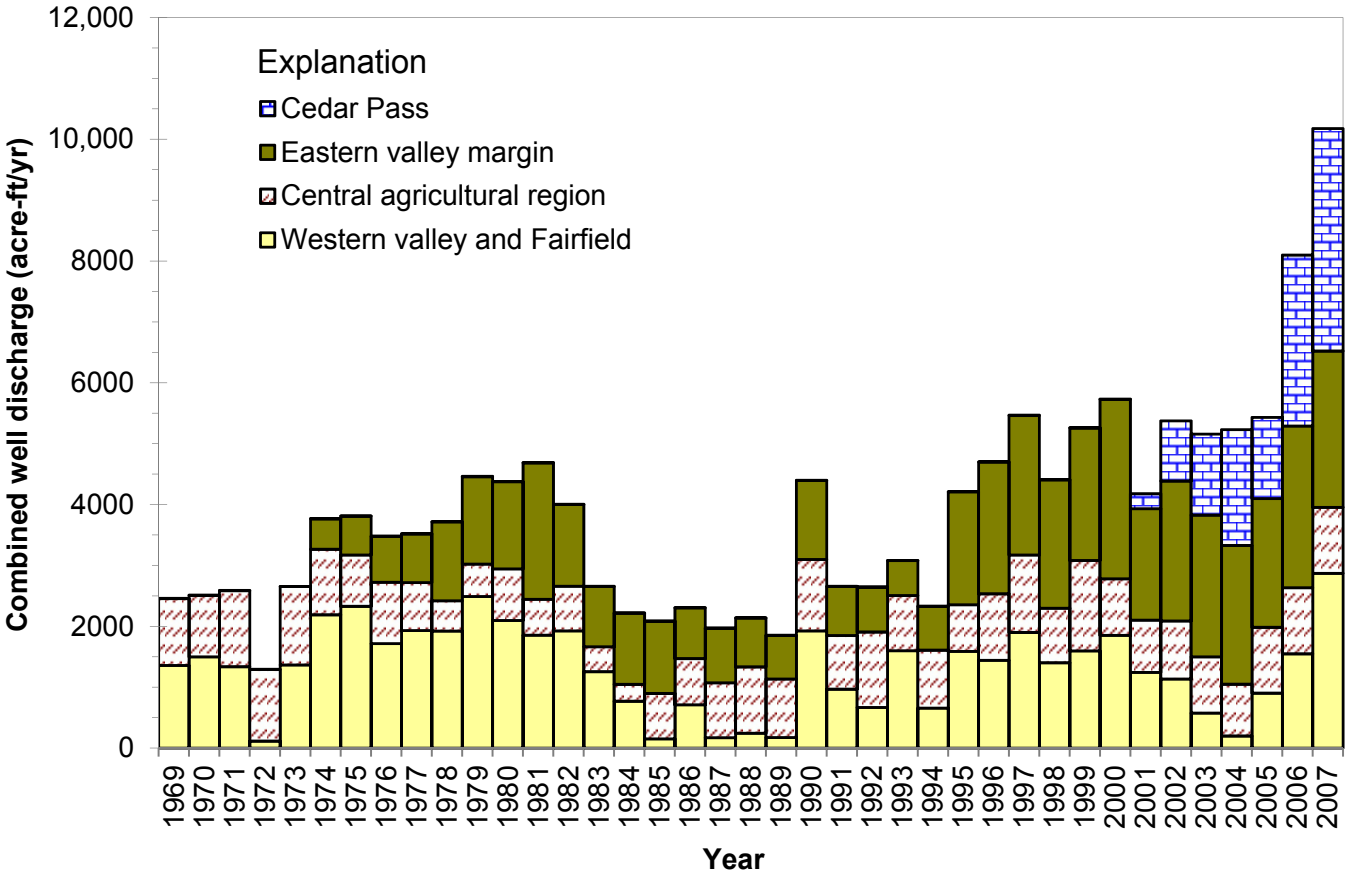


Figure 36. *Large well discharge by area in Cedar Valley, Utah County, Utah. Cumulative well discharge increased at an average rate of 3.4% per year from 1969 to 2005 and 44% per year from 2005 to 2007.*

Springs

Reported measurements indicate that spring discharge is between 3900 and 7300 acre-ft/yr (4.8–9.0 hm^3/yr) (table F-1). There are four large springs and at least 13 small springs in Cedar Valley. The largest, Fairfield Spring, issues from the base of an alluvial fan west of the town of Fairfield (figure 1). Fairfield Irrigation Company and the Utah Division of Water Rights have monitored the spring's discharge except in the years from 1971 to 1991. We calculated the annual discharge for Fairfield Spring for years in which data were available by averaging the spot discharge measurements recorded in that year over the time interval between measurements (anywhere from minutes to a few months) and summing the averages. For the years 1971 through 1991, we estimated the annual discharge based on the relationship of the spring discharge to precipitation measured at Fairfield in years having data. The recorded flow at Fairfield Spring between 1969 and 2007, excluding 1971 through 1991, ranged from 2890 acre-feet (3.56 hm^3) in 1994 to 6320 acre-feet (7.80 hm^3) in 1999 (table 2, appendix F). We estimated flow during the years without record to be within that range, although during 1982 and 1983, above average precipitation may have caused the flow to be higher. We estimate that Fairfield Spring discharge is, on average, about 13% of the total conceptual model discharge (figure 35).

Three springs are located west of Cedar Fort. Tunnel and North Spring Creek Springs are located approximately 1 and 1.5 miles northwest of Cedar Fort, respectively. Both issue from the Butterfield Peaks Formation of the Oquirrh Group. South Spring is located on the west edge of Cedar Fort town in young alluvial-fan deposits. Its location approximately 900 feet (300 m) east of Butterfield Peaks Formation outcrop, on a probable buried range-front normal fault, and at the elevation of Lake Bonneville shoreline (Biek, 2004) leads us to suspect that South Spring discharges bedrock aquifer water that intersects the fault and travels along the fault to beach gravels or alluvial-fan deposits.

Only a few instantaneous discharge measurements were available for the springs near Cedar Fort (Feltis, 1967; Utah Division of Water Rights, 2004a) (table 2, table F-1). Normalizing the spot measurements to annual flow volume, North Spring Creek Spring annual flow may be approximately 400 to 500 acre-ft/yr (0.5– 0.6 hm^3/yr) (two measurements), and Tunnel Spring (two measurements) and South Spring (four measurements) may each discharge 100 to 200 acre-ft/yr (0.1–0.2 hm^3/yr) annually. Combined flow from North Spring Creek and Tunnel springs has been measured more often. Estimates of the discharge at numerous small springs were reported in Feltis (1967). We did not investigate these springs in this

study because they represent only approximately 5% of spring flow, are located in the mountains away from our primary focus of study, and most likely represent shallow flow systems (Feltis, 1967).

Evapotranspiration

We initially estimated evapotranspiration from groundwater (ET_g) using methods similar to those used in hydrogeologic studies of Goshen and southern Utah Valleys (Cordova, 1970; Brooks and Stolp, 1995), Salt Lake Valley (Lambert, 1995), Sanpete Valley (Wilberg and Heilweil, 1995), and Cache Valley (Kariya and others, 1994). These studies generally attempt to estimate the area covered by phreatophytes, their water use, and the water available to them. We assumed vegetation will use the available precipitation and applied irrigation water sources to meet its water needs and take up groundwater from below only if those sources are not adequate. We chose 10 feet (3 m) as the maximum depth to water that the alfalfa and pasture grasses growing around Fairfield could be taking up groundwater based on work by Hill (1998). We calculated the amount of water used by vegetation in the shallow-groundwater area around Fairfield and subtracted all other sources of water available to the vegetation, including applied irrigation, septic-tank recharge, and precipitation for each year. The remainder is an estimate of groundwater discharge we attribute to evapotranspiration in the shallow-groundwater area around Fairfield. Appendix F contains the details of this method.

Our initial estimates for evapotranspiration from groundwater (ET_g) using the above method ranged from 0 to 2400 acre-ft/yr (0–3.0 hm^3/yr), but our water budget showed an excess of approximately 7700 acre-ft/yr (9.5 hm^3/yr). Because ET_g is more poorly constrained than most of our other budget components, we re-evaluated our original estimate to include ET_g from areas where the water table is greater than 10 feet (3 m) deep.

Approximately 1200 acres (490 ha) around the Sinks are bare ground and 35,500 acres (14,400 ha) are covered with phreatophytes including rabbitbrush (*Chrysothamnus* sp.) and greasewood (*Sarcobatus vermiculatus*) (Automated Geographic Reference Center, 2001). The roots of rabbitbrush can extend to 15 feet (6 m) and greasewood to 60 feet (18 m) or more below ground (Robinson, 1958). Where greasewood is the dominant vegetation in the study area, the dominant lithology is clay from the surface to 100 to 200 feet (30–60 m) depth and the water table is between 15 to 185 feet (5–56 m) deep. We surmise that the phreatophytes in this area are primarily using soil moisture from precipitation, perched zones within the clay layer, and/or recharge from the Sinks as their primary water source when available, but are likely using groundwater to survive when other sources dry up. In Sanpete Valley, Utah, Wilberg and Heilweil (1995, p. 18) cited estimates of water use by greasewood from 0.4 to 4.8 ft/yr (0.1–1.5 m/yr) and leaned toward the low end of this range based on growing conditions. In Juab (Thiros and others, 1996) and Panguitch Valleys (Thiros and Brothers, 1993), the ET rate from phreatophytes where the water table was shallow was 35.5 and 23 inches/yr (90–58 cm/yr), respectively. One recent study (Moreo and others, 2007) measured ET rates from desert shrubland composed of greasewood and rabbitbrush in the Great Basin at sites receiving 6.4 to 9.6 inches (16–24 cm) of precipitation (slightly less than Cedar Valley) and approximately 1000 feet (300 m) higher in elevation than Cedar Valley. In this study, the sites were shown to have ET_g of 0.77 to 3.82 inches per year (2–10 cm/yr) (total ET 10.02 to 12.77 inches per year [25–32 cm/yr]) (Moreo and others, 2007). The deeper the water table, the less groundwater phreatophytes can be expected to use (Robinson, 1958; Hill, 1998); however, in Moreo and others (2007), ET_g did not directly correlate to depth to water, which ranged from approximately 7 to 32 feet (2–10 m), because soil type, precipitation, and vegetation density varied across the measurement sites.

In addition to the volume of ET_g from the area where groundwater is less than 10 feet (3 m) deep, we estimate an additional 1400 to 1700 acre-ft/yr (1.7–2.1 hm^3/yr) of discharge from the Cedar Valley basin-fill aquifer via evapotranspiration from the large area of greasewood in Cedar Valley. Combining the two types of estimates, from the less than 10 feet (3 m) deep water table area and the 10 to 35 feet (3–11 m) deep water table area, the initial ET_g estimates used as starting values for the groundwater flow model ranged from approximately 1700 to 4000 acre-ft/year (2.1–4.9 hm^3/yr) (table 2). ET_g is, on average, approximately 11% of total discharge budget (figure 35). The groundwater modeling sections of this report further detail our ET_g estimates.

Feltis (1967) estimated evapotranspiration (ET) in Cedar Valley to be 5100 acre-ft/yr (6.3 hm^3/yr); however, Feltis' estimation was based on ET from individual sources (the creek, springs, and wells), and therefore, is not comparable to our estimate of ET_g directly from the groundwater table.

West Canyon Creek

A U.S. Geological Survey gaging station monitors West Canyon Creek discharge at the mouth of West Canyon. Daily discharge data are available for the study period except from 1976 through 1986 (U.S. Geological Survey–Utah Water Science Center, 2006a). For these years, we used annual precipitation at Fairfield as a proxy for the amount of water in the hydrologic system and estimated the stream flow based on the relationship of the flow measured at the gaging station to precipitation measured at Fairfield in years having data. Discharge of West Canyon Creek is between 440 and 6300 acre-ft/yr (0.54–7.8 hm^3/yr) at the mouth of the canyon based on reported measurements and including estimated values (table F-1). Stream flow in the very wet years of 1982 and 1983 may have been higher than our estimated 6000 acre-ft/yr (7.4 hm^3/yr).

West Canyon Creek is a gaining stream above the mouth of the canyon (Feltis, 1967), meaning some fraction of the discharge measured at the gaging station is base flow into the stream from the Paleozoic bedrock aquifer. We chose a simple graphical method of stream flow separation over more sophisticated methods because base flow is less than 5% of the water budget and occurs in the bedrock layer of our groundwater model from which no head data are available for model calibration. Our method involved graphically separating spring runoff from baseflow based on the change in slope of the monthly average discharge curve. We estimate base flow to West Canyon Creek to be between 200 and 1800 acre-ft/yr (0.2–2.2 hm^3/yr) (table 2), which is approximately 3% of the conceptual model discharge budget (figure 35).

Water Budget

The conceptual water budget (table 2) showed that recharge from precipitation accounts for the vast majority of water input to the Cedar Valley groundwater system, and that the annual variability in precipitation was more than all other recharge sources or discharge sources. By far the largest discharge component was interbasin subsurface outflow. Annual variability in the various components was due mostly to the annual variability in precipitation, i.e., more precipitation created more water in the system, which allowed for more seepage from surface sources and less need for well withdrawal.

The total of initial discharge estimates from the basin-fill aquifer in Cedar Valley (well withdrawal, ET, Fairfield Spring, plus Feltis's estimate of basin-fill discharge) was significantly less than our estimate of total recharge to the groundwater system, suggesting that a significant portion of recharge from precipitation in the Oquirrh Mountains was not interacting with the basin fill. The most likely flow path for the excess recharge is to flow in bedrock underneath the basin-fill aquifer (in most places less than 1250 ft [116 m] deep, figure 4), and discharge as interbasin flow to adjacent northern Utah Valley. One of the objectives of groundwater flow modeling was to investigate this possibility further.

Using our best approximation of recharge and discharge sources (table 2), recharge was, on average, 3700 acre-ft/yr (4.6 hm^3/yr) or 13% more than the total discharge. Because of the overall excess in the input terms, we focused special attention on annual water budgets in the modeling exercise to understand where the conceptual model was overestimating recharge or underestimating discharge. The conceptual model estimated values given in table 2 were refined during modeling as discussed in the Model Calibration and Assessment of Model Calibration sections of this report.

Conceptual Model of Groundwater Flow

We base our conceptual model of groundwater flow on our hydrogeochemistry, water-level, aquifer-test, and recharge and discharge information and on analysis presented previously. We contoured a potentiometric map (plate 2) using data collected in 2004, a year in which precipitation was near the 30-year average and in which we collected the most comprehensive spatial and temporal set of water-level observations.

Groundwater Flow Direction and Gradient

Potentiometric contours (plate 2) indicate that groundwater in Cedar Valley moves from the primary recharge area in the Oquirrh Mountains and the alluvial fans on the western side of the valley and from the East Tintic Mountains, east or southeast through the basin fill and through bedrock underlying the basin fill. Similarity of general chemistry and isotope signatures support a west to east groundwater flow pattern. Based on new water-level and isotope chemistry information gathered from recent well drilling showing discontinuous aquifers between Rush and Cedar Valleys, the volume of eastward interbasin groundwater flow from Rush Valley is less than previous estimates (Hood and others, 1969) and may be close to zero. Groundwater flow in the basin-fill aquifer is generally under confined conditions. Well drilling, water-level, and aquifer-test data suggest groundwater flowing eastward through the basin-fill aquifer is diverted by geologic structures around the main block of the Lake Mountains to exit the valley as subsurface flow through the bedrock at Cedar Pass and Mosida Hills. Geochemical data suggesting a long residence time and a small horizontal hydraulic gradient in the basin fill of the southern arm of the valley indicate less flow through these clay-rich and low-permeability strata than in the central and northern basin fill.

Water-level data in northwest Cedar Valley show that the bedrock aquifer underlying West Canyon has a different groundwater flow direction and a lower hydraulic head than the basin-fill aquifer of northern Cedar Valley, as indicated by our separate bedrock and basin-fill potentiometric contours in plate 2. These data suggest limited aquifer connectivity and a downward head gradient between the principal basin-fill aquifer and the bedrock aquifer in this area, contrary to the upward gradient that we would expect in an area of bedrock to basin fill flow. However, well data prove that areas of high potentiometric pressure exist in the Oquirrh Mountain bedrock block; in well ID 832 located 1 mile north of Cedar Fort town, groundwater is confined by the Manning Canyon Shale to create a pressure head 400 feet (120 m) above land surface at the well head (plate 2) (Utah Division of Water Rights, 2004b; D.C. Hansen, Psomas civil engineering project manager, written communication, January 3, 2005; also measured for this study). Groundwater likely moves from bedrock in the Oquirrh Mountains to the basin fill along geologic contacts or structures from this and similar areas having upward gradients. Evidence of structurally controlled groundwater flow in the Oquirrh Mountain bedrock block is shown by two bedrock wells (IDs 68 and 145) located approximately two miles northeast of Cedar Fort town, which are completed along the projected axis of the Long Ridge

anticline and possibly near a concealed normal fault (plate 1, plate 2). Both wells produce warm (approximately 23°C [73°F]) water (table D-2) which is likely moving along the fold axis and/or the fault after being heated at depth. Fault-controlled upwelling of heated meteoric water has been described in northern Utah by Cordova (1970), Murphy and Gwynn (1979), Klauk (1984a, 1984b), Klauk and Davis (1984), and Mayo and Loucks (1995).

The vertical gradient within the basin fill is upward from the basin-fill aquifer to the clay unit near Fairfield where a number of flowing wells are completed in the basin-fill aquifer. Feltis (1967, p. 19) reported a downward gradient in two wells installed to monitor vertical gradient located 1.5 miles east of Fairfield. Data collected since 1967 indicate that a downward vertical gradient of up to 0.045 (17 feet [5 m] water-level difference between screen-elevation difference of 380 feet [116 m]) exists during the fall, but the gradient is much smaller (0 to 0.015) during the spring. The periods of greatest downward gradient at these wells, and presumably other wells in the center of the valley, are when water levels in the basin-fill aquifer are lower than average due to either seasonal pumping or long-term downward trend in the amount of recharge entering the aquifer from the west.

Structural Control on Groundwater Flow

Faults and fractures within the Paleozoic sedimentary units and the position of younger volcanic and unconsolidated units in relation to faults are important controls on groundwater movement. The normal fault on the western side of the Lake Mountains, the Lake Mountains syncline, and probably older structures cropping out in sections 29 and 32, T. 6 S., R. 1 W., SLB&M (plate 1) complicate the hydrogeology along the eastern side of the valley. Groundwater is upwelling along the fault as indicated by 28°C (82°F) water in several wells located southeast of Eagle Mountain town center (figure 19). The source of the warm water, based on its isotope chemistry, is meteoric water recharged in the Oquirrh Mountains, which circulates to depths great enough to be warmed by geothermal heat (at least a few thousand feet), and then flows upward to the shallow groundwater zone along the damage zone of the normal fault (i.e., the intermediate region between the principal slip plane and undisturbed rock). Much higher hydraulic conductivity along the fault (figure 5, plate 1) and decreasing temperature (figure 19) and hydraulic gradients away from this area (plate 2) indicate that the warm water mixes with water that has moved laterally across the valley in the basin-fill aquifer, and moves north or south in the damage zone of the fault (plate 2). Fault damage zones typically are several orders of magnitude more permeable than the surrounding rock because of open fractures in lithified sediments and shearing of clays in poorly lithified sediments (Fairley and Hinds, 2004; Bense and Person, 2006). A high hydraulic-conductivity zone along the fault provides the heated water a conduit to the shallow groundwater zone. Water-level data suggest the basin-fill aquifer in eastern Cedar Valley is hydraulically connected to the bedrock aquifer on the western side of the Lake Mountains (e.g., in sections 6, 7, 18, 19, and 30, T. 6 S., R. 1 W., SLB&M, plate 2), and that groundwater primarily exits the basin fill of Cedar Valley by flowing north along the fault zone and into fractured bedrock at Cedar Pass, or south along the fault zone and into fractured bedrock at Mosida Hills, and not through the main mass of the Lake Mountains.

Fault damage zones can be conduits for groundwater flow, but clay smearing and grain crushing can greatly reduce permeability in the fault core (i.e., the actual main fault plane) (Fairley and Hinds, 2004; Bense and Person, 2006; Hamaker and Harris, 2007). Lachmar and Schieb (2007) showed that a normal fault in the Navajo Sandstone aquifer in east-central Utah acts as a barrier to flow perpendicular to the fault plane, but that the hydraulic properties of the fault were highly variable. Three wells drilled through Paleozoic limestone and shale located two to three miles southeast of Eagle Mountain town center, located in sections 20 and 29, T. 6 S., R. 1 W., SLB&M, (well IDs 1019, 1020, and 1021, plate 2), were either dry or had a water level roughly 100 feet (30 m) lower than basin-fill and bedrock wells located one mile (1.6 km) west, indicating the existence of a barrier to groundwater flow between these two groups of wells and across the concealed normal fault on the western side of the Lake Mountains (plate 1) (Hurlow, 2004). These data support the idea presented by Hurlow (2004) that the core of this fault forms a barrier to groundwater flow across its plane.

A head difference of approximately 200 feet exists between bedrock wells at Cedar Pass and wells in basin fill one mile west. UGS-supervised well drilling in 2007 (Jordan, 2008) showed perched water west of Cedar Pass in volcanic rocks underlying unconsolidated sediments and overlying Paleozoic bedrock (plate 2). The volcanic unit extends to the north and creates a wedge of saturated volcanic rocks between the basin fill overlying and west of the wedge and the Paleozoic bedrock below and east of it. Our aquifer-test results (Jordan, 2013) indicate that the bedrock aquifer at Cedar Pass encountered a barrier to groundwater flow located in the approximate location of the volcanic wedge and the concealed normal fault. These geologic, potentiometric, and aquifer-test data support the conclusion that the volcanic wedge and the concealed normal fault zone are inhibiting eastward groundwater flow out of the basin-fill aquifer to the bedrock aquifer at Cedar Pass.

The Manning Canyon Shale, in the north-south trending Lake Mountains syncline, may also limit eastward groundwater flow horizontally through the Lake Mountains, adding to the barrier effect of the fault and volcanic rocks, and limiting westward flow of recharge from the Lake Mountains to the basin-fill aquifer.

Faults in poorly lithified sediment such as the Quaternary and Tertiary basin fill in Cedar Pass have been shown to impede cross-fault flow (Rawling and others, 2001). Faults that po-

sition unconsolidated sediment against unconsolidated sediment or bedrock have been documented in Cedar Pass (Hurlow, 2004, plate 3; Cederberg and others, 2009). Faults appear to control the location of the perched basin-fill aquifer and at least the western perched bedrock zone at Cedar Pass shown on plate 2. The perched shallow aquifer in unconsolidated sediments at Cedar Pass is not hydraulically connected to the underlying bedrock aquifer, which has water-level elevations roughly 200 feet (60 m) lower than the perched aquifer. The recharge for this perched water table, based on groundwater flow direction and its geochemical signature, is most likely from the Traverse Mountains to the north.

Long, deep groundwater flow paths are indicated by stable and radioactive isotope water-quality data that show recharge from high elevation and/or cool climates and old or mixed-age water in the central and eastern part of the basin-fill aquifer. These flow paths provide the source of upwelling warm water along geologic structures.

NUMERICAL SIMULATION OF GROUNDWATER FLOW

We created a digital groundwater flow model to simulate the groundwater flow system in the basin-fill aquifer in Cedar Valley. The specific objectives of the modeling exercise were to (1) define the spatial and temporal distribution of the groundwater head and the direction of groundwater flow movement, (2) define and verify the flow rates of the various components of the conceptual water budget, (3) define the hydrologic characteristics of the principal basin-fill aquifer and its relation to the underlying consolidated bedrock, (4) define the boundary conditions that control the groundwater flow regime, (5) calibrate the digital groundwater flow model for approximate steady-state conditions present in 1969, (6) calibrate the model for transient flow conditions for the years 1969 through 2007, and (7) predict the response of the aquifer system to future changes in the withdrawal and/or recharge rates.

Model Construction and Conversion

We developed a conceptual model of groundwater flow using data and analysis described in the Hydrogeology section of this report, which includes water level, well withdrawal, spring discharge, stream discharge, spatial distribution of precipitation and recharge, hydraulic conductivity, specific yield, specific storage, topographic map, geologic map, structural and isopach map, pumping-test analysis, and well-log data. We converted the conceptual model into a digital groundwater flow model using Groundwater Modeling System (GMS) version 6.5 (Aquaveo, LLC, 2008) and the embedded U.S. Geological Survey MODFLOW-2000 computer code (Harbaugh and others, 2000; Hill and others, 2000). This model used the Geometric Multigrid (GMG) Solver (Wilson and Naff, 2004). We used the Layer Property Flow (LPF) Package to simulate groundwater flow because it calculates the leakance from our input of vertical hydraulic conductivity and aquifer thickness. The LPF Package was more suitable for the Cedar Valley models because leakance estimated manually and fed as input data, in our opinion, has a higher degree of uncertainty than our horizontal and vertical hydraulic conductivity and aquifer thickness estimates.

Model Discretization

We developed the groundwater flow model by discretizing the hydrologic properties of the groundwater system and assigning the model boundary conditions, recharge rates, and groundwater withdrawal rates for the steady-state simulation and for each stress period of the transient simulation.

A set of model parameters define the various hydrologic properties and flow rates for the model domain. Time-independent model parameters are those whose locations, zone boundaries, and rates do not change with time during the simulation and calibration of the model, and include horizontal hydraulic conductivity, vertical anisotropy, specific yield, and specific storage. Time-dependent model parameters values change for each time step. The time-dependent parameters are the specified flow terms and their flow rates and are defined as points for wells and springs, arcs for drains and streams, and polygons for recharge and ET zones.

Spatial discretization: We originally constructed the model using three layers: a surface clay layer, a principal basin-fill aquifer, and a bedrock aquifer, and created an outer boundary consistent with the groundwater drainage basin boundary. Because of the lack of data from the clay and bedrock layers and instability in the calibration process of the steady-state model, we simplified and concentrated our modeling efforts on the basin fill and underlying bedrock. We combined clay and basin-fill aquifer units by estimating their combined equivalent hydraulic conductivity. The bedrock in this groundwater flow model works as a source of recharge and discharge, but we could not calibrate the bedrock groundwater flow due to lack of observed head and subsurface discharge data. In the final model, we combined all unconsolidated deposits into one layer (layer 1) referred to as the basin fill in this discussion (figure 37). We combined all consolidated bedrock units to create the bottom or bedrock layer in this modeling study, layer 2 (figure 38). We brought the lateral boundary of the original model domain (expanded grid area on figures 37 and 38) inward accordingly to match the extents of the basin-fill layer.

The new focused modeled area lateral boundary is consistent with the approximate limit of unconsolidated basin fill in Cedar Valley and includes both the basin-fill and underlying bedrock aquifers. We discretized the 163 square-mile (422 km^2) area into a three-dimensional rectangular grid of 138 rows, 49 columns, and two layers (figures 37 and 38). The groundwater

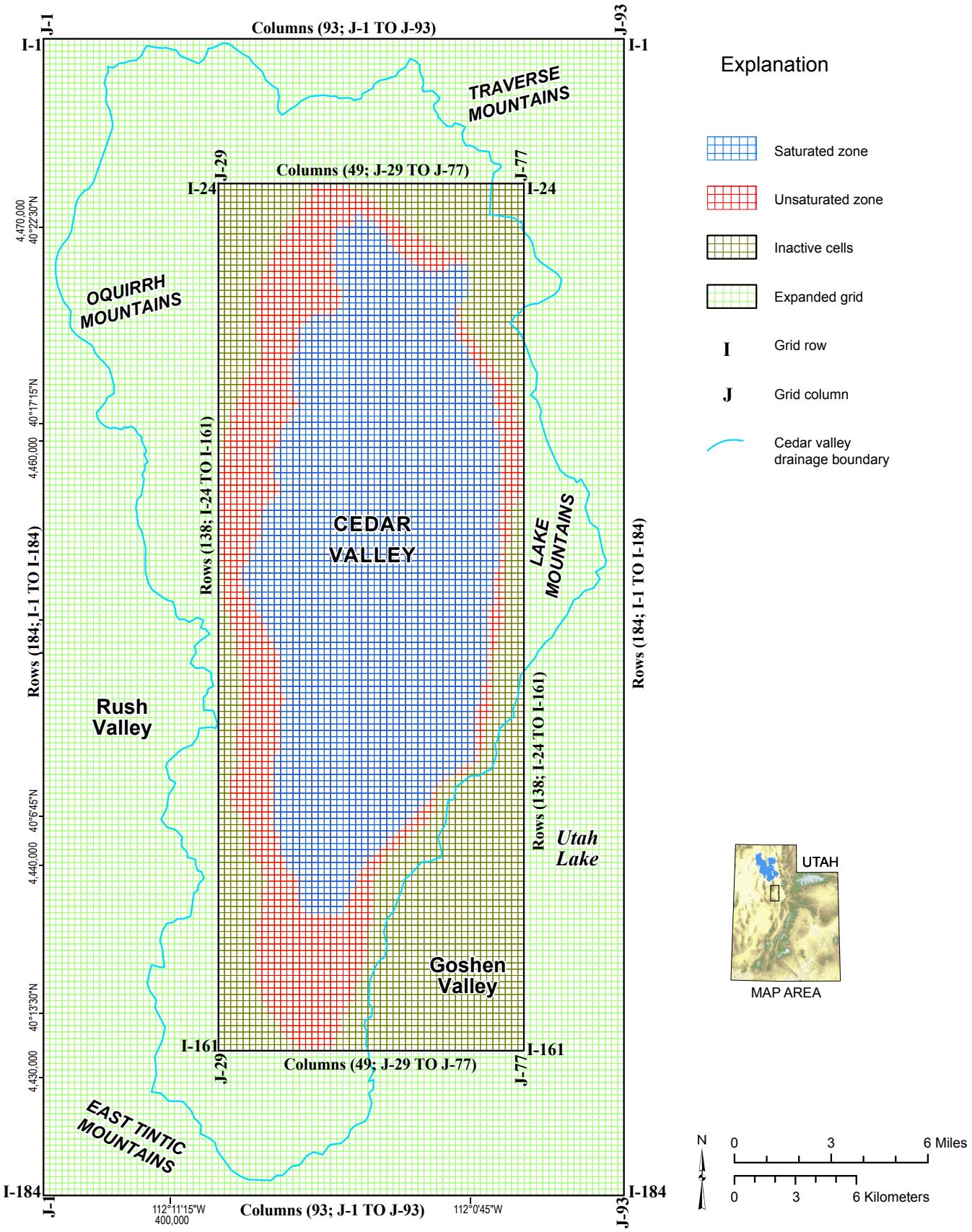


Figure 37. *Digital groundwater flow model grid layout for layer 1 (basin fill).*

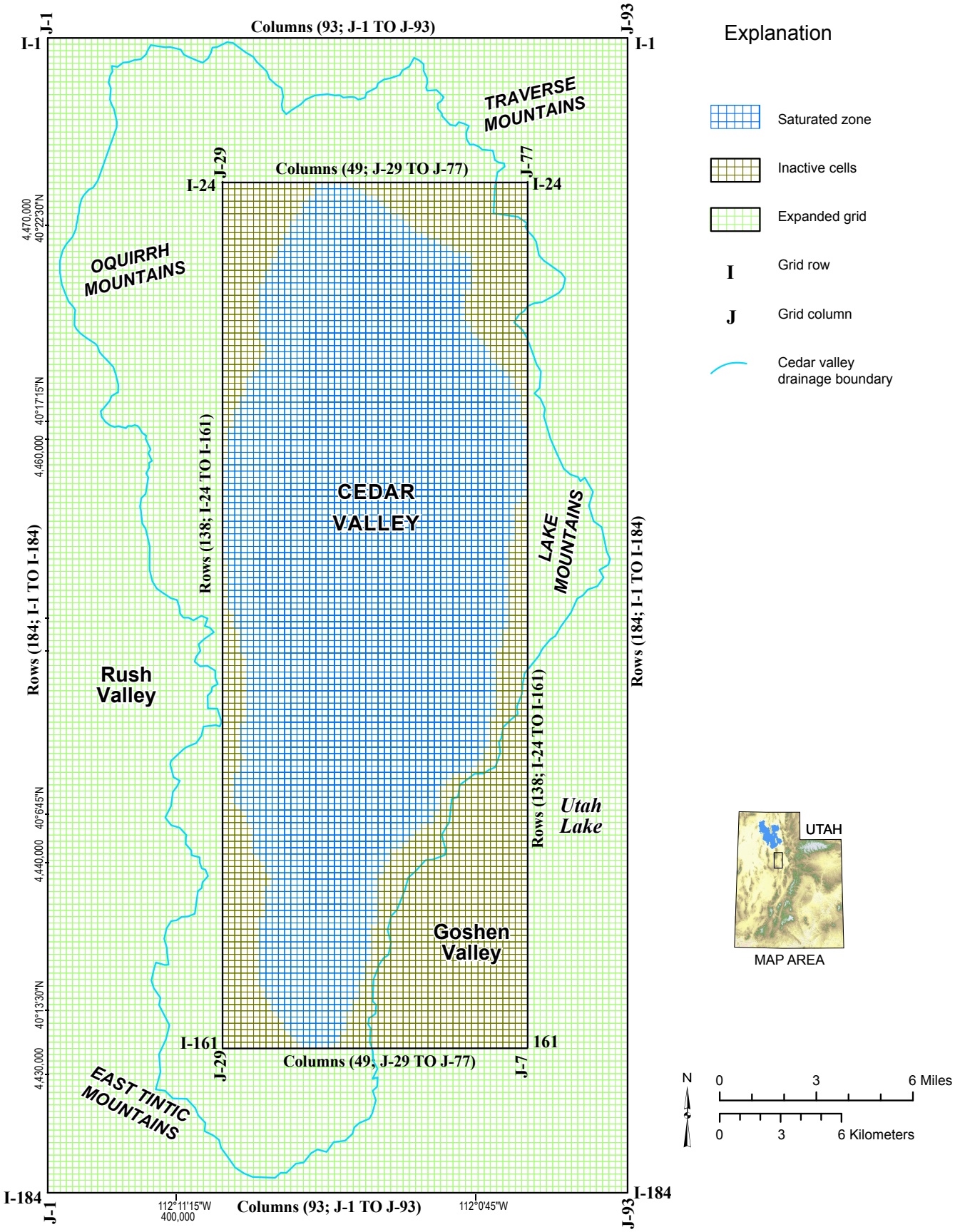


Figure 38. *Digital groundwater flow model grid layout for layer 2 (bedrock).*

flow equations are formulated at the center of each model cell (finite difference scheme), and each cell is assumed to have homogeneous properties. Cells are 1000 feet by 1000 feet (305 m x 305 m) in the horizontal plane, and cell dimension in the vertical plane depends on the thickness of the layers.

The geometry of the model layers is defined by the surface elevation (top of layer 1), the bottom of the basin fill (bottom of layer 1 and top of layer 2), and the bottom of the bedrock aquifer (bottom of layer 2). The elevation value for the top of each cell value was derived from a digital elevation model (DEM) of the ground surface. We modified Hurlow's (2004) basin-fill isopach map using new drill-hole data and used it to estimate the bottom elevation of layer 1/top of layer 2. The thickness of the basin-fill layer ranges from zero at the edges of the valley to 2275 feet (693 m) in the north-central part of the valley (figure 39). The elevation of the bottom of layer 2 is also the bottom of the model domain. We set this elevation at 2000 feet (609 m) above mean sea level to accommodate flow in bedrock beneath the basin fill, if required, but to exclude bedrock too deep to significantly participate in the Cedar Valley groundwater flow system. Also, no well data are available deeper than approximately 2000 feet (609 m) above sea level. The model cells representing the bedrock aquifer range in thickness from 581 feet (177 m) at the center of the valley under the deepest part of the basin fill to 4246 feet (1294 m) at the edges of the modeled area (figure 40).

Temporal discretization: The steady-state model simulates conditions in 1969. We consider 1969 to best approximate steady-state conditions for several reasons. March water levels over the transient modeling period (1970 to 2007) generally vary by 10 to 30 feet (3–9 m) in most wells; conversely, March water-levels for the three years preceding 1969 in 27 out of 31 wells for which data are available generally varied by less than 2 feet (0.6 m) with no apparent trend. Several irrigation wells were drilled and put into production in the early 1960s, and no other large wells were brought online until the mid 1970s, making 1969 relatively unaffected by new areas of groundwater extraction. Precipitation measured at Fairfield from 1961 to 1971 was less variable and nearer to the 30-year average than in the preceding decade. These data indicate the groundwater system was nearer to steady state in 1969 than any other year for which data are available; therefore, we used 1969 to approximate steady-state conditions. The main purpose for simulating steady-state conditions is to calculate calibrated values of aquifer parameters for use in the transient model.

The transient model simulates yearly stress periods from 1970 to 2007; each stress period is divided into one time step. Since water-level observations used in the model were usually measured in early- to mid-March, before seasonal pumping began, we used March 1 as the reference date for the start of each stress year. Calibrated water levels from the steady-state simulation were used as starting water levels in the transient simulation. Well withdrawal data were generally available on a calendar-year basis, and we calculated evapotranspiration, septic tank seepage, and precipitation recharge for each calendar year. We summed or estimated creek, canal, and spring flow for each water year (October 1 to September 30), but assigned the flow to the calendar year corresponding to the end of the water year to be consistent with the calendar-year data sources in the model input.

Distribution of Aquifer Characteristics

The basin-fill layer (layer 1) is simulated as a "convertible" layer, meaning individual cells within that layer may act as unconfined if the head (water level) is within the cell or confined if the head is above the top elevation of the cell. Layer 2 simulates confined conditions in the bedrock aquifer, which is overlain by the basin fill. Hydraulic characteristics that control simulated water levels are horizontal hydraulic conductivity, horizontal-to-vertical anisotropy of hydraulic conductivity, specific yield in layer 1, and specific storage in layer 2.

Hydraulic conductivity and vertical anisotropy: Distribution and values of horizontal hydraulic conductivity from aquifer tests and specific capacity data from Jordan (2013) shown on figure 5 were the basis for creating four hydraulic-conductivity zones in each of the original basin-fill and bedrock aquifer layers. To combine the clay layer and the basin-fill aquifer layer into layer 1, we modified the horizontal hydraulic conductivity coverage to reflect the average horizontal hydraulic conductivity (K_{avg}) for the entire vertical saturated thickness of layer 1. We calculated K_{avg} for the combined layer at the 22 locations where we had estimates of the hydraulic conductivity of the producing portion of the basin-fill aquifer using an averaging technique (Fetter, 1988, p. 110) in which the hydraulic conductivity of each lithologic unit is weighted according to its thickness. Because we had no hydraulic conductivity estimates for the clay layer or the deep sediments underlying the producing portions of the aquifer, we assumed values of $3x10^{-6}$ ft/d ($9x10^{-7}$ m/d) for the clay and $3x10^{-2}$ ft/d ($9x10^{-3}$ m/d) for the deep basin fill from published values (Fetter, 1988; Anderson and Woessner, 1992). The resulting K_{avg} is lower than the values from aquifer tests and estimated from specific capacity data because the lower assumed hydraulic conductivity in the clay layer and deep basin sediments decreases the average.

We averaged the calculated K_{avg} values in each of the four hydraulic-conductivity zones in the basin-fill aquifer to determine the initial horizontal hydraulic conductivity values used in the groundwater flow model. We used the same technique for the bedrock aquifer. Early steady-state model runs required more than four hydraulic-conductivity zones to produce a reasonable head distribution. We let the sensitivity analysis and calibration runs of the steady-state model guide us in locating the boundaries of new hydraulic-conductivity zones. As a result, we replaced the initial four hydraulic-conductivity zones

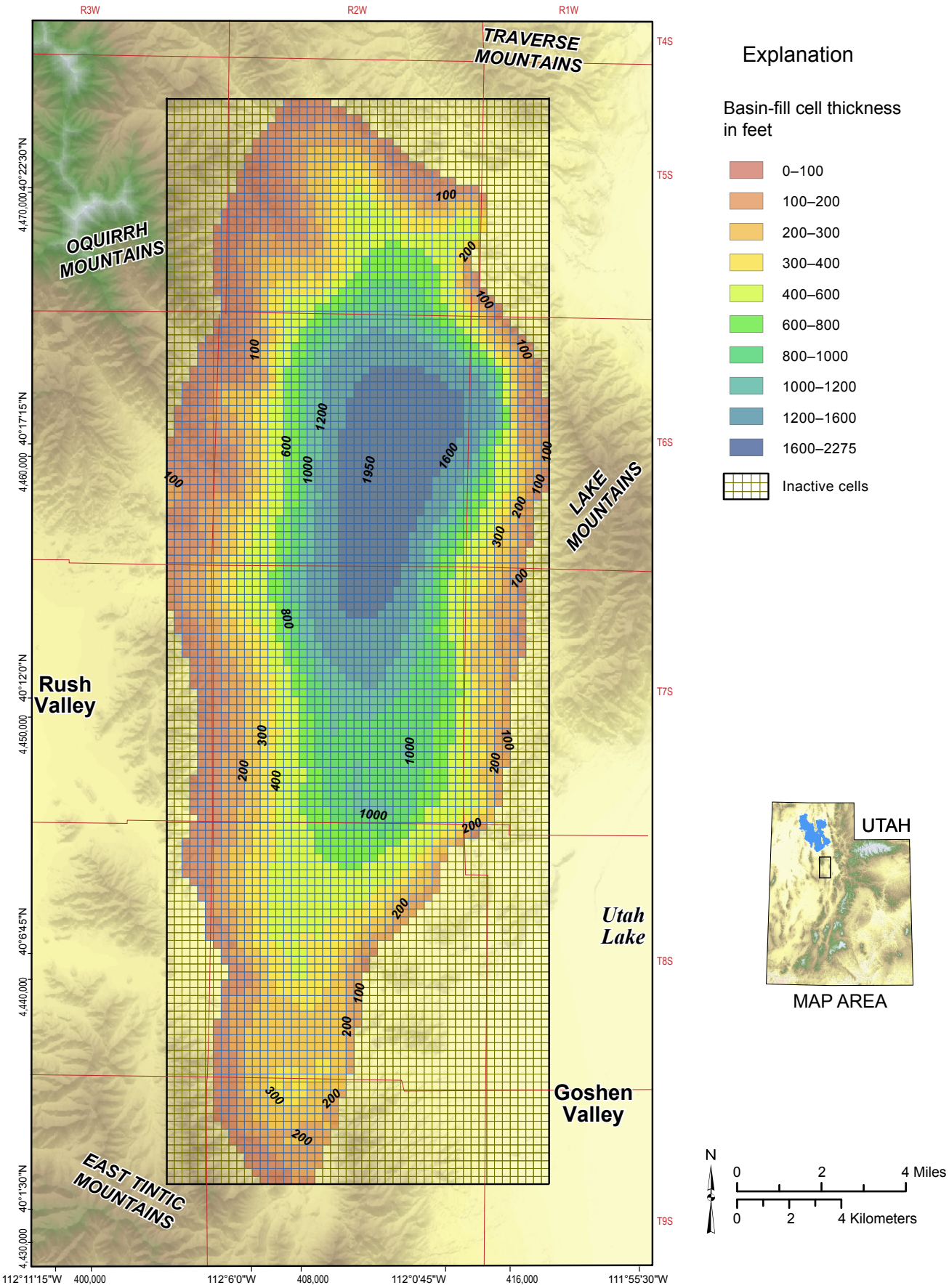


Figure 39. *Cell thickness for model layer 1 (basin-fill aquifer).*

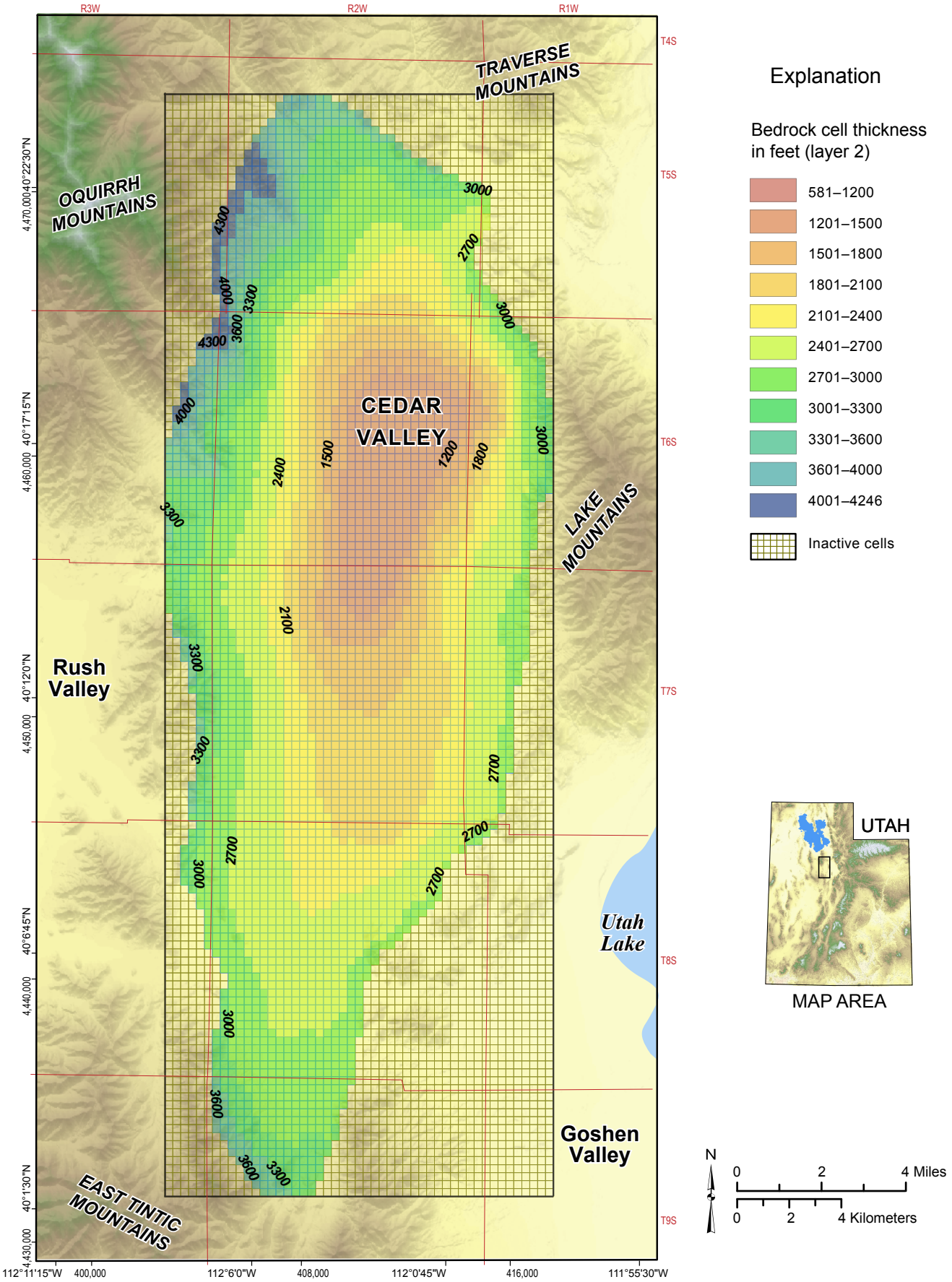


Figure 40. *Cell thickness for model layer 2 (bedrock aquifer).*

in each layer with 38 new hydraulic-conductivity zones. We interpolated the initial hydraulic conductivity value of each zone in layer 1 based on the K_{avg} values calculated at the 22 well locations. The initial input values of horizontal hydraulic conductivity (kh) for layer 1 ranged from 2.5 to 15 ft/d (0.8–4.6 m/d), and for layer 2 values ranged from 12.5 to 47.5 ft/d (3.8–14 m/d). Figure 41 illustrates the 38 zone boundaries and the final calibrated values of horizontal hydraulic conductivity for the model. Results of model calibration are discussed in a later part of this report. Appendix G, table G-1 lists all parameters, key values, initial, and final calibrated values for all hydraulic properties in both model layers.

We used vertical anisotropy, defined as the ratio between horizontal hydraulic conductivity and vertical hydraulic conductivity, to define vertical hydraulic conductivity. Because no field data were available for vertical hydraulic conductivity, we assigned an initial vertical anisotropy value of four model-wide, i.e., the horizontal hydraulic conductivity is four times larger than the vertical hydraulic conductivity. Initial and final vertical anisotropy are shown on figure 42 and table G-1.

Specific yield and specific storage: We used the hydraulic-conductivity zone boundaries to define zones of specific yield (SY) in layer 1 and specific storage (SS) in layer 2. We extracted initial values of SY and SS from textbook standards (Fetter, 1988) based on the lithology of the earth materials in each layer, which were consistent with the few values we determined by multiple-well aquifer tests (Jordan, 2013). Our initial aquifer-test estimates of specific yield ranged from 0.02 to 0.22; SY was set to 0.11 in the model and allowed to vary between 0.0001 and 0.22. Initial values of specific storage ranged from 1.0×10^{-6} to 2.1×10^{-5}/ft (3.4×10^{-7} –6.4×10^{-6} /m) (Anderson and Woessner, 1992); SY in the model was set to 1.1×10^{-5}/ft (3.4×10^{-6}/m) and allowed to vary between 1.0×10^{-9} to 1.0×10^{-4}/ft (3×10^{-10}–3×10^{-5}/m) for layer 2. Figure 43 and table G-1 contain initial and final calibrated values of SY and SS.

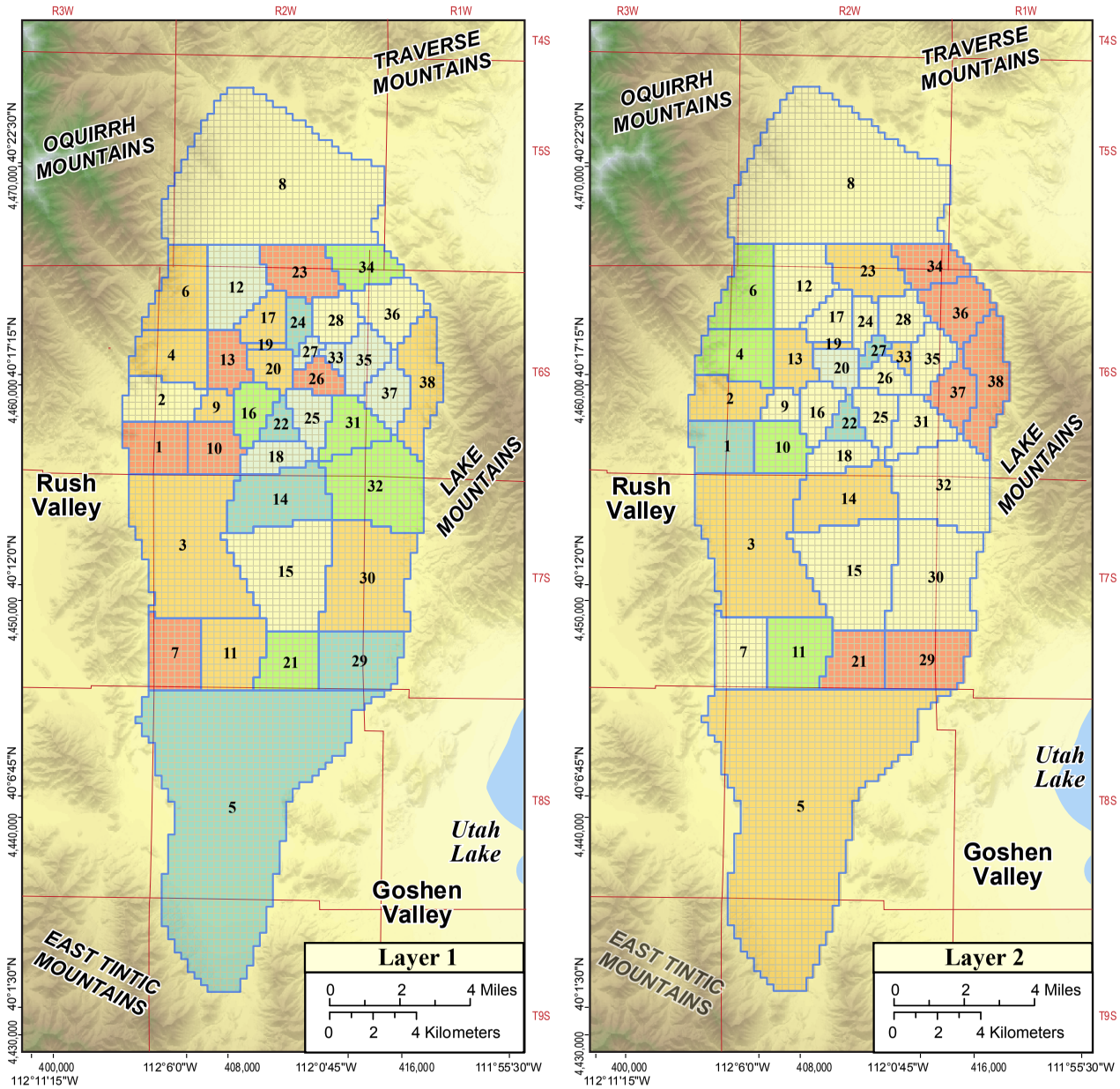
Boundary Conditions

We assigned a set of boundary conditions to the lateral and bottom edges of the model. The boundary conditions dictate how the model simulates the groundwater system response to external natural (springs and streams) and artificial (wells) stresses and how it interacts with the surrounding hydrologic system (subsurface inflows and outflows) (figure 44). We used the following boundary types: (1) no-flow boundaries to simulate a plane across which no flow is expected to occur, (2) specified-flow boundaries to simulate sources and sinks with known or estimated flow, and (3) head-dependent flow boundaries to simulate the flow across a boundary that is dependent on the difference in heads across the boundary.

No-flow boundaries: The outer edge of layer 1 is effectively a no-flow boundary because the outermost cell of layer 1 represents the thinned edge of the basin fill as it laps onto the mountain front and therefore has zero thickness (figure 39). The outer edge of layer 2 represents the interface between the modeled area and the mountains and hills surrounding Cedar Valley. We assigned no-flow boundaries to the edge of layer 2 between the modeled area and (1) Thorpe and Topliff Hills area between Cedar and Rush valleys, (2) the southern part of the Mosida Hills area, (2) the northern part of the Mosida Hills area, (4) the western side of the Lake Mountains, (5) the southwestern part of the Traverse Mountains, and (6) the bottom of the model (figure 44). No-flow boundaries were the most appropriate boundary condition to use at these locations because either the area is composed of low permeability materials and groundwater flow direction is parallel to the boundary, as in the southwestern Traverse Mountains, or geologic, potentiometric, and geochemical information support a theory of no-flow, as in the Thorpe and Topliff Hills area and on the western side of Lake Mountains as discussed previously. Although there is no direct evidence about the nature of the bottom of the model at 2000 feet elevation (609 m), a no-flow boundary was assigned here under the assumption that fractures would be essentially closed by the weight of overlying strata and permeability would be greatly reduced.

Recharge boundaries: We divided our estimation of recharge from precipitation into eight regions (figure 44). Precipitation on four of those regions is not simulated as recharge in the refined, smaller model area because either a no-flow boundary separates the region from the model domain, as for region 3 (Thorpe and Topliff Hills), region 7 (Lake Mountains), and part of region 6 (Cedar Pass), or the recharge area is downgradient of the model domain, as for region 8 (Mosida Hills) and part of region 6 (Cedar Pass) (also true for region 7–Lake Mountains). The four recharge regions that provide recharge to the aquifer system in the model domain are region 1 (West Canyon drainage area), region 2 (Oquirrh Mountains), region 4 (East Tintic Mountains), and region 5 (valley floor).

The valley floor receives recharge from precipitation, irrigation return flow, stream and canal leakage, and other minor sources from the land surface. We simulated the valley floor as a specified-flow boundary, and applied recharge to the active cells in layer 1 using the Recharge Package embedded in MODFLOW-2000. We divided the valley floor into 39 recharge zones (figure 45) and assigned the volume of precipitation recharge that we had estimated using the geology-refined Maxey-Eakin method to the zone in which it occurred. Figures 45 and 46 show the difference between the initial estimates of recharge to the top of the basin-fill model layer and the model-simulated and calibrated recharge for the steady-state and end of the transient model, respectively. Estimated recharge from non-precipitation sources, including stream and canal seepage (100–2200 acre-ft/yr [0.1–2.7 hm^3/yr]), unused irrigation seepage (550–1500 acre-ft/yr [0.7–1.9 hm^3/yr]), the Sinks (200–400 acre-ft/yr [0.2–0.5 hm^3/yr]) and wastewater treatment seepage (30–130 acre-ft/yr [0.04–0.16 hm^3/yr]) (figure 47, table 2, appendix E) was not added to the



Explanation

Model-calibrated hydraulic conductivity (ft/day)

- 0.02–0.50
- 0.51–2.50
- 2.51–7.50
- 7.51–10.0
- 10.1–50.0
- 50.1–150
- 21 Hydraulic conductivity zone ID

Initial hydraulic conductivity model input (ft/day)

ID	Layer 1	Layer 2	ID	Layer 1	Layer 2
1	15	12.5	20	15	47.5
2	15	12.5	21	2.5	12.5
3	15	12.5	22	2.5	12.5
4	15	12.5	23	15	47.5
5	2.5	12.5	24	15	47.5
6	15	12.5	25	15	47.5
7	2.5	12.5	26	15	47.5
8	15	12.5	27	2.5	47.5
9	15	47.5	28	15	47.5
10	15	12.5	29	2.5	12.5
11	2.5	12.5	30	15	12.5
12	15	12.5	31	15	47.5
13	15	47.5	32	15	12.5
14	15	12.5	33	15	47.5
15	15	12.5	34	15	47.5
16	15	12.5	35	15	47.5
17	15	47.5	36	15	47.5
18	15	12.5	37	15	47.5
19	15	47.5	38	15	47.5

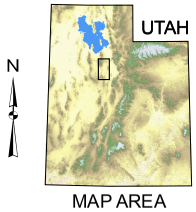


Figure 41. *Model-calibrated horizontal hydraulic conductivity values for basin-fill and bedrock model layers. A pattern of higher hydraulic conductivity in the bedrock aquifer on the east side of the valley observed in aquifer test and specific capacity field data (figure 5B) was reproduced in the model; however calibrated basin-fill hydraulic conductivity is more randomly distributed than shown in the field data (figure 5A).*

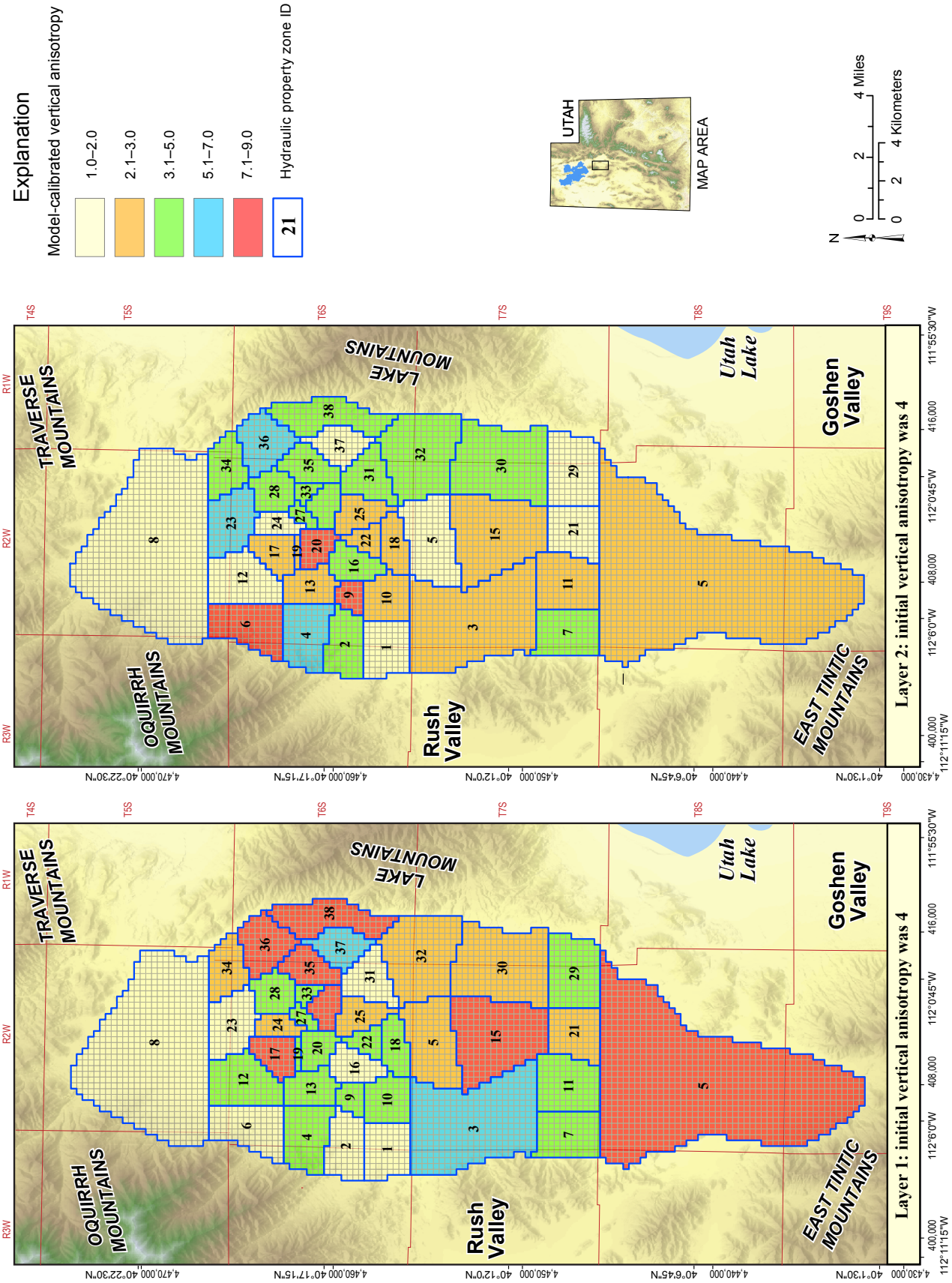


Figure 42. *Final (model-calibrated) vertical anisotropy values for both model layers.*

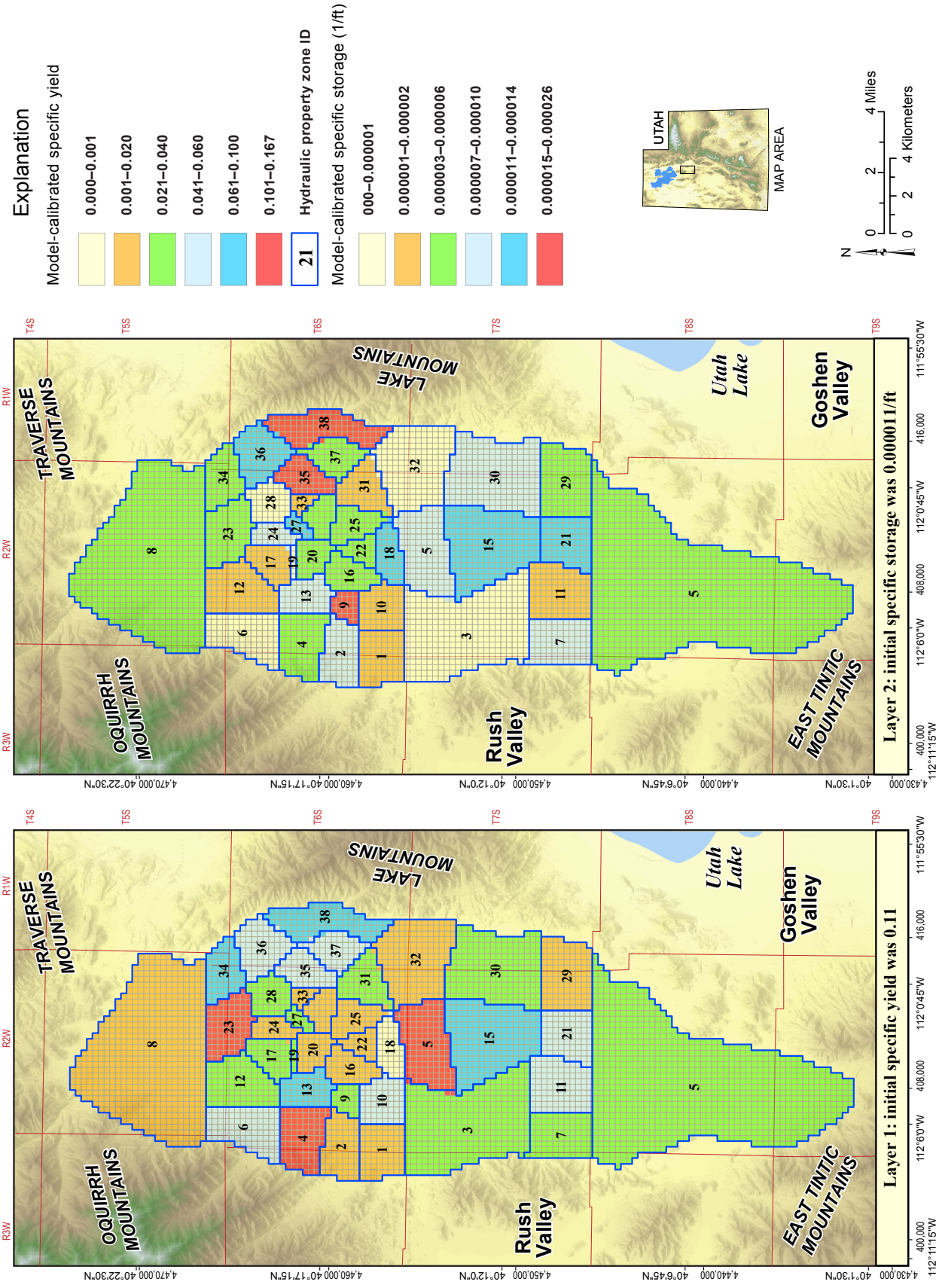


Figure 43. Final (model-calibrated) specific yield and specific storage values for both model layers.

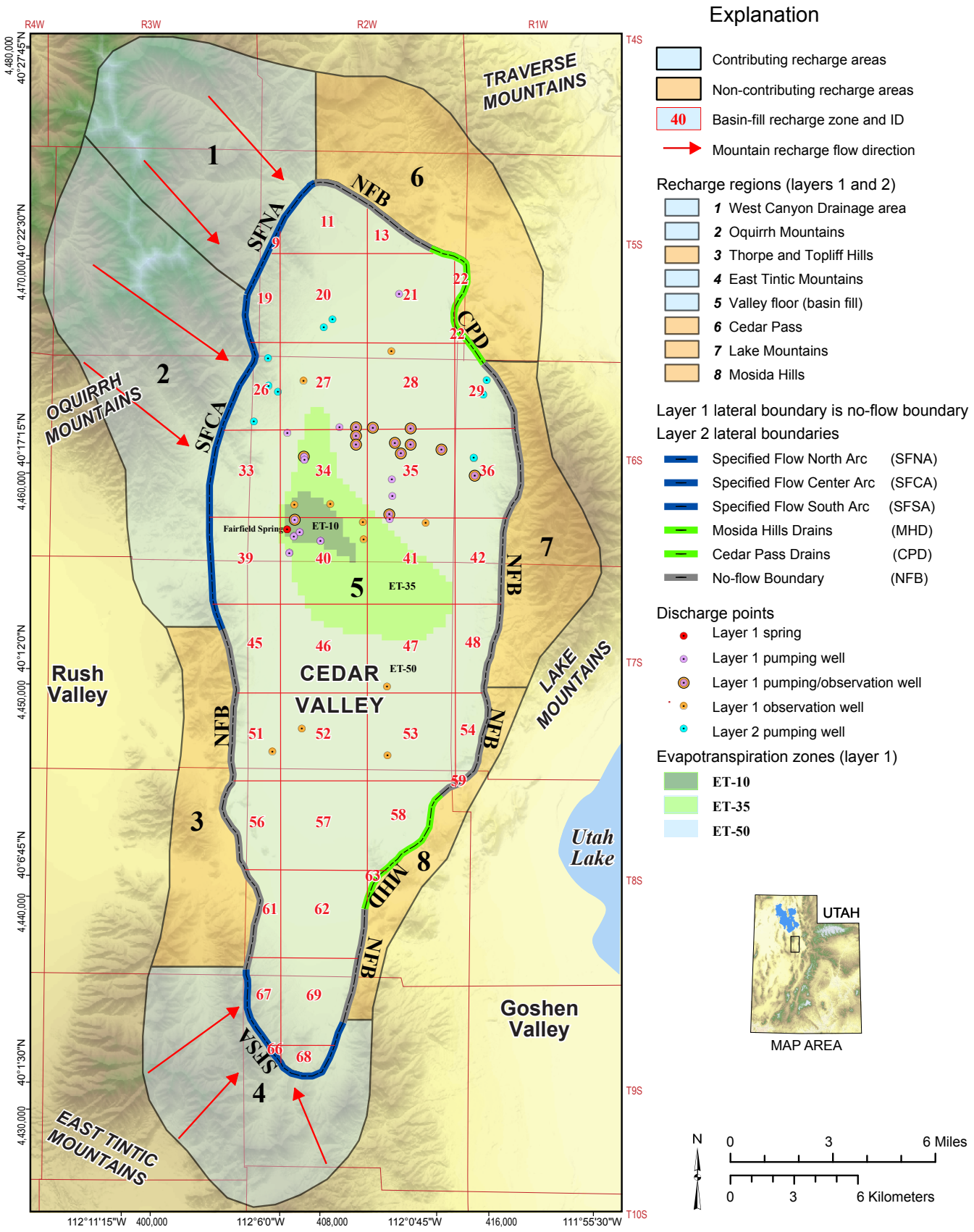
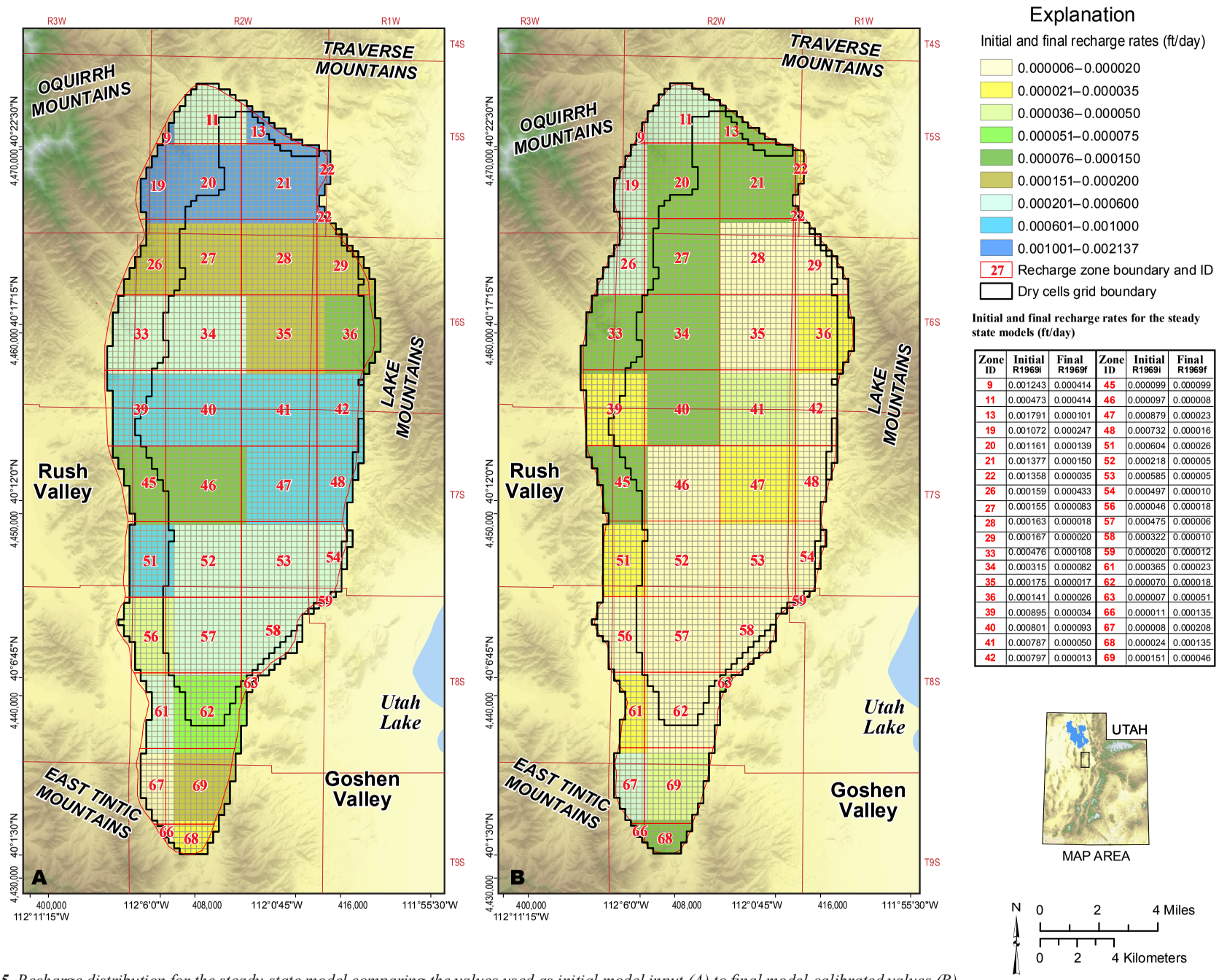


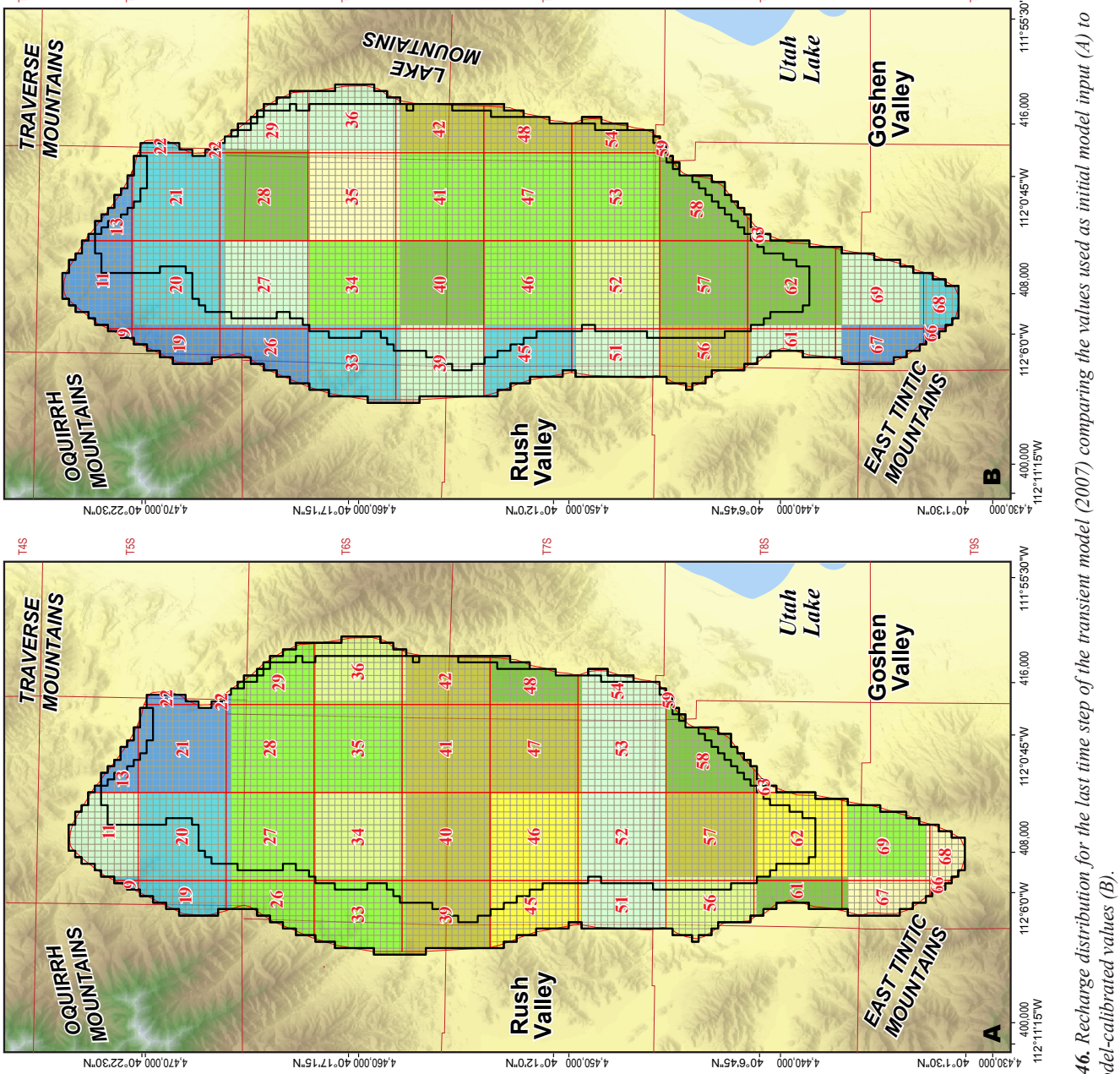
Figure 44. *Boundary conditions, recharge regions, and discharge locations in Cedar Valley.*



Initial and final recharge rates for the steady state models (ft/day)

Zone ID	Initial R1969i	Final R1969f	Zone ID	Initial R1969i	Final R1969f
9	0.001243	0.000414	45	0.000099	0.000099
11	0.000473	0.000414	46	0.000097	0.000008
13	0.001791	0.000101	47	0.000879	0.000023
19	0.001072	0.000247	48	0.000732	0.000016
20	0.001161	0.000139	51	0.000604	0.000026
21	0.001377	0.000150	52	0.000218	0.000005
22	0.001358	0.000035	53	0.000585	0.000005
26	0.000159	0.000433	54	0.000497	0.000010
27	0.000155	0.000083	56	0.000046	0.000018
28	0.000163	0.000018	57	0.000475	0.000006
29	0.000167	0.000020	58	0.000322	0.000010
33	0.000476	0.000108	59	0.000020	0.000012
34	0.000315	0.000082	61	0.000365	0.000023
35	0.000175	0.000017	62	0.000070	0.000018
36	0.000141	0.000026	63	0.000007	0.000051
39	0.000895	0.000034	66	0.000011	0.000135
40	0.000801	0.000093	67	0.000008	0.000208
41	0.000787	0.000050	68	0.000024	0.000135
42	0.000797	0.000013	69	0.000151	0.000046

Figure 45. *Recharge distribution for the steady-state model comparing the values used as initial model input (A) to final model-calibrated values (B).*



Initial and final recharge rates in 2007 in (ft/day)

Zone ID	Initial	Final	Zone ID	Initial	Final
9	0.000958	0.002039	45	0.000035	0.000805
11	0.000437	0.002137	46	0.000035	0.000059
13	0.001369	0.001132	47	0.000180	0.000053
19	0.000802	0.002045	48	0.000149	0.000197
20	0.000893	0.000921	51	0.000558	0.000331
21	0.001058	0.000916	52	0.000203	0.000049
22	0.001044	0.000913	53	0.000541	0.000055
26	0.000059	0.001332	54	0.000459	0.000156
27	0.000057	0.000270	56	0.000049	0.000181
28	0.000060	0.000129	57	0.000193	0.000077
29	0.000062	0.000248	58	0.000131	0.000090
33	0.000069	0.000804	59	0.000018	0.000181
34	0.000045	0.000066	61	0.000149	0.000256
35	0.000058	0.000046	62	0.000029	0.000116
36	0.000047	0.000255	63	0.000006	0.000431
39	0.000183	0.000366	66	0.000009	0.001659
40	0.000164	0.000103	67	0.000006	0.001768
41	0.000161	0.000062	68	0.000020	0.000885
42	0.000163	0.000193	69	0.000055	0.000434

Figure 46. *Recharge distribution for the last time step of the transient model (2007) comparing the values used as initial model input (A) to final model-calibrated values (B).*

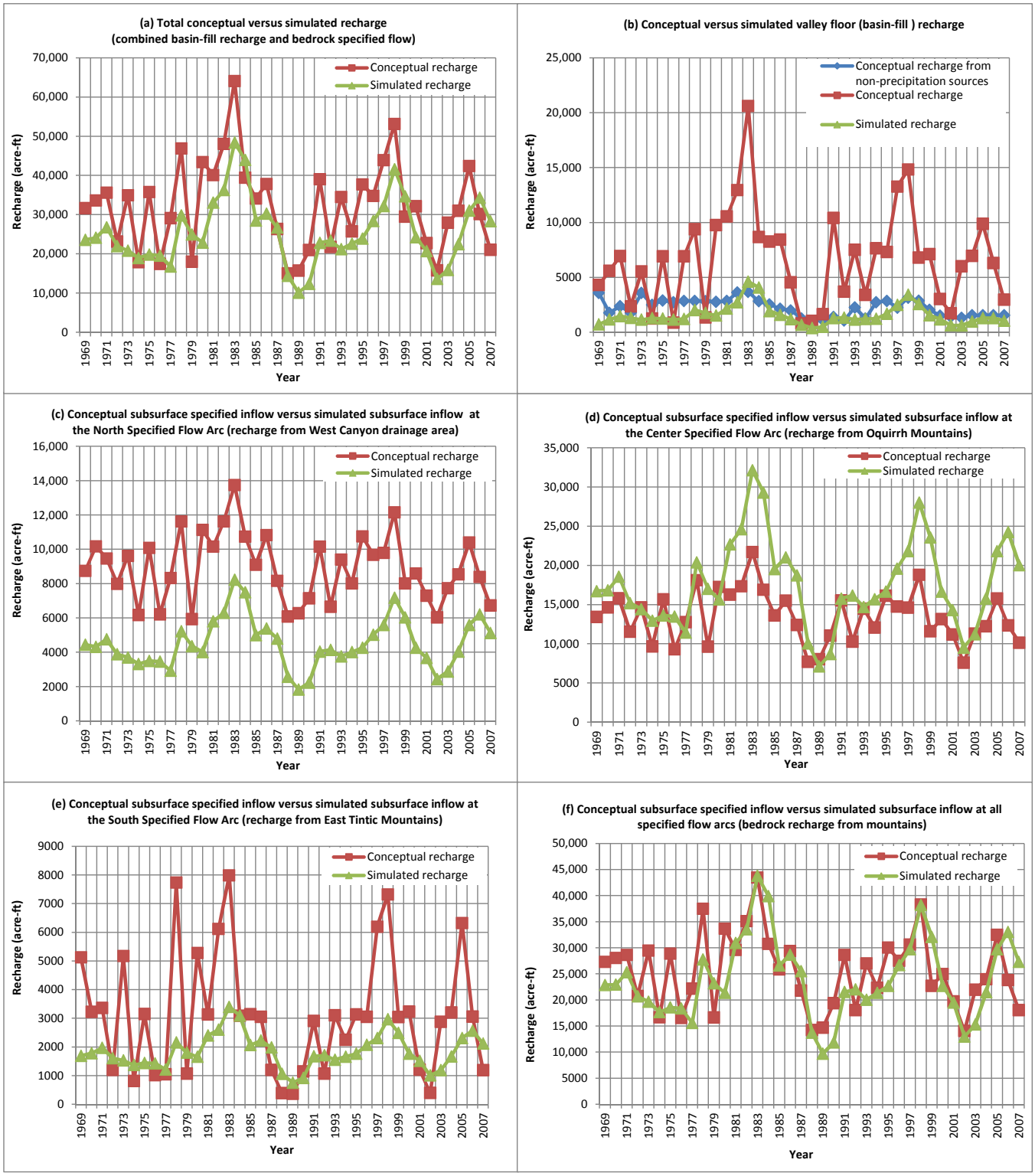


Figure 47. *Initial (conceptual) and final simulated (model-calibrated) recharge through time for various recharge locations.*

initial recharge estimates, but was used to guide changes in the recharge distribution in the trial and error calibration of the steady-state model. The initial values of valley-floor recharge from precipitation used in the groundwater model range from 800 acre-ft/yr (1 hm^3/yr) in 1988 to 20,600 acre-ft/yr (25.4 hm^3/yr) in 1983 and have a 39-year average of 6600 acre-ft/yr (8.1 hm^3/yr) (table E-1).

We entered the volume of recharge, estimated using the geology-modified Maxey-Eakin method, from the mountain recharge regions into the groundwater model through the sides of the bedrock layer of the model. We assigned recharge to layer 2 from the West Canyon, Oquirrh, and East Tintic recharge regions to the north, center, and south specified flow arcs, respectively, (figure 44). When we transformed the conceptual model into a numerical model, we assigned the recharge represented by the specified flow arcs to injection wells in the grid cells intersected by each flow arc using MODFLOW's Well Package. Recharge from the West Canyon, Oquirrh, and East Tintic recharge regions was assigned to 24, 27, and 62 wells, respectively. The initial values of recharge assigned to each flow arc each year from its respective recharge region are shown on figure 47 and given in appendix E, and averaged approximately 8900 acre-ft/yr (11 hm^3/yr) from the West Canyon drainage basin, 13,500 acre-ft/yr (16.6 hm^3/yr) from the Oquirrh Mountains, and 3100 acre-ft/yr (3.8 hm^3/yr) from the East Tintic Mountains range. Total initial estimates of recharge from consolidated bedrock input to the model through the three specified flow arcs (i.e. bedrock recharge) ranged from 14,100 acre-ft/yr (17.3 hm^3/yr) in 2002 to 43,500 acre-ft/yr (53.6 hm^3/yr) in 1983 and had a 39-year average of 25,500 acre-ft/yr (31.5 hm^3/yr) (appendix E).

Discharge boundaries: Discharge to production wells, springs, subsurface outflow, and evapotranspiration is simulated in this model. Figure 44 shows discharge boundary conditions.

We simulated discharge to wells using the Well Package. Reported or estimated groundwater withdrawal from all wells in the study area are provided in appendix F. Only wells within the model domain that pumped or were expected to pump more than 4 acre-ft/yr ($5x10^{-3}$ hm^3/yr) were included in the model (figure 44). Wells outside the model domain are identified in appendix F and include most of the bedrock and perched aquifer wells in the Cedar Pass area. The 23 wells in the basin-fill aquifer included in the model discharged a combined total of between 1040 and 4250 acre-ft/yr (1.28–5.24 hm^3/yr), with the general trend increasing over the years. Discharge to 10 wells in the bedrock aquifer included in the model ranged from zero before 1974 to 2950 acre-ft/yr (3.64 hm^3/yr) in 2000. The combined two-layer model groundwater withdrawal from these 33 wells ranged from approximately 1300 acre-feet (1.60 hm^3/yr) in 1972 to approximately 6530 acre-feet (8.02 hm^3/yr) in 2007 with a 39-year average of 3560 acre-ft/yr (4.39 hm^3/yr).

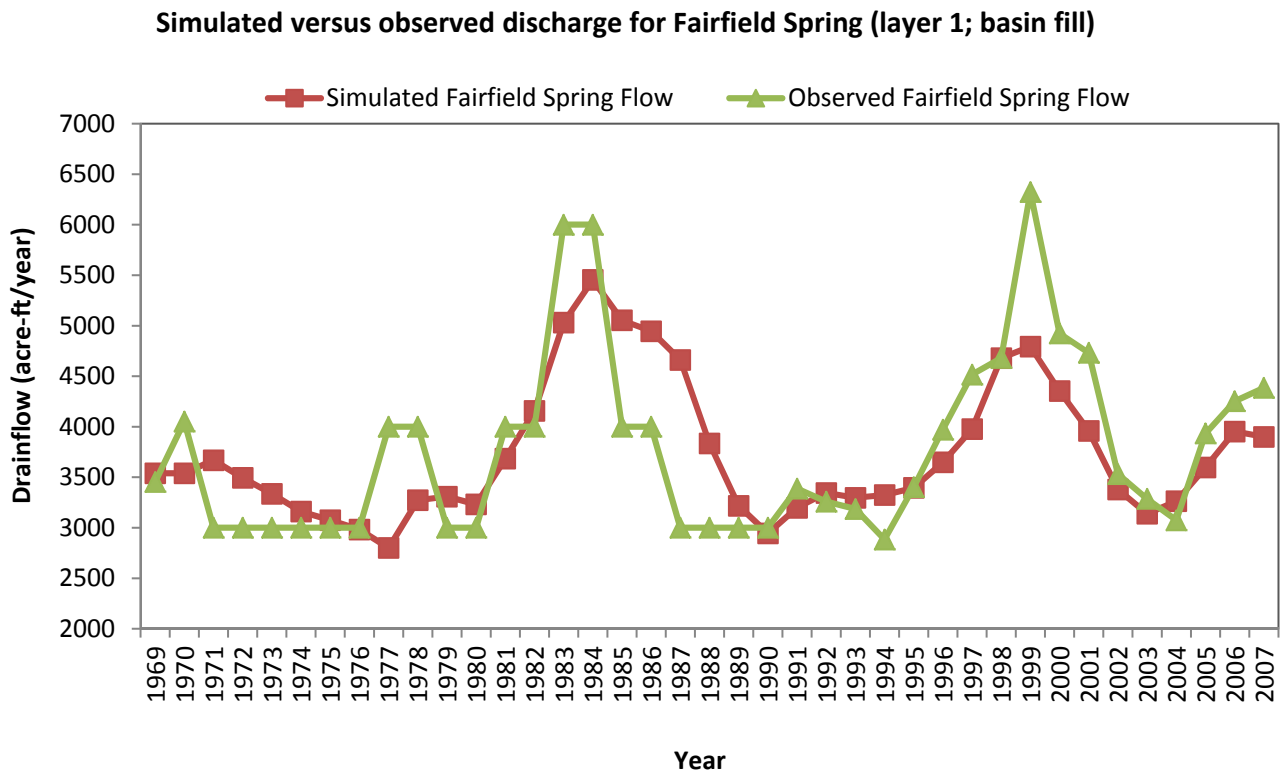
We simulated discharge to Fairfield Spring as a head-dependent flow boundary in layer 1 using the Drain Package. Observed or estimated spring discharge for Fairfield Spring ranged from approximately 2900 acre-ft/yr (3.6 hm^3/yr) in 1994 to approximately 6300 acre-ft/yr (7.8 hm^3/yr) in 1999 as shown on figure 48 and in appendix F, table F-1. Fairfield Spring was assigned an initial drain conductance value of 5000 ft^2/d/ft (465 m^2/d/m).

Three medium-sized springs are present in the study area; however, only one of these, South Spring, is located within the model domain near Cedar Fort town. Only four measurements of South Spring discharge are available; in these measurements, taken in 1965 and 1966, discharge varied from 79 to 125 gpm (5.0–7.9 L/s) (normalized to 127 to 202 acre-ft/yr [0.16–0.25 hm^3/yr]) or less than 5% of the discharge from Fairfield Spring. Because of the relatively minor discharge compared to Fairfield Spring and lack of measured discharge data, we did not include South Spring as a calibration target in the model; however, we reduced recharge input to the model cell where the spring is located by South Spring's average flow so that spring discharge was somewhat represented in the model.

We simulated discharge to subsurface outflows as head-dependent boundaries (figure 44). Subsurface outflow occurs along two boundaries in layer 2 (bedrock): the northeastern Cedar Pass boundary and the southeastern Mosida Hill boundary, which were simulated as drain flow arcs using the Drain Package. We assigned the drain flow arcs initial conductance values of 20 ft^2/d/ft (2 m^2/d/m) and bottom elevations of 200 feet (60 m) below the top elevation of layer 2 at either end of the arcs (table G-1). When we converted the conceptual model into a numerical model, the Cedar Pass and Mosida Hills drain arcs became 14 and 18 drain cells, respectively. We adjusted the values of conductance and bottom elevations during model calibration.

We simulated discharge from the model area via evapotranspiration from layer 1 using the Evapotranspiration Package. In this discussion, ET refers to the evapotransipiration from the model's groundwater reservoir, analogous to our calculated ET_g. The rate of ET in the model depends on the maximum ET rate, the extinction depth (the depth below ground surface at which evapotranspiration does not occur), and the simulated groundwater level (McDonald and Harbaugh, 1988). We assumed the ET surface to be the ground surface. We divided the study area into three ET zones: ET-10, ET-35, and ET-50 (figure 49), which represent the 10 feet (3 m), 35 feet (11 m), and 50 feet (15 m) extinction depths, respectively. Initial estimates of ET from the conceptual model and final simulated values for ET are shown on figure 49 and figure 50 and tabulated in appendix G, table G-3.

ET-10 roughly represents the area around Fairfield where the water table is within 10 feet (3 m) of the surface. It has an area of 1560 acres (631 ha) (1.6% of the model area) and was



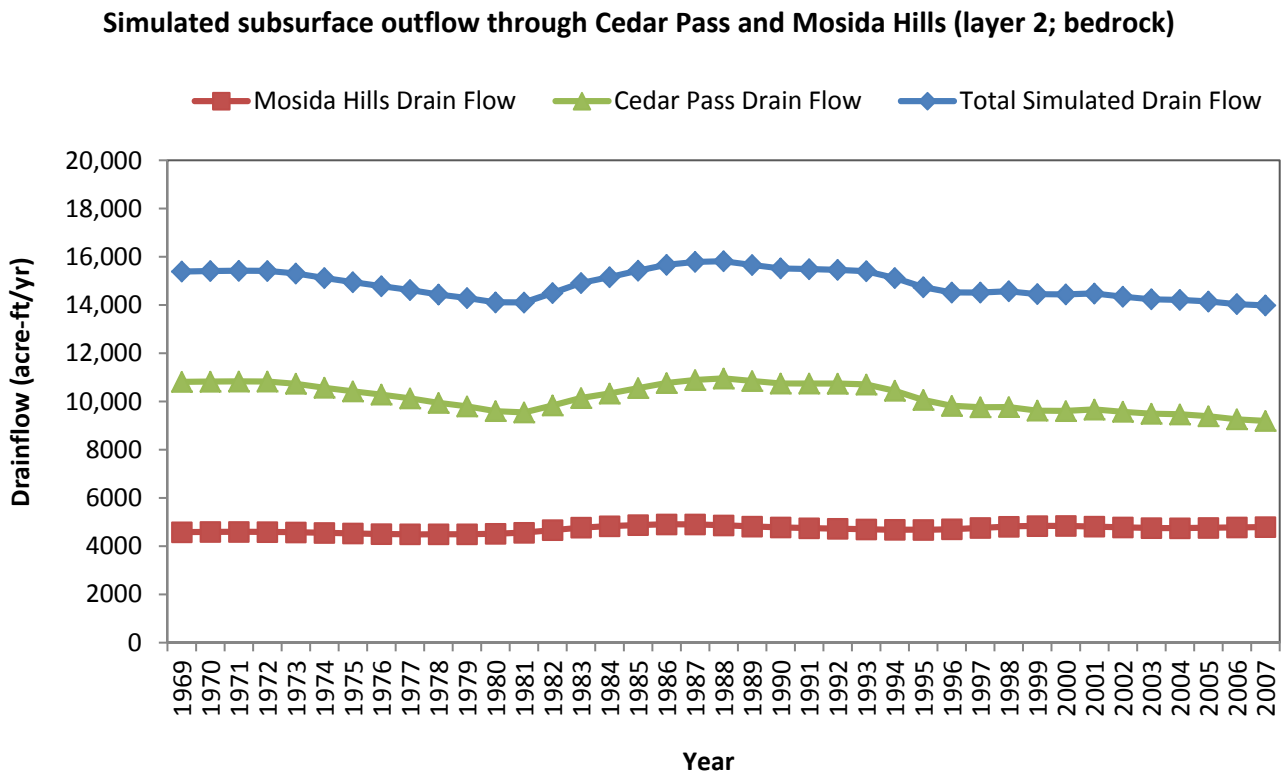


Figure 48. *Simulated drainflow discharge from Fairfield Spring, Cedar Pass, and Mosida Hills.*

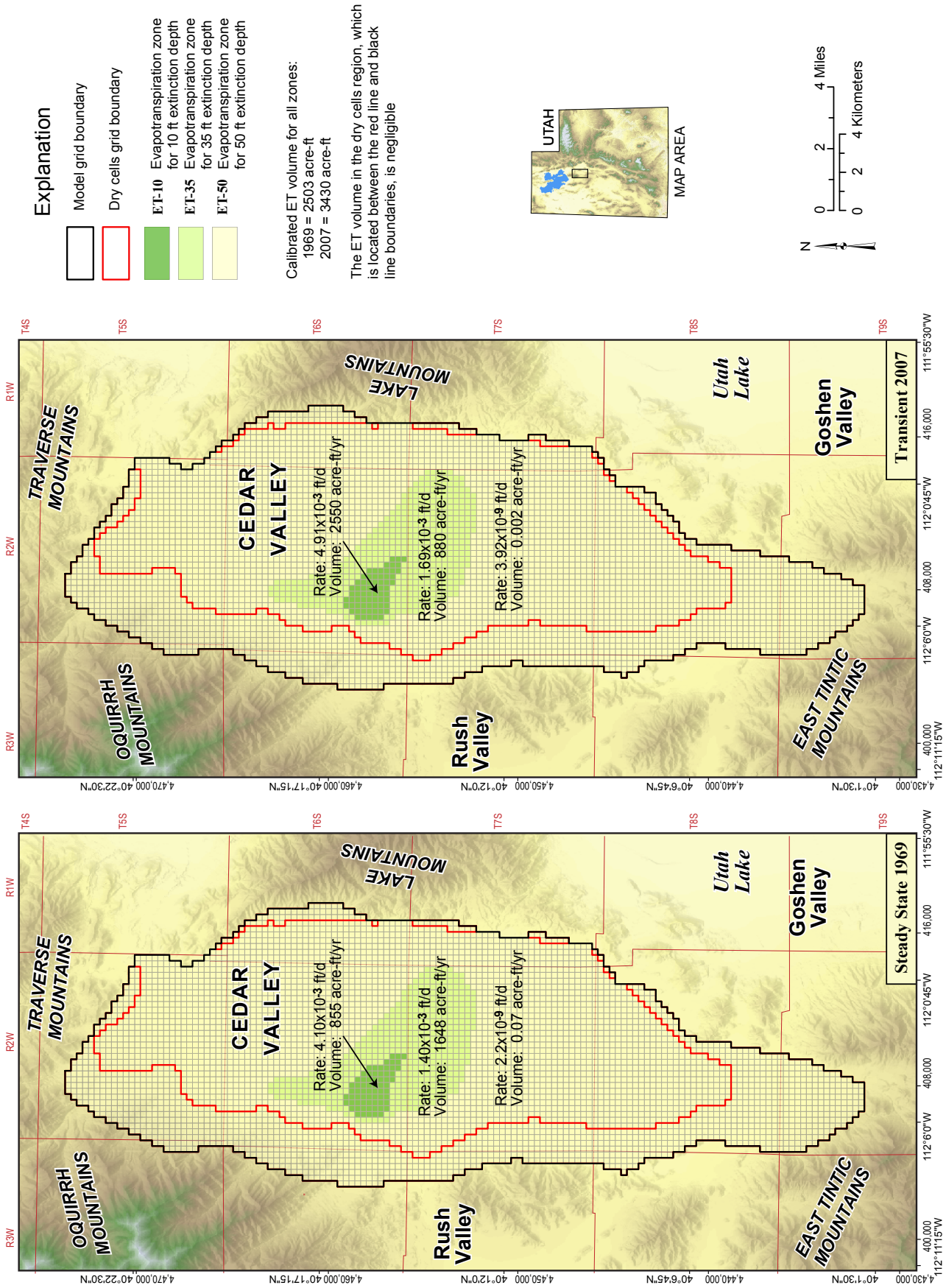


Figure 49. *Final ET distribution for steady-state (1969) and the last time step of the transient model (2007).*

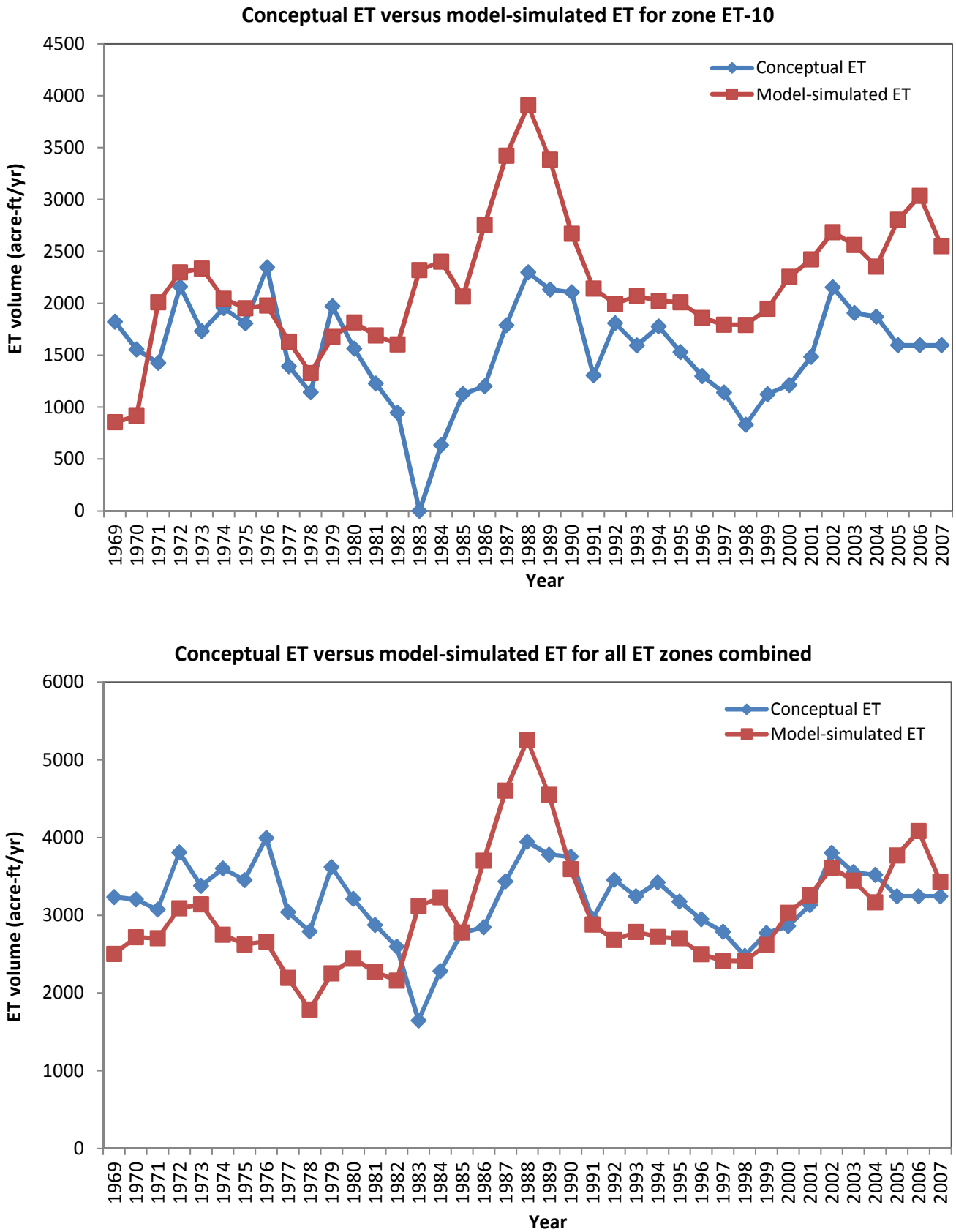


Figure 50. *Conceptual versus model-simulated evapotranspiration (ET).*

assigned an extinction water depth of 10 feet (3 m). We estimated the ET from zone ET-10 using the methods discussed earlier in the water budget section on discharge to be between zero acre-ft/yr in 1983 and 2400 acre-ft/yr (0–3.0 hm^3/yr) in 1976 with a 39-year average volume of approximately 1600 acre-ft/yr (2.0 hm^3/yr) of water being evapotranspirated from groundwater. Those initial volume estimates correspond to ET rates ranging from 0 ft/day to $4.4x10^{-3}$ ft/day (0–$1.4x10^{-3}$ m/d). ET-35 is where the water table is between 10 and 35 feet (3–11 m) below the surface. It has an area of 9837 acres (3981 ha) and was given an extinction depth of 35 feet (11 m). This zone represents the area where greasewood and other phreatophytes may be extracting water from the groundwater table, and it is one of the least-well-defined parameters in our conceptual model. We started the steady-state simulation with an initial ET rate for zone ET-35 of $1.0x10^{-3}$ ft/day ($3.0x10^{-4}$ m/d), which equates to a volume of 1413 acre-ft/yr (1.74 hm^3/yr). Then we used the calibrated ET rate from the steady-state simulation, $1.4x10^{-3}$ ft/day ($4.3x10^{-4}$ m/d), which equals 1648 acre-ft/yr (2.03 hm^3/yr), as an initial ET rate for all stress periods in the transient simulation. The remaining basin-fill area, 88,870 acres (35,970 ha), represents the area where the water table is greater than 35 feet (11 m) below the surface. It was assigned zone ET-50, and has an extinction depth of 50 feet (15 m). The initial ET rate assigned to this zone in the steady-state simulation was $1.0x10^{-9}$ ft/d ($3.0x10^{-10}$ m/d), which equates to an ET volume of 0.03 acre-ft/yr, or essentially zero ET. Then we used the rate from the calibrated steady-state model, $2.2x10^{-9}$ ft/d ($6.7x10^{-10}$ m/d) or 0.07 acre-ft/yr ($9x10^{-5}$ hm^3/yr), as an initial ET rate for all stress periods in the transient simulation. We allowed ET to vary over a wide range of values during model calibration because ET is a poorly constrained parameter.

Model Calibration

The goal of model calibration is to closely match the conceptual and modeled groundwater recharge, discharge, flow regime, and the measured water levels in the model domain area. The differences (residuals) between simulated and measured water levels (heads) and flows should meet the anticipated purpose of the model. We developed this model to simulate the groundwater flow and water-level fluctuations in Cedar Valley from 1969 to 2007, and also to better understand the model boundaries that control the groundwater system.

Head and Discharge Distribution

Figure 44 shows the spatial distribution of the 24 water-level observation locations, all wells that have their open interval wholly or primarily in layer 1, that we used in model calibration. Most of the wells are distributed across a narrow band that spans the valley from east to west in the northern half of the valley, leaving the most northern and the entire southern half of the valley with few head observations available for model calibration. Many of the wells are also pumping wells, which makes calibrating to them more difficult.

The initial head input for the steady-state model was the ground-surface elevation minus 30 feet (9 m). After running the MODFLOW-2000 simulation, simulated water-level values were compared to the observation values in March 1969 at the 24 wells. The differences between observed values and simulated values are the residual heads.

Our only discharge calibration target was Fairfield Spring. The estimated 1969 annual discharge for Fairfield Spring was compared to simulated discharge in the steady-state model.

In the transient flow model calibration, we used one water-level observation at each of the 24 wells for each of the years modeled and the estimated discharge from Fairfield Spring each year.

Methods and Results of Parameter Adjustment

Calibration methods included trial and error at the beginning of the model calibration process followed by inverse/automatic model calibration using Parameter ESTimation software (PEST). PEST is a nonlinear parameter estimator that is used to adjust model parameters until model-generated numbers fit a set of observations (Doherty, 2005). PEST continues adjusting model parameters until the fit between model outputs and field observations is optimized for weighted least squares error (Doherty, 2005).

We used PEST during a sensitivity analysis (Hill and others, 2000) to determine which parameters needed adjustment and how much to adjust them during model construction and calibration. We adjusted the initial values of the time-independent parameters of hydraulic conductivity and vertical anisotropy for each of the 38 hydraulic-conductivity zones in each model layer during steady-state calibration. We made minor adjustments to these parameters during transient calibration mostly in areas where there was significant well withdrawal during transient simulation but not during steady-state simulation. We adjusted values and distribution of specific yield and specific storage during transient calibration. We then used the parameter values that resulted from the transient model calibration as starting values in a steady-state model run to assure the steady-state model remained adequately calibrated within the calibration target limits while using the final values.

During model calibration, we adjusted model parameters to achieve a model that reasonably represents the groundwater system with minimal sum of squared errors between simulated and measured water levels and flows. We compared the simulated groundwater budget to the conceptual groundwater budget to check the degree of match in the groundwater system throughout the model time domain. We used the behavior of simulated hydraulic heads and spring discharge in response to changes we made in the values of drain/spring flow conductance, recharge, horizontal hydraulic conductivity, and vertical anisotropy to modify these parameters

within reasonable values to obtain better matches to observed head and flow. During transient model calibration, we made changes to the groundwater flow budget and hydraulic characteristics based on available information. For example, we changed recharge and vertical anisotropy to get a better match to water levels in areas that were not stressed during steady-state model calibration. Simulated heads in the southern half of the modeled area are relatively uncertain because there are fewer well-performance and lithologic data on which to base hydraulic property estimates.

Hydraulic conductivity: The initial and final model-calibrated hydraulic properties are shown on figures 41 through 43 and in table G-1. The initial input values of horizontal hydraulic conductivity (KH) for layer 1 ranged from 2.5 to 15 ft/d (0.8–4.6 m/d), and the final values range from 0.0024 to 150 ft/d ($7.3x10^{-4}$–46 m/d). Calibration of the groundwater model produced a horizontal hydraulic conductivity distribution in the basin-fill aquifer (layer 1) that is more random and covers a wider range of values than the field data, as shown by comparing figure 41 to figure 5. The final calibrated values are reasonable for basin-fill porous media. Calibrated KH values for layer 1 are generally lower than field measurements, as expected because the calibrated value should reflect an average for all unconsolidated units as compared to observed values, which we determined from aquifer tests and specific capacity data at producing wells.

The initial horizontal hydraulic conductivity (KH) for layer 2 ranged from 12.5 to 47.5 ft/d (3.8–14.5 m/d), and the final values range from 0.0044 to 150 ft/d ($1.3x10^{-3}$–46 m/d). The final calibrated hydraulic conductivity distribution and values in the bedrock (layer 2) (figure 41) are more similar to field values than are the basin-fill calibrated values, and the distribution shows a high hydraulic conductivity zone in the bedrock along the eastern side of the valley, coincident with an area having high capacity production wells. Four of 38 zones have final KH values 3 to 5 times larger than the initial values, which we attributed to the complexity of bedrock structures and lack of measured bedrock hydraulic conductivity data.

Vertical anisotropy: The initial value of vertical anisotropy (VANI) for both model layers was set at 4 and final average values were 3.9 and 3.4 for layer 1 and layer 2, respectively. Figure 42 shows the final calibrated vertical anisotropy in each hydraulic property zone. To calibrate the model to observed water levels, we lowered the vertical anisotropy ratios in the northern and western parts of the valley so that bedrock recharge could move upward into the basin-fill material. Lower VANI ratios allow vertical flow more easily than high ratios; high ratios are consistent with clay units impeding vertical flow, which is the case for much of the basin-fill layer where we combined the clay unit and the basin-fill aquifer. The lower ratios in the north and west fit the conceptual model of a thin or non-existent clay layer in these areas (see figures 3 and 4).

Specific yield and specific storage: The initial value of specific yield (SY) was set to 0.11 and allowed to vary between 0.0001 and 0.22 for all zones in layer 1. The calibrated values ranged from 0.001 to 0.17 and averaged 0.04. The initial value of specific storage (SS) was set to $1.1x10^{-5}$ per foot ($3.4x10^{-6}$ m^{-1}) and allowed to vary between $1.0x10^{-9}$ and $1.0x10^{-4}$ per foot ($3.1x10^{-10}$–$3.1x10^{-5}$ m^{-1}) for all zones in layer 2. The calibrated values range from $4.7x10^{-8}$ to $2.6x10^{-5}$ per foot ($1.4x10^{-8}$–$7.9x10^{-6}$ m^{-1}) and averaged $6.6x10^{-6}$ per foot ($2.0x10^{-6}$ m^{-1}) (figure 43 and table G-1). The model-calibrated values of each parameter were, in most zones, lower than the initial values by up to approximately 80% for specific yield and generally by a factor of two for specific storage. The initial estimates of SY and SS were based on textbook values and aquifer tests. Calibrated values are lower because in combining the basin-fill aquifer and clay layer into one layer, and in taking the bedrock aquifer thickness down to 2000 feet (609 m) above sea level, we combined strata having lower storage capacity than those in which we conducted our aquifer tests. Values were within a reasonable range for unsorted and generally fine-grained basin-fill material (0–0.19, Fetter, 1988) and carbonate rocks (less than 0.001, Fetter, 1988).

Recharge and subsurface inflow: We simulated recharge in this model as originating from either: (1) direct recharge received by the basin fill from precipitation, runoff, and seepage divided into 39 zones, or (2) the specified flow arcs assigned to the boundaries of the consolidated bedrock layer, which simulate recharge from precipitation through the mountain block entering the model domain as subsurface flow. We adjusted the values of these zones and arcs during model calibration until we obtained an acceptable match between observed and simulated head and spring discharge.

In the calibrated transient model, the combined basin-fill and bedrock 39-year average simulated recharge was 25,600 acre-ft/yr (31.6 hm^3/yr). The bedrock portion of recharge, which is simulated as specified flow arcs using the Well Package, was approximately 24,000 acre-ft/yr (30 hm^3/yr), and the yearly simulation matched the trend of the conceptual subsurface recharge very well (figure 47f). The 39-year average basin-fill simulated recharge was 1600 acre-ft/yr (2.0 hm^3/yr) (figure 47b, numbers given in appendix G, table G-4). The initial and final model calibrated recharge rates are given in table G-4.

Discharge: The values of drain conductance for Fairfield Spring, Cedar Pass, and Mosida Hills were adjusted first through trial and error and later by automatic calibration using PEST. We narrowed the linear extent of the drains that represent interbasin flow through Cedar Pass and Mosida Hills from the original estimated locations. The final location of the Cedar Pass drain (figure 44) coincides with an area of known high transmissivity in Paleozoic bedrock at Cedar Pass based on well logs and one aquifer test. The drain location at Mosida Hills coincides with an area where potentiometric contours indicate groundwater flow occurs. The

final calibrated values of drain conductance were 7000 ft^2/d (650 m^2/d) for Fairfield Spring and 16.41 ft^2/d (1.52 m^2/d) and 11.09 ft^2/d (1.03 m^2/d) for the Cedar Pass and Mosida Hills drains, respectively. Fairfield Spring discharge was a model calibration target; refer to the Assessment of Model Calibration section below for discussion.

We simulated subsurface outflow through Cedar Pass and Mosida Hills using drains whose conductance and bottom elevations we changed during model calibration. The conceptual values for subsurface discharge to neighboring valleys were based on simple hydrologic calculations using Darcy's law (Feltis, 1967) and early modeling attempts (Brooks and Stolp, 1995). More recently, Gardner (2009) used MODFLOW to estimate the subsurface flow through Cedar Pass as 8800 acre-ft/yr (11 hm^3/yr). Because our initial values were rough estimates, we used them only as a general guide for the reasonableness of model predicted values and not as calibration targets. The final calibrated model flow through Cedar Pass ranged from 9200 to 11,000 acre-ft/yr (11–13.5 hm^3/yr) with a 39-year average of 10,200 acre-ft/yr (12.5 hm^3/yr). The final subsurface outflow though Mosida Hills in the calibrated model ranged from 4500 to 4900 acre-ft/yr (5.5–6.0 hm^3/yr) with a 39-year average of 4700 acre-ft/yr (5.8 hm^3/yr). The total subsurface outflow through Cedar Pass and Mosida Hills ranges from 14,000 to 15,800 acre-ft/yr (17.2–19.5 hm^3/yr) with a 39-year average of 14,900 acre-ft/yr (18.3 hm^3/yr) (figure 48 and table G-2).

We adjusted evapotranspiration by changing the parameter values and by using a multiplier array to modify the distribution of maximum ET rate. The initial rates of ET used in the steady-state model were $3.452x10^{-3}$, $1.00x10^{-3}$, and $1x10^{-9}$ ft/d ($1.105x10^{-3}$, $3x10^{-4}$, and $3x10^{-10}$ m/d) for ET-10, ET-35, and ET-50 zones, respectively. We adjusted these initial values of zones ET-10 and ET-35 within a range of $1x10^{-6}$ to $5x10^{-3}$ ft/d ($3x10^{-7}$–$1.5x10^{-3}$ m/d) until head and spring discharge calibration targets were met. The initial value of zone ET-50 was adjusted within a range of $1x10^{-10}$ to $1x10^{-6}$ ft/d ($3x10^{-11}$–$3x10^{-7}$ m/d). The final adjusted ET rates in the steady-state simulation were $4.1x10^{-3}$, $1.40x10^{-3}$, and $2.2x10^{-9}$ ft/d ($1.3x10^{-3}$, $4.3x10^{-4}$, and $6.7x10^{-10}$ m/d) for ET-10, ET-35, and ET-50 zones, respectively (table G-1). These rates equate to total ET volume in 1969 of approximately 900 acre-feet (1 hm^3) from ET-10 zone, 1600 acre-feet (2.0 hm^3) from ET-35, and 0.07 acre-feet ($9x10^{-5}$ hm^3) from ET-50 (figure 49 and table G-3).

In the transient model, the initial annual ET rates used for zone ET-10 were calculated from the volume of ET we estimated for the years 1970 to 2007 using methods described in the Evapotranspiration section under the Hydrogeology heading above. These ET rates were adjusted during transient model calibration, which resulted in ET rates ranging from $1.643x10^{-2}$ $6.097x10^{-3}$ ft/d ($5.008x10^{-3}$–$1.858x10^{-3}$ m/d) and had a 39-year average of $4.150x10^{-3}$ ft/d ($1.265x10^{-3}$ m/d). Those rates equate to a volume of water lost to ET ranging from approximately 900 to 3900 acre-ft/yr (1–4.8 hm^3/yr) and with a 39-year average volume of 2200 acre-ft/yr (2.7 hm^3/yr). Table G-3 contains initial and final rates and volumes of ET used in and calculated by this model.

We used the steady-state calibrated ET rates for zones ET-35 and ET-50 as initial ET rates for each time step from 1970 to 2007. These initial values of ET were then adjusted within the same value range as in the steady-state model (between $1x10^{-10}$ ft/d and $5x10^{-3}$ ft/d) until calibration targets were met. The final adjusted ET rates for zone ET-35 in the transient simulation range from $5.67x10^{-4}$ to $2.104x10^{-3}$ ft/day ($1.728x10^{-4}$–$6.413x10^{-4}$ m/d), with a 39-year average of $1.432x10^{-3}$ ft/day ($4.365x10^{-4}$ m/d). Those rates equate to a volume of water lost to ET ranging from 500 to 1800 acre-ft/yr (0.6–2.2 hm^3/yr) and with a 39-year average volume of 800 acre-ft/yr (1 hm^3/yr). The final adjusted ET rates for zone ET-50 in the transient simulation were so small as to render the recharge through zone ET-50 to be zero.

The estimated total ET values used as initial input for this model ranged from approximately 1700 to 4000 acre-ft/yr (2.0–4.9 hm^3/yr) and had a 39-year average of 3200 acre-ft/yr (3.9 hm^3/yr), and the values in the calibrated model ranged from 1800 to 5300 acre-ft/yr (2.2–6.5 hm^3/yr) and had a 39-year average of 3000 acre-ft/yr (3.7 hm^3/yr) (figure 50 and table G-3). The difference between initial and final ET values (ET residual) each year ranged from -1400 to 1500 acre-ft/yr (-1.7–1.8 hm^3/yr) and averaged -200 acre-ft/yr (-0.2 hm^3/yr).

Assessment of Model Calibration

We chose calibration targets for this model of ±10 feet (3 m) of observed head and ±1000 acre-ft/yr (1.23 hm^3/yr) of Fairfield Spring discharge for the years in which discharge measurements were available (1969 through 1970 and 1991 through 2007). The calibration targets are relatively large in comparison to the changes in head in each observation well over the model time domain (between 5 and 60 feet [1.5–18 m] for each well, with most wells having heads within a 20-foot [6 m] range over the model time domain) and annual spring discharge over the time domain (from about 1000 to 6500 acre-feet [1.2–8.0 hm^3]). We tried smaller calibration targets, but because the modeled area is large (163 square miles [422 km^2]) in comparison to the number of head (24) and flow (1) calibration points, and because the calibration points are not evenly distributed throughout the spatial domain, we were unable to achieve that level of calibration.

We set a target of ±20% of the estimated values for the groundwater budget components, except for subsurface inflow from Rush Valley, subsurface outflow through Cedar Pass and Mosida Hills, and evapotranspiration, which were allowed to vary within reasonable values because these components of the groundwater budget were poorly constrained.

Spatial Head Distribution and Hydrographs

Figure 51 shows the spatial distribution of simulated head for the steady-state model (1969) and last time step (TS) of the transient model (TS#39, year 2007). Figure 51 shows that the simulated head is higher on the western side of the aquifer, where recharge enters from the Oquirrh Mountains. The sharp change in head and drawdown apparent across an east-west line at the northern end of the valley on the map of simulated head results from a large difference in hydraulic conductivity between the two zones on either side of the apparent boundary. If better resolution in hydraulic conductivity and more water-level data were available in this area, the results would likely show a more gradual gradient.

We used a calibration target of ±10 feet (3 m) at each observation well to evaluate the acceptability of head calibration. Figure 52 shows the location of each observation well and its residual head (which is the difference between simulated and observed head) for the steady-state calibrated model. In the steady-state calibration, the residual was within the acceptable limits for 21 out of 24 observations while three head observations have residuals between 10 and 20 feet (3–6 m). Figure 53 shows that the residual heads for the last time step of the transient model were less than 10 feet (3 m) for 19 out of 24 head observations. Five head observations have residuals between 10 and 20 feet (3–6 m). Data for observed heads, simulated heads, and head residuals for the 24 observations are provided in appendix G, table G-5.

We compared the 2004 model-simulated head distribution to our potentiometric contour map from 2004, the last year basin-wide water levels were measured for this study (figure 54). The contours match well in the north-central part of the valley, where observation wells are more closely spaced. Contours are dissimilar in the most northern and northeastern parts of the basin-fill aquifer, where fewer points constrain the 2004 potentiometric map, most of which represent one water level collected under less-than-ideal well conditions (plate 2). Contours of simulated head in the northernmost part of the basin-fill aquifer imply groundwater flow from the Oquirrh and Traverse Mountains into the basin-fill aquifer.

Figure 55 shows eight hydrographs comparing simulated head to observed head over time in wells distributed throughout the valley. These and the additional 16 hydrographs for all observation wells are included in appendix G, figure G-1. The residual head for each year is less than or equal to 10 feet (3 m) in 10 out of the 24 observation wells (well IDs 45, 118, 134, 852, 883, 884, 1031, 1054, 1118, and 1124), which we consider to be good matches. The head residual is greater than 20 feet (6 m) in wells 44, 879, 880, and 1122 in some years, and the residual in the other 10 observation wells is between 10 and 20 feet (3–6 m), with the majority of years having residuals of less than 10 feet (3 m).

Equally important as minimizing head residual in evaluating the performance of the groundwater flow model in representing real-world conditions is whether or not the model accurately simulates the trends observed in water levels over time. Our model did a reasonable job of simulating the rise of water levels observed during and immediately following the high-water years in the early 1980s and other more subtle trends over time. A few of the hydrographs demonstrate the difficulty the model had simulating the upward trend observed in water levels in the early years of the transient simulation (wells 45, 1040, 1041 and 1120, figure 55). We assumed steady state conditions prevailed in 1969 throughout the valley for reasons described earlier; however, certain areas were experiencing upward water-level trends during that time. Since our modeling period begins in 1969 at steady state, we were unable to simulate the causes of upward water-level trend before 1969, and therefore unable to duplicate the trend in the first several years of the transient model.

The hydrograph for well 877 demonstrates that the model did not accurately simulate observed water levels after 1981. The most likely explanation is that the model is not accurately simulating localized recharge from irrigation return flow at a sod farm directly west of well 877, which likely increased as the operation expanded. The average discharge from the farm's two irrigation wells for the years 1974 to 1984 was 344 acre-ft/yr (0.42 hm^3/yr), whereas the average for the years 1985 to 1999 was 987 acre-ft/yr (1.22 hm^3/yr). We surmise that infiltration of unused irrigation water masked the regional water-level trend.

Fairfield Spring Discharge

We set a model calibration target of ±1000 acre-ft/yr (1.23 hm^3/yr) for Fairfield Spring discharge for the years in which discharge measurements were available (1969 through 1970 and 1991 through 2007). No calibration target was set for years 1971 through 1990 because observed discharge measurements were not available for those years; we estimated flow based on precipitation. The measured or estimated spring discharge ranged from 2890 to 6320 acre-ft/yr (3.56–7.80 hm^3/yr) and had a 39-year average of 3780 acre-ft/yr (4.66 hm^3/yr), and the final calibrated values ranged from 2800 to 5450 acre-ft/yr (3.45–6.73 hm^3/yr) with a 39-year average of 3730 acre-ft/yr (4.60 hm^3/yr) (figure 48 and table G-2). The difference between initial input and final calibrated values of spring discharge ranges from 1 to 1660 acre-ft/yr ($1x10^{-3}$–2.05 hm^3/yr) and the 39-year average absolute difference is 460 acre-ft/yr (0.56 hm^3/yr), which is less than the 1000 acre-ft/yr (1.23 hm^3/yr) calibration target. The calibrated flow is outside the target calibration range in one year, 1999. In three other years (1977, 1985, 1987) the calibrated flow was outside the target calibration range, but the "observed" flow was only an estimated flow based on precipitation, so no actual calibration target was set. Overall, the simulated values matched the observed values within approximately 8% in years in which flow was measured, although the difference between simulated and observed values was up to 24% in several years.

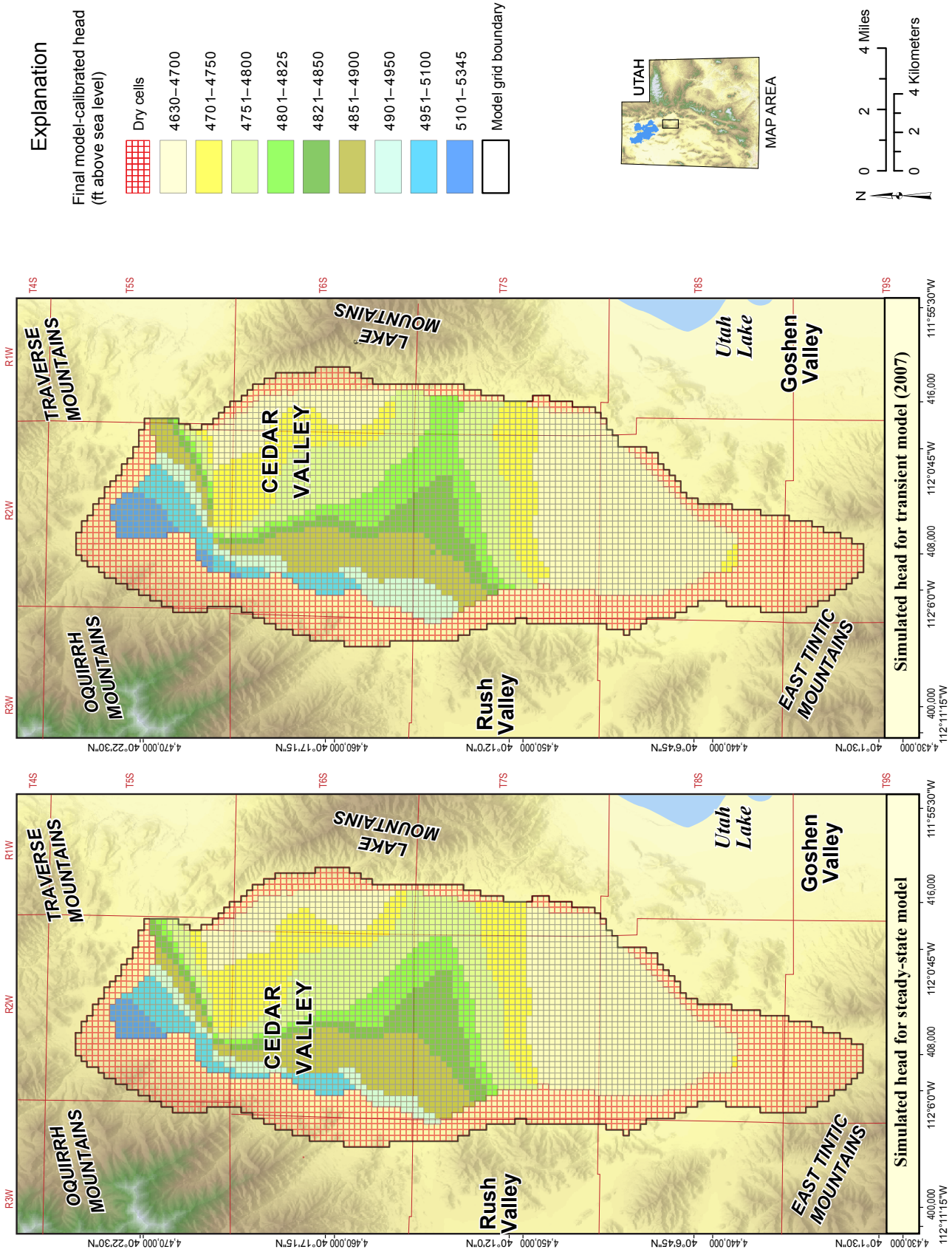
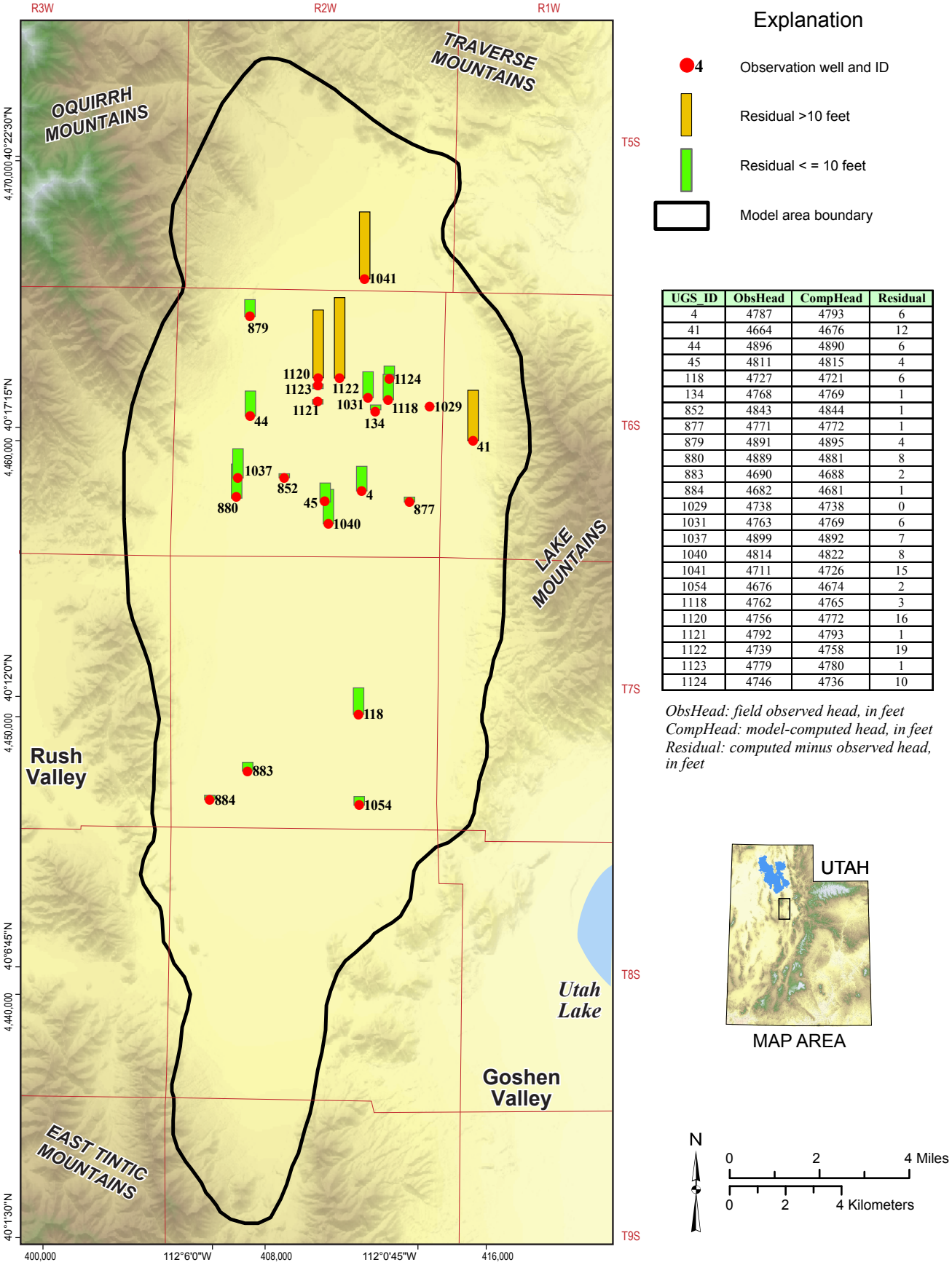


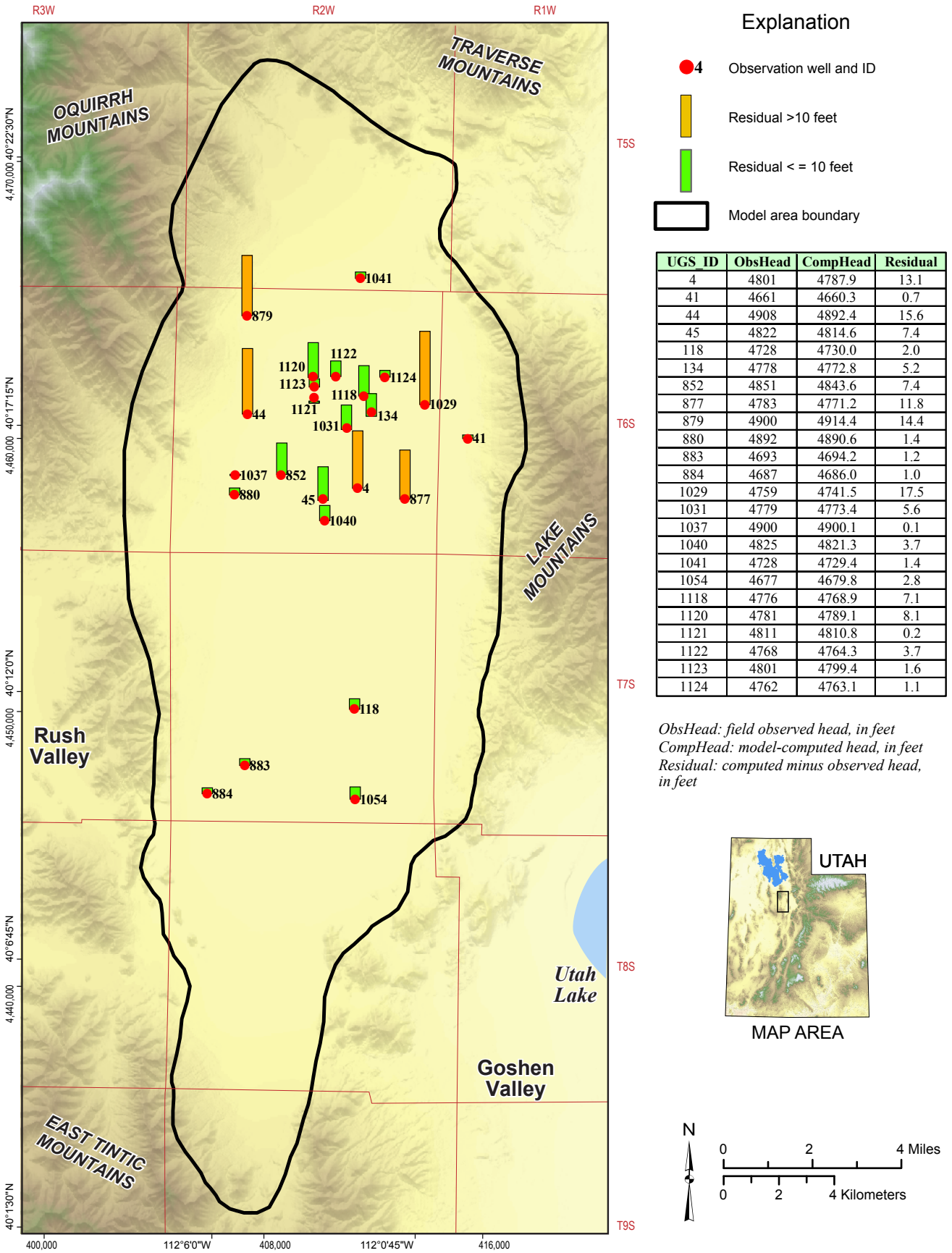
Figure 51. *Final head distribution for steady-state (1969) and transient (time step 39, 2007) models.*



UGS_ID	ObsHead	CompHead	Residual
4	4787	4793	6
41	4664	4676	12
44	4896	4890	6
45	4811	4815	4
118	4727	4721	6
134	4768	4769	1
852	4843	4844	1
877	4771	4772	1
879	4891	4895	4
880	4889	4881	8
883	4690	4688	2
884	4682	4681	1
1029	4738	4738	0
1031	4763	4769	6
1037	4899	4892	7
1040	4814	4822	8
1041	4711	4726	15
1054	4676	4674	2
1118	4762	4765	3
1120	4756	4772	16
1121	4792	4793	1
1122	4739	4758	19
1123	4779	4780	1
1124	4746	4736	10

ObsHead: field observed head, in feet
CompHead: model-computed head, in feet
Residual: computed minus observed head, in feet

Figure 52. *Steady-state model water-level observation well locations and the observed, simulated, and residual head at each location.*



UGS_ID	ObsHead	CompHead	Residual
4	4801	4787.9	13.1
41	4661	4660.3	0.7
44	4908	4892.4	15.6
45	4822	4814.6	7.4
118	4728	4730.0	2.0
134	4778	4772.8	5.2
852	4851	4843.6	7.4
877	4783	4771.2	11.8
879	4900	4914.4	14.4
880	4892	4890.6	1.4
883	4693	4694.2	1.2
884	4687	4686.0	1.0
1029	4759	4741.5	17.5
1031	4779	4773.4	5.6
1037	4900	4900.1	0.1
1040	4825	4821.3	3.7
1041	4728	4729.4	1.4
1054	4677	4679.8	2.8
1118	4776	4768.9	7.1
1120	4781	4789.1	8.1
1121	4811	4810.8	0.2
1122	4768	4764.3	3.7
1123	4801	4799.4	1.6
1124	4762	4763.1	1.1

ObsHead: field observed head, in feet
CompHead: model-computed head, in feet
Residual: computed minus observed head, in feet

Figure 53. *Transient model (time step 39; 2007) water-level observation well locations and the observed, simulated, and residual head at each location.*

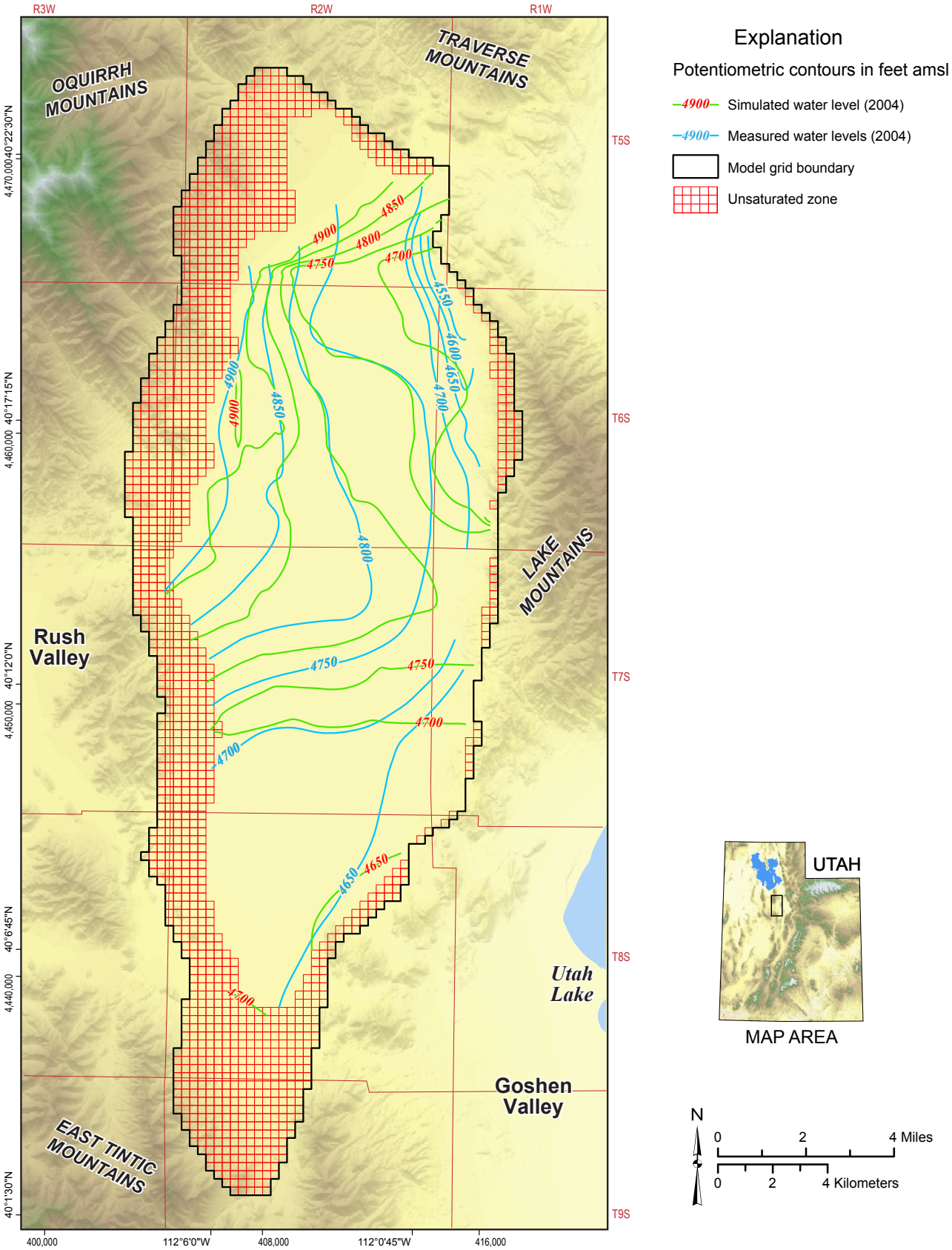


Figure 54. *Year 2004 model-simulated head compared to contours of water levels measured in 2004. The simulated head distribution compares well with measured water levels in the central and southern parts of the valley, where data are more closely spaced or water-level change over the modeled time period was minimal. The potentiometric head in the northern part of the valley is not well defined and complicated by probable upwelling of bedrock recharge.*

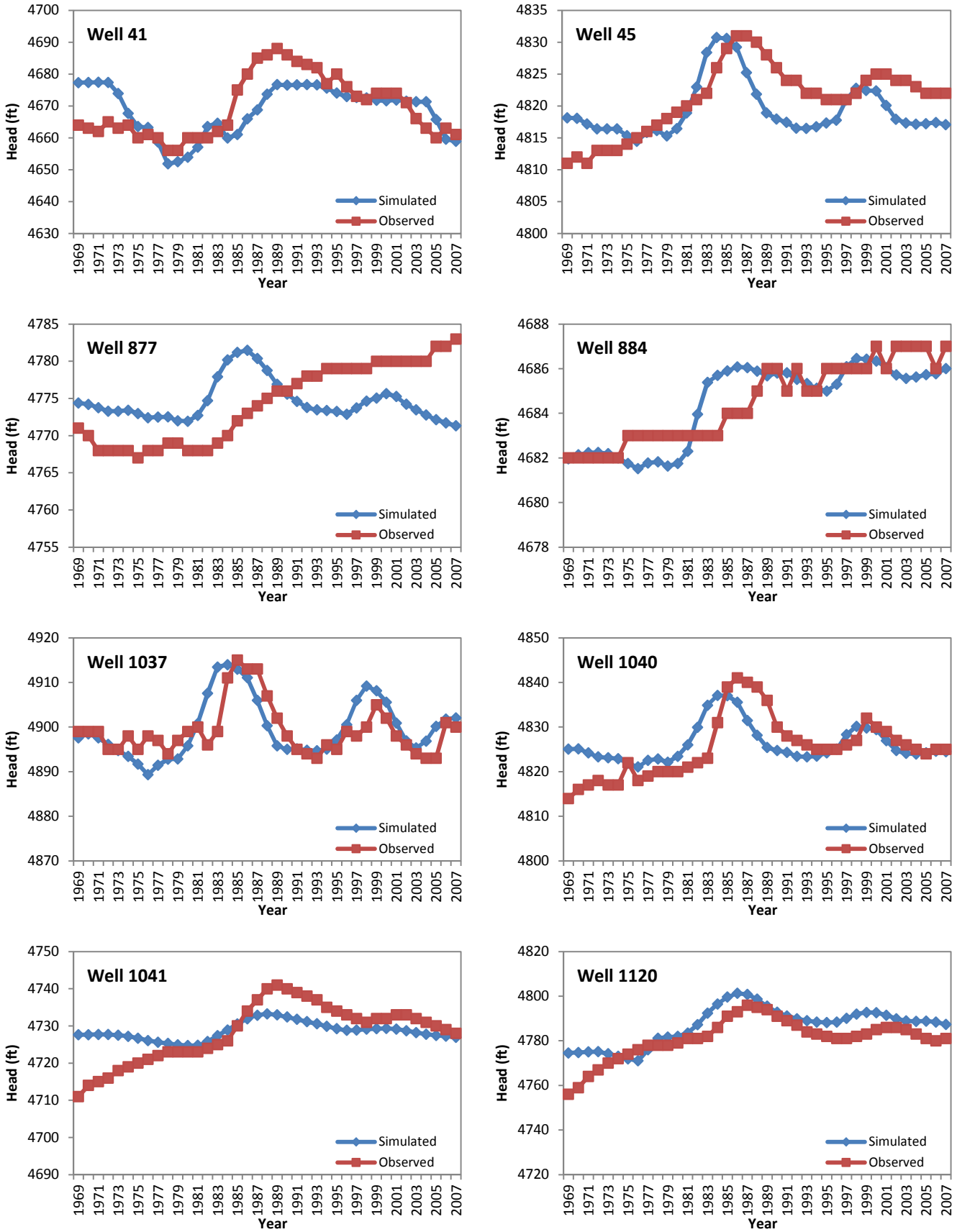


Figure 55. *Selected hydrographs of simulated versus observed heads over time for the calibrated transient model.*

Statistical Analysis of Residual/Error for Calibrated Models

We evaluated statistical errors and head and discharge residuals for the calibrated steady-state and transient models to determine the acceptability of calibration. The residual is the difference between the model-simulated and the observed or estimated values from the conceptual model. We used three types of errors in the statistical evaluation of our calibration. (1) Mean error is the mean of errors for all the calibration points; it can be misleading because positive and negative errors cancel each another (Aquaveo, LLC, 2008). (2) Mean absolute error is the mean of the absolute values of the errors; it is a true mean and positive and negative errors do not cancel (Aquaveo, LLC, 2008). (3) Root mean square is the square root of the sum of the square of the errors; this norm tends to give more weight to cases where a few extreme error values exist (Aquaveo, LLC, 2008).

Figure 56 shows the statistical error of head and discharge at each time step of the calibrated model; values are given in appendix G, table G-6. The acceptable head and flow errors we set for this model were ±10 feet (3 m) and ±1000 acre-ft/yr (1.23 hm^3/yr), respectively.

Head errors are generally less than our 10-foot (3 m) target range. The mean error of head is less than ± 10 feet (3 m) for each time step. The mean absolute error of head is less than 10 feet for each time step, and the root mean squared error is less than 10 feet (3 m) for all but three time steps (figure 56 and table G-6). The average head residual for all time steps as represented by mean absolute error is 4.7 feet (1.4 m) and root mean squared error is 6.2 feet (1.9 m).

We estimated flow error by subtracting the observed flow from simulated flow at Fairfield Spring. Because we only use one flow observation location as a calibration target in this model, the "mean" errors are means of only one value, and the root mean squared error is identical to the absolute value of the error. The errors are less than ±1000 acre-ft/yr (1.23 hm^3/yr) for all time steps except four (figure 56 and table G-6). The flow residual at these four time steps is 1200, 1054, 1662, and 1530 acre-ft/yr (1.48, 1.30, 2.05, and 1.89 hm^3/yr) in years 1977, 1985, 1987, and 1999, respectively. The average error is 36 acre-ft/yr (0.044 hm^3/yr), and the average absolute and root mean squared error are 449 acre-ft/yr (0.55 hm^3/yr), which is less than the target of 1000 acre-ft/yr (1.23 hm^3/yr) flow residual.

Sensitivity Analysis

We conducted sensitivity analyses (Hill and others, 2000) on the calibrated steady-state and transient models to determine the degree of sensitivity of computed head and flow to change in the values of model parameters. In this exercise, we independently increased and decreased the values for each model parameter by 1%, 5%, 10%, 20%, and 50% in a stepwise fashion in the calibrated steady-state and transient models. In the steady-state model, we varied horizontal hydraulic conductivity and vertical anisotropy in both model layers, recharge and evapotranspiration in layer 1, and specified flow (i.e., bedrock recharge) in layer 2. In addition, we tested the transient model for sensitivity to changes in specific yield in layer 1 and specific storage and specified flow in layer 2. After each change, we compared the new simulated heads to the calibrated heads and new simulated flow at Fairfield Spring to the calibrated flow.

The sensitivity analysis indicates that the models are largely stable for up to 20% changes in all model parameters. That is, the heads in the observation wells changed by less than 10 feet (3 m) after independently varying the values of each parameter by up to 20%. The models were most sensitive to changes in the hydraulic parameters of the bedrock aquifer. Generally, decreases in the horizontal hydraulic conductivity values caused heads and Fairfield Spring discharge to increase and increases in hydraulic conductivity caused heads and flow to decrease. Heads for some of the observation wells were still within the ±10 feet (3 m) margin after 50% variation in horizontal hydraulic conductivity values. The models are generally more sensitive to decreasing horizontal hydraulic conductivity than increasing hydraulic conductivity. Neither model produced more than 10 feet (3 m) of head change in response to 50% variations in vertical anisotropy. Variations of 50% in specific yield and specific storage in the transient model produced less than 10 feet (3 m) of head change.

Both models were somewhat sensitive to variations in the specified flow and recharge; heads in observation wells varied by up to 50 feet (15 m) in response to 50% variations in the recharge and specified flow.

The models did not show any appreciable changes in heads in the observation wells and discharge at Fairfield Spring after a 50% variation in evapotranspiration. Considering the high degree of uncertainty with which we estimated initial evapotranspiration values, we extended the sensitivity analysis for this parameter to include 200%, 300%, 400%, and 500% variations. Heads in observation wells were well within the calibration target of 10 feet (3 m), even after a 500% increase in the evapotranspiration values. Similarly, discharge from Fairfield Spring showed minimal responses to 200%, 300%, 400%, and 500% increase in evapotranspiration.

Figure 57 shows the model's relative sensitivity to each model parameter and to the seven major model parameter groups. The model has the highest relative sensitivity to the parameters or parameter groups that affect the most change in the values of the calibration targets. Conversely, the calibrated value of parameters having low relative sensitivity can change a great deal and not change the results of the model very much. In order of decreasing model sensitivity, the parameter groups are:

horizontal hydraulic conductivity for layer 2 (31%), horizontal hydraulic conductivity for layer 1 (26%), recharge (20%), specific storage (11%), vertical anisotropy of layer 2 (5%), vertical anisotropy of layer 1 (4%), and specific yield (2%).

Results

Digital groundwater flow model results discussed in the following sections focus on how the model responded to changes in recharge input, the change in storage over the transient model period, how well the model matched our conceptual model of groundwater flow and what we learned from the differences between our conceptual model and the digital model, and the groundwater flow budget.

Model Response to Hydrologic Variability

To evaluate how the groundwater system responds to variations in climate as predicted by the model, we studied three snapshots of the historical hydrologic cycle: a wet year, a dry year, and a normal year. Classification as wet, normal, or dry was based on the annual precipitation received at Fairfield that year in comparison to the average over the model period. We illustrate the snapshots using head and "drawdown" maps for

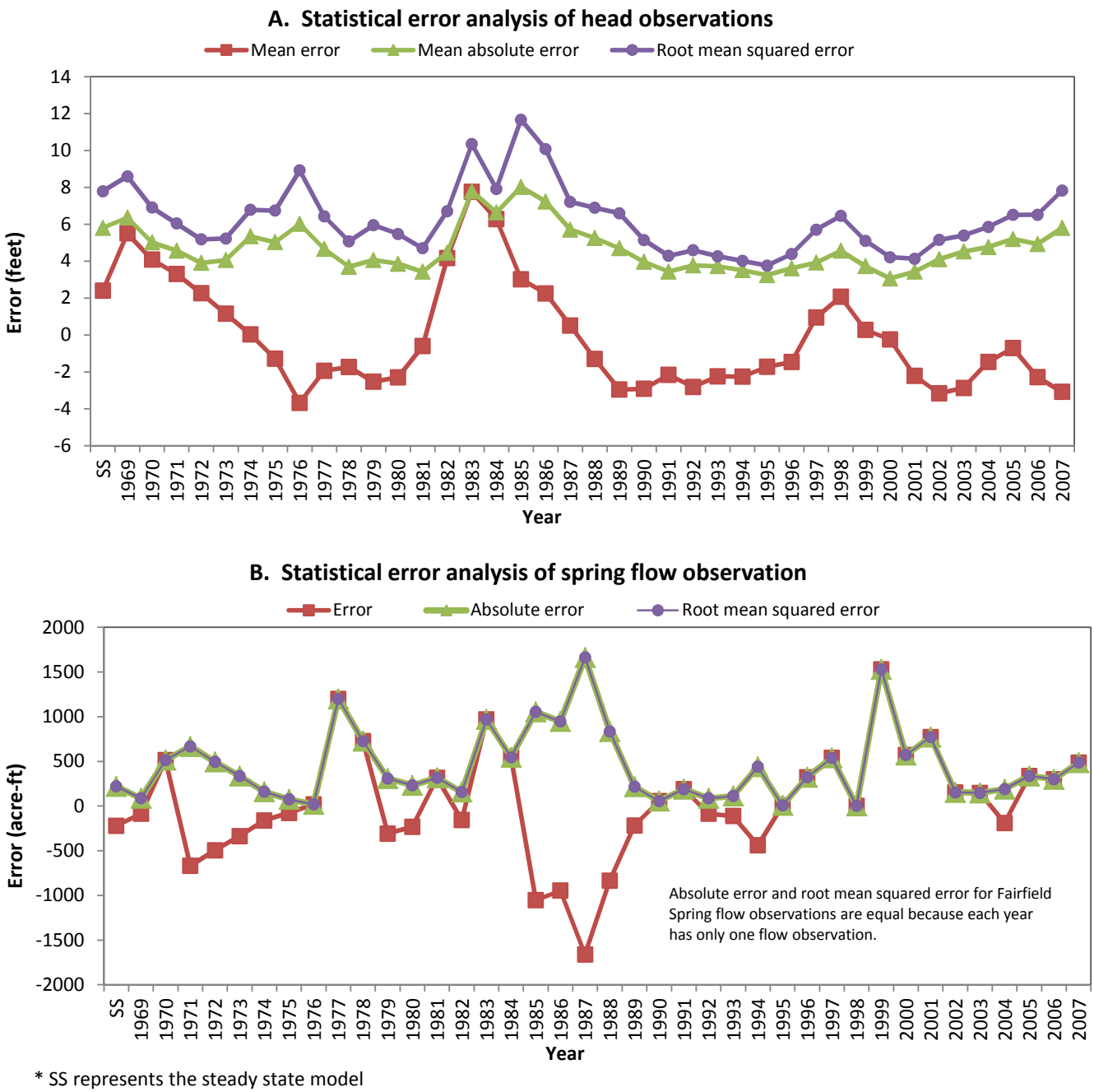


Figure 56. *Statistical error analysis of simulated head (A) and spring discharge (B).*

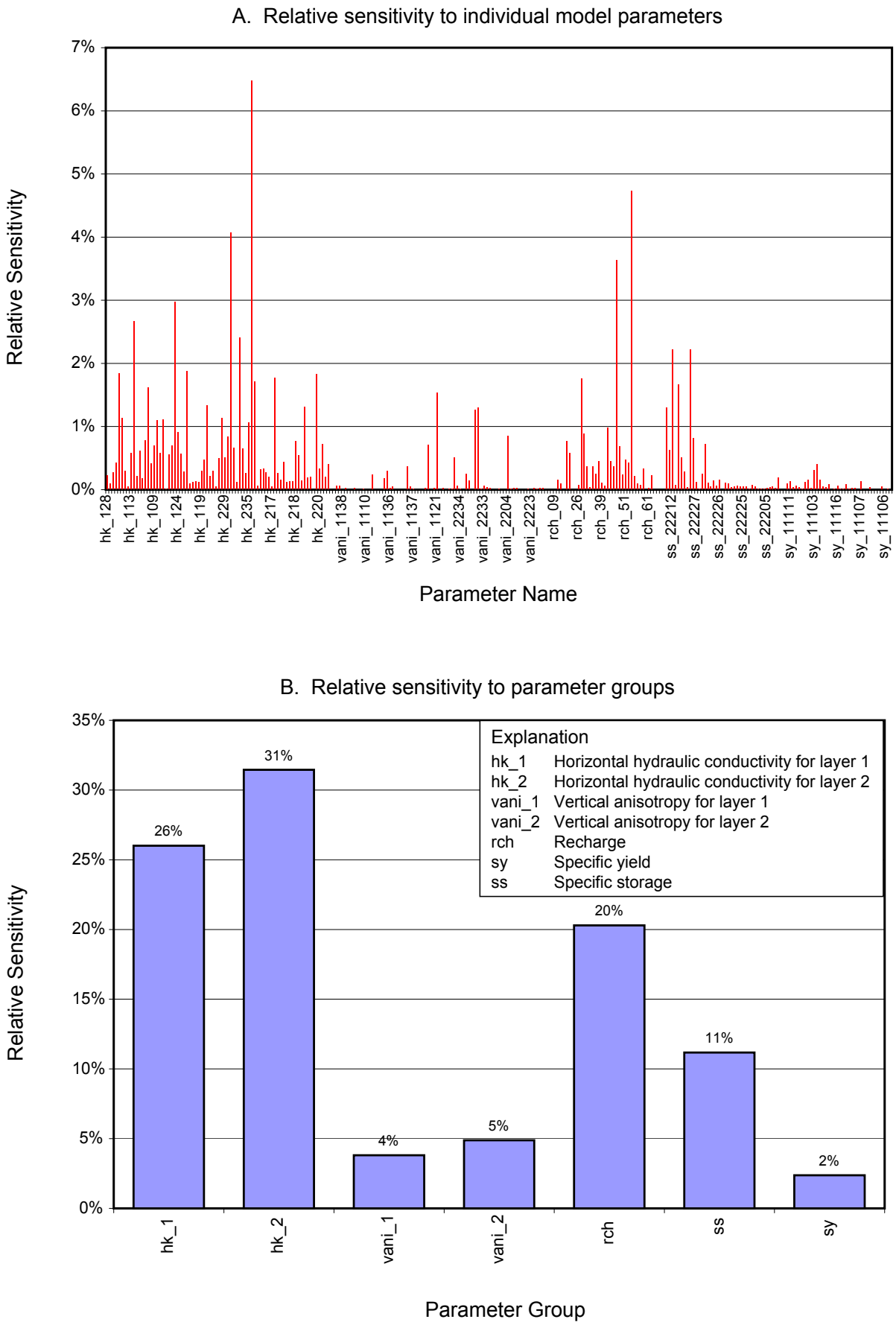


Figure 57. *Relative sensitivity of the Cedar Valley groundwater model to individual model parameters (A) and parameter groups (B).*

these three hydrologic years; wet 1983 (figure 58), normal 2004 (figure 59), and dry 2007 (figure 60). Drawdown for the purposes of this discussion is the difference between the simulated head in a particular year and the head in 1970. Positive values for drawdown indicate the water level was lower in the year depicted than in 1970.

The simulated drawdown map for 1983 (figure 58) shows that in much of the aquifer, simulated head was higher (indicated by "negative drawdown" values and green and yellow colors) in 1983 than in 1970, and this was indeed the case as can be seen on the hydrographs of observed head (figure 55). We attribute the rise in water level ranging from 0 to 60 feet (0–18 m) to the high precipitation and recharge in 1983.

The simulated drawdown map for normal hydrologic year 2004 shows water-level rise over approximately two-thirds of the model domain area as compared to water levels in the year 1970 (figure 59). The rise in water level ranges from 0 to 27 feet (0–8 m) with most of that area showing a water-level increase of less than 5 feet (1.5 m). The other third of the area showed 0 to 61 feet (0–19 m) of drawdown with most of that area showing a drawdown of less than 10 feet (3 m). Hydrographs of observed heads (figure 55) confirm that water levels in many of the observation wells, especially those near wells that were heavily pumped in the 1960s and 1970s, were higher in 2004 than in 1970.

The simulated drawdown map for dry hydrologic year 2007 shows 0 to 109 feet (0–33 m) of drawdown over 40% of the model area, with more than one half of that area showing a drawdown of less than 10 feet (3 m) (figure 60). The other approximately 60% of the model domain shows higher water levels as compared to 1970. The rise in water level is as much as 147 feet (45 m), but most of the area shows a water-level increase of less than 20 feet (6 m). A rise in water levels in a dry year is contradictory to expected trends, and in this case probably results because those areas showing the rising water levels have few observation wells and poor constraints on aquifer parameters. The map indicates that the problem areas in our model are the very northernmost basin fill and the southern third of the basin fill. The north-central part area of the valley, where we have more observation points, shows a broad area of 1 to 20 feet (0.3–6 m) of drawdown, as expected in a dry year.

Change in Storage

The hydrological term "storage" describes the amount of water stored in the pore spaces of an aquifer. When recharge is greater than discharge, water is "put into" storage, and when discharge is greater than recharge, water is "released from" storage. Storage as it applies to groundwater modeling is the amount of water needed to balance the flow equation of transient flow models. When the overall recharge volume is greater than the overall discharge volume of any time step in a transient flow model, the extra water goes into storage, (denoted by positive values in our tables). When discharge is greater than recharge, water comes out of storage (negative values). Figure 61 shows the simulated flow released from and into storage for each model layer through time. Values for each layer and the net change for the model are given in appendix G, table G-7.

The model had a positive change in storage (recharge > discharge) in 19 of the 39 years modeled, which generally coincide with wetter than normal hydrologic years (figure 61 and table G-7). An overall net flow of approximately 5600 acre-feet (6.9 hm^3) went into storage in the basin fill during the 39 years of the model simulation, which equates to an average of 140 acre-ft/yr (0.17 hm^3/yr). Similar results were obtained for the bedrock layer; simulations show a net positive change in storage (recharge > discharge) of 8400 acre-feet (10 hm^3) over 39 years of simulation for a long-term average of 210 acre-ft/yr (0.26 hm^3/yr). Over the 39 simulated years, the net change for the whole model was approximately 14,000 acre-feet (17 hm^3) or an average of 360 acre-ft/yr (0.44 hm^3/yr). Storage is discussed in more detail in the model water budget section below.

Comparison to Conceptual Groundwater Flow Budget

Table 5 is a comparison of simulated to conceptual groundwater flow budget. Budget components agree to within 20%, except recharge through the basin fill. The 39-year average simulated recharge (25,600 acre-ft/yr [31.6 hm^3/yr]) is 20% lower than the 39-year average estimated conceptual recharge (32,100 acre-ft/yr [39.6 hm^3/yr]) due mostly to the difference in basin-fill recharge. The reasons for the difference are best examined in their individual parts of bedrock recharge and basin-fill recharge.

In the calibrated transient model, the 39-year average simulated bedrock recharge (24,000 acre-ft/yr [29.6 hm^3/yr]) was 94% of the estimated (conceptual) recharge (25,500 acre-ft/yr [31.5 hm^3/yr]) (table 5), and the yearly simulation matched the trend of the conceptual subsurface recharge very well (figure 47f). The difference of 6% is within the error associated with other basin-wide recharge estimates (Stonestrom and others, 2007) and within the error (24%) of the Maxey-Eakin recharge estimation method found by Avon and Durbin (1994).

The 39-year average simulated recharge through the valley floor (basin fill) (1600 acre-ft/yr [2.0 hm^3/yr]) was only 24% of the 39-year average estimated (conceptual) recharge (6600 acre-ft/yr [8.2 hm^3/yr]) (table 5, figure 47b and table G-4). There are two possible explanations for the poor match: (1) numerical restrictions in the modeling software excluded some recharge through the unsaturated zone, and (2) overestimation of conceptual valley-floor recharge through the clay layer. First, MODFLOW-2000 does not allow recharge to occur through dry cells in the model. Dry cells occur in the model wherever the simulated head elevation is lower than the bottom elevation of a cell; in this model, dry cells occupy one-

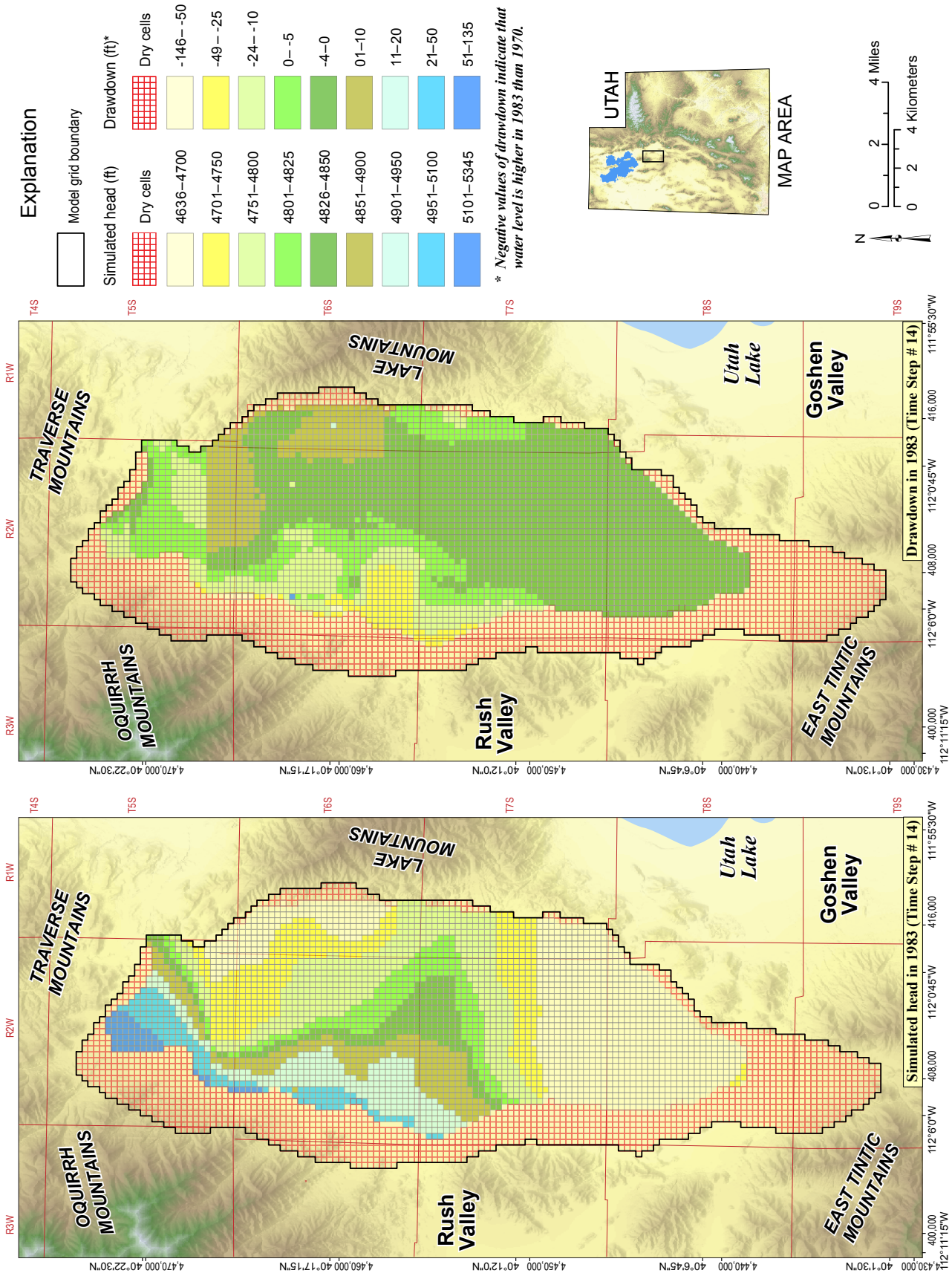


Figure 58. Simulated 1983 head distribution for the transient model and drawdown (difference between simulated head in 1970 and 1983) for the wet hydrologic year of 1983.

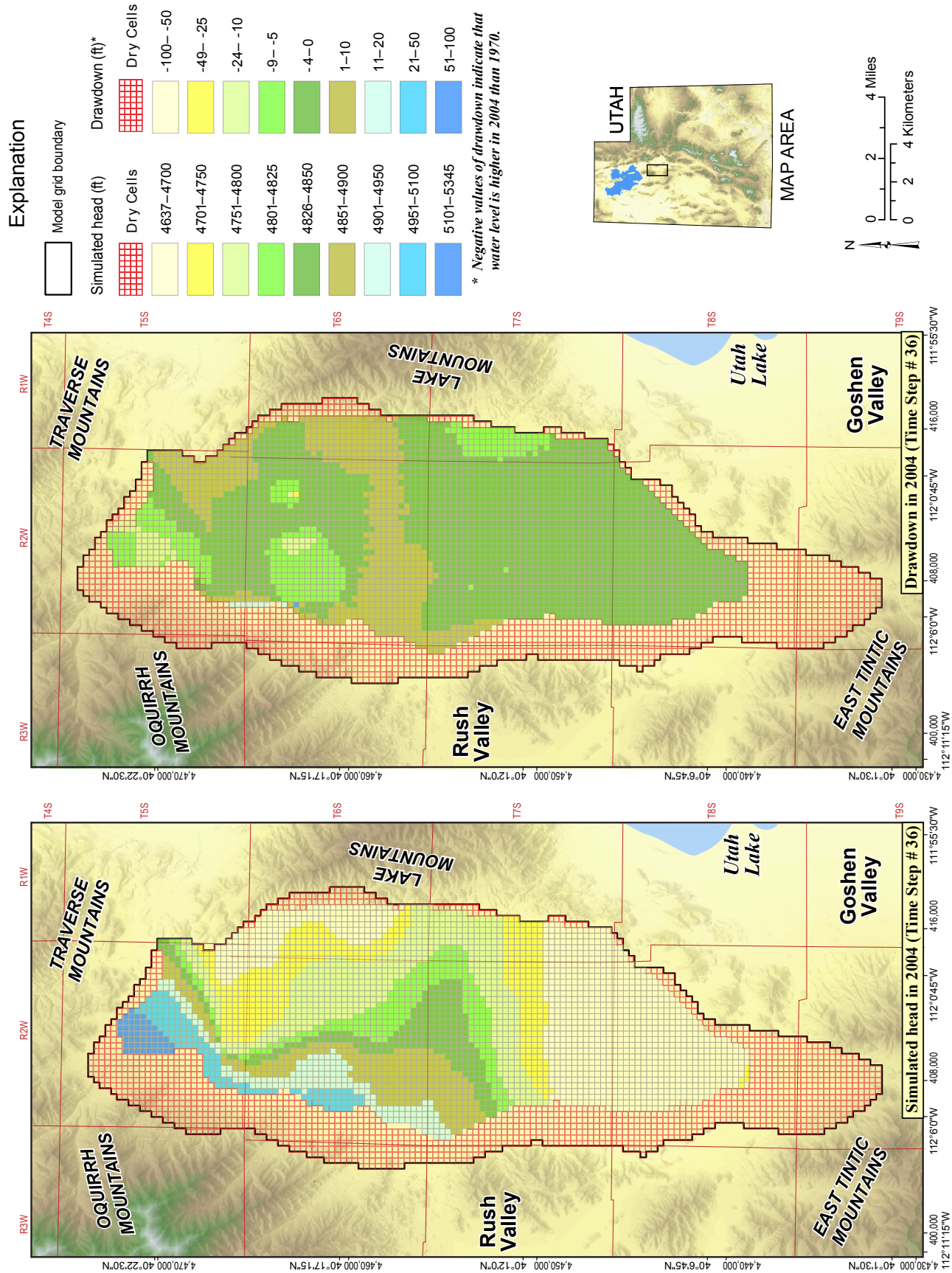


Figure 59. *Simulated 2004 head distribution for the transient model and drawdown (difference between simulated head in 1970 and 2004) for the normal hydrologic year of 2004.*

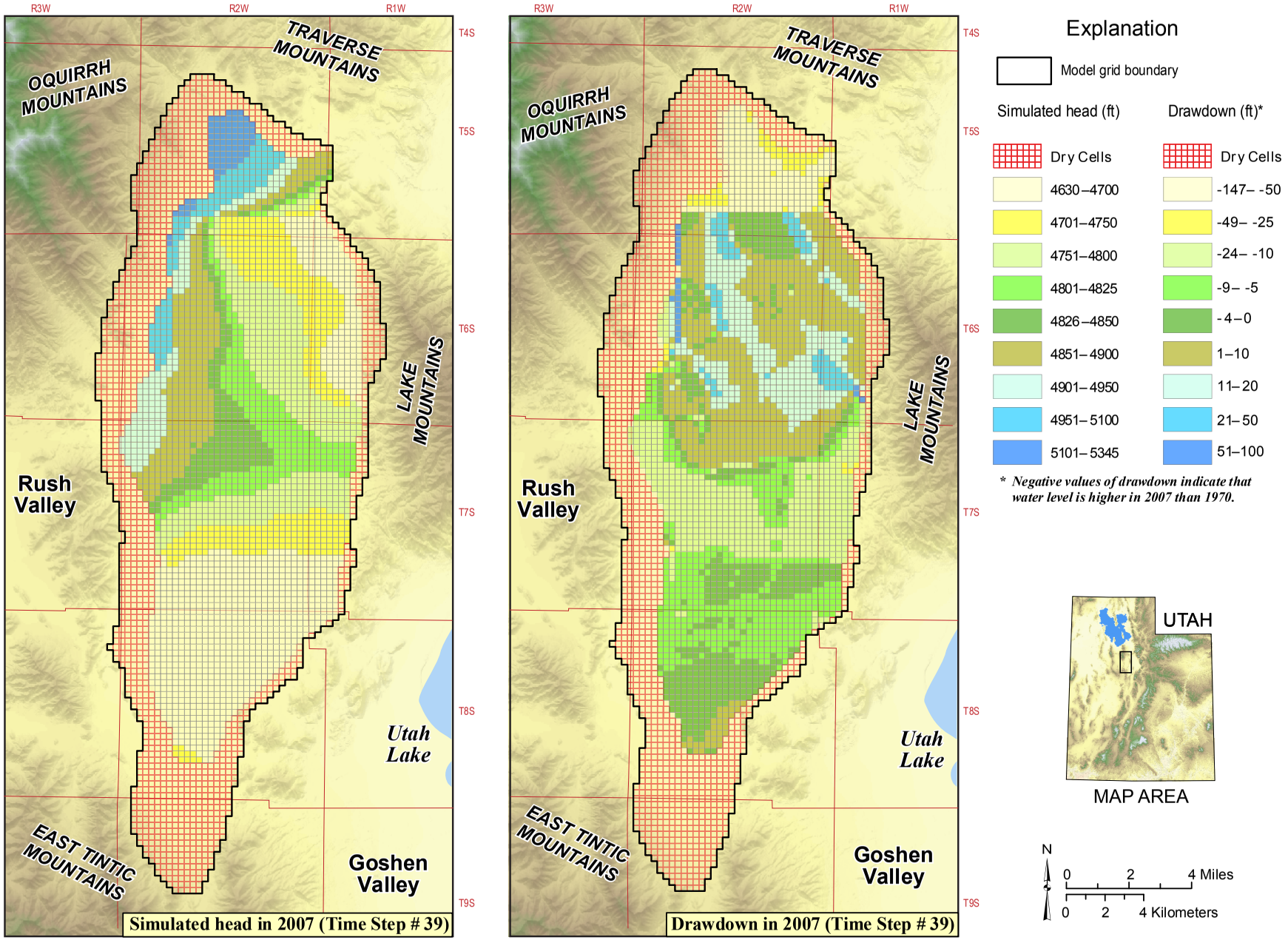


Figure 60. *Simulated 2007 head distribution for the transient model and drawdown (difference between simulated head in 1970 and 2007) for the dry hydrologic year of 2007.*

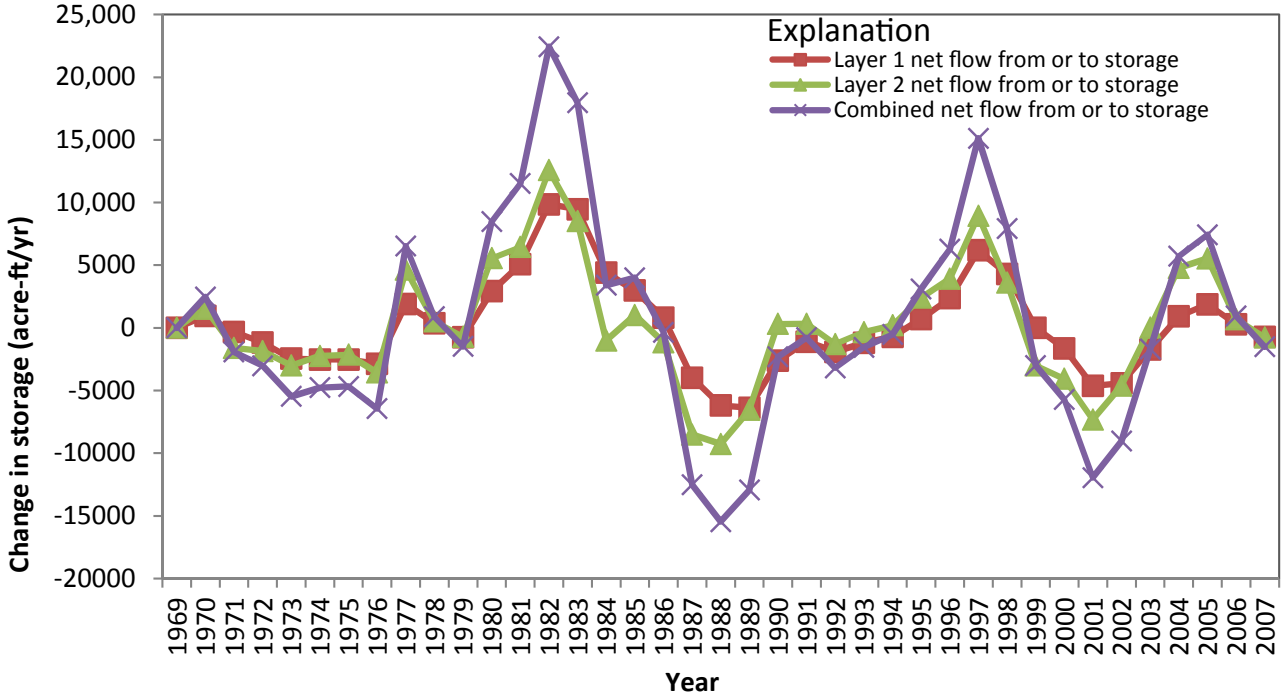


Figure 61. *Simulated net change in storage for both model layers. Net change in storage is equal to the volume released into storage minus the volume released from storage. Positive values indicate that water is put into storage, and negative values indicate that water is released from storage back into the model.*

Table 5. *Comparison of 39-year average values for conceptual and simulated groundwater flow budget components in the modeled area.*

Budget component	Method of simulation	Conceptual Range	Conceptual Average[1]	Simulated Range	Simulated Average[1]
RECHARGE		acre-ft/yr	acre-ft/yr	acre-ft/yr	acre-ft/yr
Precipitation infiltration on mountains	Specified flow in Well Pkg.	14,000–43,500	25,500	9700–43,800	24,000
Precipitation infiltration on valley floor	Specified flow in Recharge Pkg.	0–16,900[2]	4500[2]	400–4600	1600
West Canyon Creek seepage	Specified flow in Recharge Pkg.[3]	70–1600	800		
Cedar Fort Ditch seepage	Specified flow in Recharge Pkg.[3]	40–600	300		
Unused irrigation seepage	Specified flow in Recharge Pkg.[3]	550–1500	1100		
Fairfield Sinks seepage	Specified flow in Recharge Pkg.[3]	200–400	200		
Septic tank and wastewater seepage	Specified flow in Recharge Pkg.[3]	30–130	40		
Total recharge[1]		**15,000–64,100**	**32,100**	**10,100–48,400**	**25,600**
DISCHARGE		acre-ft/yr	acre-ft/yr	acre-ft/yr	acre-ft/yr
Withdrawal from wells in model area	Specified flow in Well Pkg.	1300–6530	3560	1900–6500	3600
Evapotranspiration	Head-dependent flow in ET Pkg.	1700–4000	3200	1800–5300	3000
Fairfield Spring	Head-dependent flow in Drain Pkg.	2900–6300	3800	2800–5500	3700
South Spring	Specified flow in Recharge Pkg.[4]	160	160	–	–
Subsurface outflow to Cedar Pass	Head-dependent flow in Drain Pkg.	7700–14,600	12,000	9200–11,000	10,200
Subsurface outflow to Mosida Hills	Head-dependent flow in Drain Pkg.	2300–4400	4000	4500–4900	4700
Total discharge[1]		**24,300–30,600**	**26,700**	**23,600–28,000**	**25,200**

[1] Average values are the average of 39 annual values for each budget component, whereas the average total recharge and discharge values are the average of the annual sum of recharge or discharge components, and therefore, the ranges and averages for total recharge and discharge may not be the sum of the range and average values for each component.

[2] Estimate for the conceptual model water budget is the geology-refined Maxey-Eakin estimate of recharge from precipitation infiltration on the valley floor (6600 acre-ft/yr average) minus the indirect recharge (seepage) source estimates.

[3] Indirect sources were included in the application of estimated precipitation recharge over the valley floor.

[4] Poor discharge data were available for South Spring, so spring discharge was not modeled. To compensate, 160 acre-ft/yr was subtracted from the recharge in the cell in which the spring is located.

third of the basin fill's recharge area (the area between black bold lines on figures 45 and 46). We applied the geology-refined Maxey-Eakin recharge to the entire surface of the basin fill using the Recharge package; however, the recharge that was applied to the top of the dry cells did not travel through those cells to the water table (because the water table is below the bottom of those cells) and therefore did not enter into the flow regime of the model.

Second, the poor match between conceptual and simulated basin-fill recharge could occur if we overestimated the conceptual recharge when we applied the geology-refined Maxey-Eakin method by not using a high enough limiting factor to prevent recharge through the basin fill's clay layer. An overestimate of basin-fill recharge is consistent with our need to increase the ET estimates during model calibration to achieve water balance.

Overall, we believe that the model-simulated bedrock recharge value is the best estimate available, and that the basin-fill estimate is fair but could be improved by mathematically adding some portion of the recharge on the dry cells to the underlying bedrock or adjoining basin fill, or by additional experimental work to measure ET and basin-fill infiltration.

The conceptual values for subsurface discharge to neighboring valleys through Cedar Pass and Mosida Hills were taken from earlier studies (Feltis, 1967; Brooks and Stolp, 1995; Gardner, 2009). The initial estimate in our conceptual model for flow through Cedar Pass to northern Utah Valley ranged from 7700 to 14,600 acre-ft/yr (9.50–18.1 hm^3/yr) and the final calibrated model flow ranged from 9200 to 11,000 acre-ft/yr (11–13.5 hm^3/yr) with a 39-year average of 10,200 acre-ft/yr (12.5 hm^3/yr) (table 5). For subsurface flow under Mosida Hills, we estimated roughly 2300 to 4400 acre-ft/yr (2.8–5.4 hm^3/yr), and the final subsurface outflow though Mosida Hills in the calibrated model ranged from 4500 to 4900 acre-ft/yr (5.5–6.0 hm^3/yr) with a 39-year average of 4700 acre-ft/yr (5.8 hm^3/yr) (table 5). Thus, our model-estimated values were within reason of how much water we thought could conceptually be discharging as subsurface flow. The total subsurface outflow through Cedar Pass and Mosida Hills simulated by the model ranges from 14,000 to 15,800 acre-ft/yr (17.2–19.5 hm^3/yr) with a 39-year average of 14,900 acre-ft/yr (18.3 hm^3/yr) (figure 48 and table G-2). Approximately two-thirds of the subsurface discharge from Cedar Valley is through Cedar Pass and the other third discharges under Mosida Hills, which is consistent with our conceptual model of the area.

Well withdrawal is one of the best constrained inputs to the model so we did not allow the simulated values to vary from the known values.

The estimated ET_g values used as initial input for this model ranged from 1700 to 4000 acre-ft/yr (2.0–4.9 hm^3/yr) and had a 39-year average of 3200 acre-ft/yr (3.9 hm^3/yr), and the values in the calibrated model ranged from 1800 to 5300 acre-ft/yr (2.2–6.5 hm^3/yr) and had a 39-year average of 3000 acre-ft/yr (3.7 hm^3/yr) (table 5, figure 50, and table G-3). The difference between initial and final ET values (ET residual) each year ranged from approximately -1400 to 1500 acre-ft/yr (-1.7–1.8 hm^3/yr) and averaged -200 acre-ft/yr (-0.2 hm^3/yr), which is within the calibration target of ±1000 acre-ft/yr (1.23 hm^3/yr). Initial evapotranspiration estimates varied widely, and the final values for this groundwater model can be used to constrain the ET estimates.

Fairfield Spring discharge was a calibration target, and the range and average of simulated annual flow volume fit the estimated or observed flow volume quite well (table 5). The individual annual simulated flow volumes matched the observed values (in 1969–1970 and 1991–2007, the years in which flow was measured) within 24% but normally within approximately 8% (table G-2). A comparison of measured to simulated flow from South Spring is not possible because discharge data were extremely scarce; therefore, we did not model the spring as a drain. Previous estimates of the subsurface recharge from Rush Valley and discharge via bedrock on the eastern side of the valley were poorly constrained and based on either Darcy's law calculations with little data (Feltis, 1967; Hood and others, 1969) or groundwater models in which flow in the Cedar Pass and Mosida Hills areas were not the main focus of the study (Brooks and Stolp, 1995; Gardner, 2009). Our modeling provides a better estimate of the interbasin flow to northern Utah and Goshen Valleys than the previous estimates. The average net change in storage of approximately 360 acre-ft/yr (0.44 hm^3/yr) was a reasonable 1% of the water budget.

Groundwater Model Flow Budget

We can use a schematic representation of the water-budget components and the 39-year average of the model-simulated annual values for those components to illustrate what we have learned about the Cedar Valley groundwater flow system from our transient groundwater flow model (figure 62). Table 6 and several of the tables in appendix G (tables G-2, G-4, and G-8) contain yearly and averaged values for the various water-budget components. Figure 62 and the discussion below use rounded values from the tables. Based on the accuracy with which we were able to estimate inputs and the level of model calibration, the values in the tables and figures are accurate to plus or minus 10%. Table 6 lists water budget values for steady state (1969), the last year of the transient model (2007), and the average of all 39 years modeled. We chose to show values for the year 2007 to illustrate a single year's budget and the most current groundwater pumping scenario for which we had data.

The groundwater flow budget shows that the average total recharge to the modeled area (basin-fill aquifer and bedrock underlying the basin fill) over the 39 years simulated was 25,600 acre-ft/yr (31.6 hm^3/yr), and that most of that recharge (24,000 acre-ft/yr [29.6 hm^3/yr] falls as precipitation and enters bed-

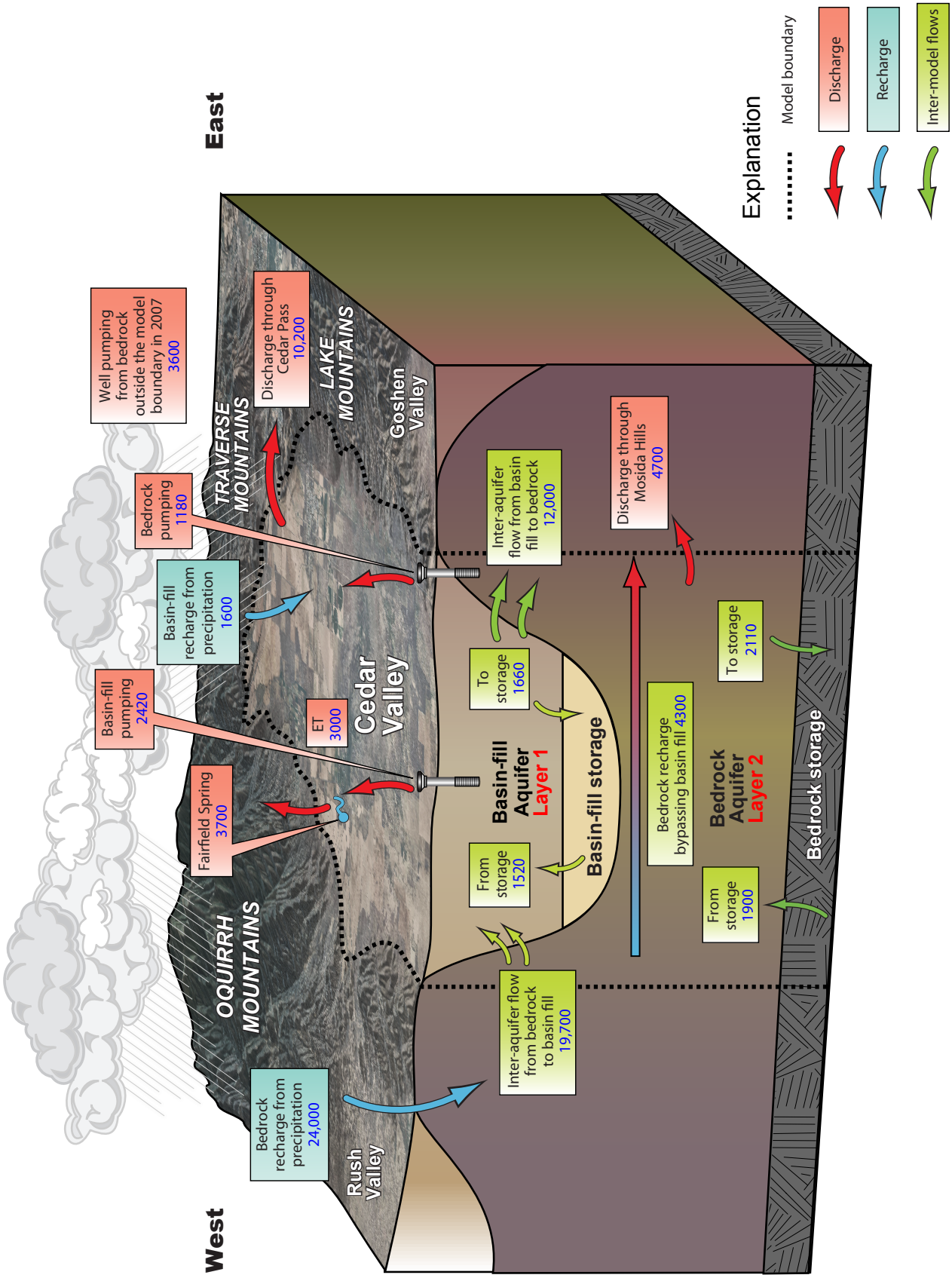


Figure 62. *Components of the 39-year average simulated annual groundwater flow budget shown on a schematic west-east cross section of Cedar Valley. Values are in acre-ft/yr.*

Table 6. *Water budget simulated by the steady-state and transient groundwater flow models for 1969 and 2007 and the 39-year average values.*

Budget component	**1969** (steady-state model)	**2007** (transient model)	**39-yr average**
RECHARGE	acre-ft/yr	acre-ft/yr	acre-ft/yr
Recharge on valley floor into layer 1[1]	1200	1000	1600
Recharge from precipitation through subsurface to layer 2[1]	23,000	25,000	24,000
Total recharge	**24,100**	**26,000**	**25,600**
DISCHARGE	acre-ft/yr	acre-ft/yr	acre-ft/yr
Well withdrawal from layer 1	2490	4190	2420
Well withdrawal from layer 2	0	2300	1180
Spring outflow from layer 1	3500	4000	3700
Evapotranspiration from layer 1	2700	3100	3000
Subsurface outflow from layer 2	15,400	14,000	14,900
Total discharge	**24,100**	**27,500**	**25,200**
STORAGE[2]	acre-ft/yr	acre-ft/yr	acre-ft/yr
From storage to either layer	NA	-2220	-3420
To storage from either layer	NA	720	3780
Net storage, layer 1	NA	-720	140
Net storage, layer 2	NA	-790	220
Net storage, both layers	NA	**-1510**	**360**
INTER-AQUIFER FLOW	acre-ft/yr	acre-ft/yr	acre-ft/yr
Flow from layer 1 to layer 2	10,800	11,500	12,000
Flow from layer 2 to layer 1	18,600	21,000	19,700
Net inter-aquifer flow from layer 2 to layer 1	**7800**	**9500**	**7700**
MOUNTAIN RECHARGE UNDERFLOW	acre-ft/yr	acre-ft/yr	acre-ft/yr
Recharge from precipitation through subsurface to layer 2	23,000	25,000	24,000
Flow from layer 2 to layer 1	18,600	21,000	19,700
Recharge from mountains not entering basin fill	**4400**	**4000**	**4300**

Values may not sum due to rounding.

NA: Not Applicable.

[1] Model layers 1 and 2 represent the basin-fill and bedrock aquifers, respectively.

[2] Positive values indicate that water is going into storage. Negative values indicate that water is coming out of storage.

rock (table 6, figure 62). A large portion of the bedrock recharge (19,700 acre-ft/yr [24.3 hm^3/yr] on average) finds its way into the basin-fill aquifer, mostly on the western side of the valley. The basin-fill aquifer received on average only an additional 1600 acre-ft/yr (2.0 hm^3/yr) of recharge through the valley floor, which is less than 2% of the precipitation that falls on the valley floor (table E-1). Most of the precipitation evaporates or is consumed by vegetation, but some of the precipitation recharge that we applied to dry cells on the perimeter of the top model layer did not enter the groundwater flow regime because of the modeling software.

Average total discharge from the modeled area over the 39 years simulated was 25,200 acre-ft/yr (31.1 hm^3/yr). More than half of that discharge (14,900 acre-ft/yr [18.4 hm^3/yr] average) is subsurface flow in bedrock from the Cedar Valley groundwater basin to adjacent northern Utah (10,200 acre-ft/yr [12.6 hm^3/yr] on average) and Goshen (4700 acre-ft/yr [5.8 hm^3/yr] on average) Valleys. Other discharge components and their 39-year average annual values are Fairfield Spring flow from basin fill (3700 acre-ft/yr [4.6 hm^3/yr]), ET from basin fill (3000 acre-ft/yr [3.7 hm^3/yr]), basin-fill well pumping (2420 acre-ft/yr [2.99 hm^3/yr]), and bedrock well pumping (1180 acre-ft/yr [1.46 hm^3/yr]). Note that withdrawal from wells within the model boundary has generally increased during the duration simulated in our model, from approximately 2500 to 6500 acre-ft/yr (3.1–8.0 hm^3/yr), whereas the other model parameters have varied mostly as a function of climate. Additionally, groundwater development in the Cedar Pass area in the past decade (e.g., 3600 acre-feet [4.4 hm^3] pumped in 2007 shown on figure 62) is outside our model boundary and is therefore not included as discharge.

The biggest component of flow out of the basin-fill aquifer, an average of 12,000 acre-ft/yr (14.8 hm^3/yr), is inter-aquifer flow to bedrock, which then contributes to the subsurface

bedrock flow out of the model area to adjacent valleys. Real discharge out of the model from the basin fill, as listed above, was from Fairfield Spring, ET, and pumping, which combined averaged 9200 acre-ft/yr (11 hm^3/yr) over the 39 years simulated.

Flow between the basin-fill and bedrock aquifers is shown as inter-aquifer flow in table 6 and on figure 62. Considerably more water moves from the bedrock (on the western side of the valley from the Oquirrh, West Canyon, and East Tintic mountain blocks, 19,700 acre-ft/yr [6.49 hm^3/yr] on average) to the basin-fill aquifer than moves from the basin fill to the bedrock (on the eastern side of the valley as flow out of the basin-fill aquifer into the bedrock aquifer, 12,000 acre-ft/yr [14.8 hm^3/yr] on average) (figure 62). The net average flow from bedrock to basin fill was 7700 acre-ft/yr (9.5 hm^3/yr) over the modeled period. The net flow goes to meet the discharge requirements of well withdrawal, ET, and Fairfield Spring.

Detailed examination of the model results provides insight to the nature of subsurface flow. Feltis's (1967) estimate of between 10,000 and 19,000 acre-ft/yr (12–23 hm^3/yr) of interbasin flow was an estimate of flow exiting the basin fill and passing through the bedrock of Cedar Pass, Lake Mountains, and Mosida Hills. Our model shows that a portion of the interbasin flow out through Cedar Pass and Mosida Hills is water that never enters the basin fill but instead flows in the bedrock under the basin fill. The 39-year average drain flow (interbasin flow) from layer 2 (bedrock) through Cedar Pass (10,200 acre-ft/yr [12.6 hm^3/yr]) and Mosida Hills (4700 acre-ft/yr [5.8 hm^3/yr]) combined averaged 14,900 acre-ft/yr (18.4 hm^3/yr), yet the flow from the basin fill (layer 1) to the bedrock (layer 2) averaged only 12,000 acre-ft/yr (14.8 hm^3/yr). This means that, on average, about a fourth (2900 acre-ft/yr [3.6 hm^3/yr]) of the interbasin flow through Cedar Pass and Mosida Hills is mountain recharge that bypasses the basin-fill aquifer by traveling in bedrock under the basin fill. Furthermore, the recharge to the model area from the western mountain block averages 24,000 acre-ft/yr (29.6 hm^3/yr), of which 19,700 acre-ft/yr (24.3 hm^3/yr) moves from layer 2 to layer 1, leaving approximately 18%, or 4300 acre-ft/yr (5.3 hm^3/yr), to travel under the basin fill and discharge via bedrock wells or interbasin flow through Cedar Pass or Mosida Hills. Our model shows that there is significant flow in the bedrock underlying the Cedar Valley basin fill aquifer.

The 39-year average recharge of 25,600 acre-ft/yr (31.6 hm^3/yr) was 360 acre-ft/yr (0.44 hm^3/yr) more than discharge. To balance recharge and discharge, the groundwater model allocated this additional 360 acre-ft/yr (0.44 hm^3/yr) into aquifer storage. In much wetter than average years, large volumes of water replenished aquifer storage; for example, in 1982, over 22,000 acre-feet (27 hm^3) replenished aquifer storage. Conversely, water released from aquifer storage composed a large part of the water budget in much dryer than average years; for example, in 1988 almost 16,000 acre-feet (20 hm^3) of water came out of aquifer storage to meet the discharge requirements of interbasin flow, well withdrawal, spring flow, and ET. A 39-year average net flow of approximately 140 acre-ft/yr (0.17 hm^3/yr) went from the basin-fill aquifer into aquifer storage, and approximately 220 acre-ft/yr (0.27 hm^3/yr) went from the bedrock aquifer into storage (table G-7). Over the 39 years simulated by our groundwater flow model, approximately 14,000 acre-feet (17 hm^3) more water went into aquifer storage than was released.

Model Projections

We converted the calibrated transient model into eight 30-year prediction models to simulate response to hypothetical future increases in groundwater withdrawal and/or decrease in recharge (table 7). We added 30 one-year stress periods of one time step each, representing the years 2008 to 2037, to the transient model. Projection scenario 1 simulates the aquifer response to pumping at 2007 levels in the model domain (approximately 6500 acre-ft/yr [8.0 hm^3/yr]) and an average rate of recharge. Projection scenarios 2 through 5 are designed to simulate aquifer response to increased well extraction at existing pumping wells by multiplying the 2007 extraction rate at each well by a multiplier (projections 2 and 3) or focusing future development of existing basin-fill pumping wells (scenario 4) or bedrock wells (scenario 5). Projection 6 simulates the aquifer response to a different distribution of future extraction, one that is spread out over all existing wells (those pumping in 2007, those historically pumped, and wells that have never pumped). Projection scenarios 7 and 8 simulate drought conditions by reducing recharge in the middle of the projection (simulated years 2019 to 2028) to the average level observed from 1972 to 1981 (17% less than the 39-year average) or to a more extreme drought characterized as having 30% less recharge than the 39-year average, respectively. We also increased pumping rates in the drought scenarios by 25% over 2007 levels at each well pumped in 2007 (to approximately 8100 acre-ft/yr [10 hm^3/yr]) to simulate the growth and groundwater development that has already occurred in Cedar Valley since 2007.

Because most recharge is simulated as specified-flow boundaries, we simulate decreased recharge from the western mountains by decreasing the flow across the specified flow arcs on the western side of the bedrock layer. The natural discharge components that can change in response to our modifications are evapotranspiration, subsurface outflow via the drain arcs at Cedar Pass and Mosida Hills, and discharge to Fairfield Spring.

Projection Results

We evaluated projection simulations in terms of the difference between groundwater levels at the end of the calibrated transient model (year 2007; time step #39) and the projected groundwater levels at the end of the 30-year projection period, defined here as drawdown. Figures 63 through 70 show the projected head and drawdown at the end of each scenario.

Table 7. *Cedar Valley groundwater model projection scenarios.*

Scenario number	Scenario description	Recharge	Withdrawal (acre-ft/yr) Location	Layer 1	Layer 2	Total
1	2007 conditions	1969–2007 average	Continue 2007 pumping rate at wells pumping in 2007	4194	2295	6489
2	Pumping increase of 25%	1969–2007 average	2007 rate x 1.25	5243	2869	8111
3	Pumping increase of 50%	1969–2007 average	2007 rate x 1.5	6291	3443	9734
4	Basin-fill development	1969–2007 average	Basin-fill wells: 2007 rate x 2. Bedrock wells: 2007 rate.	8388	2295	10,683
5	Bedrock development	1969–2007 average	Basin-fill wells: 2007 rate. Bedrock wells: 2007 rate x 2.	4194	4590	8784
6	Pumping doubles	1969–2007 average	2007 total extraction x 2 then distributed evenly over ***all*** wells in each layer	8388	4590	12,978
7	Historical 10-year drought and moderate development	Historical drought level (17% less than average) in middle 10 years of projection.	2007 rate x 1.25	5243	2869	8111
8	Severe 10-year drought and moderate development	30% less recharge in middle 10 years of projection.	2007 rate x 1.25	5243	2869	8111

Positive drawdown values indicate decline in water levels; negative values indicate a rise in water levels.

All projected head scenarios except scenario 4 show a similar groundwater-flow pattern to 2007 groundwater flow, in which the area of highest head is nearest to the Oquirrh Mountains and a groundwater divide bisects the valley from east to west at the approximate latitude of Fairfield and the Sinks. In scenario 4, a cone of depression forms in the central part of the basin-fill in response to doubling the extraction from basin-fill wells in the center of the valley (figure 66).

While the direction of groundwater flow is similar in all scenarios except number 4, the absolute head and difference in head across the valley (and therefore, the groundwater gradient) are very different. As with the transient simulation results, the sharp change in head and drawdown apparent across an east-west line at the northern end of the valley is related to a large difference in modeled hydraulic conductivity between the two zones on either side of the apparent boundary. The model is not accurately representing the aquifer in this location because few data were available to estimate aquifer properties; therefore, we regard projected effects in the most northern part of the basin fill with caution. If better resolution on the hydraulic conductivity were available in this area, the results would likely show a more gradual gradient.

The projected potentiometric surface and drawdown in layer 1 at the end of each 30-year projection simulation shows the effects of increasing withdrawal and/or decreasing recharge. Major drawdown in the aquifers ranges from 40 to 300 feet (12–91 m) and occurs mainly in the northeastern portion of the basin-fill close to Cedar Pass in all projection scenarios except scenario 4 (figures 63–70). Drawdown is greatest in the Cedar Pass area, partially because of the low calibrated hydraulic conductivity explained above and probably also because of new groundwater development in the projection scenarios in the Cedar Pass area.

In the southern half of the study area, projection simulations show only slight decline or even increase in water level, i.e., negative drawdown values cover most of the southern half of the study area. The increase is probably the model's response to balancing recharge from the East Tintic Mountains to the modeled changes in well withdrawal.

Projected Water-Level Response in Wells

Figure 71 shows the location and projected head variation at six selected observation wells for the eight projection scenarios over the 30-year projection period (2008–2037). Note the differences in the scale of simulated head (x axis) in comparing the projected hydrographs on figure 71. Predicted water-level elevations are tabulated in appendix G, table G-9. The continuous decline of groundwater levels indicates that groundwater is being removed from storage and that a new steady-state flow budget has not been reached at the end of the 30-year projection period.

The head response in most of the selected wells shown on figure 71 to most of the projection scenarios is between about 5 and about 40 feet (1.5–12 m). Exceptions to this are well 883, in which head increases by a few feet in most scenarios, and scenarios 4 and 6 in wells 1120 and 134, which see much higher head decline. Well 883 is located in the fine-grained southern part of the basin fill, which historically has seen very little water-level change regardless of past recharge or discharge variability. Similarly, future pumping and recharge scenarios have little effect on the water level in this part of the basin, and the resulting rise in water by about 4 feet (1 m) is probably the model's response to balancing recharge from the East Tintic Mountains to the modeled changes in well withdrawal.

Scenarios 4 and 6 involve doubling the pumping rate in basin-fill wells, which creates a large area of more than 25 feet (8 m) of drawdown throughout the central area of the valley (figure

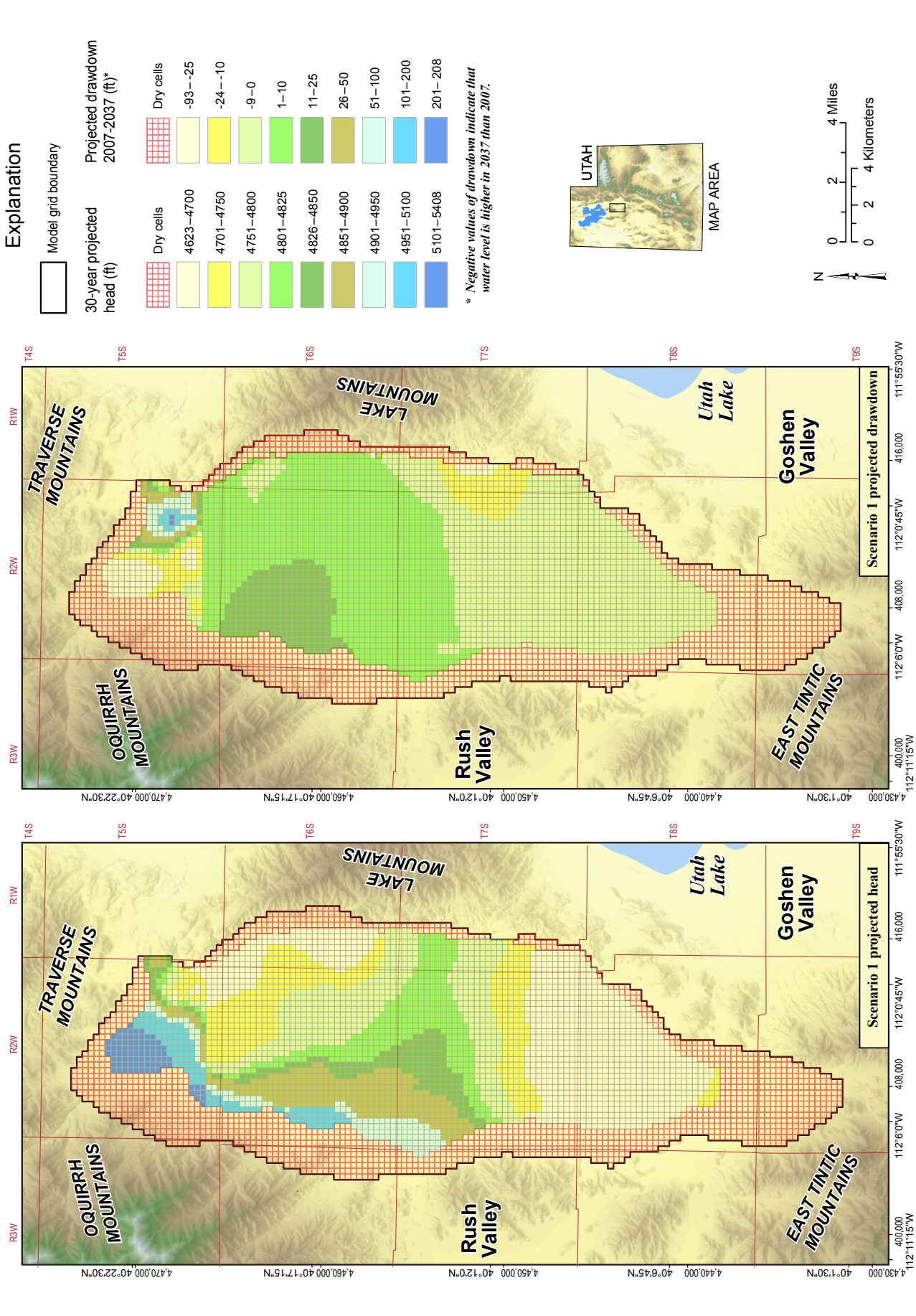


Figure 63. *Projected potentiometric head and drawdown at the end of projection scenario 1 (2037) in which withdrawal continues at 2007 rates and recharge and ET are set to the 39-year average. Drawdown is calculated from 2007 computed head.*

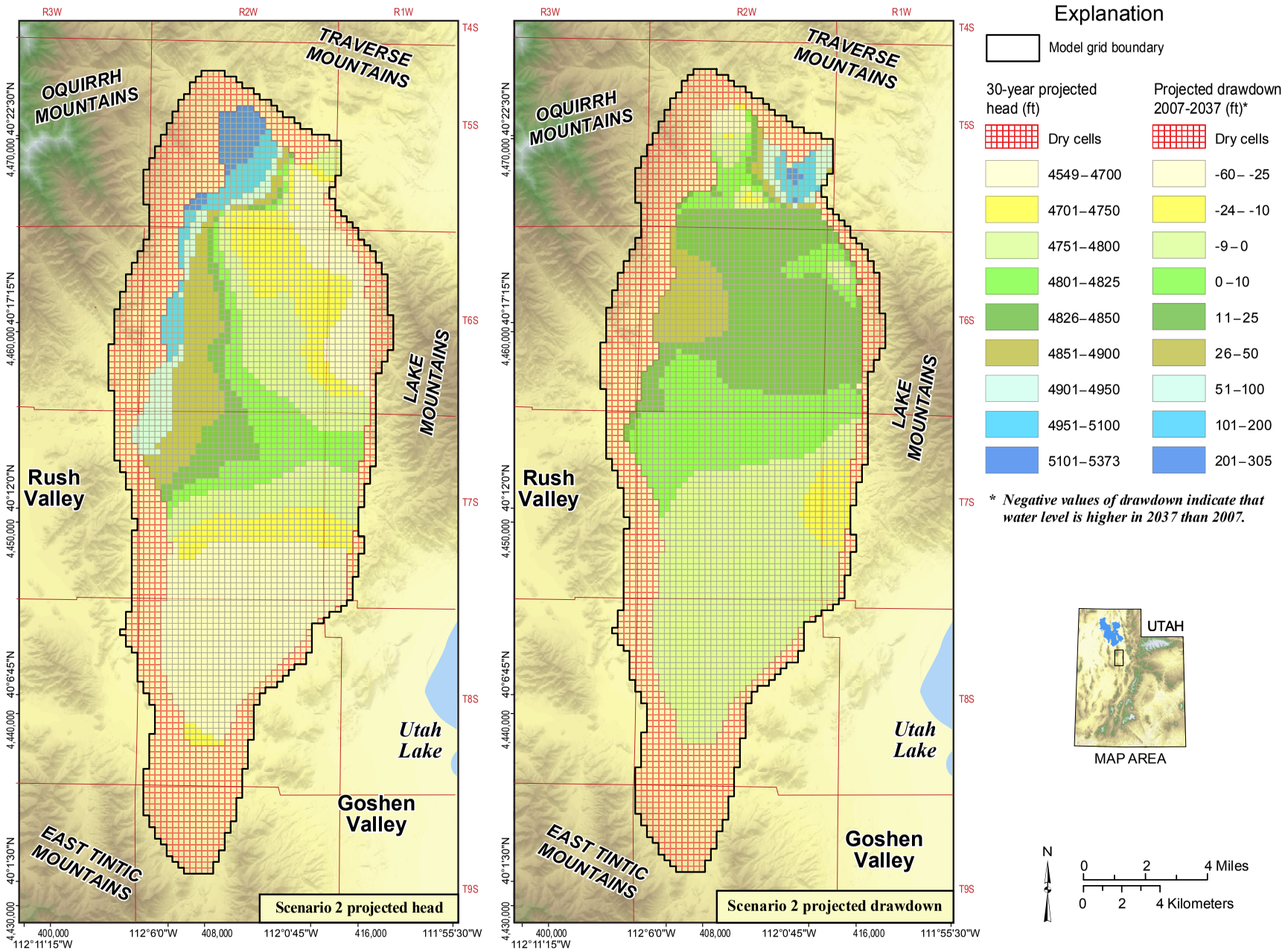


Figure 64. *Projected potentiometric head and drawdown at the end of projection scenario 2 (2037) in which withdrawal increases by 25% over 2007 rates and recharge and ET are set to the 39-year average. Drawdown is calculated from 2007 computed head.*

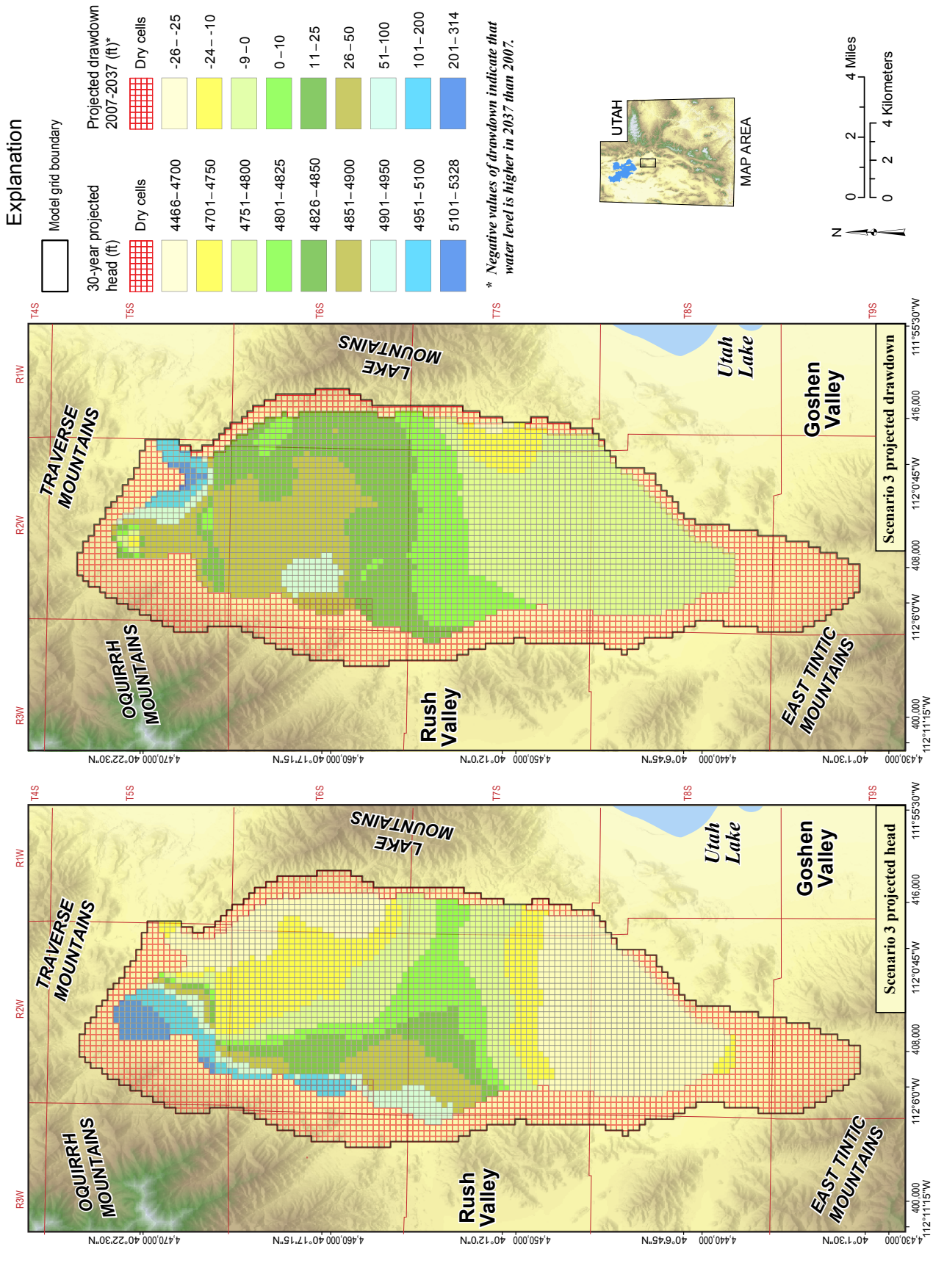


Figure 65. *Projected potentiometric head and drawdown at the end of projection scenario 3 (2037) in which withdrawal increases by 50% over 2007 rates and recharge and ET are set to the 39-year average. Drawdown is calculated from 2007 computed head.*

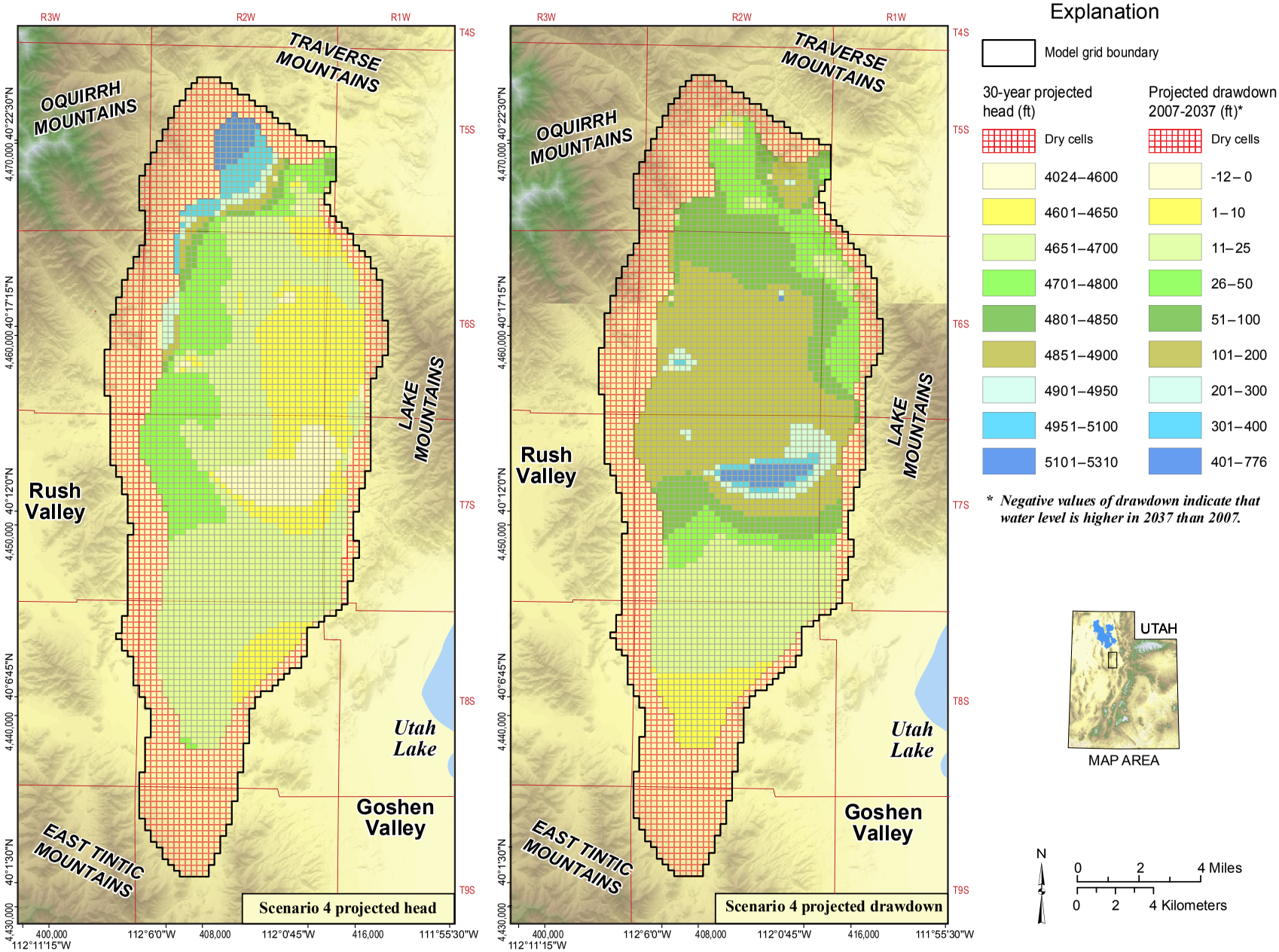


Figure 66. *Projected potentiometric head drawdown at the end of projection scenario 4 (2037) in which withdrawal from basin-fill wells doubles compared to 2007 rates and bedrock wells pump at 2007 rates; recharge and ET are set to the 39-year average. Drawdown is calculated from 2007 computed head.*

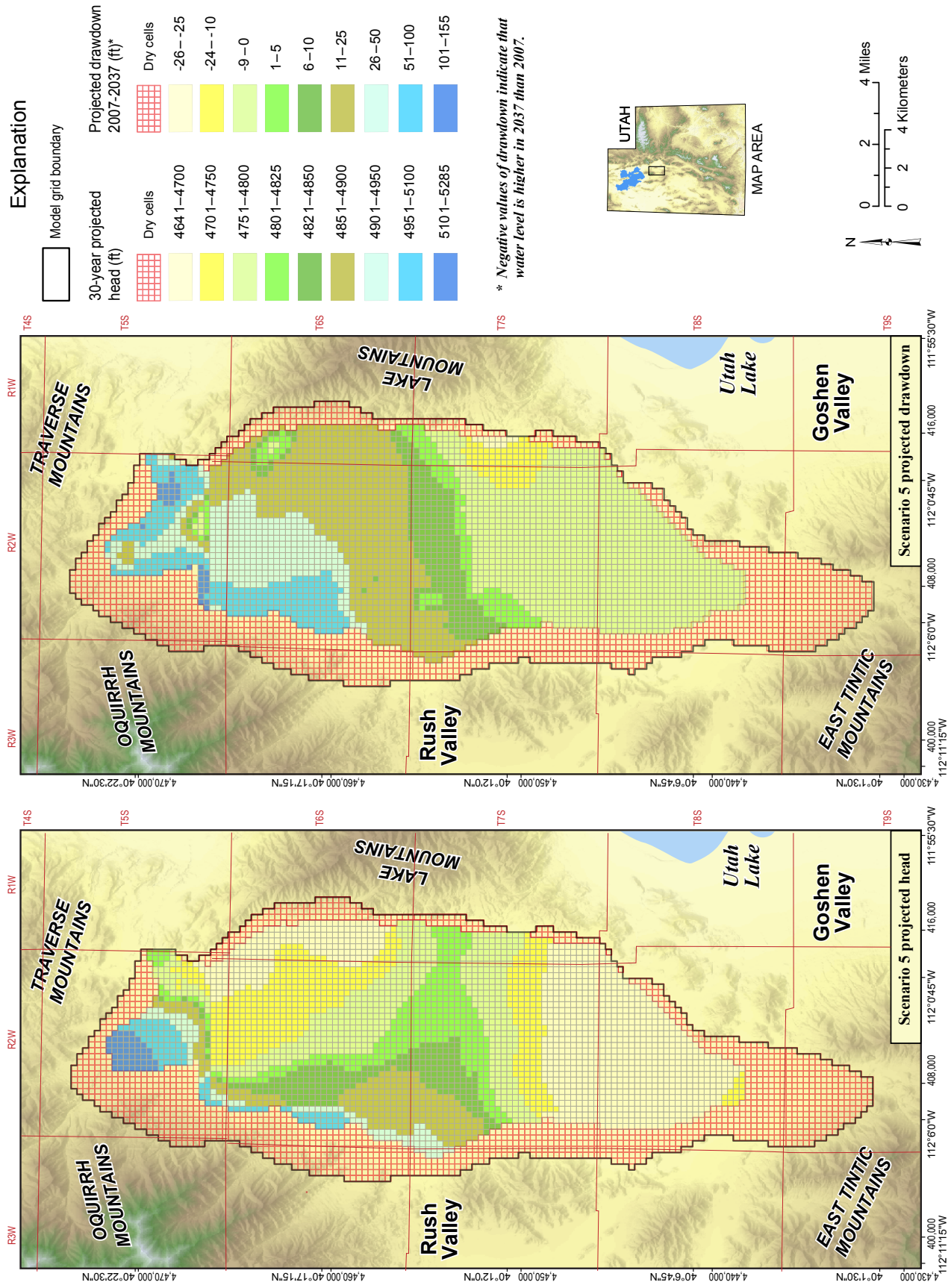


Figure 67. *Projected potentiometric head drawdown at the end of projection scenario 5 (2037) in which withdrawal from bedrock wells doubles compared to 2007 rates and basin-fill wells pump at 2007 rates; recharge and ET are set to the 39-year average. Drawdown is calculated from 2007 computed head.*

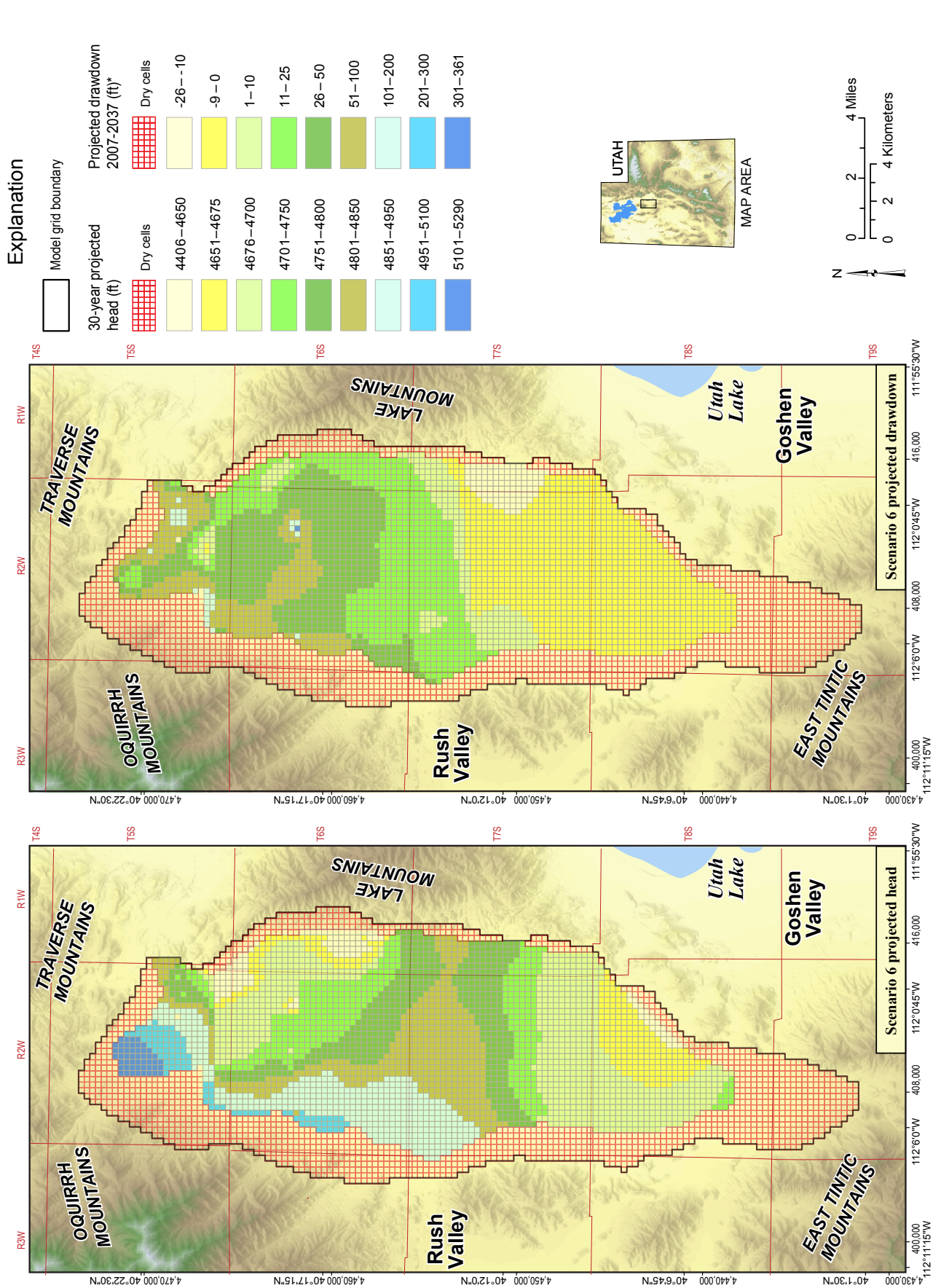


Figure 68. *Projected potentiometric head and drawdown at the end of projection scenario 6 (2037) in which withdrawal from all wells doubles compared to 2007 rates and recharge and ET are set to the 39-year average. Drawdown is calculated from 2007 computed head.*

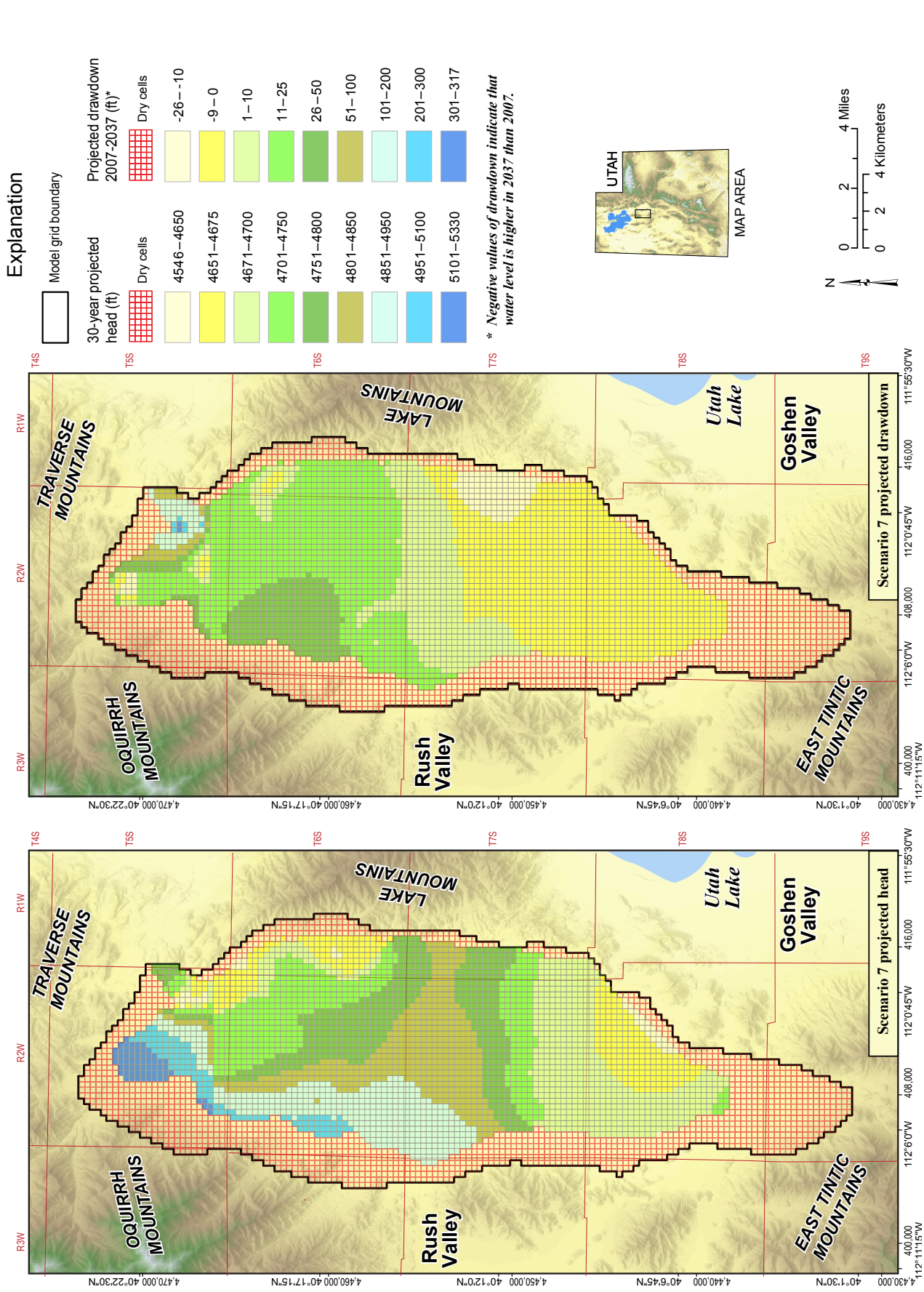


Figure 69. *Projected potentiometric head and drawdown at the end of projection scenario 7 (2037) in which withdrawal increases by 25% over 2007 rates and recharge and ET are decreased to simulate a historical 10-year drought in the middle 10 years of the projection. Drawdown is calculated from 2007 computed head.*

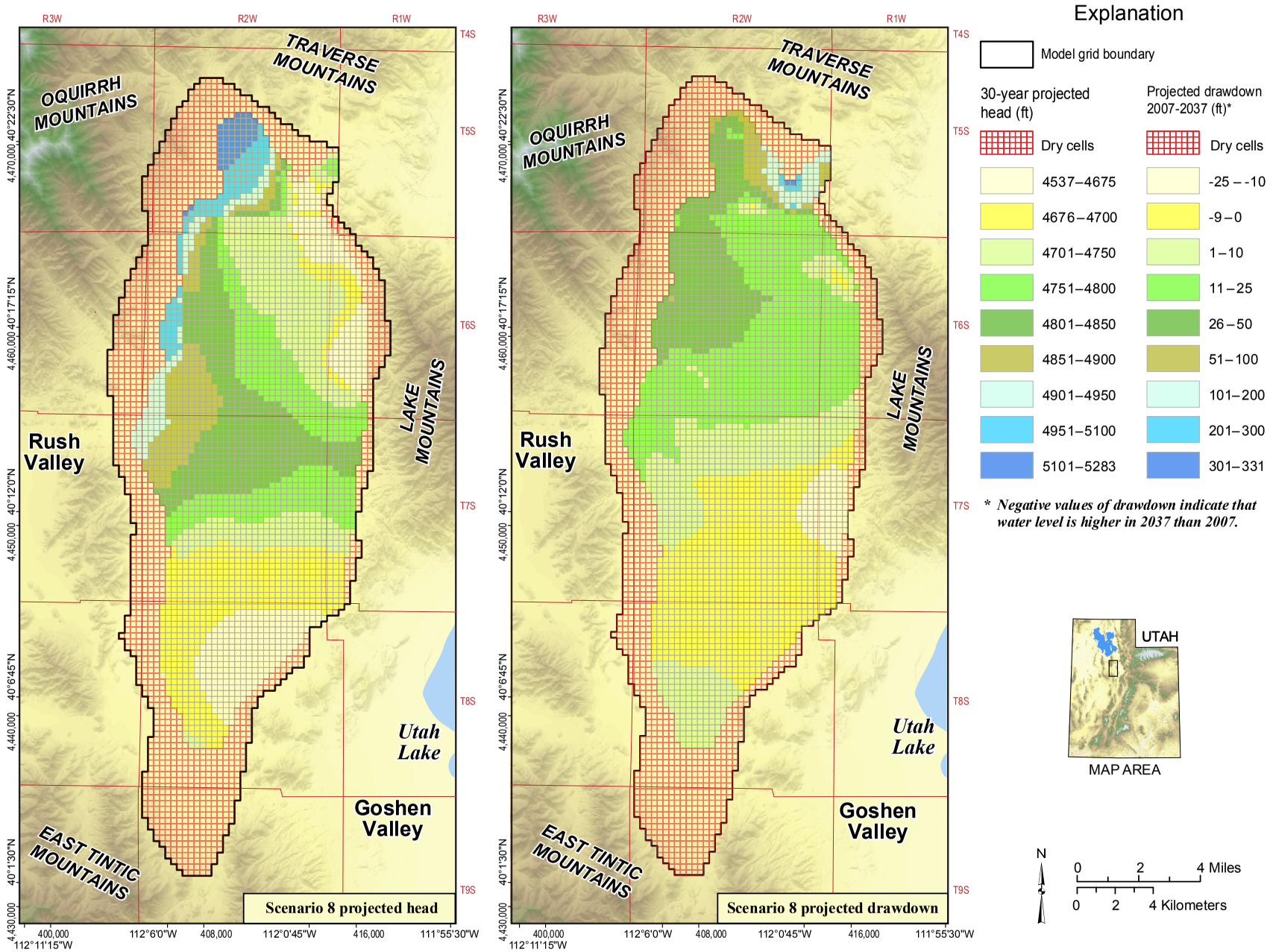


Figure 70. *Projected potentiometric head and drawdown at the end of projection scenario 8 (2037) in which withdrawal increases by 25% over 2007 rates and recharge and ET are decreased to simulate a severe 10-year drought in the middle 10 years of the projection. Drawdown is calculated from 2007 computed head.*

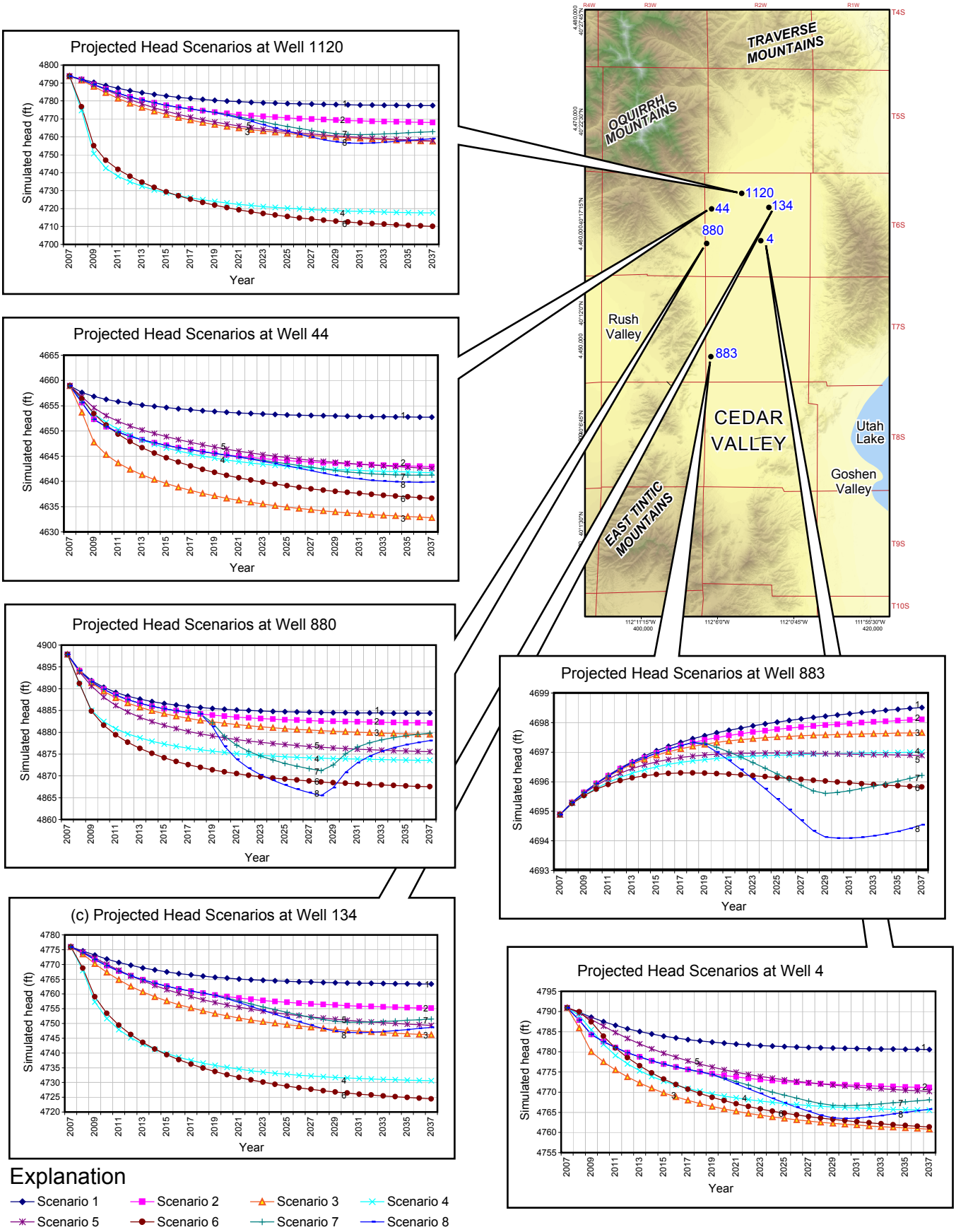


Figure 71. *Projected water-level response in selected observation wells to projection scenario conditions.*

66 and figure 68). The basin-fill aquifer near these wells has a relatively low hydraulic conductivity compared to other developed areas of the basin fill, so increased pumping amplifies drawdown in these wells.

All water levels decline and subsequently recover after projected drought conditions in the years 2018 to 2028 (scenarios 7 and 8), but the drought has a larger predicted effect on water level compared to the effect from pumping alone in wells 880 and 883 (figure 71). In well 880, the head is controlled by the volume of recharge entering the aquifer from the west and to a lesser extent by pumping at the White irrigation wells as discussed in the section Fairfield Spring and Irrigation Well Withdrawal. Well 880 is also very close to Fairfield Spring, and we surmise that the decreased recharge of the droughts and the continued nearby discharge point of the spring are the causes of the pronounced head response in well 880. The response to drought in well 883, while pronounced in comparison to the reaction to other scenarios, is only 3 feet (1 m), and probably reflects subtle changes in head regime in this southern arm of Cedar Valley.

Not surprisingly, drawdown is higher in most of the observation wells shown on figure 71 in the scenarios that include the most increased production in the basin fill (scenarios 3, 4, and 6) because the wells shown on figure 71 are completed in the basin-fill aquifer. The water-level decline in scenarios having increased bedrock development (scenarios 5 and 6) have more drawdown on the western and northern fringes of the valley, where there are more bedrock wells, than in the center of the valley.

Changes in Flow Regime

Some evapotranspiration from groundwater continues throughout the simulation period in all projections, mostly in the area of simulated high horizontal-to-vertical anisotropy.

The water extracted from wells in pumping scenarios involving increased withdrawal is supplied in the model by the decrease in drain discharge to Fairfield Spring and Cedar Pass and by water released from storage (decreasing groundwater levels). The results of the projection simulations indicate reduced discharge to Fairfield Spring of approximately 10% to 30% depending on the level of simulated withdrawal, especially in the first decade of the simulations (figure 72). The simulated drought years (2018 to 2028) have a large effect on Fairfield Spring. By decreasing the availability of groundwater recharge to the western edge of the basin-fill, the decreased precipitation simulated in the droughts quickly decreases the spring discharge by 400 to 600 acre-ft/yr (0.5–0.7 hm^3/yr) by the end of the drought. We ran an additional set of simulations focused on Fairfield Spring and the White irrigation wells near White Hills (well IDs 44 and 1035). One of these simulations, which included average recharge and the combined 2007 well withdrawal from the irrigation wells, showed no ill effect on spring discharge. Simulations using average recharge, but increased pumping at the White irrigation wells and 2007 pumping levels at all other wells, show that the irrigation wells must double their 2007 pumping level to a combined 5300 acre-ft/yr (6.5 hm^3/yr) before Fairfield Spring discharge noticeably decreases more than predicted using 2007 pumping levels.

Our projections predict interbasin flow through Cedar Pass will decrease by between 10% (scenario 1–2007 withdrawal levels) and 50% (scenario 6–double 2007 pumping) over the next 30 years (figure 72). The drier than normal years (scenarios 7 and 8), produce an additional decrease of approximately 15% during the drought years. Projected subsurface outflow through the Mosida Hills drain boundary increases by about 5% in the continued current condition or increased pumping scenarios (1 through 6) (figure 72), which is probably a model response to balance recharge from the East Tintic Mountains against most of the changes in withdrawal, which occur in the northern half of the valley. During the drier than normal years, simulated Mosida Hills subsurface flow decreases by about 5% but rebounds once simulated recharge returns to normal.

SUMMARY AND CONCLUSIONS

Setting

This report summarizes the results of a comprehensive groundwater study of the basin-fill aquifer in Cedar Valley, Utah County, Utah, conducted by UGS. The study used the data collected from new field investigations (including periodic water-level measurement, aquifer testing, and water-quality sampling) and existing data to create conceptual and digital groundwater flow models. This study was prompted by an increase in water extraction from private, irrigation, and municipal wells within the study area, which grew from an estimated 2200 acre-ft/yr (2.7 hm^3/yr) in the mid-1960s to 10,500 acre-ft/yr (13.0 hm^3/yr) in 2007, following population growth trends and growth in urban land use.

Our 334-square-mile (865-km^2) study area encompasses all of the Cedar Valley closed surface-water drainage basin and the western half of the West Canyon Creek drainage. The valley floor is roughly 20 miles long north to south and 6 miles wide west to east. Bedrock in the surrounding Oquirrh, East Tintic, Traverse, and Lake Mountains is primarily Paleozoic sedimentary rock with significant Tertiary volcanic rock outcrops (Hurlow, 2004). The basin-fill is composed of interbedded fine-grained lacustrine and coarser grained alluvial deposits up to 1900 feet (560 m) thick in the center of the valley, but the deepest part of the basin fill is clay rich and unproductive. A continuous clay unit, up to 240 feet (70 m) thick, confines groundwater flow in the basin-fill aquifer over all but the western and northern parts of the aquifer.

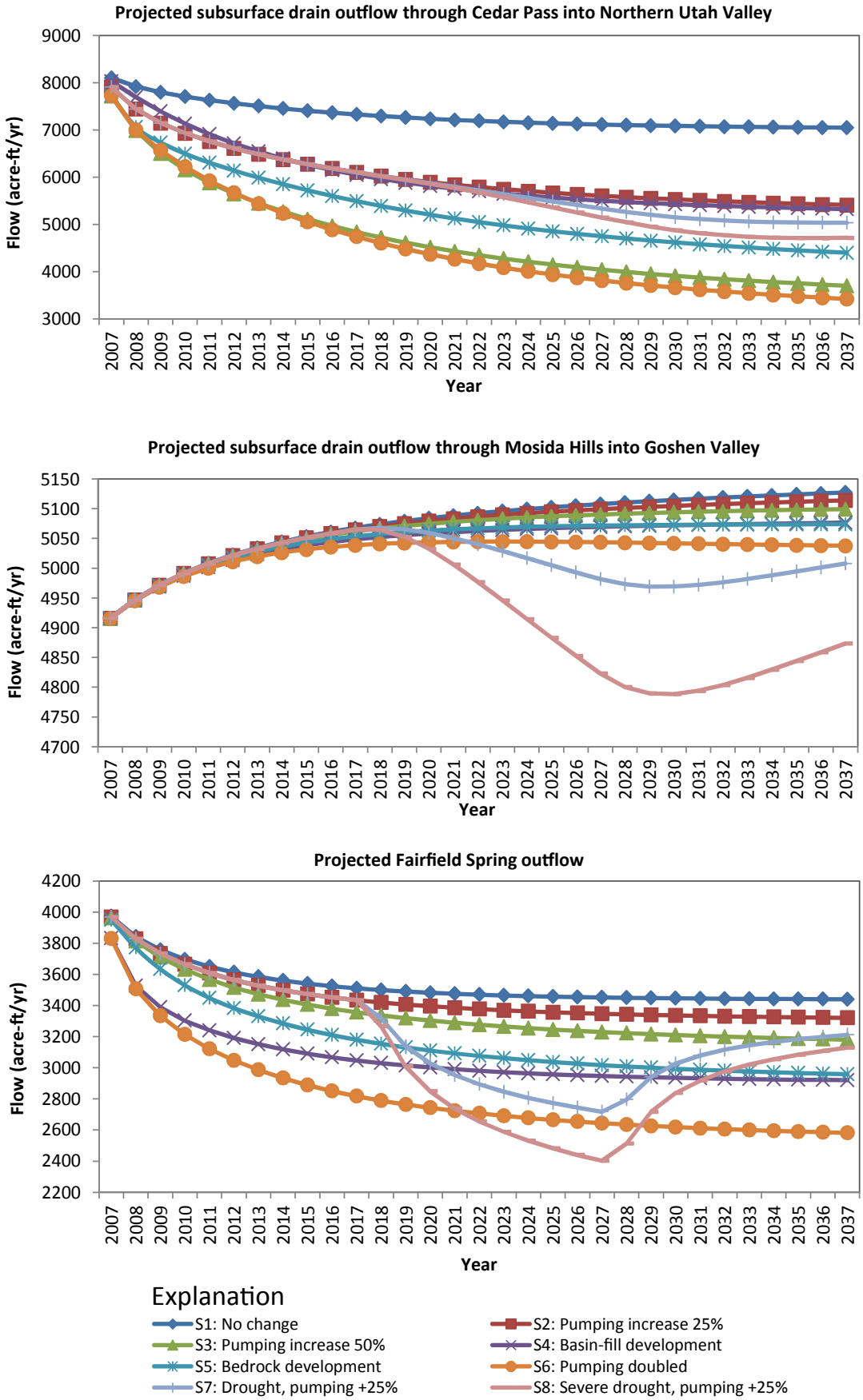


Figure 72. *Projected interbasin and spring flow from 2007 to 2037 under various projected pumping and climate scenarios. S1 through S8 indicate Scenario 1 through Scenario 8. See text for further description of scenarios.*

The flow of West Canyon Creek, the only perennial stream in the valley, is small in comparison to rivers in other northern Utah valleys, and most of its water is diverted via a ditch to the area surrounding Cedar Fort town. Three springs near Cedar Fort (combined flow less than 2 cfs [60 L/s]) and Fairfield Spring near Fairfield (1 to 10 cfs [30–300 L/s]) also provide irrigation and culinary water to the residents of Cedar Valley. Excess Fairfield Spring water flows to the Sinks, in the center of the closed basin.

Aquifer Tests and Potentiometric Trends

The geometric mean of aquifer transmissivity values, determined by five new aquifer tests and review of existing aquifer-test and specific capacity data, was 260 ft^2/d (24 m^2/d) in the basin fill and 360 ft^2/d (33 m^2/d) in the bedrock. Values from the most productive wells in the coarsest basin-fill sediments and highly fractured and porous bedrock, ranged up to 25,000 ft^2/d (2300 m^2/d) and 120,000 ft^2/d (11,000 m^2/d), respectively. The zones of highest transmissivity were on the western and eastern valley margins and in the bedrock near Cedar Pass.

New aquifer testing in the basin fill showed that principal basin-fill aquifer on the western side of Cedar Valley is confined and elongated in the north-south direction, becomes unconfined to the west, and becomes finer grained and of lower transmissivity to the east toward the valley center, which limits the volume of aquifer available to transmit water to wells. From a six-month drawdown and recovery test on the Oquirrh Group bedrock aquifer, we determined that the aquifer is productive but anisotropic (has higher transmissivity in the direction parallel to structural folding) and bounded by a wedge of low-transmissivity volcanic bedrock and most likely the normal fault bounding the western side of the Lake Mountains. Groundwater discharge out of the basin fill must go around (north or south) or under the geologic barriers. Another long-term aquifer test on the Great Blue Limestone aquifer east of Cedar Pass showed that the aquifer is moderately transmissive, confined, and not affected by potential aquifer boundaries during one-month pumping periods.

Long-term groundwater levels in the basin-fill aquifer are affected by the volume of recharge entering the aquifer at its western margin. Surges of recharge propagate across the valley from west to east and northeast, taking longer than four years to travel across the valley. The southern arm of the valley sees little water-level fluctuation, probably due to relatively less groundwater flow through these clay-rich sediments and lack of large production wells.

Increased groundwater pumping in the last decade may be lowering water levels near pumping centers but it has had no drawdown effect on most of the aquifer as of 2007. The volume of recharge entering the Cedar Valley basin-fill aquifer at its western margin is the most important influence on long-term water-level trends.

The similarity between the chemistry of water in wells in Fairfield and Fairfield Spring water suggests the spring and the confined aquifer are fed by the same source. The high correlation between Fairfield Spring discharge and water levels in the confined aquifer shows that discharge is controlled by the potentiometric head in the aquifer near the spring and in the confined aquifer east of the spring, which is controlled primarily by the volume of recharge to the aquifer. Based on groundwater modeling, we predict spring discharge will decrease as the aquifer adjusts to the greater levels of well extraction observed since 2004, but we show that pumping would have to increase to approximately 5300 acre-ft/yr (6.5 hm^3/yr) (twice the 2007 level) in the aquifer two miles north of the spring to produce additional drawdown given average recharge conditions. Less than average recharge has a larger and more immediate effect on Fairfield Spring discharge than nearby pumping. Drier than average years combined with increased pumping will decrease aquifer storage in the confined aquifer and thereby decrease spring discharge.

Water Chemistry

Water quality is generally very good and dominated by calcium and bicarbonate in wells and springs in the basin fill and carbonate and sandstone bedrock of the Pennsylvanian Oquirrh Group. Groundwater in the basin fill in the southeast part of the valley, however, has poorer water quality (e.g., TDS up to 2020 mg/L), probably due to influences by volcanic rocks and/or playa sediments in the subsurface. Water quality in Mississippian-aged formations is generally suitable for human consumption, although it often exceeds several secondary drinking water standards and is dominated by sodium and chloride.

Water in the perched unconsolidated aquifer at Cedar Pass and an upgradient spring is clearly distinct from other waters in the study area in being dominated by calcium and chloride, having a more enriched isotopic signature than surrounding water, and having a young relative age. The chemistry and the southerly groundwater flow direction in the perched aquifer indicate that the source of the groundwater recharge for the perched aquifer is the nearby low-elevation Traverse Mountains to the north.

Our isotope chemistry data from wells in Paleozoic bedrock at Cedar Pass suggest there may be a component of modern recharge in an otherwise quite old fractured bedrock flow system (mixed relative age), which receives its recharge from precipitation in the Oquirrh Mountains (depleted stable isotope values).

Cedar Fort and the perched aquifer at Cedar Pass have slightly elevated nitrate concentration in groundwater. The groundwater around Cedar Fort also contains higher total dissolved solids, and the long-term presence of livestock (source of nitrate) and irrigated agriculture (a pathway for nitrate in the seepage)

in the same area implies that the source of nitrate is anthropogenic. Our data do not point to a clear source for the nitrate in the perched aquifer at Cedar Pass.

Tritium concentrations are relatively high in wells and springs on the western side of Cedar Valley, which indicates that the average travel time for recharge to the springs is probably less than 50 years. The occurrence of young water on the western side of the valley implicates the Oquirrh Mountains as the primary recharge area. The center of many closed basins in Utah are discharge areas, but a very enriched stable isotope signature ($\delta^{18}O$ and $\delta^{2}H$ ratios) and high TDS in a well downgradient from the Sinks is evidence for recharge to the groundwater from seepage at the Sinks in the center of this closed basin.

The stable isotope signature of the water in the majority of the principal basin-fill aquifer is depleted relative to the low-to-mid elevation western springs and wells. High elevation recharge in this part of Utah has depleted isotope signatures, and we conclude that water in the northern and central parts of the principal basin-fill aquifer has a component that fell as precipitation higher than approximately 7000 feet (2100 m), infiltrated to bedrock in the Oquirrh Mountains and traveled through the bedrock to enter the basin-fill aquifer at depth. The mid-range stable isotope values found in wells completed in the confined aquifer along the western margin of the valley are evidence that wells here have a lower elevation recharge area, comparatively. Water in deep wells in the northeast basin fill either was recharged at the highest elevation in the Oquirrh Mountains or was recharged thousands of years ago during a period of cooler climate, based on its stable isotope signature and old relative age. The southwest area of the valley also has wells having depleted isotope values and old water. Long travel times are consistent with the fine-grained sediments and low production capacity of wells in the southern part of the valley.

Wells in downgradient Goshen Valley have dissimilar water quality and younger water than wells in the southern arm of Cedar Valley, suggesting that, although potentiometric data indicate groundwater flows from Cedar Valley to Goshen Valley, at least a portion of the water in Goshen Valley likely has a source other than interbasin flow through Mosida Hills.

Isotope chemistry and water levels in new wells in the low hills between Cedar Valley and Rush Valley show that a deep isolated aquifer exists there, and that this area is most likely not a conduit for groundwater flow from Rush Valley to Cedar Valley.

The distribution and chemical and isotopic signature of warm water in productive wells located near faults and structural folds is good evidence for structurally controlled movement of water that has traveled deep enough to be heated geothermally.

Conceptual Groundwater Flow Model

We used the chemical and isotopic composition of water, potentiometric data, and measured aquifer parameters to refine our conceptual model of groundwater flow in Cedar Valley. Meteoric water recharges the bedrock aquifer in the Oquirrh Mountains. Low- to medium-elevation recharge follows relatively short flow paths to recharge the principal basin-fill aquifer on the western alluvial fans. Recharge that fell as precipitation high in the Oquirrh Mountains enters the confined basin-fill aquifer at depth and mixes with the low- to medium-elevation water from the west. A clay layer confines flow in most of the basin-fill aquifer as groundwater flows from west to east in the basin-fill. Recharge from the Sinks is evident, but is not a major component of recharge to the basin fill. Upwelling of warm water, which has a mixed age signature, along geologic structures is evidence for old water following deep flow paths and mixing with younger water along high hydraulic-conductivity zones, which are probably coincident with fault locations. Intersection of the east-west groundwater flow direction in the basin fill with one such structure, the north-south trending Lake Mountains normal fault zone, likely controls movement of the basin fill water out of the basin fill and around the Lake Mountain structural fold. A buried low-permeability wedge of volcanic rocks west of Cedar Pass is a barrier to water moving from the basin fill to bedrock. The perched aquifer at Cedar Pass is not hydrologically connected to the basin-fill and bedrock aquifer system.

Recharge to the groundwater system is from (1) precipitation infiltration and runoff on the Oquirrh Mountains, Traverse Mountains, East Tintic Mountains, and the valley floor, (2) seepage from streams, canals, and the Sinks, (3) infiltration of unused irrigation water, and (4) seepage from septic tanks and wastewater treatment plants. We estimated the recharge volumes from each mountain range by allotting an increasing percentage of precipitation to recharge as elevation increases (Maxey and Eakin, 1949), and further modified the method to account for assumed differences in susceptibility of rock types to accept recharge. In our conceptual model water budget, recharge from precipitation accounted for, on average, 93% of the total recharge. Seepage from all other sources amounted to less than 3000 acre-ft/yr (3.7 hm^3/yr). Our initial conceptual model water budget included about 5000 acre-ft/yr (6.2 hm^3/yr) of recharge to the groundwater system from interbasin flow from Rush Valley to the west, but we refined this value to zero using the digital groundwater flow model.

The largest component of discharge in our conceptual model water budget was 16,000 acre-ft/yr (20 hm^3/yr) of water that exits the valley in the subsurface through bedrock in the northeast and southeast areas of the valley. Other discharge components in order of decreasing estimated volume were well withdrawal, spring discharge, and evapotranspiration.

Digital Groundwater Flow Model

We converted our conceptual groundwater flow model into steady-state and transient digital groundwater flow models using MODFLOW 2000 computer code (Harbaugh and others, 2000). The two-layer models included an upper basin-fill layer and a lower bedrock layer. Due to a lack of historical groundwater levels and pumping records from bedrock wells, we treated the bedrock layer in these models only as a source of recharge and discharge.

We used no-flow boundaries on the edges of the models to simulate areas where faults and folds inhibit groundwater flow into or out of the model area. Specified flow boundaries on the edges of the models simulate recharge to the model area. The Recharge Package in MODFLOW-2000 simulated recharge through the valley floor. The Drain Package of MODFLOW-2000 simulated discharge at Fairfield Spring and subsurface discharge out of the model area through bedrock as head-dependent boundaries. Wells within the modeled area, simulated using the Well Package in MODFLOW-2000, extracted between 1300 and 6500 acre-ft/yr (1.6–8.0 hm^3/yr) over the simulated time period. The ET Package in MODFLOW-2000 simulated evapotranspiration, which was our most poorly constrained discharge parameter.

We calibrated the groundwater flow model for steady-state conditions using head and flow data collected in 1969. We then converted the calibrated steady-state model into a transient groundwater flow model to simulate the groundwater flow conditions from 1970 through 2007. We achieved an acceptable calibration by matching the simulated water levels at 24 wells to observed levels and Fairfield Spring simulated annual flow volume to observed flow. The groundwater head and flow distributions of the calibrated steady-state and transient models show adequate simulated results as compared to the observed water levels (± 10 ft of measured water levels), spring discharge (± 1000 acre-ft/yr of measured values), and conceptual flow budget (± 20% of conceptual values). Simulated groundwater levels respond more to variation in horizontal hydraulic conductivity than any other model parameter. The accuracy of the groundwater flow model is best in areas where water-level and flow measurements are available, which is in in the central part of the valley between Fairfield and Cedar Fort on the west and Eagle Mountain on the east. Sensitivity analysis showed the models to be stable when we varied input parameters by up to 20%. The models were most sensitive to changes in the hydraulic conductivity of the bedrock aquifer and least sensitive to vertical anisotropy and specific yield changes.

The simulated groundwater model flow budget showed a 39-year (1969–2007) average recharge of 25,600 acre-ft/yr (31.6 hm^3/yr) and discharge of 25,200 acre-ft/yr (31.1 hm^3/yr). The simulated transient groundwater flow budget showed that the bedrock (layer 2) receives, on average, 24,000 acre-feet (29.6 hm^3) of recharge per year from precipitation infiltration, of which approximately 4300 acre-ft/yr (5.3 hm^3/yr), or 18% travels only within the bedrock and does not move into the basin fill. The basin fill, which is our main focus in this study, received on average approximately 19,700 acre-ft/yr (24.3 hm^3/yr), or over 90% of its recharge, from the underlying bedrock aquifer while only 1600 acre-ft/yr (2.0 hm^3/yr) enters through the valley floor. Much of the recharge (12,000 acre-ft/yr [15 hm^3/yr] on average) entering the basin fill passes through the aquifer to the bedrock on the northeast and southeast sides of the valley, but there is a net average inter-aquifer recharge of 7700 acre-ft/yr (9.5 hm^3/yr) from the bedrock (layer 2) to the basin fill (layer 1).

A small positive change in storage (recharge > discharge) was simulated by the model in the basin fill in 19 of the 39 years modeled. Over the 39 simulated years, the net change for the entire model was approximately 14,000 acre-ft (17 hm^3) (average 360 acre-ft/yr [0.44 hm^3/yr]), or approximately 1% of the water budget, which is well within the error of estimating water budget components. In general, the water budget is balanced.

Simulated groundwater flow budget values generally compare well to conceptual values. Simulated precipitation recharge through bedrock was 24,000 acre-ft/yr (30 hm^3/yr) or 94% of the value we estimated in our conceptual model calculations. Fairfield Spring discharge was a calibration target, and the simulated values (2800 to 5500 acre-ft/yr [3.5–6.8 hm^3/yr]) matched measured values during years when flow measurements were recorded, usually within 10%. Our conceptual values for subsurface interbasin flow to northern Utah and Goshen Valleys, although poorly constrained, were within the range estimated by the model. Our original estimates of ET were poorly constrained and ranged from 1700 to 4000 acre-ft/yr (2.1–4.9 hm^3/yr). Our calibrated model provides better estimates of ET, which range from 1800 to 5300 acre-ft/yr (2.2–6.5 hm^3/yr) and have a 39-year average of 3000 acre-ft/yr (3.7 hm^3/yr).

Simulated recharge through the valley floor was much less than our original estimates of recharge from precipitation and seepage from various sources. We presented two possible explanations for the discrepancy: (1) some recharge through the unsaturated zone is numerically unaccounted for in the model because of dry cells around the perimeter of the valley floor, and (2) we overestimated recharge through the clay layer. The end result implies that less than 2% of the precipitation that falls on the valley floor (average 114,400 acre-ft/yr [141.1 hm^3/yr], table E-1) ends up as recharge (average 1600 acre-ft/yr [2.0 hm^3/yr], table G-4).

Based on our conceptual water-budget calculations and aquifer-test results showing high transmissivity in some areas of the bedrock aquifer, we suspected that a significant portion of the recharge from precipitation in the Oquirrh Mountains may travel as bedrock flow underneath the relatively shal-

low basin-fill aquifer. Modeling results substantiated our theory and demonstrated that, on average, approximately 18% (4300 out of 24,000 acre-ft/yr [5.3 of 29.6 hm^3/yr]) of the recharge from the western mountain ranges to the model domain may travel only in bedrock under the basin fill, not moving through the basin fill, on its journey to northern Utah and Goshen Valleys.

Our model shows a subsurface outflow through Cedar Pass and Mosida Hills that averaged 14,900 acre-ft/yr (18.4 hm^3/yr) during the modeled period. Approximately two-thirds of the subsurface discharge from Cedar Valley is near Cedar Pass, and the other third discharges under Mosida Hills, which is consistent with our conceptual model of the area. The subsurface discharge is likely captured downgradient of the location at which our model estimates outflow from Cedar Pass, where wells serving Cedar Pass residents pumped 3600 acre-ft/yr (4.4 hm^3/yr) in 2007, in addition to other large groundwater appropriations in northern Utah and Goshen Valleys.

Aquifer Response to Projected Groundwater Conditions

We used the transient groundwater flow model to predict possible effects on water levels, spring discharge, and interbasin flow caused by drought conditions and increased withdrawal from wells. We regard projected effects in the most northern part of the basin fill with caution because this area of the model is poorly characterized. The continuous decline in projected water levels during most projection scenarios indicates that groundwater is being removed from storage and that new steady-state equilibrium is not reached within the 30-year projections. The groundwater flow direction was not altered in most of the projection scenarios, but drawdown and decreased discharge were significant. The northern and central parts of the valley were projected to experience generally less than 50 feet (15 m) of drawdown when increasing well withdrawal to as much as twice the 2007 level (up to 13,000 acre-ft/yr [16 hm^3/yr]) or decreasing recharge by up to 30%. The largest amount of and most widespread drawdown in the basin-fill aquifer was predicted in scenarios that involved doubling the withdrawal from wells in the basin fill. Fairfield Spring discharge and interbasin flow through Cedar Pass are projected to decrease by approximately 10% to 30% and 10% to 50%, respectively, depending on the level of simulated withdrawal. The southern part of the valley is projected to see minor changes in groundwater level or discharge through Mosida Hills under any scenario.

Model projections should not be used to predict actual groundwater levels at some future date, but they can give a general idea about the water-level declines and flow directions likely to occur throughout Cedar Valley under future stresses of the modeled aquifers. In general, developing future water resources in the study area should avoid zones with considerable drawdown. For example, we recommend avoiding zones with drawdown greater than 25 feet (8 m) and reducing well withdrawal in zones with drawdown greater than 50 feet (15 m). To minimize future drawdown, we recommend conducting additional field work to locate new production wells rather than increasing withdrawal at existing wells.

We consider the transient groundwater flow model developed for this study an adequate tool to help determine the valley-wide effects on water levels under changing groundwater conditions. While our conceptual understanding of the Cedar Valley groundwater system is good, it could be improved by refining the models. Long-term water-level fluctuations in areas with no current field measurements would help refine the estimated specific yield, specific storage, and horizontal-to-vertical anisotropy in the transient simulation.

ACKNOWLEDGMENTS

This study was partially funded by the Utah Division of Water Rights. We are grateful for the cooperation of, and information provided by, water users and well owners in Cedar Valley, without whose cooperation this study could not have been completed. Particularly helpful were the managers of Eagle Mountain, Cedar Fort, and Fairfield. Grant and Jim Smith, Keith Jonnson, Michael Burch, and Eagle Mountain allowed us to conduct aquifer tests on their wells. James Greer of the Utah Division of Water Rights provided guidance on the objectives of the modeling exercise. Dr. S. Mark Yidana, University of Ghana (formerly with the UGS), provided insight into alternative modeling techniques and assistance with model construction and calibration. Rich Emerson and Kim Nay made most of the illustrations for the publication. Technical reviewers Stefan Kirby and Paul Inkenbrandt, UGS, and James Greer and Cheryl Heying, Utah Division of Water Rights, provided valuable suggestions for increasing this document's usefulness and readability. Additional reviews by Mike Lowe, Robert Ressetar, Kimm Harty, and Rick Allis improved the manuscript.

REFERENCES

Allmendinger, R.W., 1992, Fold and thrust tectonics of the western United States exclusive of accreted terranes, *in* Burchfiel, B.C., Lipman, P.W., and Zoback, M.L., editors, The Cordilleran orogeny—conterminous U.S.: Geological Society of America, The Geology of North America, v. G-3, p. 583–607.

Anderson, M.P., and Woessner, W.W., 1992, Applied groundwater modeling—simulation of flow and advective transport: San Diego, California, Academic Press, 381 p.

Anderson, P.B., Susong, D.D., Wold, S., Heilweil, V.M.,

and Baskin, R.L., 1994, Hydrogeology of recharge areas and water quality of the principal aquifers along the Wasatch Front and adjacent areas, Utah: U.S. Geological Survey Water-Resources Investigations Report 93-4221, 74 p.

Aquaveo, LLC, 2008, Groundwater Modeling System (GMS) software: Provo, Utah, version 6.5.

Automated Geographic Reference Center, 2001, SGID.U500.DominantVegetation GIS Coverage: Online, http://gis.utah.gov/component/option,com_dbquery/Itemid,87/task,ExecuteQuery/qid,2/previousTask,PrepareQuery/, accessed May 28, 2008.

Avon, L., and Durbin, T.J., 1994, Evaluation of the Maxey-Eakin method for estimating recharge to ground-water basins in Nevada: Water Resources Bulletin, v. 30, no. 1, p. 99–111.

Balch, D.P., Cohen, A.S., Schnurrenberger, D.W., Haskell, B.J., Valero-Garces, B.L., Beck, J.W., Cheng, H., and Edwards, R.L., 2005, Ecosystem and paleohydrological response to Quaternary climate change in the Bonneville Basin, Utah: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 221, no. 1-2, p. 99–122.

Barcelona, M.J., Gibb, J.P., Helfrich, J.A., and Garske, E.E., 1985, Practical guide for ground-water sampling, EPA/600/2-85/104, 169 p.

Bense, V.F., and Person, M.A., 2006, Faults as conduit-barrier systems to fluid flow in siliciclastic sedimentary aquifers: Water Resources Research, v. 42, W05421, doi:10.1029/2005WR004480.

Biek, R.F., 2004, Geologic map of the Saratoga Springs 7.5' quadrangle, Utah County, Utah and Geologic Map of the Cedar Fort 7.5' quadrangle, Utah County, Utah: Utah Geological Survey Map 201 and 202, 3 plates, scale 1:24,000.

Biek, R.F., 2005, Geologic map of the Jordan Narrows quadrangle, Salt Lake and Utah Counties, Utah: Utah Geological Survey Map 208, 2 plates, scale 1:24,000.

Biek, R.F., 2006, Geology of the Rose Canyon Area, Salt Lake County, Utah, *in* Harty, K.M., and Tabet, D.E., editors, Geology of Northwest Utah: Utah Geological Association, Utah Geological Association Publication 34.

Biek, R.F., Clark, D.L., and Christiansen, E.H., 2009, Geologic map of the Soldiers Pass quadrangle, Utah County: Utah Geological Survey Map 235, 3 plates, scale 1:24,000.

Biek, R.F., Solomon, B.J., Keith, J.D., and Smith, T.W., 2005, Geologic map of the Tickville Spring quadrangle, Salt Lake and Utah Counties, Utah: Utah Geological Survey Map 214, 2 plates, scale 1:24,000.

Bishop, C.E., Wallace, J., and Lowe, M., 2007, Recommended septic tank soil-absorption-system densities for the shallow unconfined aquifer in Cache Valley, Cache County, Utah: Utah Geological Survey Report of Investigations 257, 35 p.

Blackett, R., 2004, Geothermal gradient data for Utah, *in* Blackett, R., and Wakefield, S., compilers, Geothermal resources of Utah—2004: Utah Geological Survey Open-File Report 431, variously paginated.

Blasch, K.W., and Bryson, J.R., 2007, Distinguishing sources of ground water recharge by using δ^2H and $\delta^{18}O$: Ground Water, v. 45, no. 3, p. 294–308.

Brooks, L.E., and Stolp, B.J., 1995, Hydrology and simulation of ground-water flow in southern Utah and Goshen Valleys, Utah: Utah Department of Natural Resources Technical Publication 111, 96 p., 2 plates.

Brouste, L., Marlin, C., and Dever, L., 1997, Geochemistry and residence time estimation of groundwater from the upper aquifer of the Chihuahua desert (Comarca Lagunera, Northern Mexico): Applied Geochemistry, v. 12, p. 775–786.

Bryant, B.B., and Nichols, D.J., 1988, Late Mesozoic and early Tertiary reactivation of an ancient crustal boundary along the Uinta trend and its interaction with the Sevier orogenic belt, *in* Schmidt, C.J., and Perry, W.J., editors, Interaction of the Rocky Mountain foreland and the Cordilleran thrust belt: Geological Society of America Memoir 171, p. 411–430.

Cederberg, J.R., Gardner, P.M., and Thiros, S.A., 2009, Hydrology of northern Utah Valley, Utah County, Utah, 1975–2005: U.S. Geological Survey Scientific Investigations Report 2008-5197, 114 p.

Christiansen, E.H., Baxter, N., Ward, T.P., Zobell, E., Chandler, M.R., Dorais, M.J., Kowallis, B.J., and Clark, D.L., 2007, Cenozoic Soldiers Pass volcanic field, central Utah—implications for the transition to extension-related magmatism in the Basin and Range province, *in* Willis, G.C., Hylland, M.D., Clark, D.L., and Chidsey, T.C., Jr., editors, Central Utah—diverse geology of a dynamic landscape: Utah Geological Association Publication 36, p. 123–142.

Clark, D.L., Biek, R.F., and Christiansen, E.H., 2009, Geologic map of the Goshen Valley North quadrangle, Utah County, Utah: Utah Geological Survey Map 230, 2 plates, scale 1:24,000.

Clark, D.W., 1984, The ground-water system and simulated effects of ground-water withdrawals in northern Utah Valley, Utah.: U.S. Geological Survey Water-Resources Investigations Report 85-4007, 56 p.

Clark, D.W., and Appel, C.L., 1985, Ground-water resources of northern Utah Valley, Utah: Utah Department of

Natural Resources Technical Publication 80, 115 p.

Clark, I., and Fritz, P., 1997, Environmental isotopes in hydrogeology: Boca Raton, Lewis Publishers, 352 p.

Cooper, H.H., and Jacob, C.E., 1946, A generalized graphical method for evaluating formation constants and summarizing well field history: American Geophysical Union Transactions, v. 27, p. 526–534.

Cordova, R.M., 1970, Ground-water conditions in southern Utah Valley and Goshen Valley, Utah: Utah Department of Natural Resources Technical Publication 28, 79 p., 4 plates.

Cordova, R.M., and Subitzky, S., 1965, Ground water in northern Utah Valley, Utah—a progress report for the period 1948-63: Utah State Engineer Technical Publication 11, 41 p.

Cruff, R.W., 1980, Seepage study of the West Side and West Canals, Box Elder County, Utah: Utah Department of Natural Resources Technical Publication 67, 38 p.

Currey, D.R., 1990, Quaternary palaeolakes in the evolution of semidesert basins, with special emphasis on Lake Bonneville and the Great Basin, U.S.A.: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 76, p. 189–214.

Dames & Moore, 1976, Ground water investigation—phase II, plant site, west shore of Utah Lake, for Ireco Chemicals: Salt Lake City, unpublished consultant's report, 5 p.

Demographic and Economic Analysis Section, 1991, Utah data guide, January 1991: Salt Lake City, Utah Governor's Office of Planning and Budget, 16 p.

Demographic and Economic Analysis Section, 2000, 2000 Economic Report to the Governor: Salt Lake City, Utah Governor's Office of Planning and Budget, 215 p.

Demographic and Economic Analysis Section, 2001, Utah data guide, spring 2001: Salt Lake City, Utah Governor's Office of Planning and Budget, 8 p.

Demographic and Economic Analysis Section, 2004, Utah data guide, summer 2004: Salt Lake City, Utah Governor's Office of Planning and Budget, 8 p.

Demographic and Economic Analysis Section, 2006a, Population by community and census precincts from 1890 to 2000: Online, http://www.governor.utah.gov/dea/HTMLBriefs/CityCountyBrief/Historic/CityPop.htm, accessed September 28, 2006.

Demographic and Economic Analysis Section, 2006b, 2006 Economic Report to the Governor: Salt Lake City, Utah Governor's Office of Planning and Budget, 192 p.

Demographic and Economic Analysis Section, 2006c, Utah data guide, summer 2006: Salt Lake City, Utah Governor's Office of Planning and Budget, 2 p.

Demographic and Economic Analysis Section, 2008a, 2008 baseline highlights: Salt Lake City, Utah Governor's Office of Planning and Budget, 32 p.

Demographic and Economic Analysis Section, 2008b, Utah data guide, summer 2008: Salt Lake City, Utah Governor's Office of Planning and Budget, 12 p.

Doherty, J., 2005, PEST—Model-independent Parameter Estimation user manual (5th ed.): Brisbane, Australia, Watermark Numerical Computing, 336 p.

Duffield, G.M., 2007, AQTESOLV for Windows aquifer test analysis software, professional edition: Reston, Virginia, HydroSOLVE, Inc., version 4.5.

Dustin, J.D., and Merritt, L.B., 1980, Hydrogeology of Utah Lake with emphasis on Goshen Bay: Utah Geological and Mineral Survey Water Resources Bulletin 23, 50 p.

Epic Engineering, 2001, Drinking water source protection plan for John Walden well: Heber City, Utah, unpublished consultant's report submitted to Utah Department of Environmental Quality, Division of Drinking Water, for Eagle Mountain City, 15 p., 4 appendices.

Epic Engineering, 2004, Preliminary well evaluation report for Eagle Mountain City Pony Express Well: Heber City, Utah, unpublished consultant's report submitted to Utah Department of Environmental Quality, Division of Drinking Water, for Eagle Mountain City, variously paginated.

EPW Engineering, Inc., 1999, Drinking water source protection plan, Cook Well: Salt Lake City, unpublished consultant's report submitted to Utah Department of Environmental Quality, Division of Drinking Water, variously paginated.

ESI Engineering, Inc., 2003, Drinking water source protection plan, Community Center Well: Salt Lake City, unpublished consultant's report submitted to Utah Department of Environmental Quality, Division of Drinking Water for the town of Cedar Fort, 13 p., 5 appendices.

Fairley, J.P., and Hinds, J.J., 2004, Rapid transport pathways for geothermal fluids in an active Great Basin fault zone: Geology, v. 32, no. 9, p. 825–828.

Feltis, R., 1967, Ground-water conditions in Cedar Valley, Utah County, Utah: Utah State Engineer Technical Publication 16, 31 p.

Fetter, C.W., 1988, Applied hydrogeology: New York, Macmillan, 592 p.

Flint, A.L., Flint, L.E., Hevesi, J.A., and Blainey, J.B., 2004, Fundamental concepts of recharge in the desert Southwest—a regional modeling perspective, *in* Phillips, F.M., Hogan, J., and Scanlon, B., editors, Groundwater

recharge in a desert environment—the southwestern United States: Washington, D.C. American Geophysical Union, p. 159–184.

Floyd, A.R., 1993, An integrated gravity and magnetic analysis of the Mosida Hills, Utah County, Utah: Provo, Utah, Brigham Young University, M.S. thesis, 77 p.

Fontes, J., and Garnier, J.M., 1979, Determination of initial ^{14}C activity of the total dissolved carbon—a review of the existing models and a new approach: Water Resources Research, v. 15, no. 2, p. 399–413.

Gammons, C.H., Poulson, S.R., Pellicori, D.A., J., R.P., Roesler, A.J., and Petrescu, E.M., 2006, The hydrogen and oxygen isotopic composition of precipitation, evaporated mine water, and river water in Montana, USA: Journal of Hydrology, v. 328, p. 319–330.

Gardner, P.M., 2009, Three-dimensional numerical model of ground-water flow in northern Utah Valley, Utah County, Utah: U.S. Geological Survey Scientific Investigations Report 2008-5049, 95 p.

Goode, H.D., 1978, Thermal waters of Utah: Utah Geological and Mineral Survey Report of Investigation 129, 183 p.

Hall, J., 1949, History of pumping at the Chief Consolidated Mine, Eureka, Juab County, Utah: Mining Transactions, v. 184, p. 229–234.

Hamaker, S., and Harris, R., 2007, Fault-related groundwater compartmentalization in the East Tintic mining district, Utah, *in* Willis, G.C., Hylland, M.D., Clark, D.L., and Chidsey, T.C., Jr., editors, Central Utah—diverse geology of a dynamic landscape: Utah Geological Association Publication 36, p. 405–423.

Hansen, Allen & Luce, Inc., 2001, Municipal and industrial water supply and uses in the Utah and East Juab Counties area: Utah Division of Water Resources municipal and industrial water supply and use report, 36 p.

Harbaugh, A.W., Banta, E.R., Hill, M.C., and McDonald, M.G., 2000, MODFLOW-2000, the U.S. Geological Survey modular ground-water model—user guide to modularization concepts and the ground-water flow process: U.S. Geological Survey Open-File Report 00-92, 121 p.

Harrill, J.R., and Prudic, D.E., 1998, Aquifer systems in the Great Basin Region of Nevada, Utah, and adjacent states—summary report: U.S. Geological Survey Professional Paper 1409-A, 66 p.

Harvey, F.E., 2005, Stable hydrogen and oxygen isotope composition of precipitation in northeastern Colorado: Journal of the American Water Resources Association, v. 41, no. 2, p. 447–459.

Heilweil, V.M., Freethey, G.W., Stolp, B.J., Wilkowske, C.D., and Wilberg, D.E., 2000, Geohydrology and numerical simulation of ground-water flow in the central Virgin River basin of Iron and Washington counties, Utah: Utah Department of Natural Resources Technical Publication 116, 139 p.

Heilweil, V.M., and Hsieh, P.A., 2006, Determining anisotropic transmissivity using a simplified Papadopulos method: Ground Water, v. 44, no. 5, p. 749–753.

Hely, A.G., 1971, Water resources of Salt Lake County, Utah: Utah Department of Natural Resources Technical Publication 31, 244 p., 5 plates.

Hem, J., 1992, Study and interpretation of the chemical characteristics of natural water: U.S. Geological Survey Water-Supply Paper 2254, 263 p., 2 plates.

Henrickson, A., 2000, New heat flow determinations from oil and gas wells in the Colorado Plateau and Basin and Range of Utah: Salt Lake City, University of Utah, MS thesis, 70 p.

Hill, M.C., Banta, E.R., Harbaugh, A.W., and Anderman, E.R., 2000, MODFLOW-2000, the U.S. Geological Survey modular ground-water model—user guide to observation, sensitivity, and parameter-estimation processes and three post-processing programs: U.S. Geological Survey Open-File Report 00-184, 209 p.

Hill, R.W., 1998, Consumptive use of irrigated crops in Utah: Utah Agricultural Experiment Station Research Report 145, 361 p.

Hood, J.W., Price, D., and Waddell, K.M., 1969, Hydrologic reconnaissance of Rush Valley, Tooele County, Utah: Utah Department of Natural Resources Technical Publication 23, 63 p., 1 plate, scale 1:250,000.

Hood, J.W., and Waddell, K.M., 1968, Hydrologic reconnaissance of Skull Valley, Tooele County, Utah: Utah Department of Natural Resources Technical Publication 18, 57 p., 2 plates, scale 1:250,000.

Hurlow, H.A., 2004, The geology of Cedar Valley, Utah County, Utah, and its relation to ground-water conditions: Utah Geological Survey Special Study 109, 36 p., 4 plates.

Ingebritsen, S., Sanford, W., and Neuzil, C., 2006, Groundwater in geologic processes (2nd ed.): New York, Cambridge Universtiy Press, 536 p.

Johannesson, K.H., Stetzenbach, K.J., Hodge, V.F., Kreamer, D.K., and Zhou, X., 1997, Delineation of groundwater flow systems in the southern great basin using aqueous rare earth element distributions: Ground Water, v. 35, no. 5, p. 807–819.

Jordan, J.L., 2013, Aquifer parameter estimation from aquifer tests and specific-capacity data in Cedar Valley and the Cedar Pass area, Utah County, Utah: Utah Geologi-

cal Survey Special Study 146.

Jordan, J.L., 2008, Report of 2007 monitoring well drilling for Eagle Mountain City: Salt Lake City, Utah Geological Survey, contract deliverable report for Eagle Mountain City, 72 p.

Jordan, J.L., and Sabbah, W., 2007, Ground-water flow, water-level trends, and the connection between Fairfield Spring and the basin-fill aquifer in Cedar Valley, Utah County, north-central Utah, *in* Willis, G.C., Hylland, M.D., Clark, D.L., and Chidsey, T.C., Jr., editors, Central Utah—diverse geology of a dynamic landscape: Utah Geological Association Publication 36, p. 345–359.

Kariya, K.A., Roark, D.M., and Hanson, K.M., 1994, Hydrology of Cache Valley, Cache County, Utah, and adjacent part of Idaho, with emphasis on simulation of ground-water flow: Utah Department of Natural Resources Technical Publication 108, 120 p., 2 plates.

Kazemi, G.A., Lehr, J.H., and Perrochet, P., 2006, Groundwater age: Hoboken, New Jersey, John Wiley & Sons, 325 p.

Kendall, C., and Coplen, T.B., 2001, Distribution of oxygen-18 and deuterium in river waters across the United States: Hydrological Processes, v. 15, p. 1363–1393.

Klauk, R.H., 1984a, Low-temperature geothermal assessment of the Jordan Valley, Salt Lake County, Utah: Utah Geological and Mineral Survey Report of Investigation 185, 160 p., 5 plates.

Klauk, R.H., 1984b, Summary of low-temperature geothermal studies conducted by the Utah Geological and Mineral Survey from July 1, 1977, to December 31, 1984: Utah Geological and Mineral Survey Report of Investigation 193, 16 p.

Klauk, R.H., and Davis, D.A., 1984, Evaluation of low-temperature geothermal potential in Utah and Goshen Valleys and adjacent areas, Utah, Part II—water temperature and chemistry: Utah Geological and Mineral Survey Report of Investigation 191, 45 p., 2 plates.

Lachmar, T.D., and Schieb, W.M., 2007, Impact of the Big Hole Fault on fluid flow in the Navajo Sandstone, northern San Rafael Swell, Utah, *in* Willis, G., Hylland, M., Clark, D., and Chidsey, T., editors, Central Utah—diverse geology of a dynamic landscape: Utah Geological Association Publication 36, p. 425–438.

Laes, D.Y.M., Krahulec, K.A., and Ballantyne, G.H., compilers, 1998, Geologic map of the Oquirrh Mountains, Utah, *in* John, D.A. and Ballantyne, G.H., editors, Society of Economic Geologist Guidebook 29—Geology and ore deposits of the Oquirrh and Wasatch Mountains, Utah, prepared for the Society of Economic Geologists Field Trip, 23–25 October 1997, scale 1:62,500.

Lambert, P.M., 1995, Numerical simulation of ground-water flow in basin-fill material in Salt Lake Valley, Utah: Utah Department of Natural Resources Technical Publication 110-B, 58 p.

Lambert, P.M., and Stolp, B.J., 1999, Hydrology and simulation of the ground-water flow system in Tooele Valley, Utah: U.S. Geological Survey Water-Resources Investigations Report 99-4014, 60 p.

Larsen, N., 1960, Geology and ground water resources of northern Cedar Valley, Utah County, Utah: Provo, Utah, Brigham Young University, M.S. thesis, 42 p.

Larson, K., Keller, C., Larson, P., and Allen-King, R., 2000, Water resource implications of ^{18}O and ^{2}H distributions in a basalt aquifer system: Ground Water, v. 38, no. 6, p. 947–953.

Lowe, M., and Wallace, J., 2001, Evaluation of potential geologic sources of nitrate contamination in ground water, Cedar Valley, Iron County, Utah with emphasis on the Enoch area: Utah Geological Survey Special Study 100, 50 p.

Lowe, M., Wallace, J., and Bishop, C.E., 2000, Analysis of septic-tank density for three areas in Cedar Valley, Iron County, Utah—a case study for evaluations of proposed subdivisions in Cedar Valley: Utah Geological Survey Water Resource Bulletin 27, 66 p.

Mahlknecht, J., Garfias-Solis, J., Aravena, R., and Tesch, R., 2006, Geochemical and isotopic investigations on groundwater residence time and flow in the Independence Basin, Mexico: Journal of Hydrology, v. 324, p. 283–300.

Manning, A.H., and Solomon, D.K., 2004, Constraining mountain-block recharge to the eastern Salt Lake Valley, Utah, with dissolved noble gas and tritium data, *in* Phillips, F.M., Hogan, J., and Scanlon, B., editors, Groundwater recharge in a desert environment—the southwestern United States: Washington, D.C. American Geophysical Union, p. 139–158.

Maxey, G.B., and Eakin, T.E., 1949, Ground water in White River Valley, White Pine, Nye, and Lincoln Counties, Nevada: Nevada Department of Conservation and Natural Resources Water Resources Bulletin 8, 59 p.

Mayo, A.L., and Loucks, M., 1995, Solute and isotopic geochemistry and ground water flow in the central Wasatch Range, Utah: Journal of Hydrology, v. 172, no. 1-4, p. 31–59.

Mayo and Associates LC, 2001, Investigation of thermal and non-thermal groundwaters in the vicinity of Cedar Pass Ranches, Eagle Mountain, Utah: Provo, Utah, unpublished consultant's report, 24 p.

McDonald, M.G., and Harbaugh, A.W., 1988, A modular

three-dimensional finite-difference ground-water flow model: U.S. Geological Survey Techniques of Water-Resources Investigations, book 6, chapter A1.

Montgomery, S.B., 1995, Hydrogeologic study, John Walden well, water source protection report with delineation protection zones and management areas: Salt Lake City, unpublished consultant's report submitted to Sowby & Berg Consultants, American Fork, Utah, and Utah Department of Environmental Quality, Division of Drinking Water, 15 p., 1 appendix.

Montgomery Watson, Inc., 2000, Well report for Eagle Mountain City exploration well no. 3: Salt Lake City, unpublished consultant's report for Eagle Mountain City, variously paginated.

Moreo, M.T., Laczniak, R.J., and Stannard, D.I., 2007, Evapotranspiration rate measurements of vegetation typical of ground-water discharge areas in the Basin and Range carbonate-rock aquifer system, White Pine County, Nevada, and adjacent areas in Nevada and Utah, September 2005–August 2006: U.S. Geological Survey Scientific Investigations Report 2007-5078, 37 p.

Morrison, R.B., 1991, Quaternary stratigraphic, hydrologic, and climatic history of the Great Basin, with emphasis on Lakes Lahontan, Bonneville, and Tecopa, *in* Morrison, R.B., editor, Quaternary nonglacial geology—conterminous U.S.: Geological Society of America, The Geology of North America, v. K-2, p. 283–320.

Moulton, F., 1951, Ground water geology of Cedar Valley and western Utah Valley, Utah: Provo, Utah, Brigham Young University, M.S. thesis, 50 p.

Mower, R.W., and Allred, C., 1997, Drinking water source protection plan for a new well system no. 25148, source no. 01: Fairview, Utah, unpublished consultant's report submitted to Utah Department of Environmental Quality, Division of Drinking Water for Meadow Ranch, LC., 28 p.

Murphy, P., and Gwynn, J.W., 1979, Geothermal investigations of the Warm Springs fault geothermal system, Salt Lake County, Utah: Utah Geological and Mineral Survey Report of Investigation 140, 29 p.

NOAA (National Oceanic and Atmospheric Administration) Western Regional Climate Center, 2006, Western U.S. climate historical summaries for Utah: Online, http://www.wrcc.dri.edu/summary/Climsmut.html, accessed April 5, 2006.

Nichols, W.D., 2000, Regional ground-water evapotranspiration and ground-water budgets, Great Basin, Nevada: U.S. Geological Survey Professional Paper 1628, 108 p., variously paginated.

Oviatt, C.G., Currey, D.R., and Sack, D., 1992, Radiocarbon chronology of Lake Bonneville, eastern Great Basin, USA: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 99, p. 225–241.

Parry, W.T., Forster, C.B., Solomon, D.K., and James, L.P., 2000, Ownership of mine-tunnel discharge: Ground Water, v. 38, no. 4, p. 487–496.

Pearson, F.J., and Hanshaw, B.B., 1970, Sources of dissolved carbonate species in groundwater and their effects on carbon-14 dating, *in* Isotope hydrology—a symposium, Vienna, Austria, Panel proceedings series—International Atomic Energy Agency, p. 271–286.

Plummer, L.N., Prestemon, E.C., and Parkhurst, D.L., 1994, An interactive code (NETPATH) for modeling NET geochemical reactions along a flow PATH, version 2.0: U.S. Geological Survey Water-Resources Investigations Report 94-4169, 130 p.

Plummer, L.N., and Sprinkle, C., 2001, Radiocarbon dating of dissolved inorganic carbon in groundwater from confined parts of the Upper Floridan aquifer, Florida, USA: Hydrogeology Journal, v. 9, no. 127–150.

PRISM Climate Group at Oregon State University, 2006, United States average monthly or annual precipitation, 1971–2000: Online, http://prism.oregonstate.edu/, accessed October 16, 2006.

Prudic, D.E., Harrill, J.R., and Burbey, T.J., 1995, Conceptual evaluation of regional ground-water flow in the carbonate-rock province of the Great Basin, Nevada, Utah, and adjacent states: U.S. Geological Survey Professional Paper 1409-D, 102 p.

Quilter, M., and Sanderson, I.D., 2002, 2001 State of Utah ground-water program: Utah Department of Agriculture and Food, 159 p.

Rawling, G.C., Goodwin, L.B., and Wilson, J.L., 2001, Internal architecture, permeability structure, and hydrologic significance of contrasting fault-zone types: Geology, v. 29, no. 1, p. 43–46.

Razem, A.C., and Steiger, J.I., 1981, Ground-water conditions in Tooele Valley, Utah, 1976–1978: Utah Department of Natural Resources Technical Publication 69, 95 p., 1 plate, scale 1:250,000.

Renard, P., Glenz, D., and Mejias, M., 2009, Understanding diagnostic plots for well-test interpretation: Hydrogeology Journal, v. 17, no. 3, p. 589–600.

Robinson, T.W., 1958, Phreatophytes: U.S. Geological Survey Water-Supply Paper 1423, 84 p.

Rosen, M.R., Kropf, C., and Thomas, K.A., 2006, Quantification of the contribution of nitrogen from septic tanks to ground water in Spanish Springs Valley, Nevada: U.S. Geological Survey Scientific Investigations Report 2006-5206, 12 p.

Rozanski, K., Araguas-Araguas, L., and Gonfiantiti, R., 1993, Isotopic patterns in modern global precipitation, *in* Swart, P.K., Lohmann, K.C., McKenzie, J., and Savin, S., editors, Climate change in continental isotopic records: Washington, D.C. American Geophysical Union Monograph, v. 78, p. 1–36.

Snyder, N., and Lowe, M., 1998a, Map of recharge and discharge areas for the principal basin-fill aquifer, Sevier Desert, Millard County, Utah: Utah Geological Survey Map 174, scale 1:176,000.

Snyder, N., and Lowe, M., 1998b, Recharge and discharge areas for the principal valley-fill aquifer, Sanpete Valley, Sanpete County, Utah: Utah Geological Survey Map 174, scale 1:100,000.

Stolp, B.J., Drumiler, M., and Brooks, L.E., 1993, Selected hydrologic data for southern Utah and Goshen Valleys, Utah, 1890–1992: USGS Open-File Report 93-108, 110 p., 1 plate.

Stonestrom, D.A., Constantz, J., Ferre, T.P.A., and Leake, S.A., editors, 2007, Ground-water recharge in the arid and semiarid southwestern United States: U.S. Geological Survey Professional Paper, v. 1703, 414 p.

Susong, D.D., 1995, Water budget and simulation of one-dimensional unsaturated flow for a flood- and sprinkler-irrigated field near Milford, Utah: Utah Department of Natural Resources Technical Publication 109, 32 p.

Thiros, S.A., 1995, Chemical composition of ground water, hydrogeologic properties of basin-fill material, and ground-water movement in Salt Lake Valley, Utah: Utah Department of Natural Resources Technical Publication 110-A, 59 p., 2 plates.

Thiros, S.A., 2006, Evaluation of the ground-water flow model for Northern Utah Valley, Utah, updated to conditions through 2002: U.S. Geological Survey Scientific Investigations Report 2006-5064, 19 p.

Thiros, S.A., and Brothers, W.C., 1993, Ground-water hydrology of the upper Sevier River Basin, south-central Utah, and simulation of ground-water flow in the valley-fill aquifer in Panguitch Valley: Utah Department of Natural Resources Technical Publication 102, 121 p.

Thiros, S.A., and Manning, A.H., 2004, Quality and sources of ground water used for public supply in Salt Lake Valley, Salt Lake County, Utah, 2001: U.S. Geological Survey Water-Resources Investigations Report 03-4325, 95 p.

Thiros, S.A., Stolp, B.J., Hadley, H.K., and Steiger, J.I., 1996, Hydrology and simulation of ground-water flow in Juab Valley, Juab County, Utah: Utah Department of Natural Resources Technical Publication 114, 59 p., 1 plate.

Thomas, K., and Lowe, M., 2007, Recharge and discharge areas for the principal basin-fill aquifer, Beryl-Enterprise Area, Iron,Washington, and Beaver Counties, Utah: Utah Geological Survey Map 225, 24 p., 1 plate, scale 1:125,000.

Urbano, L., Waldron, B., Larsen, D., and Shook, H., 2006, Groundwater-surface water interactions at the transition of an aquifer from unconfined to confined: Journal of Hydrology, v. 321, p. 200–212.

U.S. Census Bureau, 2000a, Population estimates for the 1990s by place and county: Online, http://www.census.gov/popest/archives/1990s/su-99-08/SU-99-8_UT.txt, accessed May 12, 2011.

U.S. Census Bureau, 2000b, State and county quick facts, profile of general demographic characteristics, 2000, Cedar Fort town: Online, http://quickfacts.census.gov/qfd/states/49000.html, accessed April 11, 2006.

U.S. Census Bureau, 2000c, State and county quick facts, profile of general demographic characteristics, 2000, Eagle Mountain town: Online, http://quickfacts.census.gov/qfd/states/49000.html, accessed April 11, 2006.

U.S. Census Bureau, 2010, Population estimates for 2000 to 2009 by place and county: Online, http://www.census.gov/popest/cities/SUB-EST2009-4.html, accessed May 12, 2011.

U.S. Department of Agriculture, Natural Resources Conservation Service, 2007, SGID.U024.SoilsNEW GIS Coverage: Online, http://gis.utah.gov/component/option,com_dbquery/Itemid,87/task,ExecuteQuery/qid,2/previousTask,PrepareQuery/, accessed May 28, 2008.

U.S. Environmental Protection Agency, 2006, Consumer factsheet on nitrates and nitrites: Online, http://www.epa.gov/safewater/contaminants/dw_contamfs/nitrates.html, accessed November 4, 2008.

U.S. Environmental Protection Agency, 2007, Arsenic in drinking water basic information: Online, http://www.epa.gov/safewater/arsenic/basicinformation.html, accessed August 1, 2008.

U.S. Environmental Protection Agency, 2010, Drinking water contaminants: Online, http://water.epa.gov/drink/contaminants/, accessed December 8, 2010.

U.S. Geological Survey–Utah Water Science Center, 1970, Project files from a Cedar Valley ground-water study: Salt Lake City, unpublished files of the Utah Water Science Center.

U.S. Geological Survey–Utah Water Science Center, 2006a, USGS national water information system—real-time water data for Utah, station 10166430 West Canyon Creek near Cedar Fort, UT: Online,

http://waterdata.usgs.gov/ut/nwis/nwisman/?site_no=10166430&agency_cd=USGS, accessed October 4, 2006.

U.S. Geological Survey–Utah Water Science Center, 2006b, USGS national water information system—USGS water data for the nation: Online, http://nwis.waterdata.usgs.gov/nwis, accessed April 4, 2006.

U.S. Geological Survey, variously dated, National field manual for the collection of water-quality data: U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chaps. A1-A9, Online, http://pubs.water.usgs.gov/twri9A, accessed June 27, 2004.

U.S. Soil Conservation Service, 1980, Soil Survey of Fairfield-Nephi Area Utah, Parts of Juab, Sanpete, and Utah Counties: U.S. Department of Agriculture, variously paginated.

Utah County District Court, 1965, Decree of civil court case no. 25,756: Provo, Utah, decided June 1, 1965, District Judge Joseph E. Nelson presiding, 6 p.

Utah Department of Environmental Quality, 2006, Water quality information in the STORET Data Warehouse maintained by the U.S. Environmental Protection Agency: Online, http://www.epa.gov/storet/dw_home.html, accessed March 1, 2006.

Utah Division of Drinking Water, 2005, Chemical analyses of drinking water sources: Salt Lake City, unpublished data reported by water providers to the Utah Division of Drinking Water.

Utah Division of Water Quality, 2008, Utah administrative rule R317-3-10—design requirements for wastewater collection, treatment and disposal systems—lagoons: Online, http://www.rules.utah.gov/publicat/code/r317/r317-003.htm, accessed June 13, 2008.

Utah Division of Water Resources, 1993, Water-related land use inventories—Utah Lake study area (data for 1988): Salt Lake City, Utah Division of Water Resources report, 60 p.

Utah Division of Water Resources, 1995, Water-related land use inventories—Utah Lake study area (data for 1995): Salt Lake City, Utah Division of Water Resources GIS data.

Utah Division of Water Resources, 2003, Water-related land use inventories—Utah Lake study area (data for 2002): Salt Lake City, Utah Division of Water Resources GIS data.

Utah Division of Water Resources, 2004, Municipal and industrial water supply and uses in the Utah Lake basin (data collected for calendar year 2003): Salt Lake City, Utah Division of Water Resources report, 136 p.

Utah Division of Water Resources, 2009, Water-related land use inventories—Utah Lake study area (data for 2008): Salt Lake City, Utah Division of Water Resources GIS data.

Utah Division of Water Rights, 2004a, Water-rights files for water-right area 54: Salt Lake City, unpublished files of the Utah Division of Water Rights.

Utah Division of Water Rights, 2004b, Water-right information for water right 0354605M00: Online, http://waterrights.utah.gov/cgi-bin/docview.exe?Folder=welllog29442, accessed December 8, 2006.

Utah Division of Water Rights, 2006, Water use and streamflow records for Fairfield Spring gage number 13081000: Online, http://waterrights.utah.gov/cgi-bin/gageview.exe?Startup, accessed April 1, 2006.

Utah Division of Water Rights, 2008, Water right information for change application a22737: Online, http://waterrights.utah.gov/cblapps/chprint.exe?chnum=a22737, accessed September 30, 2008.

Utah Division of Water Rights, 2009a, Public water supplier information for White Hills Subdivision Water Company in the Utah water use program records: Online, http://www.waterrights.utah.gov/cgi-bin/wuseview.exe?Modinfo=Pwsview&SYSTEM_ID=1446, accessed September, 24, 2011.

Utah Division of Water Rights, 2009b, Utah water use program records: Online, http://waterrights.utah.gov/distinfo/wuse.asp, accessed March 3, 2010.

Utah Valley Economic Development Association, 2002, Utah County population history 1990–2002: Online, http://www.co.utah.ut.us/dept/uveda/demograph/, accessed April 12, 2006.

van Tonder, G., Bardenhagen, I., Riemann, K., van Bosch, J., Dzango, P., and Xu, Y., 2002, Manual on pumping test analysis in fractured-rock aquifers: Bloemfontein, South Africa, Institute for Groundwater Studies, University of the Free State, 228 p.

Wallace, J., 2010, Water-quality assessment of the principal valley-fill aquifers in the southern Sanpete and central Sevier Valleys, Sanpete County, Utah: Utah Geological Survey Special Study 132, 129 p.

Wallace, J., Lowe, M., and Bishop, C.E., 2002, Water-quality assessment and mapping for the principal valley-fill aquifer in Sanpete Valley, Sanpete County, Utah: Utah Geological Survey Special Study 102, 91 p.

Wilberg, D.E., and Heilweil, V.M., 1995, Hydrology of Sanpete Valley, Sanpete and Juab Counties, Utah, and simulation of ground-water flow in the valley-fill aquifer: Utah Department of Natural Resources Technical Publication 113, 121 p., 1 plate.

Wilson, J.D., and Naff, R.L., 2004, Modflow-2000, the U.S. Geological Survey modular ground-water model—GMG linear equation solver package documentation: U.S. Geological Survey Open-File Report 2004-1261, 53 p.

Yeskis, D., and Zavala, B., 2002, Ground-water sampling guidelines for Superfund and RCRA project managers: U.S. Environmental Protection Agency report EPA 542-S-02-001, 53 p.

Zhu, C., and Murphy, W.M., 2000, On radiocarbon dating of ground water: Ground Water, v. 38, no. 6, p. 802–803.

APPENDICES

APPENDIX A

HISTORY OF WATER USE IN CEDAR VALLEY, UTAH COUNTY, UTAH

History of Water Use in Cedar Valley, Utah County, Utah

This history is constructed from interviews with water users and residents, search of the Utah Division of Water Rights' (DWRi) water-rights files, field observations, and review of historical documents.

Date	Event	Source
	Cedar Fort area	
1852	First settlers planted and irrigated grain.	Peterson, 1990
1870	Cedar Fort Irrigation Company (CFI) established to bring water from West Canyon to Cedar Fort.	Peterson, 1990
~1870	Cedar Fort Ditch built to carry water to irrigate fields near Cedar Fort east of present day highway. Ditch can convey about 40 cubic feet per second (cfs).	Peterson, 1990; Berry, 2006
1911	First dry farming in Cedar Valley.	Peterson, 1990
~1969 or ~1974–1975	CFI installed pipe from a point 3200 feet downstream from CFI's diversion of West Canyon Creek to Cedar Fort Ditch in section 8, T. 5 S., R. 2 W., SLB&M, to about the location of the present day retention pond in section 20, T. 5 S., R. 2 W., SLB&M. The purpose of pipe was to eliminate seepage from ditch during times of lower flow. Ditch is used when flow >12 cfs, which is the capacity of the pipe, and pipe is used when flow <12 cfs, which is usually in the early spring and fall (Hale, 2006). Other reports (Berry, 2006) indicate water is put into pipe around July 1 but some water is still run in the ditch all season to keep vegetation alive.	Hale, 2005, 2006; Cook, 2006; Berry, 2006
Before 1969	Before 1969, flow from Tunnel and North Spring Creek springs was conveyed via the North Ditch near Cedar Fort and flow from South Spring was conveyed via the South Ditch.	Berry, 2006
1969	Town of Cedar Fort installed a new water system in Cedar Fort to better convey water from the two springs used for culinary water (Tunnel and North Spring Creek springs). The Town then filed for a ½ cfs water right on the "saved water", that is, the water lost to seepage from the previous ditch system.	Peterson, 1990; Cook, 2006; Hale, 2006; DWRi file for right 54-256

Date	Event	Source
After 1969	When the culinary system was installed in 1969, the users of the South Spring claimed that flow decreased, so water was piped over from the other springs.	Berry, 2006
1975	CFI drilled well at mouth of West Canyon in section 7, T. 5 S., R. 2 W., to fully utilize their water right. The well is not used very much.	DWRi files; Berry, 2006.
1990–1992	CFI built an 11-acre retention pond with two outlet pipes to the fields east of Cedar Fort. Pipes facilitate a new sprinkler irrigation system for irrigation of about 1200 acres on 18 quarter-mile sprinkler lines. Some fields still on flood irrigation.	Hale, 2005; Peterson, 1990
~2000	During drought, Cedar Fort culinary system was using up to ¾ cfs for culinary and irrigation of lawns and gardens in town. The remaining water went out from the storage tank to the ditches for CFI stockholders to use on lawns and gardens in Cedar Fort town.	Hale, 2006
White wells and White Hills		
1961–1962	White irrigation wells drilled in section 17, T. 6 S., R. 2 W., SLB&M. White farm on flood irrigation.	DWRi files
~1965	White farm switched from flood to sprinkler irrigation to conserve water in response to the need to reduce production as a result of the legal battle over Fairfield Springs water rights.	Carson, 2006
~1974	White Hills clay-lined sewage ponds constructed in section 17, T. 6 S., R. 2 W, SLB&M	Carson, 2006
~1990	Grant and Dean Smith lease White farm. Irrigate 600 acres of mostly alfalfa and dry farm 9000 acres of winter wheat.	Smith J., 2005
Mid-valley		
1960s	Some of the LDS Church wells were not productive. Pumped for a few years, but poor well design caused them to pump sand. Land was flood irrigated using concrete-lined feeder ditches.	Smith, G. 2005; Tuttle, D. 2005; Berry G., 2006; Carson, V. 2006; Cook, C., 2006;

Date	Event	Source
		Ault, H. 2006; DWRi file for right 54-56
1973	LDS Church farm sold to Wallace Ohran. One source thought that perhaps the wells were used only up until this time but another remembers that Ohran farmed in sections 14, 15, and maybe 13 and/or 26, T. 6 S., R. 2 W., SLB&M, and would have used the wells.	DWRi file for right 54-50; Berry, 2006; Cook, 2006
Late 1970s	There was a large flood in Cedar Valley. Wells in section 15, T. 6 S., R. 2 W., SLB&M were underwater. They caved in and were not used anymore after the flood.	Cook, 2006
1983	Wallace Ohran sells LDS Church farm to Monte Vista Ranch (i.e., Lee Fitzgerald)	DWRi file for right 54-50
~2003	Eagle Mountain City began discharging treated waste water by land application to area west of waste water treatment ponds in section 24, T. 6 S., R. 2 W., SLB&M.	Harris, 2006
Fairfield Spring and Fairfield Sinks field observations		
Late 1980s	Fairfield Spring discharge not measured because White irrigation wells were not in use. Flow was about 6 cfs during these years.	Carson, 2006
Mid 1960s	Replacement wells drilled for Fairfield were only used for about 1.5 years because they pumped sand too badly. Artesian flow from UGS ID 1039 is about 30 gpm and is still flowing into the ditch system.	Carson, 2006
All	Fields are 100 percent flood irrigated from Fairfield Spring source.	Carson, 2006
4/6/05	Fairfield Sinks are partially wet.	Black, 2005
5/19/05	Sinks are drying up but still have standing water.	Field obs.
5/23/06	Sinks mostly dry. Some pools of standing water.	Field obs.
Before 1993	Dikes were built in Fairfield Sinks sometime prior to 1993 to impound water in the NW part of the sinks.	Black, 2005; 1993 air photo

Other historical accounts listed below added to our understanding of the Cedar Valley water use history.

References

Allred, Aaron, Harvest Irrigation Co., verbal communication, March 22, 2006.

Ault, Howard, Cedar Valley Turf Farm, verbal communication, August 7, 2006.

Carson, Vern, Fairfield Irrigation Company water master, verbal communication, April 11, 2006.

Cook, Cal, Cedar Fort Irrigation Company, verbal communication, April 6, 2006.

Berry, Glade, Cedar Valley well owner, verbal communication, April 11, 2006.

Black, Cole, Cedar Valley Mink Farm foreman, verbal communication, April 6, 2005.

Hale, Douglas, Cedar Fort Irrigation Company, verbal communication, January 5, 2005.

Hale, Douglas, Cedar Fort Irrigation Company, verbal communication, May 31, 2006.

Harris, Jordan, Eagle Mountain City water service manager, verbal communication, April 6, 2006.

Jackson, Kerry, White Hills Water Company, verbal communication, April 11, 2006.

Peterson, M., 1990, Our roots grow deep—a history of Cedar Valley: American Fork, Utah, published by Lyndon W. Cook.

Smith, Grant, Smith Farms, verbal communication, August 1, 2005.

Smith, Pat, Kennecott Exploration, verbal communication, March 31, 2005.

Smith, Jim, Smith Farms, verbal communication, November 21, 2005

Tuttle, Dell, Utah Valley Turf Farm manager, verbal communication, October 26, 2005.

Utah Division of Water Rights, 2004, Water-rights files for water-right area 54: Salt Lake City, unpublished files of the Utah Division of Water Rights.

White Ken, White Hills Water Co., verbal communication, January 20, 2005.

Widdison, Kyle, Widdison Pump Service, verbal communication, October 27, 2005.

Wolsey, S., 1964, Early days in Cedar Valley: American Fork, UT, Alpine School District, 15 p.

APPENDIX B

WELL INFORMATION FOR WELLS IN THE CEDAR VALLEY STUDY AREA

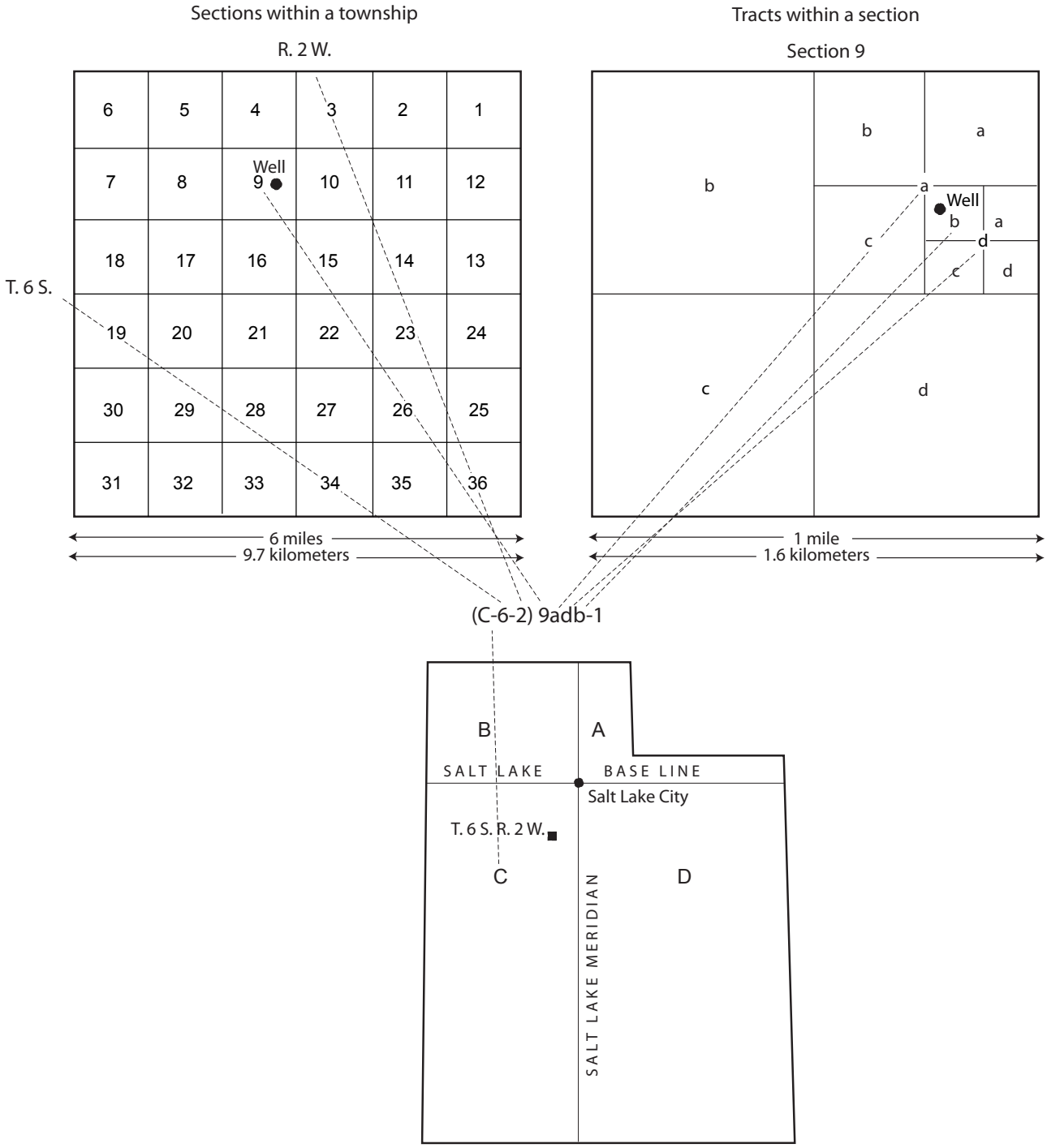


Figure B-1. *Cadastral well numbering system. The cadastral well numbering system for wells in this study is based on the Federal Government cadastral land-survey system that divides Utah into four quadrants (A-D) separated by the Salt Lake Base Line and Meridian. The study area is in the southwestern quadrant (C). The wells are numbered with this quadrant letter (C), followed by township and range, all enclosed in parentheses. The next set of characters indicates the section, quarter section, quarter-quarter section, and quarter-quarter-quarter section designated by letters a through d, indicating the northeastern, northwestern, southwestern, and southeastern quadrants, respectively. A number after the hyphen corresponds to an individual well within a quarter-quarter-quarter section. In this example, the well (C-6-2)9adb-1 is the first well in the northwestern quarter of the southeastern quarter of the northeastern quarter of section 9, Township 6 South, Range 2 West, Salt Lake Base Line and Meridian (NW¼SE¼NE¼ section 9, T. 6 S., R. 2 W. SLB&M).*

Table B-1. *Location, completion, geologic, and water right information for wells in the Cedar Valley study area. UGS well ID is cross-referenced to other well names and identifiers in table B-2.*

UGS ID	Aquifer	Geology	Clay Depth, ft	Layer	UTM Easting, m, NAD 1929	UTM Northing, m, NAD 1929	Cadastral location	Well Diame-ter, in	Hole Depth, ft	Depth to Bedrock, ft	Open Interval*, ft	Depth to Water, ft	Depth to Water Date	Well Test Yield, gpm	Draw-down, ft	Dura-tion, hrs	Land Elev., ft, 1929 datum	Completion Date	Water Right
1	BDRX	BDRX		3	404997	4477128	(C- 4- 3)25dbd- 1	6	240	55	120-240	110	8/17/77	20	-999	-999	6440	8/17/77	a7015
2	BDRX	Mmc		3	419083	4468246	(C- 5- 1)21dcc- 1	0	300	77	80-300	76	7/10/93	10	175	-999	4755	11/30/93	54-405
3	BDRX	BDRX		3	407775	4425421	(C-10- 2) 9bbb- 1	8	200	0	100-200	10	6/26/78				6320	6/26/78	53-338
4	BF	BF	210	2	411326	4457902	(C- 6- 2)26cbb- 1	18	505	>505	210-500	48	7/21/62	1115	164	624	4846.57	7/21/62	54-459
5	BF	BF	0	2	406833	4463996	(C- 6- 2) 5cca- 1	8	208	>204	150-160	106	12/15/84	30	0	0.5	5025	12/18/84	54-573
6	X	X, BDRX	192	2	414312	4446142	(C- 7- 2)36dad- 1	8	505	402	400-505	350	11/6/73	0.5	155	10	4905	1/1/73	54-235
7	BDRX	BDRX		3	415022	4465777	(C- 5- 1)31bcc- 1	8	589	52	429-572	473	5/20/91	24	3	90	4980	5/13/91	54-609
8	BF	BF	80	2	408799	4463135	(C- 6- 2) 9baa- 1	10	225	>225	80-100	72	12/18/74	150	75	8	4895	12/20/75	54-176
9	BF	BF	42	2	407734	4462061	(C- 6- 2) 8ddc- 1	6	210	>210	m58-202	5	12/13/84	31	19	4	4923.21	12/13/84	54-176
10	BF	BF	93	2	406172	4464375	(C- 6- 2) 6dab- 1	6	202	>202	202-202	109	7/2/97	16	0	2	5090	7/2/97	54-82
11	BF	BF	72	2	406313	4463794	(C- 6- 2) 6ddd- 1	6	282	>281	m250-272	230	11/8/82	9	0	-999	5125	11/6/82	54-614
12	BDRX	BDRX	0	3	405981	4463807	(C- 6- 2) 6dcd- 1	6	415	287	300-346	290	6/10/85	10	-999	2	5188	6/25/85	54-537
13	BF	BF	100	2	406511	4464446	(C- 6- 2) 6add- 1	8	274	>274	101-250	102	7/8/89	25	48	1	5062	5/24/89	54-556
14	BF	BF	0	2	406364	4464110	(C- 6- 2) 6dad- 1	8	310	>310	223-296	160	6/29/82	30	8	0.5	5090	6/29/82	54-545
15	BF	BF	0	2	406343	4464789	(C- 6- 2) 6aad- 1	6	270	>270	263-270	196	5/3/93	20	-999	-999	5098	4/30/93	54-576
16	BF	BF	62	2	406166	4464679	(C- 6- 2) 6adb- 1	6	200	>200	194-200	158	12/29/62	25	0	2	5118	12/29/62	54-593
17	BF	BF	0	2	406321	4463703	(C- 6- 2) 6ddd- 2	8	320	>320	300-320	240	8/30/93				5125	8/17/93	54-614
18	BF	BF	0	2	411768	4468245	(C- 5- 2)26bbb- 1	8	448	>448	351-448	361	6/22/60	18	-999	-999	5085.38	11/30/15	54-145
19	BF	BF	200	2	407972	4448254	(C- 7- 2)28bcc- 1	10	305	>305	210-215	171	10/5/78	10	0	1	4855	10/8/78	54-502
20	BF	BF	34	2	407661	4457130	(C- 6- 2)32aab- 1	6	285	>285	101-265	6	6/28/92	14	15	1	4868	6/24/92	54-148
21	BF	BF	35	2	407470	4457063	(C- 6- 2)32ada- 1	6	341	>341	141-284	3	7/20/90	20	25	1	4872	7/20/90	54-99
22	BF	BF	-1	1	407067	4457069	(C- 6- 2)32baa- 1	8	30	>30	0-30	8	3/25/62	20	2.1	9	4879.14	3/25/62	54-69
23	BF	BF	40	2	407006	4456979	(C- 6- 2)32bab- 1	6	210	>210	191-203	-999	-999	10	7	0.5	4880	11/3/67	54-220
24	BF	BF	34	2	407941	4457061	(C- 6- 2)32aaa- 1	6	196	>196	180-196	10	4/1/77	18	30	2	4866	4/1/77	54-417
25	BF	BF	0	2	406733	4456418	(C- 6- 2)32bcd- 1	6	125	>125	125-125	20	12/2/88				4891	11/30/88	54-618
26	BDRX	Mf?	0	3	415877	4456130	(C- 6- 1)31dab- 2	5	235	44	200-235	188	1/7/97	21	5	1	4875	1/7/97	54-47
27	BF	BF	0	2	415616	4460696	(C- 6- 1)18dca- 1	6	265	>265	235-265	125	2/10/48	20	-999	-999	4888	2/10/48	54-48
28	BF	BF	0	2	406711	4460917	(C- 6- 2)17cbd- 1	8	147	>147	125-145	96	9/28/62	100	-999	-999	4978	9/28/62	54-80
29	BF	BF	75	2	408943	4461987	(C- 6- 2)16baa- 1	10	505	>505	80-505	45	5/10/51	335	-999	-999	4874.5	5/10/51	54-34
30	BF	BF	43	2	406997	4457628	(C- 6- 2)29cac- 3	6	266	>266	m111-194	-3	3/29/94	15	8	1	4882	3/29/94	54-166
31	BF	BF	48	2	407009	4457563	(C- 6- 2)29cac- 4	6	253	>253	m90-250	-7	5/16/96	18	-999	48	4881	4/16/96	54-167
32	BF	BF	22	2	407625	4457612	(C- 6- 2)29dbd- 1	6	253	>253	112-211	-7	3/28/94	12	10	1	4867	3/28/94	54-240
33	BF	BF, Confined	236	2	413406	4468179	(C- 5- 2)25bbb- 1	8	506	>506	300-500	290	3/29/77	5	-999	-999	5005	3/29/77	54-367
34	BF	BF	86	2	408495	4457156	(C- 6- 2)33cdc- 1	6	180	>180	150-180	32	7/24/96	50	-999	5	4858	7/24/96	54-721
35	BF	BF	150	1	413766	4458669	(C- 6- 2)25abb- 1	16	505	>505	0-0	-999	-999				4844	10/20/70	54-22
36	BF	BF	154	2	408142	4457471	(C- 6- 2)28ccb- 1	6	300	>300	154-220	20	11/15/77	17	22	0.5	4861	11/15/77	54-426
37	BF	BF	-1	1-2	408452	4456914	(C- 6- 2)33bac- 1	5	280	>280	45-115	9	9/8/74				4859	9/8/74	54-160
38	BF	BF	63	2	409065	4456011	(C- 6- 2)33dbd- 1	8	302	>302	235-275	29.33	9/8/67	50	24	1	4851	9/8/67	a25043
39	BDRX	BDRX	385	3	415728	4463558	(C- 6- 1) 6dcd- 1	5	525	393	m320-500	370	8/15/97				4955	8/24/97	a20803
40	BF	BF	385	1	413586	4447407	(C- 7- 2)25cdd- 1	8	200	>200	TD200	-999	-999				4852	12/15/76	54-403
41	BF	BF	234	2	415353	4459713	(C- 6- 1)19acc- 1	16	590	>590	497-583	227	3/31/69	1400	109	64	4877.96	7/1/69	54-19
42	BF	BF	52	2	411266	4453611	(C- 7- 2)11bbc- 1	3	100	>100	80-100	27	11/20/83				4846	11/20/83	54-428
43	BDRX	BDRX	0	3	405596	4464761	(C- 6- 2) 6bda- 1	5	386	160	306-386	180	8/18/92	20	-999	-999	5237	8/18/92	54-666

Aquifer: BDRX = bedrock; BF = basin fill; X = open interval crosses basin-fill/bedrock contact; UK = unknown lithology; BFper = perched unconsolidated aquifer in Cedar Pass; BDRXp = perched bedrock aquifers
Geology from well log, outcrop, or NWIS: BDRX = bedrock, undifferentiated; BF = basin fill; cpp = Cedar Pass perched unconsolidated; X = open interval crosses basin-fill/bedrock contact;
UK = unknown lithology; IPobpl, IPowc, Mmc, Mgb etc. = keyed to geologic unit names on Plate 2; 100VLFL = valley fill; 112PLCN = Pleistocene sediment, PZ = Paleozoic sedimentary bedrock.
Clay depth: depth of shallow clay unit in well log.
Layer: 1 = valley clay unit, 2 = principal basin-fill aquifer (flow model layer 1), 3 = bedrock aquifer (flow model layer 2), 4 = Cedar Pass perched aquifer
* "m" in Open Interval indicates well is screened or perforated over multiple intervals over depth given.
-999 - null value, no data

Table B-1 continued. *Location, completion, geologic, and water right information for wells in the Cedar Valley study area.*

UGS ID	Aquifer	Geology	Clay Depth, ft	Layer	UTM Easting, m, NAD 1929	UTM Northing, m, NAD 1929	Cadastral location	Well Diame-ter, in	Hole Depth, ft	Depth to Bedrock, ft	Open Interval*, ft	Depth to Water, ft	Depth to Water Date	Well Test Yield, gpm	Draw-down, ft	Dura-tion, hrs	Land Elev., ft, 1929 datum	Completion Date	Water Right
44	BF	100VLFL	57	2	407288	4460602	(C- 6- 2)17dcc- 2	16	595	>595	m170-587	27.9	3/31/66	3600	97	24	4923.86	2/24/62	54-37
45	BF	BF	-1	1	410083	4457520	(C- 6- 2)27cca- 1	6	80	>80	35-80	35	9/16/53				4846.28	9/16/53	54-40
46	BF	BF	0	2	405911	4464170	(C- 6- 2) 6dbd- 1	6	230	>230	220-230	149	3/29/99	25	-999	2	5144	3/29/99	54-641
47	BF	BF	38	2	409846	4463714	(C- 6- 2) 3ccc- 1	8	300	>300	m195-270	164	9/10/70	20	0	0.5	4895	9/10/70	54-230
49	BF	BF	36	2	407730	4457488	(C- 6- 2)29ddb- 1	6	281	>281	262-281	6	5/9/77	31	49	7	4869.45	5/19/77	54-425
50	BF	BF	667	2	415501	4462725	(C- 6- 1) 7dbb- 1	6	755	>755	665-740	373	7/15/92	50	-999	-999	4908	7/15/92	54-649
51	BF	BF	53	2	406340	4464575	(C- 6- 2) 6add- 2	5	230	>230	210-230	134	6/22/00	21	-999	1	5081	6/22/00	54-653
52	BF	BF	437	2	415686	4462612	(C- 6- 1) 7dba- 1	6	510	>510	470-510	380	1/23/97	25	-999	1	4925	1/23/97	54-661
53	BF	BF	65	2	406856	4463973	(C- 6- 2) 5cca- 2	5	200	>200	180-200	116	6/9/00	21	6	0.5	5023	6/9/00	a22751
55	BDRX	BDRX	0	3	405793	4463725	(C- 6- 2) 6dcc- 1	4	625	212	525-625	-999	-999	80	-999	1	5238	4/14/98	54-686
56	X	X, 115' perf in BF, 98' open to IPobp?	211	3	415306	4460537	(C- 6- 1)18cdd- 1	16	471	369	m250-471	217	10/11/73	3100	7	13	4874.38	10/11/73	54-19
57	BF	BF	0	2	415735	4458665	(C- 6- 1)30aba- 1	5	335	>335	255-335	238	9/16/93	8	2	2	4900	9/16/93	54-697
58	BF	BF	35	2	415478	4458447	(C- 6- 1)30abc- 1	6	300	>300	100-300	200	6/10/95	50	-999	1.5	4870	6/11/95	54-698
59	BDRX	BDRX		3	418533	4468084	(C- 5- 1)28bba- 1	5	218	125	164-218	110	6/18/96	30	-999	8	4790	6/18/96	54-713
60	BF	BF	0	2	406248	4464604	(C- 6- 2) 6adb- 2	6	235	>235	231-235	155.9	4/10/97	25	15	2	5090	4/10/97	54-729
61	BF	BF	131	2	406745	4455530	(C- 7- 2) 5bba- 1	5	280	>280	m180-260	28	5/8/95	100	-999	-999	4895	5/8/95	54-734
62	BDRX	BDRX	78	3	415910	4464192	(C- 6- 1) 6dab- 1	5	580	191	m300-580	390	3/15/95				5015	3/15/95	54-746
63	BF	BF	194	2	406920	4447869	(C- 7- 2)29cac- 1	6	400	>400	m140-318	161	9/26/95	10	45	1	4860	9/26/95	54-748
64	BFper	cpp	64	4	415894	4469490	(C- 5- 1)19abc- 1	7	280	>280	220-280	162	10/11/96	20	-999	2	4926	10/11/96	54-761
65	BF	BF	63	2	407258	4456968	(C- 6- 2)32abb- 1	6	267	>267	101-258	5	4/16/92	14	22	1	4874	4/16/92	54-654
66	BDRX	IPobp	0	3	405705	4464151	(C- 6- 2) 6cad- 1	4.5	426	206	m320-400	306	1/3/96	13	94	-999	5180	1/3/96	54-801
67	BDRX	BDRX	20	3	405587	4463942	(C- 6- 2) 6cda- 1	4	462	55	422-462	324	3/24/98	25	-999	3	5235	3/28/98	54-808
68	BDRX	Mgb or Mh?	0	3	408200	4466687	(C- 5- 2)32aab- 1	6	580	396	480-580	-999	-999	80	-999	1	5120	4/22/97	54-809
69	BF	BF	23	2	407569	4457481	(C- 6- 2)29dca- 1	6	259	>259	100-250	6	12/18/99	12	12	6	4869.95	12/19/99	54-810
70	BF	BF	217	2	407636	4457189	(C- 6- 2)29dcd- 1	6	217	>217	100-193	4	5/26/98	12	23	1	4869	5/26/98	54-811
71	BF	BF	140	2	407712	4456965	(C- 6- 2)32aab- 2	6	242	>242	100-240	2	6/26/99	18	8	2	4868	6/26/99	54-812
72	BF	BF	51	2	406504	4464307	(C- 6- 2) 6daa- 1	6	235	>235	128-190	136	1/5/96	18	150	24	5059	1/5/96	54-823
73	BF	BF	0	2	406164	4463716	(C- 6- 2) 6ddc- 1	6	320	>320	298-320	254	11/10/99	18	-999	2	5163	11/10/99	54-824
74	BF	BF	165	2	411511	4460305	(C- 6- 2)23bbb- 1	6	578	>578	500-578	81	12/29/95	100	-999	3	4850	12/29/95	54-844
75	BDRX	BDRX	351	3	415753	4463511	(C- 6- 1) 7aba- 1	5	560	351	500-540	353	2/10/00	10	102	6	4957	2/1/00	54-885
76	BF	BF, Is last 5'	0	2	414520	4451315	(C- 7- 1)18cbb- 1	6	650	460	190-465	150	10/8/82	50	18	4	4854.73	10/8/82	54-696
77	BDRXp	X, BF, Tv, IPbpl or IPwc		2-3	415288	4469513	(C- 5- 1)19bbd- 1	5	350	175	m140-350	90	2/26/96	10	-999	2	4960	2/26/96	a18689
78	BF	BF	209	2	407702	4457190	(C- 6- 2)29ddc- 1	6	254	>254	100-240	5	4/30/98	14	25	1	4868	4/6/98	54-997
79	BF	BF	0	2	408098	4457991	(C- 6- 2)28bcc- 1	5	285	>285	m145-260	15	9/25/94				4862	8/24/94	54-712
80	BF	BF	189	2	409559	4447388	(C- 7- 2)33aaa- 1	7	405	>405	400-405	173	5/17/95	12	65	3	4852	4/12/96	54-740
81	BF	BF		2	416895	4470640	(C- 5- 1)17bcd- 1	0	139	>139	0-0	-999	-999				4984	1/26/92	a16176
82	BF	BF	49	2	407038	4457280	(C- 6- 2)29cdc- 1	6	217	>217	101-210	-3	4/30/92	5	0	-999	4879	6/6/92	54-659
83	BF	BF	54	2	407093	4457277	(C- 6- 2)29cdd- 1	6	254	>254	101-130	-2	5/6/92	6	-999	-999	4877	5/6/92	54-647
84	BF	BF		2	407263	4457086	(C- 6- 2)32abb- 2	6	286	>286	101-265	6	6/24/92	15	9	1	4876	6/25/92	54-660
85	BDRX	BDRX		3	395283	4470782	(C- 5- 4)13dac- 1	8	500	23	380-410	145.3	1/27/94	105	183	24	6890	12/7/94	a17330
86	BDRX	BDRX		3	402371	4454415	(C- 7- 3) 2dbc- 1	5	400	57	m131-389	180	9/17/96	100	-999	0.5	5178	9/17/96	a18017
87	BF	BF	67	2	406468	4457291	(C- 6- 2)29ccc- 2	6	234	>242	101-240	4	9/15/94	10	28	1	4897	9/15/94	a18162
88	BFper	cpp		4	416806	4469810	(C- 5- 1)20bba- 1	4	298	>298	224-284	156	12/3/96	30	-999	1	4950	12/3/96	a19099

Aquifer: BDRX = bedrock; BF = basin fill; X = open interval crosses basin-fill/bedrock contact; UK = unknown lithology; BFper = perched unconsolidated aquifer in Cedar Pass; BDRXp = perched bedrock aquifers

Geology from well log, outcrop, or NWIS: BDRX = bedrock, undifferentiated; BF = basin fill; cpp = Cedar Pass perched unconsolidated; X = open interval crosses basin-fill/bedrock contact;

UK = unknown lithology; IPobpl, IPowc, Mmc, Mgb etc. = keyed to geologic unit names on Plate 2; 100VLFL = valley fill; 112PLCN = Pleistocene sediment, PZ = Paleozoic sedimentary bedrock.

Clay depth: depth of shallow clay unit in well log.

Layer: 1 = valley clay unit, 2 = principal basin-fill aquifer (flow model layer 1), 3 = bedrock aquifer (flow model layer 2), 4 = Cedar Pass perched aquifer

* "m" in Open Interval indicates well is screened or perforated over multiple intervals over depth given.

-999 - null value, no data

Table B-1 continued. *Location, completion, geologic, and water right information for wells in the Cedar Valley study area.*

UGS ID	Aquifer	Geology	Clay Depth, ft	Layer	UTM Easting, m, NAD 1929	UTM Northing, m, NAD 1929	Cadastral location	Well Diame-ter, in	Hole Depth, ft	Depth to Bedrock, ft	Open Interval*, ft	Depth to Water, ft	Depth to Water Date	Well Test Yield, gpm	Draw-down, ft	Dura-tion, hrs	Land Elev., ft, 1929 datum	Completion Date	Water Right
89	BFper	cpp		4	416725	4470021	(C- 5- 1)17ccc- 1	4	258	>258	217-257	151	10/14/96	15	-999	1	4942	10/14/96	a18671
90	UK	BF? Bdrx in nr wells		4	416572	4469747	(C- 5- 1)19aaa- 1	6	405	>405	265-405	270	3/20/96	30	-999	1.5	4961	3/20/96	a18675
91	BFper	cpp		4	416268	4469841	(C- 5- 1)19aab- 1	6	255	>255	215-255	160	5/25/96	16	-999	1.5	4970	5/23/96	a18677
92	BFper	cpp		4	416237	4469747	(C- 5- 1)19aba- 1	4	380	>380	295-335	194	4/27/97	20	-999	2	4946	4/27/97	a18678
93	BFper	cpp		4	416083	4469685	(C- 5- 1)19aba- 2	4.5	283	>283	220-280	190	2/7/00	30	-999	1	4949	2/7/00	54-1075
94	BFper	cpp		4	415962	4469750	(C- 5- 1)19abb- 1	6	325	>325	265-325	260	7/1/96	25	-999	0.75	4971	7/1/96	a18680
95	BFper	cpp		4	415923	4469673	(C- 5- 1)19abb- 2	6	400	>400	m290-400	250	1/6/97	50	-999	-999	4978	1/6/97	a18681
96	BFper			3	415932	4469533	(C- 5- 1)19abc- 2	4	380	>380	310-380	180	2/25/97	40	-999	1	4929	2/28/97	a18682
97	BDRXp	BDRX, LS AND CLAY		3	415442	4469485	(C- 5- 1)19bbd- 2	4	480	119	183-223	178	4/4/96	4.5	60	5	4951	4/4/96	a18685
98	BDRXp	IPowc?	0	3	415006	4469793	(C- 5- 2)13ddd- 1	4	300	193	260-300	260	7/18/96	40	-999	0.75	4990	7/18/96	a18686
99	X	BDRX, LS		3	415345	4469409	(C- 5- 1)19bca- 1	4	602	437	580-602	310	7/22/96	15	-999	1	4955	8/8/97	a18690
100	BDRXp	X, BDRX		3	415429	4469418	(C- 5- 1)19bdb- 1	5	245	189	165-205	185	4/29/96	13	2	6	4952	4/29/96	a18691
101	BDRXp	BDRX		3	415623	4469348	(C- 5- 1)19bdb- 2	4	342	131	282-342	172	6/15/96	12	-999	2	4937	6/16/96	a18692
102	BDRX	BDRX, LS AND CLAY		3	416064	4469277	(C- 5- 1)19aca- 1	5	520	139	460-520	415	1/1/96	25	-999	1	4912	1/1/96	a18696
103	BDRX	BDRX, LS		3	416311	4469170	(C- 5- 1)19adc- 1	4	540	80	500-540	382	9/7/00	30	-999	2	4893	9/11/00	a18698
104	BDRX	BDRX		3	415795	4469152	(C- 5- 1)19bdd- 1	4	563	18	503-563	427	1/9/97	17	-999	2	4938	1/10/97	a18700
105	BDRX	BDRX		3	415634	4469096	(C- 5- 1)19bdc- 1	4	562	21	500-560	436	7/16/96	25	-999	2	4950	6/22/96	a18702
106	BDRX	BDRX		3	415140	4469049	(C- 5- 1)19bcc- 1	4	720	54	620-680	520	1/20/97	16	160	2	5030	1/31/97	a18707
107	BDRX	BDRX		3	415260	4469049	(C- 5- 1)19bcd- 1	4	680	67	620-680	-999	12/2/96	30	-999	1	5029	12/21/96	a18708
108	BDRX	BDRX		3	415351	4469048	(C- 5- 1)19bcd- 2	4	643	54	580-643	-999	11/17/96	20	-999	1	5025	10/17/96	a18709
109	BDRX	BDRX		3	416424	4469155	(C- 5- 1)19adc- 2	4	450	127	385-445	385	3/25/96	20	-999	1	4885	3/25/96	a18711
110	BDRX	BDRX		3	416257	4469268	(C- 5- 1)19adb- 1	4	465	148	425-465	415	3/8/96	35	-999	1	4900	3/8/96	a18713
111	BDRX	IPowc?		3	416160	4469317	(C- 5- 1)19aca- 2	4	560	175	480-540	390	7/23/97	23	150	2	4902	7/23/97	a18714
112	BFper	cpp		4	416072	4469453	(C- 5- 1)19abd- 1	4	260	>260	230-250	192	8/6/96				4907	8/6/96	a18715
113	BFper	cpp		4	416230	4469610	(C- 5- 1)19abd- 2	4	238	>238	191-231	139	10/15/96	20	-999	1	4930	10/15/96	a18717
114	BFper	cpp		4	416326	4469588	(C- 5- 1)19aac- 1	4	307	>307	267-307	165	2/12/97	25	-999	2	4925	2/12/97	a18718
115	BFper	cpp		4	416390	4469584	(C- 5- 1)19aac- 2	5	195	>195	175-195	145	4/22/96	25	-999	1	4934	4/17/96	a18719
116	BFper	cpp		4	416536	4469627	(C- 5- 1)19aad- 1	4	258	>258	197-237	135	12/11/96	20	-999	2	4924	12/11/96	a18721
117	BF	BF	0	2	415203	4450542	(C- 7- 1)19baa- 1	8	305	>305	260-300	-999	1/7/95	30	-999	3	4907	1/6/95	t18749
118	BF	BF	215	2	411222	4449814	(C- 7- 2)23bcc- 2	4	275	>275	235-275	-999	-999	50	-999	3	4841.61	3/7/95	54-1142
119	BF	BF	93	2	411446	4458755	(C- 6- 2)23ccc- 1	8	467	>467	m100-400	73	12/15/95	32	0	1	4844	12/15/95	a28376
120	BDRX	BDRX		3	416459	4469024	(C- 5- 1)19add- 1	7	539	96	470-530	383	8/20/96	28	-999	1	4882	8/20/96	a19032
121	BDRX	IPobp		3	416084	4468604	(C- 5- 1)19dca- 1	4	638	14	578-638	432	3/3/97	16	-999	2	4939	3/3/97	a19116
122	BDRX	BDRX		3	415904	4468356	(C- 5- 1)19dcc- 1	6	603	22	523-602	-999	9/17/96	20	-999	1	4978	9/17/96	a19294
123	BDRX	BDRX		3	415965	4468615	(C- 5- 1)19dbc- 1	4	702	18	642-702	455	5/2/97	10	-999	2	4958	5/10/97	a19296
124	BDRX	BDRX		3	415853	4468727	(C- 5- 1)19dbc- 2	4	758	8	698-758	495	2/10/97	25	-999	2	4940	2/10/97	a19297
125	BDRX	BDRX		3	416056	4468798	(C- 5- 1)19dbd- 1	4	543	29	483-543	397	3/5/97	16	-999	5	4910	3/6/97	a19300
126	BDRX	BDRX		3	415813	4468951	(C- 5- 1)19caa- 1	4	562	49	500-560	416	2/19/97	25	-999	2	4908	2/19/97	a19302
127	BDRX	BDRX		3	416145	4468346	(C- 5- 1)19dcd- 1	4	582	27	522-582	421	6/20/96	15	-999	1	4933	6/20/96	a19291
128	BDRXp	X	239	2	414789	4469224	(C- 5- 2)24adb- 1	4	480	260	360-460	295	5/27/97	20	-999	2	4984	5/27/97	a19709
129	X	X	124	2-3 (66% in lay 2, 34% in lay 3)	414318	4469528	(C- 5- 2)24abc- 1	5	583	562	523-583	-999	-999	8	-999	2	4988	6/17/98	a19699
130	BF	BF	0	2	407119	4457205	(C- 6- 2)29cdd- 2	6	279	>279	100-275	-7	3/29/00	12	-999	24	4877	3/29/00	a20047
131	BF	BF	93	2	411420	4459535	(C- 6- 2)23bcc- 1	8	322	>324	m70-280	67	11/22/97	37	0	2	4850.64	11/22/97	a20215

Aquifer: BDRX = bedrock; BF = basin fill; X = open interval crosses basin-fill/bedrock contact; UK = unknown lithology; BFper = perched unconsolidated aquifer in Cedar Pass; BDRXp = perched bedrock aquifers

Geology from well log, outcrop, or NWIS: BDRX = bedrock, undifferentiated; BF = basin fill; cpp = Cedar Pass perched unconsolidated; X = open interval crosses basin-fill/bedrock contact;

UK = unknown lithology; IPobpl, IPowc, Mmc, Mgb etc. = keyed to geologic unit names on Plate 2; 100VLFL = valley fill; 112PLCN = Pleistocene sediment, PZ = Paleozoic sedimentary bedrock.

Clay depth: depth of shallow clay unit in well log.

Layer: 1 = valley clay unit, 2 = principal basin-fill aquifer (flow model layer 1), 3 = bedrock aquifer (flow model layer 2), 4 = Cedar Pass perched aquifer

* "m" in Open Interval indicates well is screened or perforated over multiple intervals over depth given.

-999 - null value, no data

Table B-1 continued. *Location, completion, geologic, and water right information for wells in the Cedar Valley study area.*

UGS ID	Aquifer	Geology	Clay Depth, ft	Layer	UTM Easting, m, NAD 1929	UTM Northing, m, NAD 1929	Cadastral location	Well Diame-ter, in	Hole Depth, ft	Depth to Bedrock, ft	Open Interval*, ft	Depth to Water, ft	Depth to Water Date	Well Test Yield, gpm	Draw-down, ft	Dura-tion, hrs	Land Elev., ft, 1929 datum	Completion Date	Water Right
132	BF	BF	91	2	407363	4464623	(C- 6- 2) 5acb- 1	6	269	>269	m90-240	84	10/24/99	16	0	2	4988	1/24/99	a20457
133	BF	BF	89	2	407075	4464408	(C- 6- 2) 5bdc- 1	6	269	>269	100-248	89	6/29/98	16	0	1	4995	6/29/98	a21155
134	BF	BF	300	2	411857	4460749	(C- 6- 2)14cac- 1	10	1250	>1250	300-1250	80	5/4/51				4856.11	5/4/51	54-50
135	BF	BF	0	2	406091	4464903	(C- 6- 2) 6adb- 3	5	320	>320	290-320	-999	3/18/99	13	0	1.5	5146	3/18/99	a22642
136	BFper	cpp/Tsl		4	416441	4469734	(C- 5- 1)19aab- 2	5	300	>300	210-290	155	3/15/99	30	20	1	4950	3/11/99	a22737
137	BDRX	BDRX		3	416350	4469071	(C- 5- 1)19adc- 3	4	521	15	460-521	330	7/17/96	25	-999	2	4895	7/17/96	a22779
138	BF	BF	0	2	406312	4463754	(C- 6- 2) 6ddd- 3	6	285	>285	258-285	225	8/10/99	30	40	2	5125	8/10/99	54-1022
139	UK	UK, IPo outcrop 1 mi. E	0	3	415814	4462559	(C- 6- 1) 7dba- 2	6	440	151	360-420	282	5/2/96	70	-999	2	4938	5/2/96	a23067
140	BF	BF	0	2	406492	4461692	(C- 6- 2)17bbc- 1	5	320	>320	280-320	143	6/3/99	20	-999	2	5049	6/3/99	a23102
141	BFper	cpp		4	416813	4470134	(C- 5- 1)17ccb- 1	4	265	>265	204-264	127	7/8/97	25	-999	2	4930	7/10/97	a19102
142	X	cpp Tsl upper screen, Mmc? lower screen.		4-3 (60% in perched, 40% in lay 3)	416383	4469724	(C- 5- 1)19aab- 3	4	400	340	m300-400	290	2/14/96	30	-999	3	4950	2/14/96	a24272
143	BDRX	BDRX	0	3	406367	4463767	(C- 6- 2) 6ddd- 4	6.62	300	220	220-300	-999	2/28/00	20	-999	3	5117	2/28/00	a24136
144	BF	BF	0	2	406300	4463925	(C- 6- 2) 6ddb- 1	6	305	>305	302-305	214	3/8/00	30	-999	3	5110	3/8/00	a23978
145	BDRX	Md, Mh or Mgb?	120	3	408609	4467062	(C- 5- 2)28ccb- 1	6	600	278	279-600	490	9/15/75				5120	4/18/00	0054001P00
146	BF	BF			420762	4471340	(C- 5- 1)15abb- 1	6	253	>253	181-242	151	5/6/94	15	-999	1	4702	5/7/94	54-722
147	BF	BF			420700	4470591	(C- 5- 1)15acc- 1	5	260	>260	230-260	145	10/31/95	70	-999	1.5	4664	10/31/95	54-408
148	BF	BF			420693	4470685	(C- 5- 1)15acc- 2	6	280	>280	180-275	175	5/26/69	15	2	0.5	4663	5/26/69	54-414
149	BDRX	BDRX		3	420768	4471266	(C- 5- 1)15abb- 2	5	303	82	m180-300	185	5/18/97				4694	5/22/97	54-720
150	BF	BF			421200	4471027	(C- 5- 1)15aac- 1	6	256	>256	130-240	138	4/2/77	20	10	1	4632.68	4/2/77	54-364
151	BDRX	BDRX		3	419602	4470402	(C- 5- 1)16dab- 1	5.5	425	11	385-425	283	4/23/95	50	-999	2	4884	4/24/95	a17553
152	BDRX	BDRX		3	419800	4470067	(C- 5- 1)16dda- 1	4	483	0	423-483	331	12/19/96	30	-999	2	4808	12/19/96	a17553
153	BDRX	BDRX		3	419815	4470372	(C- 5- 1)16dad- 1	4	484	3	424-484	355	12/20/97	27	-999	2	4860	1/14/98	a17553
154	BDRX	BDRX		3	419547	4470174	(C- 5- 1)16ddb- 1	4	420	2	312-372	225	12/29/98	30	-999	2	4868	12/29/98	a17553
155	BDRX	BDRX		3	419547	4470366	(C- 5- 1)16dac- 1	4	420	9	340-420	240	5/17/99	25	-999	2	4858	5/17/99	a17553
156	BDRX	Mgbu, Mgbl		3	418187	4469812	(C- 5- 1)17ddd OR 20aaa- 1	14	1020	80	m510-940	423.42	2/4/00	2200	42.74	52.5	4918	2/4/00	a23093
157	BDRX	BDRX		3	419760	4470006	(C- 5- 1)16dda- 2	5	425	6	345-425	289.6	4/9/99	40	-999	1	4818	4/6/99	a17553b
158	BDRX	BDRX		3	418691	4470421	(C- 5- 1)16cab- 1	5	580	6	m520-560	457	5/31/00	12	-999	1	4944	5/31/00	a20386
159	BDRX	Mgb		3	418727	4470756	(C- 5- 1)16bdd- 1	12	585	27	451-585	427.1	5/20/98	60	-999	6	4930	4/30/98	a22996
160	BDRX	BDRX		3	416113	4468715	(C- 5- 1)19dbd- 2	6	523	35	485-523	-999	10/8/96	20	-999	1	4917	10/8/96	a19115
161	BDRX	BDRX		3	416080	4468952	(C- 5- 1)19dba- 1	4	502	65	440-502	420	6/15/96	15	480	1.5	4902	6/17/96	a19113
162	BDRX	BDRX, LS		3	416434	4469097	(C- 5- 1)19adc- 4	4	543	82	480-540	375	2/15/00	30	-999	2	4885	3/3/00	a19030
163	BDRX	BDRX		3	422359	4469018	(C- 5- 1)23acc- 1	5	200	95	m60-200	20	6/30/94	80	-999	-999	4521	6/29/94	54-681
164	BF	BF			422101	4468514	(C- 5- 1)23cda- 1	6	121	>121	100-118	31	4/30/77	20	7	0.5	4530	4/30/77	54-571
165	BF	BF			421863	4468920	(C- 5- 1)23cab- 1	8	160	>160	60-160	40	3/14/00	150	-999	2	4537	3/14/00	a23487
166	BF	BF			422074	4469018	(C- 5- 1)23bdd- 1	5	115	>115	85-115	28	6/29/96	80	-999	1	4528	6/29/96	54-690
167	BF	BF			422177	4468301	(C- 5- 1)23cdd- 1	5	125	>125	85-125	35	11/3/95	60	-999	0.75	4534	11/3/95	54-664
168	BF	BF			422177	4468339	(C- 5- 1)23cda- 2	5	125	>125	85-125	35	11/7/95	60	-999	0.67	4533	11/7/95	54-665
169	BF	BF			422243	4469301	(C- 5- 1)23bda- 2	6	162	>162	m110-162	22	10/3/95	20	0	4	4523	10/3/95	54-53
170	BF	BF			422383	4469218	(C- 5- 1)23acb- 1	5	180	>180	80-180	19	5/23/95	75	-999	0.67	4518	5/23/95	54-688
171	BF	BF			422359	4468988	(C- 5- 1)23acc- 2	5.25		>205	m100-180	22	7/1/93	25	40	8	4520	6/17/93	54-687
172	BF	BF			423110	4466669	(C- 5- 1)25ccc- 5	4	84	>84	78-84	-999	-999	100	-999	-999	4509	5/16/56	54-152
173	BDRX	Mgb??		3	421896	4467579	(C- 5- 1)26bdb- 1	6.25	501	396	501-501	55	12/10/34	80	-999	-999	4558	12/10/34	54-102
174	BF	BF			421269	4466977	(C- 5- 1)27dad- 1	6	335	>335	220-300	95	8/1/62	180	80	2	4590	8/1/62	54-67

Aquifer: BDRX = bedrock; BF = basin fill; X = open interval crosses basin-fill/bedrock contact; UK = unknown lithology; BFper = perched unconsolidated aquifer in Cedar Pass; BDRXp = perched bedrock aquifers

Geology from well log, outcrop, or NWIS: BDRX = bedrock, undifferentiated; BF = basin fill; cpp = Cedar Pass perched unconsolidated; X = open interval crosses basin-fill/bedrock contact;
UK = unknown lithology; IPobpl, IPowc, Mmc, Mgb etc. = keyed to geologic unit names on Plate 2; 100VLFL = valley fill; 112PLCN = Pleistocene sediment, PZ = Paleozoic sedimentary bedrock.

Clay depth: depth of shallow clay unit in well log.

Layer: 1 = valley clay unit, 2 = principal basin-fill aquifer (flow model layer 1), 3 = bedrock aquifer (flow model layer 2), 4 = Cedar Pass perched aquifer

* "m" in Open Interval indicates well is screened or perforated over multiple intervals over depth given.

-999 - null value, no data

Table B-1 continued. *Location, completion, geologic, and water right information for wells in the Cedar Valley study area.*

UGS ID	Aquifer	Geology	Clay Depth, ft	Layer	UTM Easting, m, NAD 1929	UTM Northing, m, NAD 1929	Cadastral location	Well Diame-ter, in	Hole Depth, ft	Depth to Bedrock, ft	Open Interval*, ft	Depth to Water, ft	Depth to Water Date	Well Test Yield, gpm	Draw-down, ft	Dura-tion, hrs	Land Elev., ft, 1929 datum	Completion Date	Water Right
175	BF	BF	205	2	406246	4465350	(C- 5- 2)31dcd- 1	8	325	>325	300-320	300	4/27/63	12	0	1	5181.4	4/27/63	54-85
176	BF	100VLFL			427430	4457391	(D- 6- 1)29dbd- 1	6	221	>221	110-210	12	12/21/98	16	0	2	4495	11/30/98	a21951
177	BDRX	Md or Mg?		3	425531	4458442	(D- 6- 1)30baa- 1	3	360	195	336-360	236	3/8/76	20	3	3	4736	3/8/76	54-368
178	BF	100VLFL			425203	4461703	(D- 6- 1) 7cdc- 1	6	103	>103	63-103	8	3/1/78	150	-999	-999	4518	3/7/78	E1201
179	BF	BF			425092	4461276	(D- 6- 1)18bbd- 1	8	300	>300	m240-274	10	7/5/88	40	100	5	4553	7/5/88	54-611
180	BF	BF			425563	4460151	(D- 6- 1)18dcc- 1	6	110	>110	100-110	55	3/31/98	30	80	2	4575	3/31/98	a19488
181	BF	BF			424831	4461144	(D- 6- 1)18bcb- 1	7	180	>180	160-180	105	1/25/98	43	-999	5	4610	2/13/98	a19329
182	BF	BF			424922	4460989	(D- 6- 1)18bcc- 1	6	180	>180	150-180	105	12/31/96	30	-999	3	4609	12/31/96	a19330
183	BF	BF			425614	4460180	(D- 6- 1)18dcc- 2	12	160	>160	120-160	7	4/15/79				4568	4/15/79	a7184
184	BF	BF?			425979	4460105	(D- 6- 1)18ddc- 1	-999	147	-999	TD147	42	4/8/98	100	-999	2	4528	4/8/98	54-622
185	BF	BF			425157	4459266	(D- 6- 1)19bcd- 1	12	351	>351	274-289	12	9/17/73	150	0	1	4720	9/20/73	a7184
186	BDRX	BDRX		3	426044	4456370	(D- 6- 1)31adb- 1	6	235	80	225-235	90	7/31/75	40	-999	-999	4720	7/31/75	54-410
188	BF	BF			422102	4447267	(C- 7- 1)26cdb- 1	5.25	190	>190	100-190	75	7/23/93	50	180	2	4534	7/26/93	a17449
189	BF	BF			395990	4448272	(C- 7- 3)30acc- 1	6	300	>300	140-300	135	7/27/47	15	0	-999	5092	7/27/47	15-1734
192	BDRX	Md, Mh, Mg?		3	417259	4439046	(C- 8- 1)20cdb- 3	16	400	205	399-400	128	10/10/72	3050	49	1	4625	10/10/72	53-642
193	BF	BF			417560	4438057	(C- 8- 1)20cdb- 1	6	205	>205	205-205	90	11/11/45	15	0	-999	4615	11/11/45	53-48
194	BDRX	BDRX?		3	417890	4437083	(C- 8- 1)32aba- 1	6	265	150	TD265	175	12/5/45	15	4	-999	4625	12/5/45	53-49
195	BF	BF			420057	4436444	(C- 8- 1)34bcc- 1	6	412	>412	250-350	42	12/17/70	35	27	1	4535	12/17/70	53-391
196	BF	BF			417552	4429421	(C- 9- 1)20cda- 1	20	575	>575	257-521	-999	-999				4700	3/20/64	53-149
197	BF	BF			422630	4427826	(C- 9- 1)26dca- 1	0	33	>31	33-33	-3	1/8/56	4	-999	-999	4501	1/17/56	53-99
198	BF	BF			421995	4425215	(C-10- 1) 2bcd- 1	6	100	>100	100-100	20	11/3/81				4528	11/3/81	53-876
199	BF	100VLFL			418395	4425075	(C-10- 1) 4cbb- 1	12	1218	880	m406-850	143.78	4/10/62	2100	78	48	4664	5/11/62	53-147
603	BF	100VLFL			420415	4477486	(C- 4- 1)27bad- 1		225		TD225						4870	12/20/89	
604	UK	UK			409503	4482235	(C- 4- 2) 9aca- 1		200		TD200						5330	9/17/76	
605	UK	UK			409216	4481837	(C- 4- 2) 9caa- 1		207		TD207						5390	4/14/76	
606	UK	UK			409004	4481809	(C- 4- 2) 9cac- 1		190		TD190						5470	7/10/75	
607	UK	UK			410896	4482526	(C- 4- 2)10abc- 1		200		TD200						5185	12/1/73	
608	UK	UK			411502	4482026	(C- 4- 2)10ada- 1		105		TD105						5440	8/23/75	
609	UK	UK			412190	4482449	(C- 4- 2)11bac- 1		283		TD283						5170	9/23/76	
610	UK	UK			417101	4473019	(C- 5- 1) 5cdc- 1		265		TD265						5640	5/18/77	
613	BF	100VLFL			421760	4471143	(C- 5- 1)14bbd- 1		204		TD204						4285	4/3/95	
615	UK	UK			422975	4468855	(C- 5- 1)23daa- 1		205		TD205						4495	9/21/76	
628	UK	UK			423454	4467185	(C- 5- 1)25cba- 1				TD						4503		
629	UK	UK			423100	4467250	(C- 5- 1)25cbb- 1				TD						4503	1/1/51	
630	UK	UK			423335	4467094	(C- 5- 1)25cbd- 1				TD						4500		
631	UK	UK			423093	4466541	(C- 5- 1)25ccc- 4				TD						4500	1/1/50	
632	UK	UK		2	408577	4464144	(C- 6- 2) 4cac- 1		445		TD445	80	11/1/74				4930	11/1/74	
633	BF	100VLFL			396068	4447068	(C- 7- 3)30acc- 1				TD						5085		
634	BDRX	Limestone and quartzite		3	396685	4445518	(C- 8- 3) 6aac- 1	10	654	204	m225-654	595	1/1/07	20			5110	1/1/07	C-4274
789	BF	BF	0	2	407203	4447825	(C- 7- 2)29dbc- 2	6	720	>720	m620-720	171	3/7/06	60	-999	2	4858.48	3/1/06	54-442
790	BDRXp	LS, prob IPobp	251	3	414824	4469703	(C- 5- 2)24aaa- 1	5	480	251	m350-480	224	9/9/05	25	136	8	4994	9/6/05	a28516
791	BF	BF	58	2	408065	4457333	(C- 6- 2)28ccc- 1	6	288	>288	m100-288	8	8/25/05	15	18	1	4863	8/25/05	a29962
792	BDRX	BDRX		3	422746	4463480	(C- 6- 1) 2ddb- 1				500-1094						4730		
794	BDRX	BDRX		3	423437	4464077	(C- 6- 1) 1bcd- 1		425	115	-280			903	0		4570		

Aquifer: BDRX = bedrock; BF = basin fill; X = open interval crosses basin-fill/bedrock contact; UK = unknown lithology; BFper = perched unconsolidated aquifer in Cedar Pass; BDRXp = perched bedrock aquifers
Geology from well log, outcrop, or NWIS: BDRX = bedrock, undifferentiated; BF = basin fill; cpp = Cedar Pass perched unconsolidated; X = open interval crosses basin-fill/bedrock contact;
UK = unknown lithology; IPobpl, IPowc, Mmc, Mgb etc. = keyed to geologic unit names on Plate 2; 100VLFL = valley fill; 112PLCN = Pleistocene sediment, PZ = Paleozoic sedimentary bedrock.
Clay depth: depth of shallow clay unit in well log.
Layer: 1 = valley clay unit, 2 = principal basin-fill aquifer (flow model layer 1), 3 = bedrock aquifer (flow model layer 2), 4 = Cedar Pass perched aquifer
* "m" in Open Interval indicates well is screened or perforated over multiple intervals over depth given.
-999 - null value, no data

Table B-1 continued. *Location, completion, geologic, and water right information for wells in the Cedar Valley study area.*

UGS ID	Aquifer	Geology	Clay Depth, ft	Layer	UTM Easting, m, NAD 1929	UTM Northing, m, NAD 1929	Cadastral location	Well Diame-ter, in	Hole Depth, ft	Depth to Bedrock, ft	Open Interval*, ft	Depth to Water, ft	Depth to Water Date	Well Test Yield, gpm	Draw-down, ft	Dura-tion, hrs	Land Elev., ft, 1929 datum	Completion Date	Water Right
795	BF	Alluvium			423077	4472259	(C- 5- 1)11add- 1				-						4518		
796	BF	Alluvium			422626	4472414	(C- 5- 1)11aca- 1				-						4560		
797	BF	Alluvium			421743	4471835	(C- 5- 1)11cbd- 1				-						4620		
798	BDRX	Mgb		3	420271	4470188	(C- 5- 1)15cbd- 1	10	1436	5	m400-1065	198.9	6/28/02	920	2.3	24	4680	7/16/02	a26478
799	BDRX	BDRX, Paleozoic ls & shale		3	416405	4470642	(C- 5- 1)18adc- 1	8.75	1000	125	m124-1000			90	95	24	4995	4/26/95	9454002P00
800	BF	BF			419862	4471914	(C- 5- 1) 9dad- 1	0.5	90	>90	TD90	-999	-999				4850	8/30/03	0354001M00
801	BF	BF			418980	4470461	(C- 5- 1)16caa- 1	0.5	102	>102	TD102	-999	-999				4868	8/30/03	0354001M00
802	X	X, BF		2	416920	4470439	(C- 5- 1)17cba- 1	0	225	140	18-200	79	11/2/92	13	-999	1	4950	11/4/92	54-1082
803	X	BF, Tv, PZ		2	416751	4470549	(C- 5- 1)17cbb- 1	7	340	180	118-183	80	4/26/95	5	-999	2	4974	4/28/95	9554002P00
804	BFper	cpp		4	416748	4470114	(C- 5- 1)17ccb- 2	5	320	>320	280-320	103	9/27/95	35	-999	2	4935	9/27/95	a18670
805	BDRX	BDRX		3	415429	4469411	(C- 5- 1)19bdb- 3	4	720	272	440-640	429	6/26/03	20	-999	4	4952	6/27/03	a18691
806	BDRX	BDRX		3	415543	4468678	(C- 5- 1)19cac- 1	5	600	78	600-640	427	10/1/03	25	-999	8	4935	10/1/03	a19515
807	BDRX	BDRX		3	416223	4468623	(C- 5- 1)19ddb- 1	5	647	23	560-647	421	5/4/04	25	-999	4	4921.3	5/4/04	a28921
808	BDRX	BDRX		3	420503	4468874	(C- 5- 1)22caa- 1	14	332	80	263-323	179.58	2/2/00	200	-999	1	4630	6/5/99	54-738
809	BDRX	BDRX		3	420231	4468606	(C- 5- 1)22cbd- 1	5.5	292	65	232-292	178.6	4/13/00	100	-999	1	4665	4/13/00	54-732
810	BDRX	BDRX		3	420650	4468282	(C- 5- 1)22dcc- 1	8.62	325	53	80-325	204	12/28/00	100	-999	0.5	4612	12/27/00	54-723
811	BF	BF			421273	4468922	(C- 5- 1)22daa- 1	5.5	201	>201	m100-160	46	9/27/93	25	28	24	4568	6/29/93	54-628
812	BDRX	BDRX		3	420422	4468708	(C- 5- 1)22cac- 1	4.5	200	99	160-200	132	5/19/94	20	-999	-999	4641	5/9/94	54-701
813	BDRX	BDRX		3	420312	4468722	(C- 5- 1)22cac- 2	4.5	245	80	205-245	158.9	6/28/94	30	-999	1	4658	6/28/94	54-702
814	BDRX	BDRX		3	420069	4468548	(C- 5- 1)22cbd- 2	6	292	17	267-281	284.7	6/23/94	40	-999	1	4695	6/23/94	a17989
815	BF	BF			420691	4469345	(C- 5- 1)22acb- 1	6	283	>238	126-215	126	12/10/94	12	22	1	4622	12/10/94	54-726
816	BDRX	BDRX		3	420312	4467921	(C- 5- 1)22bac- 1	5.25	261	72	200-260	143	12/3/94	20	-999	2	4636	12/3/94	
817	BF	BF			421183	4469267	(C- 5- 1)22adb- 1	0	174	>174	100-133	94	4/10/95	15	-999	1	4574	4/10/95	54-727
818	BF	BF			421223	4468924	(C- 5- 1)22dab- 1	0	137	>137	100-112	65	6/20/79	20	0	4	4568	6/20/79	54-437
819	BF	BF			420797	4468922	(C- 5- 1)22dbb- 1	6	140	>140	115-135	89	12/5/79	20	0	-999	4590.2	12/5/79	54-458
820	BF	BF			421018	4468918	(C- 5- 1)22dba- 1	8	130	>130	130-130	80	1/20/78				4578	1/20/78	54-436
821	BDRX	BDRX		3	421315	4468852	(C- 5- 1)22daa- 2	8.63	338	28	280-338	70	4/29/99	600	-999	3	4564	4/29/99	
822	BF	BF			421737	4469015	(C- 5- 1)23bcd- 1	5.25	280	>280	m100-250	46	6/14/93	80	-999	3	4544	6/14/93	54-683
823	BF	BF			422145	4469329	(C- 5- 1)23bda- 3	6	205	>205	128-203	22	9/21/76	18	6	0.5	4523	9/21/76	54-415
824	BF	BF		2	416511	4466657	(C- 5- 1)30ddd- 1	0.5	94	>94	TD94	-999	-999				5092	8/30/03	0354001M00
825	X	X			422194	4465293	(C- 5- 1)35cda- 1	4.5	145	118	85-145	-999	-999	35	-999	1	4572	8/17/93	54-693
826	BF	BF			422028	4465663	(C- 5- 1)35cab- 1	6	148	>147	147-148	75	4/16/88	14	0	2	4570	4/16/88	54-101
827	BF	BF			422050	4465546	(C- 5- 1)35cab- 2	6	163	>163	151-163	88	11/28/88	14	12	2	4578	11/28/88	54-603
829	BDRXp	BDRX	0	3	414860	4469636	(C- 5- 2)24aaa- 2	6	480	390	390-480	220	1/20/03	50	-999	4	4980	2/3/03	a19713
830	BDRX	BDRX	0	3	414980	4469333	(C- 5- 2)24ada- 1	6	625	81	520-625	447	12/30/03	25	-999	22	4965	12/30/03	a19710
831	BF	BF, Confined	295	2	413514	4467213	(C- 5- 2)25cbb- 1	6	473	>473	268-452	-999	-999				4972	2/19/88	54-612
832	BDRX	Mgbu on log but IPo in chemistry	0	3	406121	4466823	(C- 5- 2)30dcc- 1	6	1280	296	818-1280	-404	7/16/04	574	-999	72	5395	7/16/04	0354605M00
833	BDRX	IPowc	0	3	405556	4465238	(C- 5- 2)31cdd- 1	5	560	75	500-560	380	5/12/04	14	100	3	5320	5/12/04	a27829
834	BF	100VLFL			426216	4459080	(D- 6- 1)19adc- 1	6	120	>120	110-120	67	6/14/01	20	-999	2	4567	6/12/01	
835	BDRX	LS		3	417268	4439043	(C- 8- 1)20cdb- 4	16	300	205	210-300	127	12/18/74	50	0	10	4625	12/20/74	53-388
836	BDRX	IPobp?	140	3	415743	4463753	(C- 6- 1) 6dba- 1	5	560	140	530-560	374	2/5/03	12	-999	1.5	4963	2/5/03	a20804
837	BDRX	Mgb		3	424664	4460788	(C- 6- 1)13daa- 1	6	245	13	235-243	183	6/21/83				4728	6/21/83	54-565
838	X	X		3	424288	4462292	(C- 6- 1)12dba- 1	14	390	305	130-364	111	10/12/01	900	71	30	4598	10/12/01	a22549

Aquifer: BDRX = bedrock; BF = basin fill; X = open interval crosses basin-fill/bedrock contact; UK = unknown lithology; BFper = perched unconsolidated aquifer in Cedar Pass; BDRXp = perched bedrock aquifers

Geology from well log, outcrop, or NWIS: BDRX = bedrock, undifferentiated; BF = basin fill; cpp = Cedar Pass perched unconsolidated; X = open interval crosses basin-fill/bedrock contact;

UK = unknown lithology; IPobpl, IPowc, Mmc, Mgb etc. = keyed to geologic unit names on Plate 2; 100VLFL = valley fill; 112PLCN = Pleistocene sediment, PZ = Paleozoic sedimentary bedrock.

Clay depth: depth of shallow clay unit in well log.

Layer: 1 = valley clay unit, 2 = principal basin-fill aquifer (flow model layer 1), 3 = bedrock aquifer (flow model layer 2), 4 = Cedar Pass perched aquifer

* "m" in Open Interval indicates well is screened or perforated over multiple intervals over depth given.

-999 - null value, no data

Table B-1 continued. *Location, completion, geologic, and water right information for wells in the Cedar Valley study area.*

UGS ID	Aquifer	Geology	Clay Depth, ft	Layer	UTM Easting, m, NAD 1929	UTM Northing, m, NAD 1929	Cadastral location	Well Diame-ter, in	Hole Depth, ft	Depth to Bedrock, ft	Open Interval*, ft	Depth to Water, ft	Depth to Water Date	Well Test Yield, gpm	Draw-down, ft	Dura-tion, hrs	Land Elev., ft, 1929 datum	Completion Date	Water Right
839	X	X, BF to 335? then lPbpl? or Mgb?	0	2-3	415779	4460223	(C- 6- 1)19aba- 1	9	440	335	m246-406	234.5	12/14/93	275	-999	2	4910	12/14/93	54-225
840	BF	BF	88	2	407019	4464649	(C- 6- 2) 5bdb- 1	6	322	>322	m100-321	94	10/16/00	16	12	2	5018	10/16/00	54-1033
841	BF	BF	43	2	408074	4464530	(C- 6- 2) 5add- 1	6	212	>212	120-172	122	4/10/02	12	0	2	4958	4/10/02	a26157
842	BDRX	BDRX	0	3	405749	4464635	(C- 6- 2) 6acb- 1	5	415	135	340-360	200	4/25/03	12	-999	2	5180	4/30/03	0354001P00
843	BDRX	BDRX		3	405427	4464949	(C- 6- 2) 6bac- 1	6	362	149	302-362	278	3/13/01	16	20	4	5338	3/13/01	54-703
844	BDRX	BDRX	0	3	405728	4463869	(C- 6- 2) 6dcb- 1	4	425	147	365-425	-999	-999	15	0	0.5	5210	9/5/83	54-540
845	BF	BF	87	2	406382	4465047	(C- 6- 2) 6aaa- 1	8	352	>352	345-352	196	6/16/02	16	0	3	5124	6/16/02	a25498
846	BF	BF	84	2	406504	4464352	(C- 6- 2) 6daa- 2	8	462	>462	179-450	246	6/12/03				5058	6/12/03	54-822
847	BDRX	BDRX		3	406023	4463653	(C- 6- 2) 7aba- 1	6	465	280	380-465	302	12/4/01	42	60	9	5196.51	12/4/01	a24658
849	BDRX	Mgb, may reach older M strata		3	419659	4469992	(C- 5- 1)16dbd- 1	6.25	3512	-999	0-0	295	2/7/62	2200	-999	-999	4805	2/10/62	
850	BF	BF	24	2	408901	4458787	(C- 6- 2)21dcc- 1	8.62	290	>290	288-290	17	1/15/02	240	141	2	4856	1/5/02	a26141
851	BF	BF	-1	1	410092	4458351	(C- 6- 2)27bbd- 1	6	80	>80	35-80	35	9/6/53	-999	5	-999	4848	9/6/53	54-43
852	BF	BF	-1	1	408517	4458378	(C- 6- 2)28bac- 1	6	80	>80	20-80	15	9/17/53	-999	5	-999	4861.04	9/17/53	54-42
853	BF	BF	-1	1	409291	4458354	(C- 6- 2)28aac- 1	6	80	>80	25-80	25	9/18/53	-999	5	-999	4853	9/18/53	
854	BF	BF	110	2	406824	4457636	(C- 6- 2)29cac- 2	8	220	>220	80-220	-2	9/21/53	12	-999	-999	4888.7	9/21/53	54-153
855	BF	BF	67	2	407727	4457545	(C- 6- 2)29dac- 1	6	269	>269	102-255	-1	4/14/02	14	22	1.25	4865	4/15/02	a16648
857	BF	BF	144	2	408346	4456899	(C- 6- 2)33bbd- 1	6	226	>226	100-202	12	11/6/99	16	0	2	4862	11/6/99	a19893
858	BF	BF		1	404619	4462826	(C- 6- 3)12dab- 1	4	35	>35	TD35	-999	-999				5485	4/4/61	
859	BDRX	Tv. 220' of basalt	0	3	415223	4453346	(C- 7- 1) 7bda- 1	5	240	20	220-240	177	9/23/03	23	0	1	4885	9/23/04	a28237
860	BF	BF?			422237	4447131	(C- 7- 1)26cda- 1	-999	-999	-999	m60-114	-999	-999	171	15	24	4498	6/15/95	a17449
861	BF	BF	188	2	407123	4455072	(C- 7- 2) 5bda- 1	6	389	>389	114-380	23	9/24/03	23	0	2	4880	10/2/03	a28140
862	BF	BF	176	1-2	407015	4449451	(C- 7- 2)20cad- 1	6	392	>392	m130-382	139	10/18/03	18	35	2	4862	10/18/03	54-695
863	BDRX	PZ		3	415242	4469162	(C- 5- 1)19bcd- 3	5	660	195	m630-660	520	12/10/03	12	-999	1	5000	12/10/03	a18705
864	BF	BF	280	2	407780	4448758	(C- 7- 2)29aad- 1	5	345	>345	265-345	156	6/30/03	20	-999	2	4855	7/2/03	a27939
865	BDRX	UK		3	398177	4449423	(C- 7- 3)20ddb- 1	-999	253	-999	TD253	-999	-999				5214	8/23/00	
867	UK	BF w/ volcanics at bottom of hole?, possible ls at 382			417321	4435055	(C- 9- 1) 5bdb- 1	12	830	695	m325-798	216	7/25/02	411	179	17	4693	8/9/02	A33374aa
868	BF	BF			416740	4431667	(C- 9- 1)17bcc- 1	4.5	295	>295	253-293	263	11/22/96	1	28	2.5	4772	10/6/96	
869	BF	BF			416755	4432383	(C- 9- 1)17bbb- 1		510	>510	350-500	264.5	9/9/86				4755	9/9/86	
870	BF	BF			411261	4422799	(C-10- 2)11cdc- 1		1225	5	TD1225		3/28/00				5494	3/28/00	
871	BDRX	LS		3	420329	4468420	(C- 5- 1)22cdb- 1	6	200	106	110-200	136.98	3/9/81				4637.48	12/17/79	
872	BF	100VLFL			425161	4460970	(D- 6- 1)18bcd- 1		105	>105	100-105						4560	4/11/01	
873	BF	112PLCN			427607	4457492	(D- 6- 1)29dab- 1			>165	TD						4490	01/01/1881	
874	UK	UK		2	415377	4461524	(C- 6- 1)18bad- 1	16	712	-999	TD712	-999	-999				4879.55		
875	BF	100VLFL		2	412484	4461168	(C- 6- 2)14dba- 1	-999	-999	-999	TD-999	98	1/1/64				4857	11/30/63	
876	BF	BF	219	1-2	413479	4461496	(C- 6- 2)14aca- 1	12	1014	>1014	m150-1014	109.7	2/28/66				4862.64	2/15/54	
877	BF	BF		2	413053	4457509	(C- 6- 2)25cbc- 1	-999	-999	-999	TD-999	68.9	3/30/66				4841.22	3/30/66	
878	BF	BF		1	410052	4457188	(C- 6- 2)27ccc- 2	1	100	>100	90-100	25.1	4/7/66				4843.19	11/30/65	
879	BF	BF		1	407279	4464178	(C- 6- 2) 5cad- 1	4	200	-999	TD200	82.9	2/28/66				4975.14	11/30/29	
880	BF	BF		2	406821	4457659	(C- 6- 2)29cac- 1	4	350	-999	0-350	-0.9	4/6/66	1	-999	-999	4888.37	1/1/43	
881	BF	BF		2	407146	4457989	(C- 6- 2)29bdd- 1	3	150	-999	150-150	-13.1	4/7/66	1.8	-999	-999	4875	1/1/00	54-128
882	UK	UK		2	406782	4458447	(C- 6- 2)29bbd- 2	-999	-999	-999	TD-999	-999	-999				4890		
883	BF	BF		2	407197	4447828	(C- 7- 2)29dbc- 1	-999	-999	-999	TD-999	169	3/11/66				4859.09	1/1/20	54-442

Aquifer: BDRX = bedrock; BF = basin fill; X = open interval crosses basin-fill/bedrock contact; UK = unknown lithology; BFper = perched unconsolidated aquifer in Cedar Pass; BDRXp = perched bedrock aquifers

Geology from well log, outcrop, or NWIS: BDRX = bedrock, undifferentiated; BF = basin fill; cpp = Cedar Pass perched unconsolidated; X = open interval crosses basin-fill/bedrock contact;

UK = unknown lithology; lPobpl, lPowc, Mmc, Mgb etc. = keyed to geologic unit names on Plate 2; 100VLFL = valley fill; 112PLCN = Pleistocene sediment, PZ = Paleozoic sedimentary bedrock.

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Table B-1 continued. *Location, completion, geologic, and water right information for wells in the Cedar Valley study area.*

UGS ID	Aquifer	Geology	Clay Depth, ft	Layer	UTM Easting, m, NAD 1929	UTM Northing, m, NAD 1929	Cadastral location	Well Diame-ter, in	Hole Depth, ft	Depth to Bedrock, ft	Open Interval*, ft	Depth to Water, ft	Depth to Water Date	Well Test Yield, gpm	Draw-down, ft	Dura-tion, hrs	Land Elev., ft, 1929 datum	Completion Date	Water Right
884	UK	UK		2	405825	4446799	(C- 7- 2)31abc- 1			-999	TD						4876.09		
885	BF	BF, sand lenses in clay, confined			393310	4452086	(C- 7- 4)14aac- 1	6	875	>875	m735-875	92.1	3/17/67	40	-999	-999	5056	1/1/35	A19505
886	BF	100VLFL			418474	4434052	(C- 9- 1) 4ccc- 1		800	>800	m240-750						4620	10/14/70	
887	BF	100VLFL			418323	4429496	(C- 9- 1)20ddd- 1	20	798	>798	300-775	130	2/3/64				4640	2/5/64	53-161
888	BF	100VLFL			417654	4428455	(C- 9- 1)29acc- 1		700	>700	m280-700						4719	2/23/63	
889	BF	100VLFL			418455	4425764	(C-10- 1) 4bbb- 1	20	882	>880	525-860	153	10/1/62				4672	9/22/62	
890	UK	UK			413666	4421870	(C-10- 2)13bcc- 1		500	-999	180-220						5140		
891	UK	UK			404808	4423363	(C-10- 2)18bca- 1			-999	379-						6500	1/1/70	
892	UK	UK			405519	4423293	(C-10- 2)18acb- 1			-999	255-						6552	1/1/70	
893	UK	UK			405333	4423603	(C-10- 2)18abc- 1			-999	76-						6560	1/1/70	
894	UK	UK			404463	4422350	(C-10- 3)13aad- 1		100	-999	60-99						6600		
895	UK	UK			404167	4423309	(C-10- 3)13adc- 1			-999	60-						6465	1/1/70	
896	BF	BF		2	406551	4454372	(C- 7- 2) 5cbc- 1	72	54	>54	0-54	45	11/30/62				4902		
897	BF	BF assumed from nearby well #87		2	406500	4457290	(C- 6- 2)29ccc- 1	3	189	-999	0-189	-2.8	3/11/66	1.7	-999	-999	4897	3/11/66	
898	BFper	cpp		4	416122	4469756	(C- 5- 1)19aba- 3	4.5	320	>320	200-320	160	1/26/96	20	-999	9	4942	1/26/96	54-1075
899	BF	BF			417178	4439099	(C- 8- 1)20cdb- 1	6	205	>205	205-205	90	11/11/45	15	0	-999	4614	11/11/45	
901	BDRX	IPobp+wc		3	415486	4467418	(C- 5- 1)30cab-1	2	1210	27	m695-1205	501.64	3/1/07				4999.55	2/27/07	0754001M00
902	BDRXp	Tv		4	414051	4468259	(C- 5- 2)24cdd-1	2	556.7	240	345-365	104.89	3/12/07				4989.4	2/3/07	0754001M00
903	BDRX	IPobp		3	414051	4468259	(C- 5- 2)24cdd-2	2	556.7	240	534-554	482.59	2/6/07				4989.4	2/3/07	0754001M00
983	BDRX	IPowc	22	3	416001	4467161	(C- 5-1)30dbd-1	20	1752	22	m600-1742	489	11/9/07	3500	7	72	4998.28	11/7/07	0754006M00
984	BDRX	Mmc	74	3	418183	4466842	(C- 5- 1)29dda-2	14	870	0	m360-760	290.92	10/15/07	1000	208	72	4799	10/7/07	0754004M00
985	BDRX	Md		3	399744	4443898	(C- 8- 3) 9aad- 1	14.75	1903	61	m1087-1878	1022.27	9/5/07				5532.82	10/30/07	0615004M00
986	BDRX	Mh		3	397920	4445554	(C- 8- 3) 5abd- 1	8.75	920	9	534-554	669.1	11/2/06	6			5179.16	10/7/06	0615004M00
987	BDRX	Mgbl	42	3	400219	4444715	(C- 8- 3) 3cbd- 1	6	1395	42	m430-1380	343.41	1/1/07				5299.91	1/27/07	0615004M00
988	BDRX	Ls		3	416403	4468830	(C- 5- 1)19dab- 1	8	567	2	m495-567	397	4/27/04	25	-999	2	4905	4/27/04	a19033
989	BDRX	BDRX	-999	3	404858	4462067	(C- 6- 2) 7ccc- 1	-999	1000	360	0-0	-999	-999				5335	8/20/96	
990	BF	BF	68	2	412169	4458645	(C- 6- 2)26abb- 1	10	300	>300	80-300	71	8/6/04	110	-999	24	4848.53	8/6/04	a29374
991	BF	BF	70	2	412149	4459389	(C- 6- 2)23dbb- 1	10	400	>400	120-400	68	9/9/04	215	47	28	4850.37	9/9/04	a20215
992	BDRX	IPowc		3	415370	4467533	(C- 5- 1)30bcd- 1	16	1220	30	m700-1210	518	12/17/04	3800	139	24	5024.68	12/19/04	a28249
993	BDRX	BDRX		3	406583	4429350	(C- 9- 2)29bac- 1	8	250	154	155-250	67	10/2/72				5810	10/2/72	54-495
994	BF	BF assumed		2	411319	4457661	(C- 6- 2)26cbc- 1	18	700	-999	m400-700	-999	-999				4840		a10111
995	BF	BF	80	2	406309	4459999	(C- 6- 2)19add- 1	6	180	>180	160-180	60	11/2/04	30	-999	2	4959	11/2/04	54-733
997	BDRX	BDRX, Paleozoic ls & shale		3	417996	4469874	(C- 5- 1)17ddc- 1	8	1308	185	m650-1040	440	5/1/05	1100	40	40	4930	6/1/05	a28071
998	BF	BF	0	2	406434	4464081	(C- 6- 2) 6dad- 2	6	300	>300	70-300	140	6/30/04	20	-999	-999	5077	7/2/04	a29597
1000	BFper	cpp		4	416753	4469895	(C- 5- 1)17ccc- 2	4	255	>255	m180-255	190	6/5/96	25	-999	1.5	4957	6/5/96	a18672
1001	BDRX	BDRX		3	409928	4479561	(C- 4- 2)21aaa- 1	10	900	45	680-890	600	6/1/82	145	190	48	6382	6/1/82	A11065
1002	BDRX	Mgb		3	417950	4469694	(C- 5- 1)20aab- 1	0	2000	60	0-0	485	4/29/99				4890	4/29/99	9954002P01
1003	BDRX	BDRX, Mgb		3	416576	4471417	(C- 5- 1)18aaa- 1	4.5	830	50	m671-830	175	6/1/97	317.51	187.72	24	5108	6/16/97	
1005	BFper	cpp		4	416092	4469571	(C- 5- 1)19abd- 3	5	225	>225	180-200	160	4/8/96	35	-999	1	4920	4/8/96	a18716
1006	BDRX	BDRX, LS		3	416351	4468797	(C- 5- 1)19dac- 1	8	542	13	482-542	410	7/26/96	15	130	1	4920	7/26/96	a19037
1007	BF	BF		2	416075	4468379	(C- 5- 1)19dcd- 2	4	40	>40	0-0	>40	9/24/63				4944	9/24/63	
1008	X	X, BDRX		3	417955	4468218	(C- 5- 1)20ddc- 1	1	300	70	m60-220	93.5	5/3/66				4795	2/28/66	
1009	BDRX	BDRX		3	422200	4468117	(C- 5- 1)26baa- 1	6	285	247	247-285	40	1/5/70	20	0	8	4537	10/5/70	
1010	BDRX	Mgbu	0	3	406647	4473131	(C- 5- 2) 7aab- 1	10	410	20	80-354	70	8/26/75				5645	8/26/75	54-35

Aquifer: BDRX = bedrock; BF = basin fill; X = open interval crosses basin-fill/bedrock contact; UK = unknown lithology; BFper = perched unconsolidated aquifer in Cedar Pass; BDRXp = perched bedrock aquifers
Geology from well log, outcrop, or NWIS: BDRX = bedrock, undifferentiated; BF = basin fill; cpp = Cedar Pass perched unconsolidated; X = open interval crosses basin-fill/bedrock contact;
UK = unknown lithology; IPobpl, IPowc, Mmc, Mgb etc. = keyed to geologic unit names on Plate 2; 100VLFL = valley fill; 112PLCN = Pleistocene sediment, PZ = Paleozoic sedimentary bedrock.
Clay depth: depth of shallow clay unit in well log.
Layer: 1 = valley clay unit, 2 = principal basin-fill aquifer (flow model layer 1), 3 = bedrock aquifer (flow model layer 2), 4 = Cedar Pass perched aquifer
* "m" in Open Interval indicates well is screened or perforated over multiple intervals over depth given.
-999 - null value, no data

Table B-1 continued. *Location, completion, geologic, and water right information for wells in the Cedar Valley study area.*

UGS ID	Aquifer	Geology	Clay Depth, ft	Layer	UTM Easting, m, NAD 1929	UTM Northing, m, NAD 1929	Cadastral location	Well Diame-ter, in	Hole Depth, ft	Depth to Bedrock, ft	Open Interval*, ft	Depth to Water, ft	Depth to Water Date	Well Test Yield, gpm	Draw-down, ft	Dura-tion, hrs	Land Elev., ft, 1929 datum	Completion Date	Water Right
1011	BDRX	IPobpl	0	3	412214	4469909	(C- 5- 2)14cdc- 1	0	1100	140	42-1100	442	4/9/99				5115	4/9/99	9954001P00
1013	BDRX	BDRX		3	398013	4470047	(C- 5- 3)20baa- 1	6	500	12	25-500	-999	-999				8915	10/16/90	
1014	BDRX	BDRX		3	397386	4465341	(C- 5- 3)32ccd- 1	5	1040	0	955-1025	720	4/19/90				7118	4/10/90	
1015	BDRX	Mmc or shaly unit of IPo		3	398234	4465434	(C- 5- 3)32dcd- 1	5	440	12	365-425	220	11/10/90				7420	11/10/90	
1016	X	X, BDRX			424198	4462246	(C- 6- 1)12dbd- 1	4	390	180	m120-390	98	3/20/98	100	-999	3	4620	3/20/98	
1017	BF	BF			424221	4462254	(C- 6- 1)12dba- 2	-999	208	>205	TD208	100	1/16/98	70	-999	2	4618	1/20/98	
1018	X	BF to 349 then IPbpl? or Mgb?.	211	3	415304	4460557	(C- 6- 1)18cdd- 2	16	475	349	m355-475	217	11/30/79	3880	12	24	4875	11/30/80	a21500
1019	BDRX	BDRX	0	3	416825	4459829	(C- 6- 1)20bdb- 1	6	830	30	400-790	645	11/30/79				5195	11/30/79	
1020	BDRX	BDRX	0	3	416876	4459881	(C- 6- 1)20bad- 1	10	430	185	415-430	>430	11/30/78				5200	11/30/78	
1021	BDRX	Mmc 0-620; Mgb 620-843	0	3	417540	4458566	(C- 6- 1)29aab- 1	0	843	0	0-0	>843	8/17/98				5422	8/17/98	
1022	BDRX	Mh?"shale bedrock"		3	424861	4458014	(D- 6- 1)30bbd- 1	8	490	272	275-485	249	5/3/73	24	35	4	4916	5/17/73	54-451
1023	UK	UK, nr well 26="basalt" but maybe Mf	183	3	415867	4456128	(C- 6- 1)31dab- 1	6	223	193	190-223	185	10/30/47	6	-999	-999	4875	10/30/47	
1024	BF	BF	49	2	413865	4464355	(C- 6- 2) 1acc- 1	1	300	>300	m200-290	174.6	3/30/66				4891.46	3/1/66	
1026	BF	BF	135	2	406762	4464058	(C- 6- 2) 5cca- 3	8	190	>190	190-190	129	5/23/82	30	0	0.5	5030	5/23/82	54-543
1027	BF	BF	60	2	407281	4464333	(C- 6- 2) 5caa- 1	8	430	>430	m141-375	135	10/30/80	40	10	0.5	4975	10/30/80	54-462
1028	BDRX	BDRX	0	3	406241	4464729	(C- 6- 2) 6adb- 4	6	216	213	216-216	140	2/6/87	30	10	1	5100	2/6/87	54-579
1029	BF	BF	93	2	413783	4460942	(C- 6- 2)13caa- 1	10	525	>525	120-339	120	5/14/62	400	72	720	4859.42	5/14/62	54-1003
1030	BF	BF	105	2	414582	4460701	(C- 6- 2)13dda- 1	0	1113	1071	0-0	-999	-999				4857	12/18/53	
1031	BF	BF	98	2	411550	4461259	(C- 6- 2)14bcd- 1	16	1007	>1007	98-1007	98	4/11/54	330	-999	-999	4858.68	4/11/54	54-50
1032	BF	BF	0	2	406479	4461716	(C- 6- 2)17bbc- 2	6	292	>292	0-0	>292	11/30/70				5051	7/8/71	
1033	BF	BF	0	2	406472	4461733	(C- 6- 2)18aad- 1	16	466	462	185-448	164	5/4/71	1725	32	24	5055	5/4/71	54-36
1035	BF	BF	147	2	407285	4460461	(C- 6- 2)17dcc- 1	16	600	>600	m150-555	28	12/29/61	2400	67	63	4916.09	12/30/61	54-37
1036	BF	BF	25	2	413348	4458801	(C- 6- 2)24ccd- 1	2	110	>110	87-107	90	5/1/96				4843	5/1/96	9654001M00
1037	BF	BF	108	1-2	406843	4458367	(C- 6- 2)29bdb- 1	16	654	>654	m65-640	-2	4/19/68	125	200	20	4891.7	4/24/68	
1038	BF	BF	55	2	407221	4456219	(C- 6- 2)32dbb- 1	8	365	>365	20-365	15	9/23/53	-999	10	-999	4879.74	9/23/53	
1039	BF	BF	123	2	406796	4456866	(C- 6- 2)32bbd- 1	16	613	>613	m205-595	0	3/13/64	750	145	32	4890	11/30/63	
1040	BF	BF	275	1	410116	4456722	(C- 6- 2)34bac- 1	6	275	>275	m30-275	30	9/24/53	25	5	-999	4845.4	9/24/53	54-41
1041	BF	BF	270	2	411428	4465534	(C- 5- 2)34dab- 1	4	280	>280	280-280	250	4/9/43	3	-999	-999	4964.61	4/9/43	54-11
1042	BF	BF	138	1	412922	4456669	(C- 6- 2)36bcb- 1	16	500	>500	0-0	75	7/6/70				4837	7/30/70	
1043	BDRX	BDRX		3	398840	4464172	(C- 6- 3) 4cbd- 1	12	1020	65	0-0	-999	-999				7000	1/28/90	
1044	X	X, TAILING?		3	398732	4464148	(C- 6- 3) 4cbc- 1	5	72	65	48-68	25	11/29/89				6570	11/29/89	
1045	BDRX	BDRX		3	398656	4464514	(C- 6- 3) 4bcc- 1	0	60	17	0-0	-999	-999				7240	1/19/90	
1046	BDRX	BDRX		3	398671	4464551	(C- 6- 3) 4bcc- 2	5	331	0	247-300	272	1/19/90	0.07	-999	-999	7225	1/19/90	
1047	BDRX	BDRX		3	397354	4465221	(C- 6- 3) 5bba- 1	5	1000	0	914-975	535	9/26/92				7160	9/26/92	
1048	BDRX	IPowc		3	398827	4465287	(C- 5- 3)33ccc- 1	5	510	0	440-500	420	11/17/90				7525	11/21/90	
1049	BDRX	BDRX		3	397154	4465238	(C- 5- 3)31ddd- 1	5	500	0	353-433	>500	4/21/90				6965	4/21/90	
1050	BDRX	BDRX	-999	3	404901	4462259	(C- 6- 2) 7ccb- 1	6	547	200	200-547	487	4/18/81				5345	4/18/81	54-584
1051	BDRX	BDRX		3	424256	4451417	(C- 7- 1)13adc- 1	16	452	103	20-452	180	6/21/73	10	270	1	4708	9/20/73	a7184
1052	BF	100VLFL			422245	4447040	(C- 7- 1)26cdd- 1	8	125	>125	116-125	22	3/5/79	26	10	4	4495	3/7/79	
1053	BF	BF	180	2	411210	4449872	(C- 7- 2)23bcc- 1	4	220	>220	180-220	150	7/22/48	10	20	-999	4842.22	7/22/48	
1054	BF	BF	190	2	411231	4446603	(C- 7- 2)35bcc- 1	5	225	>190	190-225	185	7/14/48	10	15	-999	4856.19	7/14/48	
1055	BDRX	BDRX, LS		3	419194	4444035	(C- 8- 1) 4dcb- 1	10	160	87	92-160	-999	-999				4570	5/28/91	
1056	BDRX	BDRX		3	417646	4441319	(C- 8- 1)17acc- 1	12	392	60	300-392	43	6/10/49				4620	6/10/49	

Aquifer: BDRX = bedrock; BF = basin fill; X = open interval crosses basin-fill/bedrock contact; UK = unknown lithology; BFper = perched unconsolidated aquifer in Cedar Pass; BDRXp = perched bedrock aquifers
Geology from well log, outcrop, or NWIS: BDRX = bedrock, undifferentiated; BF = basin fill; cpp = Cedar Pass perched unconsolidated; X = open interval crosses basin-fill/bedrock contact;
UK = unknown lithology; IPobpl, IPowc, Mmc, Mgb etc. = keyed to geologic unit names on Plate 2; 100VLFL = valley fill; 112PLCN = Pleistocene sediment, PZ = Paleozoic sedimentary bedrock.
Clay depth: depth of shallow clay unit in well log.
Layer: 1 = valley clay unit, 2 = principal basin-fill aquifer (flow model layer 1), 3 = bedrock aquifer (flow model layer 2), 4 = Cedar Pass perched aquifer
* "m" in Open Interval indicates well is screened or perforated over multiple intervals over depth given.
-999 - null value, no data

Table B-1 continued. *Location, completion, geologic, and water right information for wells in the Cedar Valley study area.*

UGS ID	Aquifer	Geology	Clay Depth, ft	Layer	UTM Easting, m, NAD 1929	UTM Northing, m, NAD 1929	Cadastral location	Well Diame-ter, in	Hole Depth, ft	Depth to Bedrock, ft	Open Interval*, ft	Depth to Water, ft	Depth to Water Date	Well Test Yield, gpm	Draw-down, ft	Dura-tion, hrs	Land Elev., ft, 1929 datum	Completion Date	Water Right
1057	BDRX	Md, Mh, Mg?		3	417267	4439047	(C- 8- 1)20cdb- 2	16	345	207	227-345	125	2/27/67	1902	8	6	4625	3/2/67	53-58
1058	BDRX	BDRX, LS		3	416744	4440077	(C- 8- 1)20bbc- 1	8	340	20	20-340	180	11/1/80				4655	11/1/80	53-864
1059	BDRX	BDRX		3	417329	4438171	(C- 8- 1)29bdc- 1	12	700	320	383-700	137	4/5/69	80	50	1	4628	4/6/67	
1060	X	X			418285	4437590	(C- 8- 1)29dda- 1	12	690	307	m100-595	104	11/17/73	1500	38	8.5	4595	11/23/73	a20677
1063	BDRX	BDRX		3	414873	4437792	(C- 8- 2)25dac- 1	8	600	135	300-390	276	5/24/72	15	70	1	4770	1/1/72	
1066	BF	CLAY			395621	4444310	(C- 8- 3) 6cdc- 1	6	540	>540	270-540	232	9/6/00	12	-999	-999	5128	1/1/52	P00150004M01
1067	BF	CLAY			396112	4443826	(C- 8- 3) 7acb- 1	6	290	>290	270-290	220	10/16/52	10	50	-999	5136	10/16/52	A24258
1075	BF	100VLFL			419564	4434021	(C- 9- 1) 4ddc- 1	18	690	>690	200-683	90	4/2/64				4570	4/2/64	
1076	BF	100VLFL			418101	4434180	(C- 9- 1) 5ddc- 2	16	823	284	m280-740	163	3/30/70	1200	49	6	4642	3/30/70	
1077	BDRX	BDRX		3	418322	4432420	(C- 9- 1) 8ddd- 1	4	210	82	175-189	146	11/26/71	5	0	1	4625	11/26/71	
1078	BF	BF			417152	4431821	(C- 9- 1)17bca- 1		270	>270	230-270	245	11/27/96	-999	-999	4	4745	12/6/96	
1081	BF	BF			418398	4428305	(C- 9- 1)28ccb- 1	20	802	>802	m350-800	130	12/30/62				4643	12/31/62	
1082	BF	BF			419975	4425938	(C- 9- 1)34ccc- 1	10	650	>650	m70-650	30	5/9/66	150	-999	-999	4555	5/9/66	53-1416
1083	BF	BF			421375	4425940	(C- 9- 1)34ddd- 1	2	275	>265	256-275	-0.5	10/10/61	3	3	-999	4515	10/15/61	53-138
1084	BF	BF			422303	4427365	(C- 9- 1)35baa- 1		35	>35	35-35	-5	6/10/49	5	5	-999	4501	6/10/49	
1085	BF	BF			422174	4428098	(C- 9- 1)26cdc- 1		37	>34	37-37	-0.5	9/14/56	0.5	0.5	-999	4495	9/14/56	
1086	BF	BF			398598	4424660	(C-10- 3) 9cdc- 1			>380	334-374						6193	7/27/00	
1088	BF	BF			421210	4428342	(C- 9- 1)27adc- 1		106	>106	106-106	-24	5/28/49	6	24	-999	4498	5/28/49	
1089	BF	BF			394694	4437754	(C- 8- 4)36aab- 1	8	1002	>1002	800-1000	305	5/21/70				5335	5/21/70	
1090	BF	BF			427255	4457241	(D- 6- 1)29dbc- 1	6	140	>140	140-140	-999	-999	60	-999	-999	4496	6/1/73	54-300
1091	BDRX	BDRX		3	426421	4455025	(D- 7- 1) 5bbc- 1	5	150	9	45-90	72	9/2/92	15	-999	3.5	4564	9/2/92	
1092	BDRX	BDRX		3	426337	4453794	(D- 7- 1) 5ccc- 1	6	233	15	100-233	3	2/1/62	250	62	6	4510	2/1/62	
1093	BF	BF			425474	4451118	(D- 7- 1)18dbb- 1	6	173	>173	166-173	12	9/27/58	25	-999	-999	4502	9/27/58	
1095	BDRX	BDRX		3	416726	4439841	(C- 8- 1)19add- 1	6	400	110	120-400	-999	-999	20	-999	-999	4651	6/30/73	53-388
1096	BF	BF			417156	4437572	(C- 8- 1)29cca- 1	8	236	>236	185-236	110	12/30/85	30	2	7	4655	12/31/85	53-903
1097	BDRX	BDRX, Tv		3	416390	4438059	(C- 8- 1)30adc- 1	6	325	165	165-325	125	1/11/96				4675	1/15/96	
1098	BDRX	Tv		3	417087	4433232	(C- 9- 1) 8bcd- 1	14	445	335	345-445	175	3/12/96				4730	3/15/96	9553001P00
1099	BF	BF			422564	4435795	(C- 8- 1)35dcc- 1	4	212	>212	TD212	-999	-999				4490	1/5/45	
1100	X	BF&LS			418230	4436462	(C- 8- 1)32add- 1	15.5	712	673	m230-700	226	11/30/97	1300	280	24	4609	11/30/97	a19390
1101	X	X, BF perf., LS open			417754	4436200	(C- 8- 1)32dbc- 1	15.5	675	550	m180-675	148.6	4/5/95	755	200	24	4631	4/9/95	53-1277
1104	BF	BF			421112	4471061	(C- 5- 1)15aac- 2	6	231	>231	231-231	131	11/21/73	20	0	0.5	4639	11/21/73	
1105	BF	BF			420708	4470599	(C- 5- 1)15acc- 3	6	257	>257	249-250	175	12/20/77	15	0	0.5	4664	12/20/77	
1106	BF	BF			421381	4471097	(C- 5- 1)15aad- 1	8	235	>235	m100-216	16	8/3/91	20	5	1	4614	8/3/91	
1107	BF	BF			422243	4469311	(C- 5- 1)23bda- 1	6	102	>102	102-102	30	7/19/55				4522	7/19/55	
1109	BF	BF			422116	4468292	(C- 5- 1)23cdd- 2	6	131	>131	100-130	43	3/11/93	14	18	1	4535	3/11/93	54-663
1110	BF	BF			421877	4468157	(C- 5- 1)23cdc- 1	6	140	>140	m75-140	45	7/8/94	80	-999	30	4548	7/7/94	54-675
1111	BF	112PLCN			423181	4466820	(C- 5- 1)25ccb- 2	3	147	>147	141-147	-999	-999	100	-999	-999	4510	8/6/52	
1112	BF	BF			419824	4467610	(C- 5- 1)27bcb- 1	0	142	>121	0-0	>142	7/1/61				4670	7/1/61	
1113	X	X, BDRX	0	2	414795	4469830	(C- 5- 2)24aab- 1	1	155	60	m55-155	127.3	5/3/66				4991.71	11/30/65	
1114	BF	BF	725	1-2	414150	4461900	(C- 6- 2)13a- 1	20	1258	>1258	m150-1254	120	1/14/54	75	100	28	4865	1/14/54	
1115	BF	BF		2	401578	4460305	(C- 6- 3)22aaa- 1	-999	100	>100	TD100	>100	9/8/99				5655	9/8/99	
1116	X	X		3	400096	4462331	(C- 6- 3)10ccb- 1	-999	40	20	TD40	>40	9/8/99				6162	9/8/99	
1117	BF	BF	226	2	410028	4457158	(C- 6- 2)27ccc- 1	1	505	>505	m265-495	27.9	4/7/66				4843.21	11/30/65	
1118	BF	BF	95	2	412301	4461163	(C- 6- 2)14dba- 2	10	810	>810	m120-600	102	3/19/64	130	174	720	4859.69	3/21/64	54-50

Aquifer: BDRX = bedrock; BF = basin fill; X = open interval crosses basin-fill/bedrock contact; UK = unknown lithology; BFper = perched unconsolidated aquifer in Cedar Pass; BDRXp = perched bedrock aquifers
Geology from well log, outcrop, or NWIS: BDRX = bedrock, undifferentiated; BF = basin fill; cpp = Cedar Pass perched unconsolidated; X = open interval crosses basin-fill/bedrock contact;
UK = unknown lithology; IPobpl, IPowc, Mmc, Mgb etc. = keyed to geologic unit names on Plate 2; 100VLFL = valley fill; 112PLCN = Pleistocene sediment, PZ = Paleozoic sedimentary bedrock.
Clay depth: depth of shallow clay unit in well log.
Layer: 1 = valley clay unit, 2 = principal basin-fill aquifer (flow model layer 1), 3 = bedrock aquifer (flow model layer 2), 4 = Cedar Pass perched aquifer
* "m" in Open Interval indicates well is screened or perforated over multiple intervals over depth given.
-999 - null value, no data

Table B-1 continued. *Location, completion, geologic, and water right information for wells in the Cedar Valley study area.*

UGS ID	Aquifer	Geology	Clay Depth, ft	Layer	UTM Easting, m, NAD 1929	UTM Northing, m, NAD 1929	Cadastral location	Well Diame-ter, in	Hole Depth, ft	Depth to Bedrock, ft	Open Interval*, ft	Depth to Water, ft	Depth to Water Date	Well Test Yield, gpm	Draw-down, ft	Dura-tion, hrs	Land Elev., ft, 1929 datum	Completion Date	Water Right
1119	BDRX	IPobp or IPowc?	0	3	410192	4470297	(C- 5- 2)15ccb- 1	6	496	468	496-496	437	9/12/72	9	0	1	5240	9/12/72	54-263
1120	BF	BF	85	2	409744	4461976	(C- 6- 2)15bbb- 1	16	835	>835	185-835	85	6/25/57	515	134	792	4874.3	6/25/58	
1121	BF	BF	190	2	409734	4461185	(C- 6- 2)15bcc- 1	16	455	>455	m190-405	77	8/16/57	500	138	720	4862.67	8/16/57	
1122	X	X, BF	82	2	410520	4461964	(C- 6- 2)15abb- 1	16	2366	2042	m222-2070	200	10/29/60	75	0	1	4867.64	2/21/61	54-1003
1123	BF	BF	152	2	409739	4461587	(C- 6- 2)15bcb- 1	16	955	>955	278-955	120	7/3/59	390	140	720	4867.7	7/4/59	
1124	BF	BF	70	2	412323	4461941	(C- 6- 2)14aba- 1	12	1258	>1254	TD1258	121.7	3/28/66	90	-999	-999	4868.52	11/30/53	
1125	BDRX	Mgbu		3	417553	4469840	(C- 5- 1)17dcc- 1	0	1500	135	TD1500	-999	-999				4920	4/18/99	
1126	BDRX	IPobpl		3	415806	4467660	(C- 5- 1)30bda- 1	0	1000	35	TD1000	462	8/19/99	100	-999	-999	4990	8/19/99	
1127	BF	BF	-999	2	410950	4442129	(C- 8- 2)15aad- 1	-999	275	-999	240-275	240.8	3/11/66				4895		
1128	UK	UK, Prob BF. Dug well.	-999	2	413241	4448337	(C- 7- 2)25bdb- 1	-999	200	-999	200-200	-999	-999				4849.09		
1129	UK	UK, IPowc 0.25 mi. W but hand dug so BF?	-999	2	404701	4442059	(C- 8- 2)18bcb- 1	72	290	-999	0-290	-999	-999				4930	11/30/16	54-170
1130	UK	UK, Tvo <0.5 mi W but hand dug BF?	-999	2	405797	4437318	(C- 8- 2)31adb- 1	6	365	-999	343-365	343	3/11/66				5016	11/30/18	54-134
1131	BF	BF	-999	1	406574	4456093	(C- 6- 2)32cbc- 1	15	64	>64	36-64	-999	-999	6	-999	-999	4900.16		54-60
1132	BF	BF	-999	2	408049	4456659	(C- 6- 2)33bcb- 1	2	525	>525	525-525	-10.6	4/7/66	1	-999	-999	4865.03		
1136	UK	UK	0	2	407679	4473035	(C- 5- 2) 8baa- 1	8	358	-999	82-358	73	11/23/74				5605		
1137	UK	UK		3	415794	4468882	(C- 5- 1)19caa- 2	6	105	-999	TD105	>105	8/17/65				4896		
1140	BDRX	IPo		3	398742	4465392	(C- 5- 3)32d- 1				400-400						7400		
1141	BDRX	IPo		3	398970	4465109	(C- 6- 3) 4b- 1				400-400						7360		
1142	BDRX	Mmc or shaly unit of IPo		3	398823	4464765	(C- 6- 3) 4b- 2				400-400						7390		
1143	BDRX	Mmc or shaly unit of IPo		3	398825	4464846	(C- 6- 3) 4b- 3				400-400						7390		
2001	BF	Alluvium		2	411945	4476977	(C- 4- 2)26cbc- 1			-999	0-0						5595		
2002	BDRX	IPobp, basal, on contact w/ IPowc		3	397530	4479060	(C- 4- 3)20dba- 1			0	0-0						9800		
2003	BDRX	IPowc on contact w Mmc in W Canyon		3	402368	4477117	(C- 4- 3)26cbd- 1			0	0-0						6400		
2004	BDRX	IPobp, basal, on contact w/ IPowc		3	403471	4477264	(C- 4- 3)26dda- 1			0	0-0						6600		
2005	BDRX	IPowc		3	401085	4478214	(C- 4- 3)27bab- 1			0	0-0						7040		
2006	BFper	cpp		4	417045	4470741	(C- 5- 1)17bdc- 1			-999	0-0						4980		
2007	BDRX	IPowc or IPobp		3	399452	4473517	(C- 5- 3) 4cdc- 1			0	0-0						7800		
2008	BF	Alluvium		2	400000	4473388	(C- 5- 3) 4dcd- 1			-999	0-0						7400		
2009	BDRX	IPobp		3	404037	4465831	(C- 5- 3)36cba- 1			0	0-0						6280		54-256
2010	BF	BF		2	405659	4464227	(C- 6- 2) 6cad- 2			-999	0-0						5180		54-254
2011	BF	BF		1	406467	4457211	(C- 6- 2)29ccc- 3			-999	0-0						4895		
2012	BDRX	IPobp		3	404747	4465089	(C- 6- 3) 1aad- 1			0	0-0						5720		54-256
2013	BDRX	IPowc on contact w/ Mmc		3	400800	4461819	(C- 6- 3)15bad- 1			0	0-0						6080		
2014	BF	Alluvium		2	406523	4429280	(C- 9- 2)29bac- 1			-999	0-0						5830		
2015	BDRX	IPowc on contact w/ Mmc		3	404507	4467810	(C- 5- 3)25acc- 1			0	0-0						6007		
2016	BDRX	IPowc on contact w/ Mmc		3	403340	4470321	(C- 5- 3)14dbb- 1			0	0-0						6960		
2017	BDRX		0	3	408145	4476240	(C- 4- 3)32aba- 1			0	0-0						5960		54-10
3001	BF	Alluvium		3	406665	4473153	(C- 5- 2) 7aab- 2			20	0-0						5636		
3005	BF	BF			428400	4448400	(C- 7- 1)- 1			0	0-0						4485		

Aquifer: BDRX = bedrock; BF = basin fill; X = open interval crosses basin-fill/bedrock contact; UK = unknown lithology; BFper = perched unconsolidated aquifer in Cedar Pass; BDRXp = perched bedrock aquifers
Geology from well log, outcrop, or NWIS: BDRX = bedrock, undifferentiated; BF = basin fill; cpp = Cedar Pass perched unconsolidated; X = open interval crosses basin-fill/bedrock contact;
UK = unknown lithology; IPobpl, IPowc, Mmc, Mgb etc. = keyed to geologic unit names on Plate 2; 100VLFL = valley fill; 112PLCN = Pleistocene sediment, PZ = Paleozoic sedimentary bedrock.
Clay depth: depth of shallow clay unit in well log.
Layer: 1 = valley clay unit, 2 = principal basin-fill aquifer (flow model layer 1), 3 = bedrock aquifer (flow model layer 2), 4 = Cedar Pass perched aquifer
* "m" in Open Interval indicates well is screened or perforated over multiple intervals over depth given.
-999 - null value, no data

Table B-2. *Key to UGS well ID, Utah Division of Water Rights Well Identification Number (WIN), Public Land Survey (PLS) location, USGS National Water Information System (NWIS) Site Number, and informal well name sorted by section, township, and range.*

[1] PLS location: Public Land Survey location used by Division of Water Rights given in feet from a section corner or quarter corner.

Cadastral location	UGS ID	WIN	PLS location[1]	USGS Site No.	Well Name
(C- 4- 1)27bad- 1	603			402646111561801	
(C- 4- 2) 9aca- 1	604			402916112040401	
(C- 4- 2) 9caa- 1	605			402903112041601	
(C- 4- 2) 9cac- 1	606			402902112042501	
(C- 4- 2)10abc- 1	607			402926112030501	
(C- 4- 2)10ada- 1	608			402910112023901	
(C- 4- 2)11bac- 1	609			402924112021001	
(C- 4- 2)21aaa- 1	1001		N 2702 E 5168 W4 4S 2W 21		
(C- 4- 2)26cbc- 1	2001				Tickville Spring
(C- 4- 3)20dba- 1	2002				
(C- 4- 3)25dbd- 1	1		N 1920 W 1200 SE 4S 3W 25		
(C- 4- 3)26cbd- 1	2003				Cottonwood Spring
(C- 4- 3)26dda- 1	2004				
(C- 4- 3)27bab- 1	2005				
(C- 4- 3)32aba- 1	2017				Oak Springs
(C- 5- 1) 5cdc- 1	610			402420111583701	
(C- 5- 1) 9dad- 1	800	27840	S 3625 W 65 NE 5S 1W 9		
(C- 5- 1)11aca- 1	796				Harvest Hills #2
(C- 5- 1)11add- 1	795				Lake Mtn Mutual Well
(C- 5- 1)11cbd- 1	797				Harvest Hills #1
(C- 5- 1)14bbd- 1	613			402321111552101	
(C- 5- 1)15aac- 1	150		S 1130 W 910 NE 5S 1W 15	402317111554401	
(C- 5- 1)15aac- 2	1104		S 1050 W 1200 NE 5S 1W 15		
(C- 5- 1)15aad- 1	1106		S 900 W 325 NE 5S 1W 15		
(C- 5- 1)15abb- 1	146	6489	S 125 E 300 N4 5S 1W 15		
(C- 5- 1)15abb- 2	149	15680	S 369 E 319 N4 5S 1W 15		
(C- 5- 1)15acc- 1	147	10747	N 104 W 2514 E4 5S 1W 15		
(C- 5- 1)15acc- 2	148		N 365 E 2750 W4 5S 1W 15		
(C- 5- 1)15acc- 3	1105		S 2540 E 140 N4 5S 1W 15		
(C- 5- 1)15cbd- 1	798	25459	N 1300 E 1360 SW 5S 1W 15		Hearthstone Well
(C- 5- 1)16bdd- 1	159	17290	N 500 E 2400 W4 5S 1W 16		
(C- 5- 1)16caa- 1	801	27841	S 3060 W 2895 NE 5S 1W 16		
(C- 5- 1)16cab- 1	158	21958	N 2000 E 1500 SW 5S 1W 16		
(C- 5- 1)16dab- 1	151	8837	N 2100 W 800 SE 5S 1W 16		
(C- 5- 1)16dac- 1	155	19130	N 1980 W 980 SE 5S 1W 16		
(C- 5- 1)16dad- 1	153	16793	N 2000 W 100 SE 5S 1W 16		
(C- 5- 1)16dbd- 1	849		N 1660 W 1660 SE 5S 1W 16		Collins Brothers Wild Cat
(C- 5- 1)16dda- 1	152	14583	N 1000 W 150 SE 5S 1W 16		
(C- 5- 1)16dda- 2	157	18964	N 800 W 280 SE 5S 1W 16		
(C- 5- 1)16ddb- 1	154	18546	N 1350 W 980 SE 5S 1W 16		
(C- 5- 1)17bcd- 1	81	8737	S 10 E 860 W4 5S 1W 17		
(C- 5- 1)17bdc- 1	2006				
(C- 5- 1)17cba- 1	802	8738	S 715 E 1030 W4 5S 1W 17		
(C- 5- 1)17cbb- 1	803	9130	N 2300 E 500 SW 5S 1W 17		
(C- 5- 1)17ccb- 1	141	16089	N 1000 E 900 SW 5S 1W 17		
(C- 5- 1)17ccb- 2	804	10364	N 872 E 491 SW 5S 1W 17		
(C- 5- 1)17ccc- 1	89	14126	N 600 E 300 SW 5S 1W 17		
(C- 5- 1)17ccc- 2	1000	11972	N 152 E 506 SW 5S 1W 17		
(C- 5- 1)17dcc- 1	1125		N 25 E 3100 SW 5S 1W 17		Cedar pass test well #2
(C- 5- 1)17ddc- 1	997	29778	N 475 W 1003 SE 5S 1W 17		Ranches Golf Course
(C- 5- 1)17ddd OR 20aaa- 1	156	21000	N 1 W 139 SE 5S 1W 17	402236111575101	Well # 2
(C- 5- 1)18aaa- 1	1003		S 125 W 125 NE 5S 1W 18		Harvest Haven
(C- 5- 1)18adc- 1	799	8068	S 50 W 660 E4 5S 1W 18		
(C- 5- 1)19aaa- 1	90	11544	S 300 W 200 NE 5S 1W 19		
(C- 5- 1)19aab- 1	91	11849	S 25 W 1085 NE 5S 1W 19		
(C- 5- 1)19aab- 2	136	32048	S 374 W 515 NE 5S 1W 19		
(C- 5- 1)19aab- 3	142	11375	S 408 W 706 NE 5S 1W 19		
(C- 5- 1)19aac- 1	114	14880	S 950 W 1150 NE 5S 1W 19		
(C- 5- 1)19aac- 2	115	11668	S 1000 W 700 NE 5S 1W 19		
(C- 5- 1)19aad- 1	116	14592	S 1100 W 150 NE 5S 1W 19		
(C- 5- 1)19aba- 1	92	15636	S 300 W 1300 NE 5S 1W 19		
(C- 5- 1)19aba- 2	93	11277	S 585 W 1698 NE 5S 1W 19		
(C- 5- 1)19aba- 3	898		S 304 W 1564 NE 5S 1W 19		
(C- 5- 1)19abb- 1	94	12107	S 411 W 2072 NE 5S 1W 19		
(C- 5- 1)19abb- 2	95	14602	S 575 W 2215 NE 5S 1W 19		
(C- 5- 1)19abc- 1	64	13125	S 1250 W 2600 NE 5S 1W 19		
(C- 5- 1)19abc- 2	96	14734	S 1000 W 2300 NE 5S 1W 19		
(C- 5- 1)19abd- 1	112	13116	S 1500 W 1400 NE 5S 1W 19		
(C- 5- 1)19abd- 2	113	13115	S 900 W 1600 NE 5S 1W 19		
(C- 5- 1)19abd- 3	1005	11578	S 908 W 1662 NE 5S 1W 19		
(C- 5- 1)19aca- 1	102	11076	S 1875 W 1755 NE 5S 1W 19		
(C- 5- 1)19aca- 2	111	16109	S 1600 W 1100 NE 5S 1W 19		
(C- 5- 1)19adb- 1	110	11493	S 1820 W 1180 NE 5S 1W 19		
(C- 5- 1)19adc- 1	103		S 2400 W 750 NE 5S 1W 19		
(C- 5- 1)19adc- 2	109	11471	S 2400 W 250 NE 5S 1W 19		
(C- 5- 1)19adc- 3	137	12513	S 2600 W 800 NE 5S 1W 19		
(C- 5- 1)19adc- 4	162	11759	N 232 W 567 E4 5S 1W 19		
(C- 5- 1)19add- 1	120	12594	S 3 W 484 E4 5S 1W 19		
(C- 5- 1)19bbd- 1	77	11430	S 1100 W 4300 NE 5S 1W 19		
(C- 5- 1)19bbd- 2	97	11563	S 1229 W 1143 N4 5S 1W 19		
(C- 5- 1)19bca- 1	99	12595	S 1440 W 4113 NE 5S 1W 19		
(C- 5- 1)19bcc- 1	106	14645	S 2900 W 4800 NE 5S 1W 19		
(C- 5- 1)19bcd- 1	107	14515	N 165 E 775 W4 5S 1W 19		
(C- 5- 1)19bcd- 2	108	14121	S 2900 W 3800 NE 5S 1W 19		
(C- 5- 1)19bcd- 3	863	28338	S 2250 W 4450 NE 5S 1W 19		

Table B-2 continued. *Key to well IDs and names.*

Cadastral location	UGS ID	WIN	PLS location[1]	USGS Site No.	Well Name
(C- 5- 1)19bdb- 1	100	11684	S 1700 W 3500 NE 5S 1W 19		
(C- 5- 1)19bdb- 2	101	12143	S 1641 W 3200 NE 5S 1W 19		
(C- 5- 1)19bdb- 3	805	27467	S 1435 W 3837 NE 5S 1W 19		
(C- 5- 1)19bdc- 1	105	12179	S 2378 E 1948 NW 5S 1W 19		
(C- 5- 1)19bdd- 1	104	14263	S 2250 W 2750 NE 5S 1W 19		
(C- 5- 1)19caa- 1	126	14897	N 2450 E 2500 SW 5S 1W 19		
(C- 5- 1)19caa- 2	1137				
(C- 5- 1)19cac- 1	806	28021	N 1700 E 1700 SW 5S 1W 19		
(C- 5- 1)19dab- 1	988	29540	S 3300 W 300 NE 5S 1W 19		
(C- 5- 1)19dac- 1	1006	12691	N 1901 W 839 SE 5S 1W 19		
(C- 5- 1)19dba- 1	161	12136	S 2946 W 1695 NE 5S 2W 19		
(C- 5- 1)19dbc- 1	123	14896	N 1350 E 3000 SW 5S 1W 19		
(C- 5- 1)19dbc- 2	124	14646	N 1623 E 285 S4 5S 1W 19		
(C- 5- 1)19dbd- 1	125	14898	N 1950 E 3300 SW 5S 1W 19		
(C- 5- 1)19dbd- 2	160	14036	S 930 E 3575 W4 5S 1W 19		
(C- 5- 1)19dca- 1	121	14886	S 4050 W 1700 NE 5S 1W 19		
(C- 5- 1)19dcc- 1	122	13724	N 500 E 2800 SW 5S 1W 19		
(C- 5- 1)19dcd- 1	127	12180	N 2142 E 3678 W4 5S 1W 19		
(C- 5- 1)19dcd- 2	1007		N 500 E 820 S4 5S 1W 19		
(C- 5- 1)19ddb- 1	807	29570	S 4300 W 1200 NE 5S 1W 19		
(C- 5- 1)20aab- 1	1002		S 342 E 9516 SW 5S 1W 18		Cedar Pass Test Well #3 but log says "Test Well #2"
(C- 5- 1)20bba- 1	88	14516	S 250 E 900 NW 5S 1W 20		
(C- 5- 1)20ddc- 1	1008		N 110 E 750 SE 5S 1W 20	402227111580801	USGS-T3 (Feltis, 1969) or T-1 (Hurlow, 2004)
(C- 5- 1)21dcc- 1	2	1802	N 300 W 2400 SE 5S 1W 21		
(C- 5- 1)22acb- 1	815	7519	S 1395 E 135 N4 5S 1W 22		
(C- 5- 1)22adb- 1	817	8648	S 1650 E 1750 N4 5S 1W 22		
(C- 5- 1)22bac- 1	816	7640	N 784 W 1060 S4 5S 1W 22		
(C- 5- 1)22caa- 1	808	19376	S 300 E 2200 W4 5S 1W 22		
(C- 5- 1)22cac- 1	812	6096	S 844 E 1935 W4 5S 1W 22		
(C- 5- 1)22cac- 2	813	6629	S 798 E 1574 W4 5S 1W 22		
(C- 5- 1)22cbd- 1	809	21762	N 1400 W 1300 S4 5S 1W 22	402158111562301	
(C- 5- 1)22cbd- 2	814	6753	N 1400 E 700 SW 5S 1W 22		
(C- 5- 1)22cdb- 1	871			402152111561801	
(C- 5- 1)22daa- 1	811	3187	S 120 W 588 E4 5S 1W 22		
(C- 5- 1)22daa- 2	821	19103	S 350 W 450 E4 5S 1W 22		
(C- 5- 1)22dab- 1	818	13470	S 114 W 753 E4 5S 1W 22		
(C- 5- 1)22dba- 1	820	13490	S 133 W 1426 E4 5S 1W 22	402208111554901	
(C- 5- 1)22dbb- 1	819	13471	S 120 W 2150 E4 5S 1W 22	402206111555701	
(C- 5- 1)22dcc- 1	810	20652	N 400 E 50 S4 5S 1W 22		
(C- 5- 1)23acb- 1	170	9201	N 851 E 3053 W4 5S 1W 23		
(C- 5- 1)23acc- 1	163	6637	N 193 E 2974 W4 5S 1W 23		
(C- 5- 1)23acc- 2	171	3157	N 135 E 2997 W4 5S 1W 23		
(C- 5- 1)23bcd- 1	822	2921	N 184 E 934 W4 5S 1W 23		
(C- 5- 1)23bda- 1	1107		S 1465 W 90 N4 5S 1W 23	402222111545801	
(C- 5- 1)23bda- 2	169		S 1490 W 60 N4 5S 1W 23		
(C- 5- 1)23bda- 3	823	13498	N 969 W 3037 E4 5S 1W 23		
(C- 5- 1)23bdd- 1	166	14323	N 234 E 2059 W4 5S 1W 23		
(C- 5- 1)23cab- 1	165	21718	S 90 E 1369 W4 5S 1W 23		
(C- 5- 1)23cda- 1	164		N 1200 W 500 S4 5S 1W 23	402155111550201	
(C- 5- 1)23cda- 2	168	10812	N 625 W 250 S4 5S 1W 23		
(C- 5- 1)23cdc- 1	1110	6690	N 34 W 1256 S4 5S 1W 23		
(C- 5- 1)23cdd- 1	167	10813	N 500 W 250 S4 5S 1W 23		
(C- 5- 1)23cdd- 2	1109	2008	N 476 W 472 S4 5S 1W 23		
(C- 5- 1)23daa- 1	615			402207111542601	
(C- 5- 1)25cba- 1	628			402113111540501	
(C- 5- 1)25cbb- 1	629			402115111542001	
(C- 5- 1)25cbd- 1	630			402110111541001	
(C- 5- 1)25ccb- 2	1111		N 1061 E 5717 SW 5S 1W 26	402100111541701	
(C- 5- 1)25ccc- 4	631			402052111542001	
(C- 5- 1)25ccc- 5	172		S 4806 W 5271 NE 5S 1W 25		
(C- 5- 1)26baa- 1	1009		S 100 W 300 N4 5S 1W 26	402143111550000	
(C- 5- 1)26bdb- 1	173	27891	S 1860 W 814 N4 5S 1W 26	402125111550501	
(C- 5- 1)27bcb- 1	1112		N 720 E 10 W4 5S 1W 27		
(C- 5- 1)27dad- 1	174		N 1500 E 4840 SW 5S 1W 27		
(C- 5- 1)28bba- 1	59	12185	S 310 E 1100 NW 5S 1W 28		
(C- 5- 1)29dda-2	984	430562	N 890 W 15 SE 5S 1W 29		Eagle Mountain municipal well #4
(C- 5- 1)30bcd- 1	992	30943	S 2440 W 1565 N4 5S 1W 30		Pony Express Well
(C- 5- 1)30bda- 1	1126		S 1900 W 2600 NE 5S 1W 30		Cedar pass test well #4
(C- 5- 1)30cab-1	901	429140	S 5 E 1694 W4 5S 1W 30		MW1
(C- 5- 1)30ddd- 1	824	27842	N 225 W 175 SE 5S 1W 30		
(C- 5- 1)31bcc- 1	7	1291	N 10 E 187 W4 5S 1W 31		
(C- 5- 1)35cab- 1	826	13491	S 2816 W 684 N4 5S 1W 35		
(C- 5- 1)35cab- 2	827	28579	N 2133 W 776 S4 5S 1W 35		
(C- 5- 1)35cda- 1	825	3917	N 1305 W 304 S4 5S 1W 35		
(C- 5- 2) 7aab- 1	1010	22950	N 2385 W 943 E4 5S 2W 7		
(C- 5- 2) 7aab- 2	3001				West Canyon Creek
(C- 5- 2) 8baa- 1	1136				
(C- 5- 2)13ddd- 1	98	12274	N 100 W 120 SE 5S 2W 13		
(C- 5- 2)14cdc- 1	1011	19064	N 100 E 1420 SW 5S 2W 14		Cedar Pass Test Well 1
(C- 5- 2)15ccb- 1	1119	13501	N 1242 E 123 SW 5S 2W 15		
(C- 5- 2)24aaa- 1	790	34568	S 285 W 850 NE 5S 2W 24		
(C- 5- 2)24aaa- 2	829	26437	N 2000 W 642 E4 5S 2W 24		
(C- 5- 2)24aab- 1	1113			402234112001101	USGS-T2
(C- 5- 2)24abc- 1	129	17566	S 900 W 2400 NE 5S 2W 24		
(C- 5- 2)24ada- 1	830	28714	S 1600 W 200 NE 5S 2W 24		
(C- 5- 2)24adb- 1	128	15704	S 2000 W 600 NE 5S 2W 24		
(C- 5- 2)24cdd-1	902	429141	N 110 W 475 S4 5S 2W 24		MW2A
(C- 5- 2)24cdd-2	903	429141	N 110 W 475 S4 5S 2W 24		MW2b
(C- 5- 2)25bbb- 1	33		S 195 E 75 NW 5S 2W 25	402142112011101	
(C- 5- 2)25cbb- 1	831	5527	S 641 E 498 W4 5S 2W 25		
(C- 5- 2)26bbb- 1	18		S 20 E 50 NW 5S 2W 26	402142112022001	Rosie Smith well?

Table B-2 continued. *Key to well IDs and names.*

Cadastral location	UGS ID	WIN	PLS location[1]	USGS Site No.	Well Name
(C- 5- 2)28ccb- 1	145	21885	N 1250 E 450 SW 5S 2W 28	402100112043601	Limousin Ranch #1
(C- 5- 2)30dcc- 1	832	29442	N 877 E 3077 SW 5S 2W 30		
(C- 5- 2)31cdd- 1	833	29507	N 240 E 1270 SW 5S 2W 31		
(C- 5- 2)31dcd- 1	175	13504	N 649 E 873 S4 5S 2W 31		
(C- 5- 2)32aab- 1	68	15496	S 200 W 660 NE 5S 2W 32		
(C- 5- 2)34dab- 1	1041		S 3109 W 1157 NE 5S 2W 34	402019112023201	
(C- 5- 3) 4cdc- 1	2007				
(C- 5- 3) 4dcd- 1	2008				
(C- 5- 3)14dbb- 1	2016				Fourmile Spring
(C- 5- 3)20baa- 1	1013	12986	S 100 W 200 N4 5S 3W 20		
(C- 5- 3)25acc- 1	2015				Crafts Spring
(C- 5- 3)31ddd- 1	1049		N 50 E 50 NE 6S 3W 6		
(C- 5- 3)32ccd- 1	1014		N 100 E 700 SW 5S 3W 32		
(C- 5- 3)32d- 1	1140				Barrick MW18
(C- 5- 3)32dcd- 1	1015		N 500 E 3400 SW 5S 3W 32		Barrick MW15
(C- 5- 3)33ccc- 1	1048		N 50 E 200 NE 6S 3W 5		Barrick MW16
(C- 5- 3)36cba- 1	2009				Spring Creek Spring
(C- 5- 4)13dac- 1	85	5130	N 1764 W 931 SE 5S 4W 13		
(C- 5-1)30dbd-1	983	430695	S 3468 W1988 NE 5S 1W 30		Eagle Mountain municipal well #5
(C- 6- 1) 1bcd- 1	794				Golf Course Well
(C- 6- 1) 2ddb- 1	792				Jacobs Ranch Well
(C- 6- 1) 6dab- 1	62	8435	N 2200 W 1100 SE 6S 1W 6		
(C- 6- 1) 6dba- 1	836	26580	N 1850 E 825 S4 6S 1W 6		
(C- 6- 1) 6dcd- 1	39	16375	N 49 E 946 S4 6S 1W 6		
(C- 6- 1) 7aba- 1	75	21236	S 175 E 869 N4 6S 1W 7		
(C- 6- 1) 7dba- 1	52	14682	S 472 E 3421 W4 6S 1W 7		
(C- 6- 1) 7dba- 2	139	11678	S 385 E 3911 W4 6S 1W 7		
(C- 6- 1) 7dbb- 1	50	682	S 37 E 2911 W4 6S 1W 7		
(C- 6- 1)12dba- 1	838	23279	N 2109 W 1642 NE 6S 1W 13		Rathole Well
(C- 6- 1)12dba- 2	1017		N 2000 W 1900 SE 6S 1W 12		
(C- 6- 1)12dbd- 1	1016		N 2000 W 1930 SE 6S 1W 12		
(C- 6- 1)13daa- 1	837	9085	S 250 W 300 E4 6S 1W 13		
(C- 6- 1)18bad- 1	874			401806111594401	
(C- 6- 1)18cdd- 1	56		N 776 W 291 S4 6S 1W 18	401730111594501	Howard Ault well 14
(C- 6- 1)18cdd- 2	1018		N 840 W 278 S4 6S 1W 18	401730111594502	WELL #1
(C- 6- 1)18dca- 1	27		N 1356 W 1006 SE 6S 1W 18	401739111593401	
(C- 6- 1)19aba- 1	839	4063	S 237 E 1285 N4 6S 1W 19		Limousin Ranch #3
(C- 6- 1)19acc- 1	41		S 2000 W 2500 NE 6S 1W 19	401702111594001	LDS Church well 13
(C- 6- 1)20bad- 1	1020		S 1245 W 535 N4 6S 1W 20		
(C- 6- 1)20bdb- 1	1019		S 1457 E 2072 NW 6S 1W 20		
(C- 6- 1)29aab- 1	1021	17927	S 175 W 969 NE 6S 1W 29		
(C- 6- 1)30aba- 1	57	4222	S 22 E 1190 N4 6S 1W 30		
(C- 6- 1)30abc- 1	58	9319	S 730 W 170 N4 6S 1W 30		Cedar Valley P&B #14
(C- 6- 1)31dab- 1	1023		S 264 W 957 E4 6S 1W 31	401507111561101	
(C- 6- 1)31dab- 2	26	14662	S 256 W 907 E4 6S 1W 31		
(C- 6- 2) 1acc- 1	1024		S 2000 W 2500 NE 6S 2W 1	401935112005001	USGS-T1 (Feltis, 1969) or T-3 (Hurlow, 2004)
(C- 6- 2) 3ccc- 1	47		N 300 E 300 SW 6S 2W 3	401917112034200	
(C- 6- 2) 4cac- 1	632			401929112043401	
(C- 6- 2) 5acb- 1	132	18535	S 1645 E 92 N4 6S 2W 5		
(C- 6- 2) 5add- 1	841	24922	N 230 W 190 E4 6S 2W 5		
(C- 6- 2) 5bdb- 1	840	22778	N 3234 E 1677 SW 6S 2W 5		
(C- 6- 2) 5bdc- 1	133	17510	S 2400 E 1800 NW 6S 2W 5		
(C- 6- 2) 5caa- 1	1027	13518	N 2210 W 114 S4 6S 2W 5		
(C- 6- 2) 5cad- 1	879			401930112053001	Drought relief well
(C- 6- 2) 5cca- 1	5	13516	N 1131 E 1050 SW 6S 2W 5		
(C- 6- 2) 5cca- 2	53	22122	N 977 W 1540 S4 6S 2W 5		
(C- 6- 2) 5cca- 3	1026	13517	N 1306 W 1818 S4 6S 2W 5		
(C- 6- 2) 6aaa- 1	845	25232	S 300 W 480 NE 6S 2W 6		
(C- 6- 2) 6aad- 1	15	2747	S 1150 W 600 NE 6S 2W 6		
(C- 6- 2) 6acb- 1	842	26978	S 1700 E 100 N4 6S 2W 6		
(C- 6- 2) 6adb- 1	16		N 930 W 1160 E4 6S 2W 6		
(C- 6- 2) 6adb- 2	60	15458	N 446 W 890 E4 6S 2W 6		
(C- 6- 2) 6adb- 3	135	18821	S 830 E 1250 N4 6S 2W 6		
(C- 6- 2) 6adb- 4	1028	13515	S 1343 W 941 NE 6S 2W 6		
(C- 6- 2) 6add- 1	13	28246	S 71 W 26 E4 6S 2W 6		
(C- 6- 2) 6add- 2	51	22250	N 590 W 590 E4 6S 2W 6		
(C- 6- 2) 6bac- 1	843	23333	S 720 E 1730 NW 6S 2W 6		
(C- 6- 2) 6bda- 1	43	1367	S 1350 E 2300 NW 6S 2W 6		
(C- 6- 2) 6cad- 1	66	11227	N 1549 W 2666 SE 6S 2W 6		
(C- 6- 2) 6cad- 2	2010				South Spring
(C- 6- 2) 6cda- 1	67	17144	N 894 W 338 S4 6S 2W 6		
(C- 6- 2) 6daa- 1	72	10582	N 2111 W 15 SE 6S 2W 6		
(C- 6- 2) 6daa- 2	846	26247	N 2259 W 15 SE 6S 2W 6		
(C- 6- 2) 6dab- 1	10	13514	N 2333 W 1104 SE 6S 2W 6		
(C- 6- 2) 6dad- 1	14	13513	S 1175 W 511 E4 6S 2W 6		
(C- 6- 2) 6dad- 2	998	29761	N 1424 W 249 SE 6S 2W 6		IFA drilled under 0454002M00
(C- 6- 2) 6dbd- 1	46	18888	N 1643 E 724 S4 6S 2W 6		
(C- 6- 2) 6dcb- 1	844	13512	N 654 E 125 S4 6S 2W 6		
(C- 6- 2) 6dcc- 1	55	17205	N 201 W 2348 SE 6S 2W 6		
(C- 6- 2) 6dcd- 1	12	5531	N 453 E 953 S4 6S 2W 6		
(C- 6- 2) 6ddb- 1	144	21642	N 900 W 700 SE 6S 2W 6		
(C- 6- 2) 6ddc- 1	73	20974	N 173 W 1130 SE 6S 2W 6		
(C- 6- 2) 6ddd- 1	11		N 426 W 642 SE 6S 2W 6		
(C- 6- 2) 6ddd- 2	17	4054	N 170 W 630 SE 6S 2W 6		
(C- 6- 2) 6ddd- 3	138	20147	N 278 E 2040 S4 6S 2W 6		
(C- 6- 2) 6ddd- 4	143	21545	N 380 W 480 SE 6S 2W 6		
(C- 6- 2) 7aba- 1	847	24297	S 15 W 1550 NE 6S 2W 7		Community Center Well
(C- 6- 2) 7ccb- 1	1050	13511	N 609 E 123 SW 6S 2W 7		
(C- 6- 2) 7ccc- 1	989		S 0 E 0 SW 6S 2W 7		Goat Farm Hole
(C- 6- 2) 8ddc- 1	9	13509	N 115 W 1214 SE 6S 2W 8		
(C- 6- 2) 9baa- 1	8	13510	S 1656 W 424 N4 6S 2W 9	401911112042001	

Table B–2 continued. *Key to well IDs and names.*

Cadastral location	UGS ID	WIN	PLS location[1]	USGS Site No.	Well Name
(C- 6- 2)13a- 1	1114		NE 6S 2W 13		
(C- 6- 2)13caa- 1	1029		S 645 E 2667 W4 6S 2W 13	401747112005101	LDS Church well 10, also (C- 6- 2)13caa- 2
(C- 6- 2)13dda- 1	1030		N 1300 W 25 SE 6S 2W 13		
(C- 6- 2)14aba- 1	1124			401818112014501	
(C- 6- 2)14aca- 1	876			401805112010501	
(C- 6- 2)14bcd- 1	1031		N 2984 E 665 SW 6S 2W 14	401756112022701	Monte Vista Ranch. LDS Church well 4
(C- 6- 2)14cac- 1	134	13534	N 1319 E 1689 SW 6S 2W 14	401743112021301	LDS Church well #1 in court documents
(C- 6- 2)14dba- 1	875			401754112014701	
(C- 6- 2)14dba- 2	1118	13533	N 2697 E 3128 SW 6S 2W 14	401754112015601	Feltis' (C- 6- 2)14dba- 1
(C- 6- 2)15abb- 1	1122	2527	S 117 E 2640 NW 6S 2W 15	401818112030501	LDS Church well 7
(C- 6- 2)15bbb- 1	1120		S 100 E 50 NW 6S 2W 15	401818112034201	LDS Church well 5
(C- 6- 2)15bcb- 1	1123		S 1320 E 60 NW 6S 2W 15	401806112034301	LDS Church well 8
(C- 6- 2)15bcc- 1	1121		S 2640 E 50 NW 6S 2W 15	401754112034301	LDS Church well 6, Feltis' (C-6-2)15cbb-1
(C- 6- 2)16baa- 1	29	13532	S 80 E 180 N4 6S 2W 16	401818112042001	
(C- 6- 2)17bbc- 1	140	19489	S 1140 E 25 NW 6S 2W 17		
(C- 6- 2)17bbc- 2	1032		S 1050 E 10 NW 6S 2W 17		
(C- 6- 2)17cbd- 1	28	13531	N 1421 W 1765 S4 6S 2W 17		Small Well
(C- 6- 2)17dcc- 1	1035		N 182 E 35 S4 6S 2W 17	401729112052701	S White irrigation well
(C- 6- 2)17dcc- 2	44		N 526 E 40 S4 6S 2W 17	401734112052601	N White irrigation well
(C- 6- 2)18aad- 1	1033	13530	S 1035 W 38 NE 6S 2W 18	401810112060001	Cook Well
(C- 6- 2)19add- 1	995	30874	S 75 W 1120 NE 6S 2W 19		
(C- 6- 2)21dcc- 1	850	24695	N 50 W 50 S4 6S 2W 21		
(C- 6- 2)23bbb- 1	74	11305	S 136 E 636 NW 6S 2W 23		
(C- 6- 2)23bcc- 1	131	16084	N 70 E 300 W4 6S 2W 23		
(C- 6- 2)23ccc- 1	119	10234	N 66 E 402 SW 6S 2W 23		
(C- 6- 2)23dbb- 1	991	30004	N 2000 E 50 S4 6S 2W 23		
(C- 6- 2)24ccd- 1	1036	11852	N 100 E 100 SW 6S 2W 24		EM monitoring well
(C- 6- 2)25abb- 1	35		N 0 W 2640 NE 6S 2W 25		
(C- 6- 2)25cbc- 1	877			401556112012201	
(C- 6- 2)26abb- 1	990	29853	S 250 E 150 N4 6S 2W 26		
(C- 6- 2)26cbb- 1	4	13529	S 64 E 57 W4 6S 2W 26	401607112023401	LDS Church Well 11, Turf Farm well #1
(C- 6- 2)26cbc- 1	994		S 836 E 56 W4 6S 2W 26	401600112023401	#2
(C- 6- 2)27bbd- 1	851		S 1320 E 1320 NW 6S 2W 27		
(C- 6- 2)27cca- 1	45		N 1320 E 1320 SW 6S 2W 27	401554112032701	
(C- 6- 2)27ccc- 1	1117			401543112032901	USGS Test hole #4
(C- 6- 2)27ccc- 2	878			401544112032801	USGS-T5
(C- 6- 2)28aac- 1	853		S 1310 W 1310 NE 6S 2W 28		
(C- 6- 2)28bac- 1	852		S 1220 W 660 N4 6S 2W 28	401624112043101	
(C- 6- 2)28bcc- 1	79	6994	N 137 E 144 W4 6S 2W 28		
(C- 6- 2)28ccb- 1	36	13528	N 1077 E 332 SW 6S 2W 28		
(C- 6- 2)28ccc- 1	791	34447	N 624 E 79 SW 6S 2W 28		
(C- 6- 2)29bbd- 2	882			401624112054801	
(C- 6- 2)29bdb- 1	1037		SE4 OF NW4 6S 2W 29	401620112054301	Replacement well #2
(C- 6- 2)29bdd- 1	881		N 2690 E 2390 SW 6S 2W 29	401610112053101	
(C- 6- 2)29cac- 1	880			401600112054101	
(C- 6- 2)29cac- 2	854	13527	N 1530 E 1335 SW 6S 2W 29	401557112053701	
(C- 6- 2)29cac- 3	30	5677	N 1530 W 820 S4 6S 2W 29		
(C- 6- 2)29cac- 4	31	11646	N 1375 W 730 S4 6S 2W 29		
(C- 6- 2)29ccc- 1	897			401548112060201	
(C- 6- 2)29ccc- 2	87	7110	N 436 E 178 SW 6S 2W 29		
(C- 6- 2)29ccc- 3	2011				Fairfield Spring
(C- 6- 2)29cdc- 1	82	587	N 447 W 635 S4 6S 2W 29		
(C- 6- 2)29cdd- 1	83	247	N 437 W 454 S4 6S 2W 29		
(C- 6- 2)29cdd- 2	130	21708	N 201 W 371 S4 6S 2W 29		
(C- 6- 2)29dac- 1	855	24931	N 1320 W 1030 SE 6S 2W 29		
(C- 6- 2)29dbd- 1	32	5798	N 1537 E 1292 S4 6S 2W 29		
(C- 6- 2)29dca- 1	69	21145	N 1027 E 1334 S4 6S 2W 29		
(C- 6- 2)29dcd- 1	70	17383	N 147 E 1328 S4 6S 2W 29		
(C- 6- 2)29ddb- 1	49	13526	N 1146 W 981 SE 6S 2W 29	401553112050601	
(C- 6- 2)29ddc- 1	78	17252	N 200 W 1140 SE 6S 2W 29		
(C- 6- 2)32aaa- 1	24	13525	S 223 W 355 NE 6S 2W 32	401539112045501	
(C- 6- 2)32aab- 1	20	555	S 45 E 1410 N4 6S 2W 32		
(C- 6- 2)32aab- 2	71	19574	S 587 E 1577 N4 6S 2W 32		
(C- 6- 2)32abb- 1	65	246	S 578 E 88 N4 6S 2W 32		
(C- 6- 2)32abb- 2	84	586	S 190 E 103 N4 6S 2W 32		
(C- 6- 2)32ada- 1	21	13524	S 312 E 3466 NW 6S 2W 32		
(C- 6- 2)32baa- 1	22	13523	S 310 W 550 N4 6S 2W 32		
(C- 6- 2)32bab- 1	23	13522	S 540 W 740 N4 6S 2W 32		
(C- 6- 2)32bbd- 1	1039		S 608 E 1300 NW 6S 2W 32	401537112054701	Replacement well #1
(C- 6- 2)32bcd- 1	25	28631	N 188 E 1085 W4 6S 2W 32		
(C- 6- 2)32cbc- 1	1131		S 873 E 577 W4 6S 2W 32	401509112055401	
(C- 6- 2)32dbb- 1	1038		N 2630 W 2600 SE 6S 2W 32		
(C- 6- 2)33bac- 1	37	33099	S 751 E 1349 NW 6S 2W 33		
(C- 6- 2)33bbd- 1	857	20891	S 800 E 1000 NW 6S 2W 33		
(C- 6- 2)33bcb- 1	1132			401525112045201	
(C- 6- 2)33cdc- 1	34	12623	N 41 E 1488 SW 6S 2W 28		
(C- 6- 2)33dbd- 1	38		N 1790 W 1930 SE 6S 2W 33		
(C- 6- 2)34bac- 1	1040	13519	S 1320 E 1425 NW 6S 2W 34	401530112032501	
(C- 6- 2)36bcb- 1	1042		S 1320 E 0 NW 6S 2W 36		
(C- 6- 3) 1aad- 1	2012				Tunnel Spring
(C- 6- 3) 4b- 1	1141				Barrick MW17
(C- 6- 3) 4b- 2	1142				Barrick MW2
(C- 6- 3) 4b- 3	1143				Barrick MW1
(C- 6- 3) 4bcc- 1	1045		N 2600 E 150 SW 6S 3W 4		
(C- 6- 3) 4bcc- 2	1046		N 2720 E 200 SW 6S 3W 4		
(C- 6- 3) 4cbc- 1	1044		N 1400 E 400 SW 6S 3W 4		
(C- 6- 3) 4cbd- 1	1043		N 1450 E 400 SW 6S 3W 4		
(C- 6- 3) 5bba- 1	1047	1017	S 240 E 700 NW 6S 3W 5		
(C- 6- 3)10ccb- 1	1116		N 730 E 990 SE 6S 3W 10		BG-1
(C- 6- 3)12dab- 1	858		S 150 W 820 E4 6S 3W 12		
(C- 6- 3)15bad- 1	2013				Manning Canyon Spring

Table B-2 continued. *Key to well IDs and names.*

Cadastral location	UGS ID	WIN	PLS location[1]	USGS Site No.	Well Name
(C- 6- 3)22aaa- 1	1115		S 550 W 65 NE 6S 3W 22		Barrick MW-2
(C- 7- 1)- 1	3005				Utah Lake
(C- 7- 1) 7bda- 1	859	28010	S 1600 W 350 N4 7S 1W 7		
(C- 7- 1)13adc- 1	1051	13535	S 2200 W 1300 NE 7S 1W 13	401241111534400	
(C- 7- 1)18cbb- 1	76	5682	N 2600 E 200 SW 7S 1W 18	401235112001501	
(C- 7- 1)19baa- 1	117	7852	S 125 W 263 N4 7S 1W 19		
(C- 7- 1)26cda- 1	860	9603	N 737 E 1814 SW 7S 1W 26		
(C- 7- 1)26cdb- 1	188	3591	N 1130 E 1620 SW 7S 1W 26		
(C- 7- 1)26cdd- 1	1052		N 520 E 2550 SW 7S 1W 26	401019111544101	
(C- 7- 2) 5bba- 1	61	8897	S 48 E 1135 NW 7S 2W 5		
(C- 7- 2) 5bda- 1	861	28000	S 1530 W 270 N4 7S 2W 5		
(C- 7- 2) 5cbc- 1	896				
(C- 7- 2)11bbc- 1	42		S 750 E 150 NW 7S 2W 11		
(C- 7- 2)20cad- 1	862	28049	N 1320 E 2200 SW 7S 2W 20		
(C- 7- 2)23bcc- 1	1053		N 8460 W 10560 SW 7S 1W 30	401149112023301	
(C- 7- 2)23bcc- 2	118	8515	N 88 E 51 W4 7S 2W 23	401145112023301	
(C- 7- 2)25bdb- 1	1128			401059112010701	
(C- 7- 2)25cdd- 1	40		N 210 W 150 S4 7S 2W 25		
(C- 7- 2)28bcc- 1	19	3170	N 150 E 150 W4 7S 2W 28		
(C- 7- 2)29aad- 1	864	27484	S 950 W 580 NE 7S 2W 29		
(C- 7- 2)29cac- 1	63	9679	N 1350 E 2100 SW 7S 2W 29		
(C- 7- 2)29dbc- 1	883			401040112052301	
(C- 7- 2)29dbc- 2	789	35159	N 1460 W 2380 SE 7S 2W 29		Yellowbrush well
(C- 7- 2)31abc- 1	884			401016112063101	
(C- 7- 2)33aaa- 1	80	11581	S 7 W 6 NE 7S 2W 33		
(C- 7- 2)35bcc- 1	1054		S 2400 W 10660 SW 7S 1W 30	401002112023201	
(C- 7- 2)36dad- 1	6		N 1500 W 300 SE 7S 2W 36	400948112002100	
(C- 7- 3) 2dbc- 1	86	13147	N 1500 W 2600 SE 7S 3W 2		
(C- 7- 3)20ddb- 1	865	22638	N 1300 W 1000 SE 7S 3W 20		
(C- 7- 3)30acc- 1	189		N 2640 E 1 S4 7S 3W 30		
(C- 7- 3)30acc- 1	633			401010112131401	
(C- 7- 4)14aac- 1	885			401250112052001	
(C- 8- 1) 4dcb- 1	1055		N 1105 E 58 SW 8S 1W 4		
(C- 8- 1)17acc- 1	1056		N 2178 W 2293 E4 8S 1W 17		
(C- 8- 1)19add- 1	1095	33024	S 2155 W 208 NE 8S 1W 19		
(C- 8- 1)20bbc- 1	1058	13545	S 1383 W 151 NE 8S 1W 19		
(C- 8- 1)20cdb- 1	193	13544	N 0 W 2640 E4 8S 1W 29	400600111581801	
(C- 8- 1)20cdb- 1	899		N 0 W 2640 E4 8S 1W 29		
(C- 8- 1)20cdb- 2	1057		N 575 E 1547 SW 8S 1W 20	400600111581001	#1?
(C- 8- 1)20cdb- 3	192		N 567 W 999 S4 8S 1W 20	400602111581202	
(C- 8- 1)20cdb- 4	835		N 563 E 1552 SW SL 8S W1 20		
(C- 8- 1)29bdc- 1	1059		S 2250 E 1810 NW 8S 1W 29		
(C- 8- 1)29cca- 1	1096	1289	N 1125 W 400 SE 8S 1W 29		
(C- 8- 1)29dda- 1	1060		N 1200 W 60 SE 8S 1W 29	400513111572801	
(C- 8- 1)30adc- 1	1097	11001	S 0 W 1225 E4 8S 1W 30		
(C- 8- 1)32aba- 1	194	13542	S 528 E 1056 N4 8S 1W 32		
(C- 8- 1)32add- 1	1100	11319	S 2600 W 350 NE 8S 1W 32		
(C- 8- 1)32dbc- 1	1101	8281	N 1900 E 600 S4 8S 1W 32		
(C- 8- 1)34bcc- 1	195	13541	N 28 E 375 W4 8S 1W 34	400436111561900	
(C- 8- 1)35dcc- 1	1099		N 600 E 3340 SW 8S 1W 35		
(C- 8- 2)15aad- 1	1127			400736112024201	
(C- 8- 2)18bcb- 1	1129				West Well
(C- 8- 2)25dac- 1	1063		N 1752 W 1080 SE 8S 2W 25	400517111595400	
(C- 8- 2)31adb- 1	1130		S 1400 W 1300 NE 8S 2W 31	400453112061701	Jacob Well
(C- 8- 3) 3cbd- 1	987	429190	S 1002 E 1187 W4 8S 2W 03		LA2C
(C- 8- 3) 5abd- 1	986	427499	S 830 W 1590 NE 8S 2W 05		LA1
(C- 8- 3) 6aac- 1	634			400920112124701	
(C- 8- 3) 6cdc- 1	1066		N 240 E 1524 SW 8S 3W 6		
(C- 8- 3) 7acb- 1	1067		S 1320 W 2194 NE 8S 3W 7		
(C- 8- 3) 9aad- 1	985		S 1158 W 584 NE 5S 2W 09		SP#1
(C- 8- 4)36aab- 1	1089		S 100 W 1170 NE 8S 4W 36		
(C- 9- 1) 4ccc- 1	886			400315111572001	
(C- 9- 1) 4ddc- 1	1075		N 10 W 1320 SW 9S 1W 3	400309111565101	LDS Church well 9
(C- 9- 1) 5bdb- 1	867	25741	N 3652 W 3176 SE 9S 1W 5		
(C- 9- 1) 5ddc- 2	1076		N 600 W 1000 SE 9S 1W 5	400321111573701	
(C- 9- 1) 8bcd- 1	1098	11326	S 13200 E 1050 NW 8S 1W 32		
(C- 9- 1) 8ddd- 1	1077		N 20 W 50 S4 9S 1W 8		
(C- 9- 1)17bbb- 1	869		S 50 E 50 NW 9S IW 17		
(C- 9- 1)17bca- 1	1078		S 1900 E 1300 NW 9S 1W 17		Monitor well
(C- 9- 1)17bcc- 1	868		S 2400 E 0 NW 9S IW 17		
(C- 9- 1)20cda- 1	196	2588	N 860 E 2640 SW 9S 1W 20		
(C- 9- 1)20ddd- 1	887	2595	S 4143 W 220 NE 9S 1W 20	400040111572701	
(C- 9- 1)26cdc- 1	1085		N 522 W 528 NE 9S 1W 35		
(C- 9- 1)26dca- 1	197	13639	N 1035 E 738 S4 9S 1W 26		
(C- 9- 1)27adc- 1	1088		N 10 W 1320 E4 9S 1W 27		
(C- 9- 1)28ccb- 1	1081		S 66 E 90 W4 9S 1W 28	395956111572101	
(C- 9- 1)29acc- 1	888			400015111575301	
(C- 9- 1)34ccc- 1	1082	2616	N 80 E 30 SW 9S 1W 34		
(C- 9- 1)34ddd- 1	1083	13643	N 48 W 760 SE 9S 1W 34		
(C- 9- 1)35baa- 1	1084		S 535 W 330 N4 9S 1W 35		
(C- 9- 2)29bac- 1	993	33606	S 888 E 1547 NW 9S 2W 29		
(C- 9- 2)29bac- 1	2014				Greeley Spring
(C-10- 1) 2bcd- 1	198	13703	N 367 E 1277 W4 10S 1W 2		
(C-10- 1) 4bbb- 1	889			395848111571801	
(C-10- 1) 4cbb- 1	199	13701	S 66 E 90 W4 10S 1W 4	395825111571801	
(C-10- 2) 9bbb- 1	3		S 355 E 97 NW 10S 2W 9		
(C-10- 2)11cdc- 1	870		N 500 E 1275 SW 10S 2W 11		
(C-10- 2)13bcc- 1	890			395640112003801	
(C-10- 2)18abc- 1	893			395733112063000	
(C-10- 2)18acb- 1	892			395726112062201	
(C-10- 2)18bca- 1	891			395725112065200	

Table B-2 continued. *Key to well IDs and names.*

Cadastral location	UGS ID	WIN	PLS location[1]	USGS Site No.	Well Name
(C-10- 3) 9cdc- 1	1086		N 2000 W 3400 SE 10S 3W 9		
(C-10- 3)13aad- 1	894			395652112070601	
(C-10- 3)13adc- 1	895			395723112071900	
(D- 6- 1) 7cdc- 1	178		N 150 E 1430 SW 6S 1E 7	401815111524801	
(D- 6- 1)18bbd- 1	179	13505	S 1249 E 1066 NW 6S 1E 18		
(D- 6- 1)18bcb- 1	181	16937	N 940 E 220 W4 6S 1E 18		
(D- 6- 1)18bcc- 1	182	14585	N 430 E 520 W4 6S 1E 18		
(D- 6- 1)18bcd- 1	872			401752111525001	
(D- 6- 1)18dcc- 1	180	17064	N 300 E 400 S4 6S 1E 18		
(D- 6- 1)18dcc- 2	183		N 400 E 2800 SW 6S 1E 18		
(D- 6- 1)18ddc- 1	184	17259	N 150 E 1765 S4 6S 1E 18		
(D- 6- 1)19adc- 1	834	23820	N 2050 W 400 SE 6S 1E 19	401658111521501	
(D- 6- 1)19bcd- 1	185		S 2600 E 1300 NW 6S 1E 19	401656111525000	
(D- 6- 1)29dab- 1	873			401600111510501	
(D- 6- 1)29dbc- 1	1090	13506	N 1310 E 3027 SW 6S 1E 29		
(D- 6- 1)29dbd- 1	176	18271	N 1800 E 3600 SW 6S 1E 29	401559111511401	
(D- 6- 1)30baa- 1	177	13508	S 29 E 2611 NW 6S 1E 30		Ireco Well B
(D- 6- 1)30bbd- 1	1022	13507	S 1432 E 415 NW 6S 1E 30		Ireco Well A
(D- 6- 1)31adb- 1	186		N 1080 W 930 E4 6S 1E 31	401522111521101	
(D- 7- 1) 5bbc- 1	1091	801	S 735 E 300 NW 7S 1E 5		
(D- 7- 1) 5ccc- 1	1092	13536	N 530 E 40 SW 7S 1E 5		
(D- 7- 1)18dbb- 1	1093		S 2940 E 150 N4 7S 1E 18		

APPENDIX C

WATER-LEVEL DATA MEASURED OR COMPILED FOR THIS STUDY

Table C-1. *Water-level data from wells in the Cedar Valley study area measured or compiled for this study.*

on CD: C Table C-1 Water Levels.xls

Table C-2. *Water-level elevation data used to contour potentiometric surface on plate 2.*

[1] Aquifer: Well is open to: BF= basin fill, BFper = unconsolidated perched aquifer near Cedar Pass, BDRX = consolidated bedrock, BDRXp = perched water in bedrock likely, X = crosses one or more aquifers, UK = unknown.

[2] Type: M = measured with a water-level measuring device, Dr = water level reported on drillers log, estimated accuracy usually +/- 5 feet but suspect some levels up to 50 feet different from static.

[3] Vertical datum: NGVD29 (National Geodetic Vertical Datum of 1929)

[4] Depth to water referenced to natural ground level.

UGS Well ID	UTM easting, m, (NAD 27)	UTM northing, m, (NAD 27)	Aquifer [1]	Type [2]	Water level elevation, ft [3]	Date measured	Depth to water, ft [4]
1	404997.00	4477128.00	BDRX	M	6363.41	3/15/05	76.59
2	419083.04	4468245.91	BDRX	Dr	4679	7/10/93	76
3	407775.32	4425421.30	BDRX	Dr	6310	6/26/78	10
4	411326.25	4457902.11	BF	M	4788.31	3/23/05	58.26
5	406832.92	4463995.89	BF	Dr	4919	12/15/84	106
6	414312.06	4446142.20	X	Dr	4555	11/6/73	350
7	415022.00	4465777.00	BDRX	Dr	4507	5/20/91	473
8	408799.00	4463135.00	BF	Dr	4823	12/18/74	72
9	407734.37	4462061.33	BF	M	4894.75	3/14/05	28.46
10	406172.14	4464374.77	BF	Dr	4981	7/2/97	109
11	406312.95	4463793.51	BF	Dr	4895	11/8/82	230
12	405980.55	4463807.38	BDRX	Dr	4898	6/10/85	290
13	406511.37	4464446.12	BF	Dr	4960	7/8/89	102
14	406363.55	4464109.62	BF	Dr	4930	6/29/82	160
15	406343.06	4464788.82	BF	Dr	4900.5	5/3/93	196
16	406165.84	4464678.71	BF	Dr	4960	12/29/62	158
17	406320.86	4463702.98	BF	Dr	4885	8/30/93	240
18	411768.18	4468244.51	BF	M	4729.88	3/22/05	355.5
19	407972.36	4448254.43	BF	Dr	4684	10/5/78	171
20	407661.39	4457129.98	BF	Dr	4862	6/28/92	6
21	407470.47	4457063.49	BF	Dr	4869	7/20/90	3
22	407067.00	4457069.00	BF	M	4874.36	3/14/05	4.78
24	407941.02	4457060.84	BF	Dr	4856	4/1/77	10
25	406733.01	4456417.64	BF	Dr	4871	12/2/88	20
26	415877.00	4456130.00	BDRX	Dr	4687	1/7/97	188
27	415616.00	4460696.00	BF	Dr	4763	2/10/48	125
28	406711.00	4460917.00	BF	Dr	4882	9/28/62	96
29	408943.00	4461987.00	BF	Dr	4829.5	5/10/51	45
30	406997.00	4457628.00	BF	Dr	4885	3/29/94	-3
31	407009.12	4457562.80	BF	Dr	4888	5/16/96	-7
32	407625.43	4457612.18	BF	Dr	4874	3/28/94	-7
33	413406.33	4468179.34	BF	Dr	4715	3/29/77	290
34	408494.56	4457155.54	BF	Dr	4821	7/24/96	32
36	408142.21	4457471.32	BF	Dr	4841	11/15/77	20
37	408452.19	4456914.14	BF	Dr	4850	9/8/74	9
38	409065.00	4456011.00	BF	Dr	4822	9/8/67	29
39	415728.35	4463558.03	BDRX	Dr	4585	8/15/97	370
41	415353.42	4459713.07	BF	M	4649.41	3/15/05	228.55
42	411265.97	4453611.28	BF	Dr	4819	11/20/83	27
43	405595.98	4464760.71	BDRX	Dr	5057	8/18/92	180
44	407288.33	4460601.58	BF	M	4893.24	3/14/05	30.62
45	410082.61	4457520.38	BF	M	4821.84	3/14/05	24.44
46	405910.75	4464170.09	BF	Dr	4995	3/29/99	149
47	409845.91	4463713.97	BF	Dr	4731	9/10/70	164
49	407729.71	4457487.60	BF	M	4861.84	3/14/05	7.61
50	415501.00	4462725.00	BF	Dr	4535	7/15/92	373
51	406339.58	4464575.08	BF	Dr	4947	6/22/00	134

Table C-2 continued. *Water-level elevation data use to contour potentiometric surface on plate 2.*

UGS Well ID	UTM easting, m, (NAD 27)	UTM northing, m, (NAD 27)	Aquifer (1)	Type (2)	Water level elevation, ft (3)	Date measured	Depth to water, ft (4)
52	415686.00	4462612.00	BF	Dr	4540	1/23/97	380
53	406856.00	4463973.00	BF	Dr	4907	6/9/00	116
56	415306.44	4460536.60	X	Dr	4657.38	10/11/73	217
57	415734.90	4458665.49	BF	Dr	4662	9/16/93	238
58	415478.00	4458447.00	BF	M	4699.79	11/17/04	170.21
59	418532.72	4468084.39	BDRX	Dr	4678	6/18/96	110
60	406248.03	4464603.70	BF	Dr	4932.5	4/10/97	156
61	406745.00	4455530.00	BF	Dr	4867	5/8/95	28
62	415910.25	4464191.75	BDRX	Dr	4625	3/15/95	390
63	406920.00	4447869.00	BF	Dr	4699	9/26/95	161
64	415894.00	4469490.00	BFper	Dr	4775	10/11/96	162
65	407258.45	4456967.53	BF	Dr	4869	4/16/92	5
66	405705.00	4464151.00	BDRX	Dr	4874	1/3/96	306
67	405587.05	4463941.80	BDRX	Dr	4911	3/24/98	324
68	408200.00	4466687.00	BDRX	M	4669	4/22/05	451
69	407568.78	4457481.16	BF	M	4865.66	3/14/05	4.29
70	407636.40	4457188.51	BF	Dr	4865	5/26/98	4
71	407712.29	4456964.78	BF	Dr	4866	6/26/99	2
72	406504.06	4464307.10	BF	Dr	4921.5	1/5/96	136
73	406164.21	4463716.40	BF	Dr	4909	11/10/99	254
74	411511.00	4460305.00	BF	Dr	4769	12/29/95	81
75	415753.00	4463511.00	BDRX	Dr	4594	2/10/00	353
76	414519.69	4451314.74	BF	M	4703.89	3/16/05	150.84
77	415287.80	4469512.93	BDRXp	Dr	4870	2/26/96	90
78	407701.75	4457189.77	BF	Dr	4863	4/30/98	5
79	408097.94	4457990.55	BF	Dr	4847	9/25/94	15
80	409559.00	4447388.00	BF	Dr	4677	5/17/95	173
82	407038.08	4457279.95	BF	Dr	4882	4/30/92	-3
83	407093.25	4457276.90	BF	Dr	4879	5/6/92	-2
84	407263.02	4457085.79	BF	Dr	4870	6/24/92	6
85	395283.00	4470782.00	BDRX	Dr	6745	1/27/94	145
86	402371.02	4454415.29	BDRX	Dr	4998	9/17/96	180
87	406468.28	4457291.48	BF	Dr	4893	9/15/94	4
88	416806.00	4469810.00	BFper	Dr	4778	12/3/96	156
89	416724.63	4470021.16	BFper	Dr	4791	10/14/96	151
90	416572.23	4469746.84	UK	Dr	4691	3/20/96	270
91	416267.73	4469840.59	BFper	Dr	4810	5/25/96	160
92	416236.95	4469746.84	BFper	Dr	4752	4/27/97	194
93	416083.00	4469685.00	BFper	Dr	4757	2/7/00	190
94	415962.00	4469750.00	BFper	Dr	4711	7/1/96	260
95	415923.00	4469673.00	BFper	Dr	4718	1/6/97	250
96	415932.15	4469533.48	BFper	Dr	4749	2/25/97	180
97	415442.00	4469485.00	BDRXp	Dr	4773	4/4/96	178
98	415006.00	4469793.00	BDRXp	Dr	4735	7/18/96	260
99	415344.79	4469409.30	X	Dr	4643	7/22/96	310
100	415428.61	4469417.84	BDRXp	Dr	4767	4/29/96	185
101	415623.00	4469348.00	BDRXp	Dr	4765	6/15/96	172
102	416064.00	4469277.00	BDRX	Dr	4486.5	1/1/96	415
103	416311.00	4469170.00	BDRX	Dr	4509	9/7/00	382
104	415794.99	4469152.48	BDRX	Dr	4511	1/9/97	427
105	415634.00	4469096.00	BDRX	Dr	4512	7/16/96	436
106	415140.00	4469049.00	BDRX	Dr	4458	1/20/97	520
109	416424.00	4469155.00	BDRX	Dr	4500	3/25/96	385
110	416257.00	4469268.00	BDRX	Dr	4480	3/8/96	415
111	416160.00	4469317.00	BDRX	Dr	4512	7/23/97	390
112	416072.00	4469453.00	BFper	Dr	4715	8/6/96	192
113	416230.00	4469610.00	BFper	Dr	4781	10/15/96	139
114	416326.00	4469588.00	BFper	Dr	4755	2/12/97	165
115	416390.00	4469584.00	BFper	Dr	4779	4/22/96	145

Table C-2 continued. *Water-level elevation data use to contour potentiometric surface on plate 2.*

UGS Well ID	UTM easting, m, (NAD 27)	UTM northing, m, (NAD 27)	Aquifer [1]	Type [2]	Water level elevation, ft [3]	Date measured	Depth to water, ft [4]
116	416536.00	4469627.00	BFper	Dr	4771	12/11/96	135
117	415203.00	4450542.00	BF	M	4720.44	3/16/05	186.56
118	411221.85	4449813.95	BF	M	4728.6	3/15/05	113.01
119	411446.00	4458755.00	BF	Dr	4771	12/15/95	73
120	416459.00	4469024.00	BDRX	Dr	4499	8/20/96	383
121	416084.00	4468603.84	BDRX	Dr	4507	3/3/97	432
123	415964.96	4468615.29	BDRX	Dr	4503	5/2/97	455
124	415853.00	4468727.00	BDRX	Dr	4445	2/10/97	495
125	416056.40	4468798.17	BDRX	Dr	4513	3/5/97	397
126	415812.56	4468950.57	BDRX	Dr	4492	2/19/97	416
127	416145.00	4468346.00	BDRX	Dr	4510	6/20/96	421
128	414789.00	4469224.00	BDRXp	Dr	4689	5/27/97	295
130	407118.54	4457204.96	BF	Dr	4884	3/29/00	-7
131	411419.82	4459534.53	BF	M	4780.64	3/14/05	70
132	407363.00	4464623.00	BF	Dr	4922	10/24/99	84
133	407074.58	4464407.82	BF	Dr	4906	6/29/98	89
134	411857.33	4460748.59	BF	M	4777.93	3/14/05	78.18
136	416441.46	4469734.22	BFper	Dr	4795	3/15/99	155
137	416350.00	4469071.00	BDRX	Dr	4560	7/17/96	330
138	406311.86	4463754.04	BF	Dr	4898	8/10/99	225
139	415814.00	4462559.00	BDRX	Dr	4656	5/2/96	282
140	406491.78	4461692.25	BF	Dr	4906	6/3/99	143
141	416813.00	4470134.00	BFper	Dr	4799	7/8/97	127
142	416383.25	4469723.86	X	Dr	4660	2/14/96	290
144	406299.52	4463925.48	BF	Dr	4896	3/8/00	214
145	408609.00	4467062.00	BDRX	Dr	4625	9/15/75	490
146	420762.11	4471340.00	BF	Dr	4551	5/6/94	151
147	420699.51	4470590.56	BF	Dr	4519	10/31/95	145
148	420692.89	4470684.74	BF	Dr	4488	5/26/69	175
149	420767.90	4471265.62	BDRX	Dr	4509	5/18/97	185
150	421200.38	4471026.96	BF	M	4499.9	3/3/05	131.03
151	419601.94	4470402.24	BDRX	Dr	4601	4/23/95	283
152	419800.06	4470066.96	BDRX	Dr	4477	12/19/96	331
153	419815.30	4470371.76	BDRX	Dr	4505	12/20/97	355
154	419547.08	4470173.64	BDRX	Dr	4643	12/29/98	225
155	419547.08	4470365.66	BDRX	Dr	4618	5/17/99	240
156	418187.17	4469811.68	BDRX	M	4483.3	3/15/05	434.7
157	419760.44	4470006.00	BDRX	Dr	4526.5	4/9/99	290
158	418691.01	4470420.54	BDRX	Dr	4487	5/31/00	457
159	418727.00	4470756.00	BDRX	Dr	4517	5/20/98	427
161	416080.00	4468952.00	BDRX	Dr	4480	6/15/96	420
162	416434.00	4469097.00	BDRX	Dr	4510	2/15/00	375
163	422358.71	4469017.69	BDRX	Dr	4500.25	6/30/94	20
164	422101.23	4468513.90	BF	Dr	4499	4/30/77	31
165	421863.22	4468919.50	BF	Dr	4495	3/14/00	40
166	422073.53	4469018.26	BF	Dr	4500	6/29/96	28
167	422177.43	4468300.54	BF	Dr	4497.5	11/3/95	35
168	422177.43	4468338.64	BF	Dr	4496.5	11/7/95	35
169	422242.77	4469300.97	BF	Dr	4501	10/3/95	22
170	422382.79	4469218.24	BF	Dr	4497.5	5/23/95	19
171	422359.44	4468988.08	BF	Dr	4498	7/1/93	22
173	421895.91	4467578.98	BDRX	Dr	4503	12/10/34	55
174	421269.45	4466976.86	BF	Dr	4495	8/1/62	95
175	406245.60	4465349.91	BF	Dr	4881.4	4/27/63	300
176	427430.12	4457390.83	BF	Dr	4483	12/21/98	12
177	425530.58	4458441.88	BDRX	Dr	4500	3/8/76	236
178	425203.27	4461702.75	BF	Dr	4510	3/1/78	8
179	425092.33	4461276.33	BF	Dr	4543	7/5/88	10
180	425562.58	4460150.93	BF	Dr	4520	3/31/98	55

Table C-2 continued. *Water-level elevation data use to contour potentiometric surface on plate 2.*

UGS Well ID	UTM easting, m, (NAD 27)	UTM northing, m, (NAD 27)	Aquifer (1)	Type (2)	Water level elevation, ft (3)	Date measured	Depth to water, ft (4)
181	424830.90	4461144.04	BF	Dr	4505	1/25/98	105
182	424922.34	4460988.59	BF	Dr	4504	12/31/96	105
183	425613.72	4460179.95	BF	Dr	4561	4/15/79	7
184	425978.63	4460105.20	BF	Dr	4486	4/8/98	42
185	425156.52	4459265.55	BF	Dr	4708	9/17/73	12
186	426044.22	4456370.04	BDRX	Dr	4630	7/31/75	90
188	422101.95	4447266.70	BF	Dr	4459	7/23/93	75
189	395990.05	4448272.08	BF	Dr	4957	7/27/47	135
192	417259.00	4439046.00	BDRX	Dr	4497	10/10/72	128
193	417560.00	4438056.82	BF	Dr	4525	11/11/45	90
194	417890.29	4437083.05	BDRX	Dr	4450	12/5/45	175
195	420056.52	4436443.94	BF	Dr	4493	12/17/70	42
197	422629.73	4427825.75	BF	Dr	4504	1/8/56	-3
198	421994.81	4425215.03	BF	Dr	4508	11/3/81	20
199	418394.95	4425074.99	BF	M	4503.92	3/10/05	160.08
633	396067.64	4447067.95	BF	M	4955.91	3/17/05	129.09
634	396685.24	4445517.57	BDRX	M	4515	1/1/07	595
792	422746.00	4463480.00	BDRX	M	4482.92	7/19/05	247.08
794	423437.00	4464077.00	BDRX	M	4494.11	7/19/05	75.89
795	423077.00	4472259.00	BF	M	4499.47	7/19/05	18.53
796	422626.00	4472414.00	BF	M	4512.43	7/19/05	47.57
797	421743.00	4471835.00	BF	M	4494.7	7/19/05	125.3
798	420271.00	4470188.00	BDRX	M	4476.25	7/19/05	203.75
802	416920.36	4470438.96	X	Dr	4871	11/2/92	79
803	416750.84	4470549.26	X	Dr	4894	4/26/95	80
804	416748.00	4470114.00	BFper	Dr	4836	9/27/95	103
805	415429.00	4469411.00	BDRX	Dr	4523	6/26/03	429
806	415543.00	4468678.00	BDRX	Dr	4511	10/1/03	427
807	416223.00	4468623.00	BDRX	Dr	4501	5/4/04	421
808	420502.88	4468873.54	BDRX	Dr	4450	2/2/00	180
809	420231.00	4468606.00	BDRX	M	4496.32	7/19/05	168.68
810	420650.23	4468282.31	BDRX	Dr	4408	12/28/00	204
811	421273.02	4468922.28	BF	Dr	4522	9/27/93	46
812	420422.11	4468707.73	BDRX	Dr	4509	5/19/94	132
813	420312.07	4468721.75	BDRX	Dr	4499	6/28/94	159
814	420069.00	4468547.88	BDRX	Dr	4418	6/23/94	285
815	420691.15	4469345.10	BF	Dr	4496	12/10/94	126
816	420311.90	4467921.43	BDRX	Dr	4493	12/3/94	143
817	421183.40	4469267.38	BF	Dr	4480	4/10/95	94
818	421222.72	4468924.11	BF	Dr	4503	6/20/79	65
819	420796.92	4468922.28	BF	Dr	4501.2	12/5/79	89
820	421017.59	4468918.32	BF	Dr	4498	1/20/78	80
821	421315.08	4468852.18	BDRX	Dr	4494	4/29/99	70
822	421736.92	4469014.94	BF	Dr	4498	6/14/93	46
823	422145.14	4469329.22	BF	Dr	4501	9/21/76	22
826	422028.23	4465662.68	BF	Dr	4495	4/16/88	75
827	422050.13	4465545.85	BF	Dr	4490	11/28/88	88
829	414860.00	4469636.00	BDRXp	Dr	4760	1/20/03	220
830	414979.52	4469333.22	BDRX	Dr	4518	12/30/03	447
832	406121.00	4466823.00	BDRX	M	5780.77	10/11/04	-385.77
833	405556.39	4465238.36	BDRX	Dr	4940	5/12/04	380
834	426215.67	4459079.59	BF	M	4500.72	3/3/05	66.28
835	417268.00	4439043.00	BDRX	Dr	4498	12/18/74	127
836	415743.00	4463753.00	BDRX	Dr	4589	2/5/03	374
837	424664.25	4460788.07	BDRX	Dr	4545	6/21/83	183
838	424288.00	4462292.00	X	Dr	4487	10/12/01	111
839	415779.00	4460223.00	X	Dr	4676	12/14/93	234
840	407019.00	4464649.00	BF	Dr	4924	10/16/00	94
841	408074.03	4464529.83	BF	Dr	4836	4/10/02	122

Table C-2 continued. *Water-level elevation data use to contour potentiometric surface on plate 2.*

UGS Well ID	UTM easting, m, (NAD 27)	UTM northing, m, (NAD 27)	Aquifer [1]	Type [2]	Water level elevation, ft [3]	Date measured	Depth to water, ft [4]
842	405748.59	4464635.18	BDRX	Dr	4980	4/25/03	200
843	405427.23	4464948.74	BDRX	Dr	5060	3/13/01	278
845	406381.87	4465047.15	BF	Dr	4928	6/16/02	196
846	406504.06	4464352.21	BF	Dr	4812	6/12/03	246
847	406023.40	4463652.67	BDRX	Dr	4894.51	12/4/01	302
849	419659.00	4469992.00	BDRX	Dr	4605	2/7/62	295
850	408901.00	4458787.00	BF	M	4833.99	7/18/05	22.01
851	410092.22	4458351.39	BF	Dr	4813	9/6/53	35
852	408516.91	4458377.61	BF	M	4851.06	3/14/05	9.98
853	409290.60	4458354.44	BF	Dr	4828	9/18/53	25
854	406824.35	4457635.90	BF	Dr	4890.7	9/21/53	-2
855	407727.07	4457545.38	BF	Dr	4866	4/14/02	-1
857	408345.82	4456899.21	BF	Dr	4850	11/6/99	12
859	415223.00	4453346.00	BDRX	M	4706.02	2/2/05	178.98
861	407122.99	4455071.59	BF	Dr	4857	9/24/03	23
862	407015.00	4449451.00	BF	Dr	4723	10/18/03	139
863	415242.08	4469162.41	BDRX	Dr	4480	12/10/03	520
864	407780.00	4448758.00	BF	Dr	4699	6/30/03	156
867	417321.00	4435055.00	UK	Dr	4477	7/25/02	216
868	416739.61	4431666.86	BF	Dr	4509	11/22/96	263
869	416754.85	4432383.14	BF	Dr	4491	9/9/86	264
874	415376.51	4461524.15	UK	M	4599.54	3/15/05	280.01
875	412484.00	4461168.00	BF	Dr	4759	1/1/64	98
876	413479.00	4461496.00	BF	Dr	4752.64	2/28/66	110
877	413053.36	4457508.94	BF	M	4781.78	3/14/05	59.44
878	410052.00	4457188.00	BF	Dr	4818.19	4/7/66	25
879	407278.56	4464177.59	BF	M	4894.82	3/15/05	80.32
880	406821.00	4457659.00	BF	M	4888.97	3/29/05	-0.6
881	407145.91	4457989.46	BF	Dr	4888	4/7/66	-13
883	407196.54	4447827.53	BF	M	4693.49	3/16/05	165.6
884	405824.51	4446799.26	UK	M	4686.89	3/15/05	189.2
886	418474.00	4434052.00	BF	M	4475.04	3/10/05	144.96
887	418323.11	4429495.81	BF	M	4488.75	3/10/05	151.25
888	417654.00	4428455.00	BF	M	4490.65	3/10/05	228.35
889	418455.00	4425764.00	BF	M	4505.27	3/10/05	166.73
896	406551.00	4454372.00	BF	Dr	4857	1/1/63	45
897	406500.00	4457290.00	BF	Dr	4900	3/11/66	-3
898	416121.73	4469755.56	BFper	Dr	4780.5	1/26/96	160
899	417178.00	4439099.00	BF	Dr	4524	11/11/45	90
901	415486.00	4467418.00	BDRX	M	4509.28	3/19/07	490.27
902	414051.00	4468259.00	BDRXp	M	4887.58	3/19/07	101.82
903	414051.00	4468259.00	BDRX	M	4509.27	3/19/07	480.13
983	416001.00	4467161.00	BDRX	M	4511.59	3/17/08	486.69
984	418183.00	4466842.00	BDRX	M	4510.48	10/7/07	288.52
985	399744.00	4443898.00	BDRX	M	4512.82	9/5/07	1020
986	397920.00	4445554.00	BDRX	M	4512.85	11/2/06	666.31
987	400219.00	4444715.00	BDRX	M	4957.85	1/15/07	342.06
990	412168.54	4458644.94	BF	M	4787.53	4/26/05	61
991	412149.49	4459388.66	BF	M	4783.55	3/14/05	66.82
992	415369.88	4467533.42	BDRX	M	4517.68	12/10/04	507
993	406583.00	4429350.00	BDRX	Dr	5743	10/2/72	67
995	406309.00	4459999.00	BF	M	4892.99	5/23/05	66.01
997	417996.00	4469874.00	BDRX	Dr	4490	5/1/05	440
998	406434.06	4464081.01	BF	M	4924.63	4/12/05	152.37
1000	416752.66	4469894.54	BFper	Dr	4767	6/5/96	190
1001	409927.63	4479560.74	BDRX	Dr	5782	6/1/82	600
1002	417950.28	4469693.65	BDRX	Dr	4405	4/29/99	485
1003	416576.11	4471417.44	BDRX	M	4813	3/15/05	295
1005	416092.00	4469571.00	BFper	Dr	4758	4/8/96	160

Table C-2 continued. *Water-level elevation data use to contour potentiometric surface on plate 2.*

UGS Well ID	UTM easting, m, (NAD 27)	UTM northing, m, (NAD 27)	Aquifer (1)	Type (2)	Water level elevation, ft (3)	Date measured	Depth to water, ft (4)
1006	416351.00	4468797.00	BDRX	Dr	4472	7/26/96	410
1007	416075.26	4468378.70	BF	Dr	<4904	9/24/63	>40
1008	417955.00	4468218.00	X	M	4727.76	7/28/05	67.24
1009	422199.53	4468116.92	BDRX	Dr	4497	1/5/70	40
1010	406646.67	4473130.94	BDRX	Dr	5575	8/26/75	70
1011	412214.29	4469909.07	BDRX	Dr	4673	4/9/99	442
1014	397385.79	4465340.73	BDRX	Dr	6398	4/19/90	720
1015	398233.81	4465434.01	BDRX	M	7160	11/1/04	260
1016	424197.77	4462246.30	X	Dr	4522	3/20/98	98
1017	424221.02	4462254.06	BF	Dr	4518	1/16/98	100
1018	415303.86	4460557.38	X	M	4657.9	11/17/04	217.1
1019	416825.00	4459829.00	BDRX	Dr	4550	1/1/80	645
1020	416875.98	4459881.16	BDRX	Dr	<4770	1/1/79	>430
1021	417539.55	4458566.42	BDRX	Dr	<4579	8/17/98	>843
1022	424861.24	4458014.25	BDRX	Dr	4667	5/3/73	249
1023	415867.00	4456128.00	UK	Dr	4690	10/30/47	185
1024	413864.75	4464355.43	BF	Dr	4716.46	3/30/66	175
1026	406761.98	4464057.63	BF	Dr	4901	5/23/82	129
1027	407281.36	4464333.17	BF	Dr	4840	10/30/80	135
1028	406241.36	4464729.25	BDRX	Dr	4960	2/6/87	140
1029	413783.32	4460942.37	BF	M	4755.89	3/15/05	103.53
1031	411550.27	4461259.36	BF	M	4779.69	3/15/05	78.99
1032	406478.53	4461716.36	BF	Dr	<4759	1/1/71	>292
1033	406472.00	4461733.00	BF	Dr	4891	5/4/71	164
1035	407284.92	4460461.41	BF	Dr	4888.09	12/29/61	28
1036	413348.00	4458801.00	BF	Dr	4754	5/1/96	90
1037	406843.32	4458367.26	BF	M	4893	3/14/05	-1.3
1038	407221.19	4456218.74	BF	M	4865.62	4/6/05	14.11
1039	406796.00	4456866.00	BF	Dr	4890	3/13/64	0
1040	410116.17	4456721.90	BF	M	4823.9	3/14/05	21.5
1041	411427.85	4465533.84	BF	M	4729.7	3/15/05	234.9
1042	412922.12	4456669.06	BF	Dr	4762	7/6/70	75
1044	398732.21	4464148.20	X	Dr	6545	11/29/89	25
1046	398671.25	4464550.53	BDRX	Dr	6953	1/19/90	272
1047	397354.42	4465220.57	BDRX	Dr	6625	9/26/92	535
1048	398827.07	4465287.08	BDRX	M	6992.24	11/1/04	532.76
1049	397154.38	4465237.70	BDRX	Dr	<6465	4/21/90	>500
1050	404901.00	4462259.00	BDRX	Dr	4858	4/18/81	487
1051	424256.09	4451417.00	BDRX	Dr	4528	6/21/73	180
1052	422244.68	4447039.53	BF	Dr	4473	3/5/79	22
1053	411209.59	4449872.32	BF	Dr	4692.22	7/22/48	150
1054	411230.77	4446603.15	BF	M	4677.08	3/16/05	179.11
1056	417646.05	4441319.39	BDRX	Dr	4577	6/10/49	43
1057	417267.00	4439047.00	BDRX	Dr	4500	2/27/67	125
1058	416743.67	4440076.59	BDRX	Dr	4475	11/1/80	180
1059	417328.91	4438171.02	BDRX	Dr	4491	4/5/69	137
1060	418285.00	4437590.00	X	M	4488.65	3/14/05	106.35
1063	414873.48	4437792.21	BDRX	Dr	4494	5/24/72	276
1066	395620.89	4444310.32	BF	Dr	4896	9/6/00	232
1067	396112.40	4443825.50	BF	Dr	4916	10/16/52	220
1075	419563.97	4434020.72	BF	M	4477.61	3/10/05	92.39
1076	418100.55	4434180.42	BF	Dr	4479	3/30/70	163
1077	418322.18	4432420.40	BDRX	Dr	4479	11/26/71	146
1078	417152.09	4431820.69	BF	Dr	4500	11/27/96	245
1080	422273.69	4428495.05	BDRX	Dr	4467	7/30/91	28
1081	418398.19	4428304.58	BF	M	4498.79	3/10/05	144.21
1082	419974.97	4425938.06	BF	Dr	4525	5/9/66	30
1083	421374.98	4425940.47	BF	Dr	4515	10/10/61	0
1084	422302.67	4427364.69	BF	Dr	4506	6/10/49	-5

Table C-2 continued. *Water-level elevation data use to contour potentiometric surface on plate 2.*

UGS Well ID	UTM easting, m, (NAD 27)	UTM northing, m, (NAD 27)	Aquifer (1)	Type (2)	Water level elevation, ft (3)	Date measured	Depth to water, ft (4)
1085	422174.31	4428097.56	BF	Dr	4495	9/14/56	0
1088	421209.58	4428341.85	BF	Dr	4522	5/28/49	-24
1089	394694.00	4437754.38	BF	Dr	5030	5/21/70	305
1091	426420.97	4455025.14	BDRX	Dr	4492	9/2/92	72
1092	426337.20	4453793.83	BDRX	Dr	4507	2/1/62	3
1093	425474.45	4451117.61	BF	Dr	4490	9/27/58	12
1096	417156.00	4437572.00	BF	Dr	4545	12/30/85	110
1097	416390.44	4438059.05	BDRX	Dr	4547	1/11/96	125
1098	417087.26	4433231.56	BDRX	Dr	4555	3/12/96	175
1100	418230.26	4436462.13	X	Dr	4381.5	11/30/97	226
1101	417754.01	4436200.19	X	Dr	4480.5	4/5/95	149
1104	421111.90	4471061.47	BF	Dr	4508	11/21/73	131
1105	420708.13	4470598.88	BF	Dr	4489	12/20/77	175
1106	421381.28	4471097.00	BF	Dr	4598	8/3/91	16
1107	422242.90	4469310.93	BF	M	4495.14	3/3/05	26.86
1109	422116.44	4468291.70	BF	Dr	4492	3/11/93	43
1110	421877.48	4468156.97	BF	Dr	4501.5	7/8/94	45
1112	419824.08	4467610.13	BF	Dr	<4528	7/1/61	>142
1113	414794.78	4469829.52	X	M	4901.31	3/15/05	90.4
1114	414150.00	4461900.00	BF	Dr	4745	1/14/54	120
1115	401577.93	4460304.73	BF	Dr	<5555	9/8/99	>100
1116	400096.17	4462331.32	X	Dr	<6122	9/8/99	>40
1117	410028.00	4457158.00	BF	Dr	4815.21	4/7/66	28
1118	412300.72	4461163.32	BF	M	4776.66	3/15/05	83.03
1119	410192.00	4470297.00	BDRX	Dr	4803	9/12/72	437
1120	409744.29	4461976.30	BF	M	4781.33	3/15/05	92.97
1121	409734.44	4461185.10	BF	M	4811.39	3/15/05	51.28
1122	410519.52	4461964.21	X	M	4770.31	3/15/05	97.32
1123	409739.37	4461587.26	BF	M	4801.84	3/15/05	65.86
1124	412322.52	4461940.81	BF	M	4761.96	3/15/05	106.56
1126	415806.11	4467660.07	BDRX	Dr	4528	8/19/98	462
1127	410950.00	4442129.00	BF	Dr	4654	3/11/66	241
1130	405797.00	4437318.00	UK	Dr	4673	3/11/66	343
1131	406573.96	4456092.81	BF	M	4868.01	3/14/05	32.15
1132	408049.46	4456658.89	BF	M	>4866.83	3/14/05	<-1.8
1136	407679.00	4473035.00	UK	Dr	5532	11/23/74	73
1137	415794.00	4468882.00	UK	Dr	<4791	8/17/65	>105
1140	398742.00	4465392.00	BDRX	M	6980.49	11/1/04	419.51
1141	398970.00	4465109.00	BDRX	M	6942.63	11/1/04	417.37
1142	398823.00	4464765.00	BDRX	M	7100.62	11/1/04	289.38
1143	398825.00	4464846.00	BDRX	M	7108.89	11/1/04	281.11

APPENDIX D

WATER-QUALITY METHODS AND QUALITY CONTROL

Stable and Radioactive Isotope Analytical Methods

Stable Isotopes of Oxygen, Hydrogen, and Carbon

Stable isotope ratios of oxygen, hydrogen and carbon, $\delta^{18}O_{VSMOW}$, $\delta^{2}H_{VSMOW}$, and $\delta^{13}C_{VPDB}$, were analyzed at the Laboratory of Hydrogeochemistry–Brigham Young University (BYU) Department of Geological Sciences with a Finnigan Delta^{plus} isotope ratio mass spectrometer with methods similar to that described by Epstein and Mayeda (1953), Gehre and others (1996) and McCrea (1950). Oxygen-18 and deuterium values were normalized to the VSMOW/SLAP scale following the procedure of Coplen (1988), Nelson (2000) and Nelson and Dettman (2001).

Carbon-14

Samples analyzed for ^{14}C were processed at the Laboratory of Hydrogeochemistry–BYU to concentrate the carbon by precipitation as barium carbonate ($BaCO_3$). For each water sample, the pH was raised to above 11 using purified sodium hydroxide (NaOH) solution followed by precipitation with barium chloride ($BaCl_2$). Samples were analyzed by conventional liquid scintillation counter, whereby the precipitate is acidified and the released CO_2 gas synthesized into benzene for analysis in a Perkin Elmer Quantulus 1220 ultra low-level liquid scintillation counter. Samples were evaluated against blanks and a National Institute of Standards and Technology (NIST) traceable oxalic acid standard (4990C). Carbon-14 values, reported relative to percent modern carbon (pmC), were calculated following the procedure of Stuiver and Polach (1977).

Tritium

Tritium (^{3}H) is a radioactive isotope of hydrogen. Our samples for ^{3}H analysis were distilled and electrolytically enriched at the Laboratory of Hydrogeochemistry–BYU. Each sample was electrolytically enriched to increase ^{3}H concentration by a factor of at least 10 times. Analysis was done using a Perkin Elmer Quantulus 1220 ultra low-level liquid scintillation counter. Samples were evaluated against blanks and a NIST traceable standard (SRM 4361C). ^{3}H concentrations are measured in tritium units (T.U.).

References

Coplen, T.B., 1988, Normalization of oxygen and hydrogen isotope data: Chemical Geology, v. 72, p. 293-297.

Epstein, S., and Mayeda, T.K., 1953, Variations in the $^{18}O/^{16}O$ ration in natural waters: Geochemica et Cosmochimica Acta, v. 4, p. 213-224.

Gehre, M., Hoefling, R., and Kowski, P., 1996, Sample preparation device for quantitative hydrogen isotope analysis using chromium metal: Analytical Chemistry, v. 68, p. 4414-4417.

McCrea, J.M., 1950, On the isotopic chemistry of carbonates and a palaeotemperature scale: Journal of Physical Chemistry, v. 18, p. 849-857.

Nelson, S.T., 2000, A simple, practical methodology for routine VSMOW/SLAP normalization of water samples analyzed by continuous flow methods: Rapid Communications in Mass Spectrometry, v. 14, p. 1044-1046.

Nelson, S.T., and Dettman, D., 2001, Improving hydrogen isotope ratio measurements for on-line Cr reduction systems: Rapid Communications in Mass Spectrometry, v. 15, p. 2301-2306.

Stuiver, M., and Polach, H.A., 1977, Discussion—reporting of ^{14}C data: Radiocarbon, v. 19, p. 355-363.

Table D-1. *Summary of water-quality samples in and near Cedar Valley, Utah County, Utah.*

	General chemistry	**$\delta^{18}O$ and $\delta^{2}H$**	**Tritium (^{3}H)**	**Radiocarbon (^{14}C and $\delta^{13}C$)**
	Samples collected for this study			
Wells	37	34	30	13
Springs	7	7	6	0
Surface water	1	1	1	0
Subtotal	45	42	37	13
	Sample results from other sources			
Wells	116	9	7	3
Springs	22	0	0	0
Surface water	1	0	0	0
Subtotal	139	9	7	3
	Total number of samples examined for this study			
Wells	153	43	37	16
Springs	29	7	6	0
Surface water	2	1	1	0
Total[1]	**184**	**51**	**44**	**16**

[1] Total includes multiple analyses for some sites. A total of 119 unique sites were reviewed.

Table D-2. *Major constituent water chemistry from wells, springs, and surface water, Cedar Valley study area. Values are total or dissolved concentrations (see notes at end of table).*

Sample ID[1]	Sample Date	Geo-logy[2]	pH	Temp. (°C)	Conduc-tivity (µmhos)	TDS, (mg/L)	Ca (mg/L)	Mg (mg/L)	Na[(note 3)] (mg/L)	K[(note 3)] (mg/L)	SO_4[(note 4)] (mg/L)	Cl (mg/L)	HCO_3 (mg/L)	Alkalin-ity as $CaCO_3$ (mg/L)	SiO_2 (mg/L)	NO_3 or NO_3+NO_2, as N (mg/L)[5]
4feltis	7/1/65	BF	8.20	11.7	470	298	36.0	30.0	*20*	*in Na*	27	19.0	246	-	53.0	0.2
4mont	9/13/73	BF	7.60	-	564	389	39.2	29.7	17.0	4.17	22	18.0	262	216	6.1	0.46
4usgs	6/16/75	BF	-	11.5	460	318	38.0	31.0	31.0	3.40	23	21.0	260	213	55.0	0.2
4usgs	7/20/76	BF	7.40	12.0	415	321	41.0	31.0	32.0	3.20	23	21.0	256	210	56.0	0.3
4usgs	6/7/77	BF	7.80	12.0	480	306	38.0	30.0	33.0	3.40	25	18.0	240	200	54.0	0.2
4usgs	6/7/78	BF	7.60	12.0	500	331	41.0	33.0	30.0	3.40	35	17.0	260	210	55.0	0.3
4usgs	7/10/79	BF	7.60	12.0	530	355	42.0	31.0	18.0	3.60	24	18.0	-	200	54.0	10.0
4usgs	7/10/80	BF	7.40	11.5	465	-	39.0	31.0	34.0	3.40	25	23.0	-	210	58.0	0.1
4usgs	7/13/83	BF	8.00	11.5	475	-	38.0	30.0	19.0	3.10	23	24.0	-	214	55.0	0.2
4usgs	6/4/86	BF	7.90	11.5	475	-	37.0	31.0	19.0	3.10	23	26.0	-	209	55.0	0.2
4usgs	7/5/89	BF	7.40	11.5	570	-	42.0	37.0	20.0	3.80	24	49.0	-	209	56.0	0.2
4usgs	7/28/92	BF	8.00	11.5	570	-	41.0	33.0	20.0	3.10	28	57.0	-	204	60.0	0.2
4usgs	6/13/95	BF	7.60	12.5	690	-	51.0	45.0	23.0	3.40	26	90.0	-	218	57.0	0.2
4usgs	7/15/98	BF	7.40	12.5	670	-	47.2	42.9	21.6	3.36	30	75.5	-	220	59.1	0.2
4usgs	7/18/01	BF	7.60	14.0	660	-	60.4	52.1	23.3	3.64	31	93.7	-	251	59.3	0.1
5udaf	10/24/01	BF	-	16.5	1645	982	122.5	38.6	52.5	2.00	95	159.0	297	-	-	10.0
8ugs	2/4/05	BF	7.40	-	1250	848	122.0	46.9	60.2	1.48	45	286.0	234	192	20.0	2.3
15udaf	10/24/01	BF	-	12.0	1229	734	96.7	25.8	45.3	1.88	55	57.0	320	-	-	7.0
18feltis	6/30/65	BF	7.60	11.7	572	337	80.0	14.0	*21*	*in Na*	37	34.0	262	-	19.0	1.1
18ugs	4/27/05	BF	7.30	12.6	595	334	73.3	15.0	24.6	1.42	35	38.2	262	215	10.3	0.7
20udaf	10/24/01	BF	-	13.5	1208	721	72.4	43.5	26.2	12.25	50	42.0	357	-	-	1.0
23udaf	10/24/01	BF	-	11.3	878	524	65.2	28.7	14.3	1.40	44	26.0	259	-	-	0.3
25udaf	10/24/01	BF	-	11.1	950	568	66.6	32.1	17.9	1.63	52	28.0	279	-	-	0.2
27feltis	7/1/65	BF	7.70	27.2	706	421	75.0	25.0	*35*	*in Na*	70	66.0	240	-	21.0	1.4
38ugs	1/31/05	BF	7.50	10.1	475	356	48.1	31.1	14.4	3.44	30	18.3	286	235	50.7	<0.1
41mont	6/7/69	BF	7.30	-	742	475	48.0	14.0	-	23.00	34	40.0	268	220	-	0.23
41usgs	8/10/83	BF	-	23.5	600	-	-	-	-	-	-	-	-	-	-	-
49ugs	1/31/05	BF	7.80	9.7	372	274	44.9	19.4	10.9	2.56	<20.0	15.6	224	184	33.8	0.6
50ugs	2/9/05	BF	7.70		405	294	34.0	22.1	21.5	3.25	37	36.6	165	135	-	1.3
52udaf	10/24/01	BF	-	12.4	628	375	31.0	21.4	23.64	3.73	47	30.0	142	-	-	0.1
53udaf	10/24/01	BF	-	11.0	1575	940	101.7	30.1	30.14	1.66	71	59.0	299	-	-	7.0
56mont	9/13/73	X	7.40	-	712	491	69.6	24.0	18.0	4.60	67	60.0	249	206	2.4	0.30
56usgs	6/16/75	X	-	30	680	410	68	26	64	3.9	64	64	242	198	21	0.73
56usgs	6/9/76	X	7.4	30	700	421	67	26	62	3.6	75	65	247	203	20	0.57
56usgs	6/7/77	X	7.3	30.5	690	413	70	26	62	3.8	67	64	240	200	21	0.61
56usgs	6/7/78	X	7.2	30	700	435	70	28	66	3.8	70	80	240	200	20	0.56
56usgs	6/26/81	X	-	29.5	660	-	-	-	-	-	-	-	-	-	-	-
56usgs	6/15/82	X	7.7	30	720	412	69	26	62	3.6	65	65	-	199	21	0.62
56usgs	7/2/85	X	7.4	30	705	-	70	27	39	3.5	69	65	-	197	21	0.59
56usgs	6/22/88	X	7.6	27.0	660	-	54	27	46	3.7	65	60	-	201	26	0.48
56usgs	7/28/92	X	7.4	29.5	720	-	67	26	38	3.5	69	73	-	206	20.0	0.84
56usgs	6/27/95	X		30.5	700	-	68	26	37	3.6	71	67.0	-	204	21	0.85
56usgs	7/15/98	X	7.3	29.5	760	-	66.3	25.5	37.2	3.56	64.4	69	-	202	21	0.88

Table D-2 continued. *Major constituent water chemistry from wells, springs, and surface water, Cedar Valley study area.*

Sample ID[1]	Sample Date	Geology[2]	pH	Temp. (°C)	Conductivity (µmhos)	TDS, (mg/L)	Ca (mg/L)	Mg (mg/L)	Na (note 3) (mg/L)	K (note 3) (mg/L)	SO_4 (note 4) (mg/L)	Cl (mg/L)	HCO_3 (mg/L)	Alkalinity as $CaCO_3$ (mg/L)	SiO_2 (mg/L)	NO_3 or NO_3+NO_2, as N (mg/L)[5]
56usgs	7/18/01	X	7.50	28.5	810	-	68.9	26.1	37.4	3.43	61	64	-	202	21.5	0.82
57udaf	10/24/01	BF	-	17.0	1309	783	30.1	41.6	88.9	3.26	72	85.0	279	-	-	0.4
58byu	12/13/04	BF	-	-	-	-	28.0	46.3	95.4	2.35	39	90.0	338	-	-	-
60udaf	10/24/01	BF	-	10.5	1045	624	84.9	26.0	28.4	1.62	40	24.0	317	-	-	7.0
61ugs	1/31/05	BF	7.50	11.6	526	376	57.4	29.6	19.4	2.08	44	28.2	286	235	29.1	0.3
63ugs	2/3/05	BF	7.80	11.8	466	342	28.1	25.5	33.4	5.23	45	32.8	218	179	-	-
66udaf	10/24/01	bdrx	-	12.4	931	556	80.3	22.3	22.4	1.18	39	34.0	284	-	-	1.4
66ugs	2/1/05	bdrx	7.50	11.0	515	346	71.9	19.8	16.3	<1	27	22.4	306	251	9.5	-
68ugs	5/6/05	bdrx	7.30	28.4	875	508	76.8	26.8	38.0	4.13	86	113.0	222	182	22.8	1.8
70udaf	10/24/01	BF	-	10.0	862	515	67.2	25.5	12.4	1.56	26	19.0	276	-	-	0.0
74ugs	2/1/05	BF	8.20	13.2	325	236	28.3	14.7	16.2	3.11	<20.0	15.1	170	140	53.9	0.6
76udaf	10/24/01	BF	-	12.5	2290	1367	38.5	79.8	180.4	20.13	315	138.0	380	-	-	0.0
78udaf	10/24/01	BF	-	10.4	1052	632	81.8	30.2	13.3	1.79	26	61.0	278	-	-	0.0
79udaf	6/26/02	BF	7.89	11.2	1002	601	68.7	34.0	81.0	1.95	79	131.6	291	-	-	1.2
80ugs	3/16/05	BF	8.10	12.2	734	418	20.4	38.5	73.3	5.51	68	23.5	354	290	44.2	<0.1
83udaf	10/24/01	BF	-	11.5	660	394	51.1	20.3	10.1	1.23	23	16.0	204	-	-	0.5
84udaf	10/24/01	BF	-	10	716	427	52.6	22.2	10.9	1.19	27	17.0	217	-	-	0.4
88ugs	5/23/07	BFper	7.28	13.88	2290	2252	278.0	108.0	62.8	10.20	99.8	835.0	128	105	52.9	6.86
93udaf	10/24/01	BFper	-	12.8	1608	961	120.0	37.9	41.3	5.51	75	220.0	153	-	-	4.5
93ugs	2/1/05	BFper	7.40	12.0	1120	804	126.0	40.3	42.8	4.98	74	257.0	165	135	29.3	5.2
98ugs	5/30/07	bdrxp	7.25	15.5	725	428	81.5	24.0	24.2	2.68	33.2	99.8	253	208	25.3	1.16
111ugs	5/30/07	bdrx	7.48	15.1	656	344	57.8	30.7	20.0	3.70	41.6	59.7	257	216	17.1	<0.1
114udaf	10/24/01	BFper	-	12.6	2020	1205	130.9	45.4	65.2	5.71	67	335.0	120	-	-	5.0
118ugs	5/23/06	BF	-	-	522	313	-	-	-	-	-	-	-	-	-	-
119udaf	10/24/01	BF	-	13.2	3180	1898	113.9	179.7	31.5	1.09	52	603.0	253	-	-	0.0
119ugs	2/2/05	BF	7.30	10.9	2100	1270	117.0	179.0	33.4	1.00	66	592.0	280	230	49.4	<0.1
134feltis	6/8/65	BF	8.00	15.0	344	229	31.0	14.0	*20*	*in Na*	14	16.0	170	-	53.0	1.0
138udaf	10/24/01	BF	-	13.5	1427	852	23.7	38.6	118.6	9.16	64	125.0	264	-	-	5.0
139udaf	10/24/01	UK	-	14.1	778	464	40.7	22.8	44.6	3.34	56	48.0	188	-	-	0.4
139ugs	3/16/05	UK	8.30	11.2	544	316	12.4	14.4	73.5	2.27	30	23.0	244	200	-	-
141ugs	5/23/07	BFper	7.81	15.0	1680	1114	151.0	49.4	65.6	11.10	51.7	375.0	137	116	57.0	5.22
142udaf	10/24/01	X	-	12.9	1179	704	54.3	21.4	77.9	6.66	50	109.0	211	-	-	0.1
145byu	11/22/04	bdrx	7.52	28.6	-	-	102.0	32.3	38.2	3.82	66	151.0	240	-	-	2.5
156udeq	11/23/99	bdrx	-	-	1830	1290	96.0	48.0	210.0	11.00	243	340.0	246	202	18.0	0.4
156usgs	6/4/03	bdrx	7.30	23.5	1700	1030	82.1	39.4	189.0	9.61	228	274.0	248	203	16.1	0.1
156ctf	6/1/04	bdrx	-	-	-	1020	-	-	220.0	-	250	-	-	-	-	0.1
159ugs	5/31/07	bdrx	7.37	22.3	2090	1258	111.0	55.8	188.0	16.30	296.0	327.0	264	221	14.8	1.00
173usgs	4/29/58	bdrx	7.20	30.0	1990	1230	158.0	52.0	*200.0*	*in Na*	328	312.0	310	-	29.0	-
177dm	3/30/76	bdrx	7.21	-	2530	1650	224.0	57.6	800.0	21.00	536	338.0	280	230	18.0	1.0
192usgs	7/12/89	bdrx	7.70	25.0	1350	-	-	-	-	-	-	-	-	-	-	-
196usgs	7/5/89	BF	7.90	18.0	1090	637	56.0	19.0	110.0	-	69	150.0	-	127	59.0	17.0
831ugs	5/6/05	BF	8.00	-	325	190	18.3	10.0	26.2	2.32	<20.0	17.6	133	111	23.2	0.4
832ugs	5/6/05	bdrx	7.50	17.8	554	310	53.5	17.3	22.6	<1	42	27.2	242	198	9.6	<0.1
833udaf	10/6/04	bdrx	7.97	11.8	691	415	77.1	25.0	34.1	1.80	52	41.5	329	-	-	1.0
836ugs	5/30/07	bdrx	7.91	13.7	423	230	21.8	15.7	36.8	2.71	26.7	23.5	182	153	24.8	0.58

Table D-2 continued. *Major constituent water chemistry from wells, springs, and surface water, Cedar Valley study area.*

Sample ID[1]	Sample Date	Geo-logy[2]	pH	Temp. (°C)	Conduc-tivity (µmhos)	TDS, (mg/L)	Ca (mg/L)	Mg (mg/L)	Na (note 3) (mg/L)	K (note 3) (mg/L)	SO_4 (note 4) (mg/L)	Cl (mg/L)	HCO_3 (mg/L)	Alkalin-ity as $CaCO_3$ (mg/L)	SiO_2 (mg/L)	NO_3 or NO_3+NO_2, as N (mg/L)[5]
839byu	11/22/04	X	7.80	28.4	-	-	66.8	24.8	33.6	2.65	54	60.0	236	-	-	0.9
840udaf	9/17/02	BF	8.19	12.1	682	409	88.2	33.0	17.4	2.09	83	55.3	259	-	-	3.9
859ugs	2/2/05	bdrx	7.40	14.2	1570	1188	46.3	140.0	129.0	23.00	395	113.0	560	459	53.7	<0.1
864ugs	1/31/05	BF	8.10	11.1	455	344	22.3	24.8	45.5	4.80	46	34.8	208	171	58.2	0.1
867ugs	8/4/05	UK	7.40	18.0	827	484	48.2	15.9	83.5	11.70	53	124.0	190	157	65.8	1.5
880usgs	1/3/66	BF	-	10.0	421	-	-	-	-	-	-	17.0	-	-	-	-
881feltis	7/30/65	BF	7.6	10.6	430	235	58.0	17	*6*	*in Na*	17	15.0	228	-	11.0	2.7
881usgs	6/17/75	BF	-	11	400	236	54	18	18	0.9	15	14	224	184	11	0.74
881usgs	6/9/76	BF	7.9	10.5	420	242	54	19	18.4	0.9	18	15	227	186	10	0.86
881usgs	6/7/77	BF	7.9	10.5	420	239	54	18	18.6	0.9	18	15	220	180	11	0.85
881usgs	6/7/78	BF	7.4	10	420	245	54	19	18.5	0.9	27	31	180	150	11	0.84
881usgs	6/15/82	BF	7.6	10	440	243	54	18	18.6	0.9	19	15	-	185	11	0.87
881usgs	7/3/85	BF	7.7	10	405	-	55	19	9.5	1.1	18	14	-	176	11	0.84
881usgs	6/22/88	BF	7.6	10.5	430	-	53	19	11	2.5	18	16	-	192	11	0.89
881usgs	6/17/91	BF	6.4	10.5	415	-	57	19	9.2	0.8	10	24	-	188	11	-
881usgs	6/9/94	BF	7.4	10	400	-	56	18	11	0.9	16	24	-	188	11	0.97
881usgs	7/15/98	BF	7.4	-	445	-	52.8	17.8	8.9	0.87	14.5	19.3	-	187	10.5	0.96
881usgs	7/18/01	BF	7.7	11.5	335	-	54.5	18.3	9.2	0.85	14	18.6	-	183	11.4	0.95
897feltis	9/9/65	BF	7.70	11.1	444	262	57.0	18.0	*9*	*in Na*	18	17.0	232	-	11.0	1.4
901ugs	2/27/07	bdrx	8.2	11.6	667	452	48.1	20.1	87.7	3.34	59.8	87.6	252	218	-	-
902ugs	2/1/07	bdrxp	7.85	11.1	674	460	63.5	15.2	61.7	5.94	27.9	137.0	159	130	-	2.53
903ugs	2/3/07	bdrx	8.15	15.4	686	448	58.9	17.9	72.0	2.39	54.1	101.0	220	185	-	2.51
985awal	9/20/07	bdrx	7.80	-	620	350	54.0	26.0	31.0	<1	57.0	41.0	220	-	8.6	0.09
987ugs	1/28/07	bdrx	7.22	24.8	736	544	48.9	31.0	100.0	2.56	149.0	38.7	352	295	-	<0.1
991ugs	9/7/05	BF	7.20	12.9	630	-	-	-	-	-	-	-	-	-	-	-
992ctf	12/16/04	bdrx	7.10	15.1	567	380	73.0	24.0	23.0	2.70	31	61.0	250	210	25.0	0.6
992ugs	5/30/07	bdrx	7.44	15.1	727	380	74.2	25.9	21.6	2.85	32.0	86.4	254	208	23.6	1.09
994usgs	6/12/00	BF	-	11.5	610	-	-	-	-	-	-	-	-	-	-	-
1000udaf	10/24/01	BFper	-	13.6	1923	1150	110.9	48.9	49.3	8.21	72	297.0	123	-	-	0.1
1005ugs	5/23/07	BFper	7.6	13.5	1290	1112	131.0	42.9	37.6	2.56	49.2	384.0	160	133	27.4	4.89
1015ctf	10/22/04	bdrx	-	-	-	900	180.0	38.0	71.0	1.30	180	150.0	440	360	11.0	0.3
1018mont	7/31/94	X	7.30	-	-	422	70.0	28.0	41.0	3.50	70	63.0	256	-	-	-
1018udaf	10/24/01	X	-	28.5	1058	632	67.5	27.1	39.1	3.69	74	72.0	215	-	-	0.7
1018ctf	6/1/04	X	-	-	-	512	-	-	43.0	-	71	-	-	-	-	1.0
1018ugs	3/16/05	X	7.70	29.1	736	412	60.4	25.3	36.7	3.56	72	66.6	240	197	21.2	-
1022dm	5/9/73	bdrx	8.20	-	-	669	72.0	43.0	*78*	*in Na*	94	170.0	-	210	15.0	13.0
1023feltis	7/1/65	UK	7.80	16.1	2060	1230	82.0	116.0	*179*	*in Na*	291	355.0	324	-	46.0	0.7
1029feltis	7/1/65	BF	8.00	16.1	461	300	35.0	18.0	*37*	*in Na*	38	21.0	208	-	55.0	0.4
1029mont	9/13/73	BF	7.30	-	533	368	36.0	17.0	36.8	4.87	35	22.0	218	180	2.8	0.20
1031feltis	6/8/65	BF	7.60	15.0	346	225	27.0	13.0	*26*	*in Na*	14	14.0	174	-	48.0	0.2
1033udeq	3/26/85	BF	7.30	-	510	331	78.0	17.0	18.0	1.00	80	34.0	204	167	1.0	2.0
1033udeq	7/28/92	BF	7.20	-	-	250	65.0	-	9.0	-	10	33.0	-	156	-	2.6
1033ugs	3/14/05	BF	7.50	-	439	230	53.4	12.9	9.1	<1	<20.0	14.9	228	187	9.8	1.0
1035usgs	7/10/96	BF	-	11.0	400	-	-	-	-	-	-	-	-	-	-	-
1039feltis	6/30/65	BF	8.10	-	507	290	56.0	27.0	*12*	*in Na*	40	21.0	248	-	14.0	1.0

Table D-2 continued. *Major constituent water chemistry from wells, springs, and surface water, Cedar Valley study area.*

Sample ID[1]	Sample Date	Geology[2]	pH	Temp. (°C)	Conductivity (µmhos)	TDS, (mg/L)	Ca (mg/L)	Mg (mg/L)	Na (note 3) (mg/L)	K (note 3) (mg/L)	SO_4 (note 4) (mg/L)	Cl (mg/L)	HCO_3 (mg/L)	Alkalinity as $CaCO_3$ (mg/L)	SiO_2 (mg/L)	NO_3 or NO_3+NO_2, as N (mg/L)[5]
1048ctf	10/21/04	bdrx	-	-	-	316	89.0	29.0	20.0	1.30	41	20.0	360	300	9.8	0.5
1054feltis	3/29/66	BF	7.80	-	2430	1740	42.0	114.0	*383*	*in Na*	842	94.0	487	-	23.0	0.4
1057usgs	7/7/89	bdrx	7.7	26	1340	767	76	37	130	-	100	210	-	235	20	2
1057ugs	8/4/05	bdrx	7.00	25.9	1305	712	74.0	36.1	125.0	12.00	96	198.0	284	236	19.1	0.8
1060usgs	7/11/90	X	7.70	18.5	3480	-	-	-	-	-	-	-	-	-	-	-
1118feltis	6/9/65	BF	8.10	17.8	393	253	29.0	13.0	*36*	*in Na*	22	14.0	198	-	46.0	<mdl
1120feltis	6/8/65	BF	7.70	11.7	709	451	80.0	32.0	*14*	*in Na*	36	78.0	263	-	40.0	0.7
1121feltis	6/8/65	BF	8.40	11.7	434	273	46.0	20.0	*9*	*in Na*	23	17.0	194	-	40.0	2.1
1123feltis	6/8/65	BF	8.10	11.7	512	313	55.0	26.0	*16*	*in Na*	37	26.0	248	-	38.0	<mdl
1127feltis	3/1/66	BF	8.10	-	2410	1710	30.0	92.0	*439*	*in Na*	638	84.0	764	-	52.0	0.5
1128feltis	3/31/66	UK	8.10	12.2	2870	2020	28.0	135.0	*480*	*in Na*	941	140.0	518	-	32.0	0.4
1129feltis	3/1/66	UK	7.80	-	668	391	31.0	24.0	*75*	*in Na*	72	56.0	226	-	10.0	1.5
1130feltis	3/1/66	UK	7.70	-	717	448	26.0	19.0	*101*	*in Na*	64	79.0	228	-	38.0	0.5
1130ugs	2/3/05	UK	7.90	13.3	634	434	23.6	16.7	98.8	5.12	66	78.9	218	179	44.8	0.7
1131feltis	10/4/65	BF	7.90	-	647	380	67.0	30.0	*31*	*in Na*	49	29.0	325	-	19.0	0.1
1132feltis	1/3/66	BF	8.00	-	424	237	32.0	16.0	*33*	*in Na*	34	16.0	193	-	15.0	0.3
1140ctf	11/11/04	bdrx	-	-	-	348	79.0	26.0	18.0	0.80	40	18.0	340	280	8.3	0.4
1141ctf	10/21/04	bdrx	-	-	-	444	110.0	35.0	28.0	1.30	97	35.0	360	290	10.0	3.2
1142ctf	11/11/04	bdrx	-	-	-	876	120.0	59.0	130.0	2.70	230	220.0	310	250	7.9	<0.5
1143ctf	11/11/04	bdrx	-	-	-	488	28.0	15.0	160.0	1.60	43	91.0	360	290	7.3	<0.1
2001feltis	4/7/66	BF	7.70	-	634	431	77.0	10.0	*41*	*in Na*	33	76.0	220	-	48.0	0.8
2002feltis	11/3/65	bdrx	7.60	7.2	558	323	95.0	13.0	*10*	*in Na*	25	11.0	330	-	7.0	0.3
2003feltis	11/3/65	bdrx	-	10.6	771	-	-	-	-	-	-	-	-	-	-	-
2004feltis	11/3/65	bdrx	7.70	9.4	1000	558	130.0	28.0	*47*	*in Na*	58	80.0	447	-	12.0	0.1
2005feltis	11/3/65	bdrx	-	8.9	670	-	-	-	-	-	-	-	-	-	-	-
2006feltis	8/25/65	BFper	8.50	-	1360	853	148.0	30.0	*57*	*in Na*	56	295.0	148	-	49.0	2.1
2007feltis	11/2/65	bdrx	-	7.2	477	-	-	-	-	-	-	-	-	-	-	-
2008feltis	11/2/65	BF	-	5.6	518	-	-	-	-	-	-	-	-	-	-	-
2009feltis	7/22/65	bdrx	7.60	7.8	424	227	62.0	16.0	*3*	*in Na*	15	8.0	240	-	6.5	3.5
2009udeq	8/5/87	bdrx	8.00	-	570	236	57.0	17.0	7.0	<1	15	8.0	243	199	6.0	1.1
2009ugs	5/6/05	bdrx	7.40	7.3	476	262	58.6	15.3	7.7	<1	<20.0	<10.0	270	221	8.7	1.0
2010feltis	7/22/65	BF	7.70	10.0	520	290	88.0	12.0	*6*	*in Na*	27	11.0	288	-	8.0	2.1
2010ugs	4/27/05	BF	7.10	9.4	580	308	55.8	22.3	9.2	2.19	26	10.9	322	264	-	-
2011feltis	6/3/65	BF	8.10	-	457	253	59.0	20.0	*9*	*in Na*	29	18.0	236	-	10.0	2.3
2011udeq	11/16/77	BF	7.40	-	361	233	57.0	18.0	6.0	1.00	20	14.0	234	192	9.0	0.6
2011udeq	7/30/79	BF	8.70	-	420	249	56.0	18.0	9.0	1.00	18	17.0	222	192	10.0	1.0
2011udeq	11/29/82	BF	7.50	-	440	274	56.0	18.0	11.0	1.00	20	15.0	228	187	11.0	0.9
2011udeq	6/13/88	BF	8.50	-	430	258	57.0	18.0	8.0	<1	17	17.0	233	191	9.0	0.1
2011udeq	11/4/91	BF	8.00	-	452	252	48.0	20.0	10.0	<1	26	12.0	240	197	-	0.8
2011ugs	2/1/05	BF	7.50	7.5	417	276	60.2	18.7	9.6	<1	<20.0	15.9	260	213	9.1	0.6
2012feltis	7/22/65	bdrx	8.20	8.3	436	235	65.0	16.0	*4*	*in Na*	17	8.7	248	-	6.8	3.2
2012udeq	8/15/90	bdrx	7.60	-	-	244	57.0	16.0	6.0	<1	16	10.0	230	189	-	1.1
2012ugs	5/6/05	bdrx	7.20	8.1	513	284	61.1	16.2	8.8	<1	21	10.0	286	235	9.1	1.0
2013feltis	6/21/65	bdrx	7.70	11.1	586	321	67.0	29.0	*12*	*in Na*	38	20.0	303	-	6.9	0.2
2014feltis	3/1/66	BF	-	-	581	-	-	-	-	-	-	-	-	-	-	-

Table D-2 continued. *Major constituent water chemistry from wells, springs, and surface water, Cedar Valley study area.*

Sample ID[1]	Sample Date	Geo-logy[2]	pH	Temp. (°C)	Conduc-tivity (µmhos)	TDS, (mg/L)	Ca (mg/L)	Mg (mg/L)	Na[(note 3)] (mg/L)	K[(note 3)] (mg/L)	SO_4[(note 4)] (mg/L)	Cl (mg/L)	HCO_3 (mg/L)	Alkalin-ity as $CaCO_3$ (mg/L)	SiO_2 (mg/L)	NO_3 or NO_3+NO_2, as N (mg/L)[5]
2014ugs	3/3/05	BF	7.10	7.7	925	486	90.6	21.1	54.2	1.63	77	122.0	234	192	13.3	<0.1
2015ugs	5/6/05	bdrx	6.90	7.5	1790	1110	139.0	53.9	96.5	<1	212	219.0	508	417	-	-
2016ugs	5/6/05	bdrx	7.10	8.2	982	592	114.0	22.8	37.6	<1	95	50.4	454	372	-	-
3001ugs	5/6/05	BF	8.20	5.2	617	378	77.7	16.4	16.9	<1	46	19.3	290	241	10.3	1.6
3005udeq	7/21/04	BF	8.30	-	1889	1240	56.6	74.0	264.0	21.50	334	359.0	239	196	-	0.2

Notes:

Analyses are on unfiltered samples except on the following samples: 1) those collected by UGS or USGS or 2) sample IDs 1015ctf, 1048ctf, 1140ctf, 1141ctf, 1142ctf, 1143ctf, 1018mont, or 985awal, which were filtered for "dissolved" constituents with a 0.45 µm filter prior to analysis for Ca, Mg, Na, K, and SiO_2.

[1] Sample ID consists of the UGS well identification number followed by a data source code defined as:

awal — America West Analytical Laboratory report obtained from a private well owner.

byu — Brigham Young University Laboratory of Hydrogeochemistry analyses.

ctf — Chemtech-Ford Analytical Laboratory reports obtained from Eagle Mountain city, Barrick Mining Corporation, and private well owners.

dm — Reported in Dames & Moore, 1976, Ground water investigation—phase II, plant site, west shore of Utah Lake, for Ireco Chemicals: Salt Lake City, unpublished consultant's report, 5 p.

feltis — Reported in Feltis, R., 1967, Ground-water conditions in Cedar Valley, Utah County, Utah: Utah State Engineer Technical Publication 16, 31 p.

mont — Reported in Montgomery, S.B., 1995, Hydrogeologic study, John Walden well, water source protection report with delineation protection zones and management areas: Salt Lake City, unpublished consultant's report submitted to Sowby & Berg Consultants, American Fork, Utah, and Utah Department of Environmental Quality, Division of Drinking Water, 15 p.

udaf — Utah Department of Agriculture and Food analyses collected as part of their State Ground Water Plan and analyzed in-house.

udeq — Analyses compiled by the Utah Department of Environmental Quality, Division of Drinking Water. Analyses performed by either Chemtech-Ford or Utah Public Health laboratories.

ugs — Samples collected for this study. Inorganic chemistry analyzed by Utah Public Health laboratory and isotope chemistry by Brigham Young University Laboratory of Hydrogeochemistry.

usgs — Analyses reported in the U.S.Geological Survey's National Water Information System online data.

[2] Geology codes: well is open to this rock type based on geologic logs, geophysical logs, drillers' logs, or geologic maps.

BF — Basin fill

BFper — Perched, unconsolidated material in Cedar Pass area

bdrx — Bedrock, including Paleozoic sedimentary rock and Tertiary volcanic rock

bdrxp — Perched zone in volcanic or sedimentary bedrock

UK — Unknown lithology

X — Well is open across basin fill/bedrock contact

[3] Sodium and potassium are reported together and listed in the sodium column for the following samples, shown in italics: all samples from Feltis, 1967; 173usgs collected on 4/29/1958; 1022dm collected on 5/9/1973.

[4] Sulfate concentations for UDAF samples are converted from reported sulfer concentrations.

[5] Reported as "nitrate plus nitrite as N" for UGS and USGS samples. All other sample sources report as "nitrate as N".

Table D-3. *Minor constituent water chemistry from wells, springs, and surface water, Cedar Valley study area. Values are total or dissolved concentrations (see notes).*

Sample ID[1]	Sample Date	Geo-logy[2]	As (µg/L)	Ba (µg/L)	B (ug/L)	Cd (µg/L)	Cr (µg/L)	Cu (µg/L)	F (mg/L)	Fe, diss. (µg/L)	Fe, total (µg/L)	Hg (µg/L)	Pb (µg/L)	Li (µg/L)	Mn (µg/L)	Se (µg/L)	Zn (µg/L)
4mont	9/13/73	BF	-	<mdl	<mdl	<mdl	<mdl	150.0	0.4	100	100	<mdl	<mdl	-	<mdl	<mdl	0.1
4usgs	6/16/75	BF	-	-	60.0	-	-	-	0.3	-	-	-	-	-	-	-	-
4usgs	7/20/76	BF	-	-	50.0	-	-	-	0.3	90	-	-	-	-	20.0	-	-
4usgs	6/7/77	BF	-	-	50.0	-	-	-	0.4	20	-	-	-	-	20.0	-	-
4usgs	6/7/78	BF	-	-	50.0	-	-	-	0.3	30	-	-	-	-	30.0	-	-
4usgs	7/10/79	BF	-	-	80.0	-	-	-	0.1	-	-	-	-	-	-	-	-
4usgs	7/10/80	BF	-	-	80.0	-	-	-	0.5	0	-	-	-	-	10.0	-	-
4usgs	7/13/83	BF	-	-	60.0	-	-	-	0.4	10	-	-	-	-	10.0	-	-
4usgs	6/4/86	BF	-	-	60.0	-	-	-	0.3	17	-	-	-	-	16.0	-	-
4usgs	7/5/89	BF	-	-	70.0	-	-	-	0.3	14	-	-	-	-	23.0	-	-
4usgs	7/28/92	BF	-	-	60.0	-	-	-	0.3	8	-	-	-	-	18.0	-	-
4usgs	6/13/95	BF	-	-	60.0	-	-	-	0.3	24	-	-	-	-	27.0	-	-
4usgs	7/15/98	BF	-	-	81.0	-	-	-	0.3	<10	-	-	-	-	20.6	-	-
4usgs	7/18/01	BF	-	-	-	-	-	-	0.3	10	-	-	-	-	30.5	-	-
5udaf	10/24/01	BF	<10	124	90.0	<10	<10	<20	-	-	67	-	<30	<50	<20	<50	1084.8
8ugs	2/4/05	BF	1.6	113	-	<1.0	<10.0	<24.0	-	21	-	<0.2	<3.0	-	<10.0	5.7	<30.0
15udaf	10/24/01	BF	<10	81	83.0	<10	<10	<20	-	-	84	-	<30	<50	<20	<50	280.5
18ugs	4/27/05	BF	<1.0	<100.0	-	<1.0	<5.0	<12.0	-	33	-	<0.2	<3.0	-	16.7	1.8	88.3
20udaf	10/24/01	BF	<10	113	173.0	<10	<10	29.0	-	-	<20	-	<30	<50	<20	<50	106.7
23udaf	10/24/01	BF	<10	65	<70	<10	<10	<20	-	-	22	-	<30	<50	<20	<50	128.0
25udaf	10/24/01	BF	<10	89	<70	<10	<10	<20	-	-	<20	-	<30	<50	<20	<50	136.8
38ugs	1/31/05	BF	5.5	<100.0	-	<1.0	<10.0	<24.0	-	46	-	<0.2	<3.0	-	<10.0	1.1	<30.0
41mont	6/7/69	BF	-	<mdl	<mdl	-	<mdl	10.0	0.4	140	200	-	<mdl	-	<mdl	-	0.0
49ugs	1/31/05	BF	1.2	<100.0	-	<1.0	<5.0	<12.0	-	<20.0	-	<0.2	<3.0	-	<5.0	1.5	36.7
50ugs	2/9/05	BF	8.2	<100.0	-	<1.0	5.3	<12.0	-	<20.0	-	<0.2	<3.0	-	<5.0	1.4	94.9
52udaf	10/24/01	BF	<10	100	91.5	<10	<10	<20	-	-	35	-	<30	<50	<20	<50	<40
53udaf	10/24/01	BF	<10	100	<70	<10	<10	<20	-	-	<20	-	<30	<50	<20	<50	64.4
56mont	9/13/73	X	-	<mdl	<mdl	<mdl	<mdl	200.0	0.6	100	120	<mdl	<mdl	-	<mdl	<mdl	0.0
56usgs	6/16/75	X	-	-	90	-	-	-	0.6		-	-	-	-	-	-	-
56usgs	6/9/76	X	-	-	80	-	-	-	0.5	20	-	-	-	-	<10	-	-
56usgs	6/7/77	X	-	-	80	-	-	-	0.7	20	-	-	-	-	<10	-	-
56usgs	6/7/78	X	-	-	80	-	-	-	0.1	<10	-	-	-	-	<10	-	-
56usgs	6/15/82	X	-	-	80	-	-	-	0.5	-	-	-	-	-	-	-	-
56usgs	7/2/85	X	-	-	80	-	-	-	0.6	7	-	-	-	-	<1	-	-
56usgs	6/22/88	X	-	-	100	-	-	-	0.7	5	-	-	-	-	<1	-	-
56usgs	7/28/92	X	-	-	100	-	-	-	0.5	<3	-	-	-	-	<1	-	-
56usgs	6/27/95	X	-	-	80	-	-	-	0.6	<3	-	-	-	-	<1	-	-
56usgs	7/15/98	X	-	-	109	-	-	-	0.6	<10	-	-	-	-	<4	-	-
56usgs	7/18/01	X	-	-	82	-	-	-	0.5	<10	-	-	-	-	<3	-	-

Table D-3 continued. *Minor constituent water chemistry from wells, springs, and surface water, Cedar Valley study area.*

Sample ID[1]	Sample Date	Geo-logy[2]	As (µg/L)	Ba (µg/L)	B (ug/L)	Cd (µg/L)	Cr (µg/L)	Cu (µg/L)	F (mg/L)	Fe, diss. (µg/L)	Fe, total (µg/L)	Hg (µg/L)	Pb (µg/L)	Li (µg/L)	Mn (µg/L)	Se (µg/L)	Zn (µg/L)
57udaf	10/24/01	BF	<10	65	195.1	<10	<10	<20	-	-	<20	-	<30	84.0	<20	<50	58.4
58byu	12/13/04	BF	-	-	-	-	-	-	1.0	1	-	-	-	-	-	-	-
60udaf	10/24/01	BF	<10	79	108.7	<10	<10	<20	-	-	114	-	<30	<50	<20	<50	1292.8
61ugs	1/31/05	BF	12.2	<100.0	-	<1.0	<10.0	<24.0	-	<24.0	-	<0.2	<3.0	-	<10.0	1.6	<30.0
66udaf	10/24/01	bdrx	<10	50	<70	<10	<10	<20	-	-	<20	-	<30	<50	<20	<50	1942.0
68ugs	5/6/05	bdrx	4.7	<100.0	-	<1.0	<5.0	<12.0	-	191	-	<0.2	<3.0	-	38.2	2.4	<30.0
70udaf	10/24/01	BF	<10	119	<70	<10	<10	<20	-	-	311	-	<30	<50	37.0	<50	<40
74ugs	2/1/05	BF	7.6	<100.0	-	<1.0	<10.0	<24.0	-	<20.0	-	<0.2	<3.0	-	<10.0	<1.0	73.3
76udaf	10/24/01	BF	<10	32	591.6	<10	<10	<20	-	-	304	-	<30	184.0	34.0	<50	64.9
78udaf	10/24/01	BF	<10	143	<70	<10	<10	<20	-	-	670	-	<30	<50	70.0	<50	96.1
79udaf	6/26/02	BF	<10	61	90.0	<10	<10	<20	-	-	91	-	<30	<50	<20	<50	<40
80ugs	3/16/05	BF	37.6	<100.0	-	<1.0	<5.0	<12.0	-	768	-	<0.2	<3.0	-	16.0	<1.0	92.6
83udaf	10/24/01	BF	<10	45	<70	<10	<10	<20	-	-	<20	-	<30	<50	<20	<50	118.6
84udaf	10/24/01	BF	<10	51	<70	<10	<10	<20	-	-	<20	-	<30	<50	<20	<50	164.9
88ugs	5/23/07	BFper	5.79	302	-	-	-	-	-	<20.0	-	-	-	-	<5.0	8.64	11.5
93udaf	10/24/01	BFper	<10	125	203.7	<10	<10	<20	-	-	58	-	31.0	<50	<20	<50	4398.9
93ugs	2/1/05	BFper	1.6	109	-	<1.0	<10.0	<24.0	-	<20.0	-	<0.2	<3.0	-	<10.0	4.4	815.0
98ugs	5/30/07	bdrxp	1.73	<100	-	-	-	-	-	<20.0	-	-	-	-	<5.0	2.52	13.4
111ugs	5/30/07	bdrx	<1.0	<100	-	-	-	-	-	<20.0	-	-	-	-	<5.0	<1.0	110.0
114udaf	10/24/01	BFper	<10	156	107.9	<10	<10	<20	-	-	<20	-	<30	<50	<20	<50	57.1
119udaf	10/24/01	BF	<10	146	91.8	<10	<10	<20	-	-	<20	-	<30	129.0	62.0	<50	<40
119ugs	2/2/05	BF	15.7	155	-	<1.0	<10.0	<24.0	-	<20.0	-	<0.2	<3.0	-	50.9	11.0	<30.0
138udaf	10/24/01	BF	<10	<20	<70	<10	<10	128.2	-	-	<20	-	<30	<50	<20	<50	1233.9
139udaf	10/24/01	UK	<10	74	111.7	<10	<10	<20	-	-	27	-	<30	<50	<20	<50	1335.5
141ugs	5/23/07	BFper	4.93	300	-	-	-	-	-	<20.0	-	-	-	-	<5.0	6.18	107.0
142udaf	10/24/01	X	<10	77	233.4	<10	<10	<20	-	-	78	-	<30	51.0	<20	<50	973.1
145byu	11/22/04	bdrx	-	-	-	-	-	-	0.9	-	-	-	-	-	-	-	-
156udeq	11/23/99	bdrx	-	40	300.0	<1	<5.0	10.0	2.1	-	330	<0.2	<5.0	-	20.0	4.0	10.0
156usgs	6/4/03	bdrx	13.4	32	302.0	0.1	<0.8	4.9	2.3	11	-	-	0.6	173.0	0.6	1.1	38.0
156ctf	6/1/04	bdrx	15.0	35	-	<0.5	<5	-	2.5	-	-	<0.2	-	-	-	7.3	-
159ugs	5/31/07	bdrx	4.33	<100	-	-	-	-	-	71	-	-	-	-	<5.0	4.65	20.0
177dm	3/30/76	bdrx	86.0	153	20.0	<1	<1	7.0	1.74	-	344	<1	<1	-	<1	<1	513
196usgs	7/5/89	BF	-	71	-	1.0	<3	<10	0.3	5	-	-	<10	77.0	<1	-	<3
831ugs	5/6/05	BF	1.6	<100.0	-	<1.0	9.7	<12.0	-	<20.0	-	<0.2	<3.0	-	<5.0	1.7	30.8
832ugs	5/6/05	bdrx	7.4	<100.0	-	<1.0	<5.0	<12.0	-	641	-	<0.2	<3.0	-	<5.0	<1.0	<30.0
833udaf	10/6/04	bdrx	<10	55	80.0	<10	<10	<20	-	-	<20	-	<30	<50	<20	<50	<40
836ugs	5/30/07	bdrx	8.80	<100	-	-	-	-	-	<20.0	-	-	-	-	<5.0	2.34	<10
839byu	11/22/04	X	-	-	-	-	-	-	0.9	-	-	-	-	-	-	-	-
840udaf	9/17/02	BF	<10	100	<70	<10	<10	<20	-	-	<20	-	<30	<50	<20	<50	<40
859ugs	2/2/05	bdrx	57.5	<100.0	-	<1.0	<10.0	<24.0	-	<20.0	-	<0.2	<3.0	-	<10.0	5.8	30.6
864ugs	1/31/05	BF	20.0	<100.0	-	<1.0	<10.0	<24.0	-	<20.0	-	<0.2	<20.0	-	<10.0	<1	33.6

Table D-3 continued. *Minor constituent water chemistry from wells, springs, and surface water, Cedar Valley study area.*

Sample ID[1]	Sample Date	Geo-logy[2]	As (µg/L)	Ba (µg/L)	B (ug/L)	Cd (µg/L)	Cr (µg/L)	Cu (µg/L)	F (mg/L)	Fe, diss. (µg/L)	Fe, total (µg/L)	Hg (µg/L)	Pb (µg/L)	Li (µg/L)	Mn (µg/L)	Se (µg/L)	Zn (µg/L)
867ugs	8/4/05	UK	13.2	<100.0	242.0	<1.0	5.9	<12.0	-	<20.0	-	<0.2	<3.0	-	<5.0	1.9	<30.0
881usgs	6/17/75	BF	-	-	<20	-	-	-	0.1	-	-	-	-	-	-	-	-
881usgs	6/9/76	BF	-	-	<20	-	-	-	0.1	<10	-	-	-	-	<10	-	-
881usgs	6/7/77	BF	-	-	<20	-	-	-	0.1	<10	-	-	-	-	<10	-	-
881usgs	6/7/78	BF	-	-	<20	-	-	-	0.1	-	-	-	-	-	-	-	-
881usgs	6/15/82	BF	-	-	20	-	-	-	0.1	-	-	-	-	-	<1	-	-
881usgs	7/3/85	BF	-	-	20	-	-	-	0.1	13	-	-	-	-	<1	-	-
881usgs	6/22/88	BF	-	-	20	-	-	-	0.3	10	-	-	-	-	<1	-	-
881usgs	6/17/91	BF	-	-	30	-	-	-	0.4	7	-	-	-	-	<1	-	-
881usgs	6/9/94	BF	-	-	20	-	-	-	0.1	10	-	-	-	-	<1	-	-
881usgs	7/15/98	BF	-	-	48	-	-	-	0.1	<10	-	-	-	-	<4	-	-
881usgs	7/18/01	BF	-	-	20	-	-	-	0.1	<10	-	-	-	-	<3	-	-
885usgs	3/30/65	BF	-	-	350	-	-	-	1.4	-	150	-	-	-	40.0	-	-
901ugs	2/27/07	bdrx	-	<100	-	-	-	-	-	-	-	-	-	-	-	-	-
902ugs	2/1/07	bdrxp	3.09	<100	89.6	<1.0	<5.0	<12.0	-	24.4	-	<0.2	<3.0	-	<5.0	4.10	<30.0
903ugs	2/3/07	bdrx	1.28	<100	66.0	<1.0	<5.0	<12.0	-	31.8	-	<0.2	<3.0	-	6.39	4.25	<30.0
985awal	9/20/07	bdrx	13	84	-	<4	<10	<4	<4	440		<0.2	<5	-	14.0	>5	110
987ugs	1/28/07	bdrx	7.56	<100	318.0	<1.0	7.92	<12.0	-	405.0	-	<0.2	<3.0	-	69.1	<1.0	34.9
992ctf	12/16/04	bdrx	5.9	59	-	<0.5	<0.5	<10	-	20	-	<0.2	5.0	-	<10	3.2	<10
992ugs	5/30/07	bdrx	1.20	<100	-	-	-	-	-	30	-	-	-	-	<5.0	2.89	<10.0
1000udaf	10/24/01	BFper	<10	242	96.1	<10	<10	<20	-	-	<20	-	<30	38.0	<20	<50	152.3
1005ugs	5/23/07	BFper	2.57	<100	-	-	-	-	-	<20.0	-	-	-	-	<5.0	4.41	15.0
1015ctf	10/22/04	bdrx	1.0	50	-	<0.5	<5	<10	-	1500	-	<0.2	<1	-	160.0	7.0	<10
1018udaf	10/24/01	X	<10	91	98.6	<10	<10	<20	-	-	<20	-	<30	61.0	<20	<50	<40
1018ctf	6/1/04	X	6.2	87	-	<0.5	<5	-	0.6	-	-	<0.2	-	-	-	5.6	-
1018ugs	3/16/05	X	-	-	-	-	-	<10.0	-	-	-	<0.2	<3.0	-	5.3	-	<30.0
1022dm	5/9/73	bdrx	-	-	-	-	-	-	2.0	-	150	-	-	-	-	-	-
1023feltis	7/1/65	UK	-	-	-	-	-	-	2.2	-	-	-	-	-	-	-	-
1029mont	9/13/73	BF	-	<mdl	<mdl	<mdl	<mdl	100.0	0.5	110	120	<mdl	<mdl	-	<mdl	<mdl	0.1
1033udeq	3/26/85	BF	<1	50	-	<1	<1	<10	0.1	-	<10	<0.2	<1	-	<10	-	4.0
1033udeq	7/28/92	BF	<1.	40	-	<3	<30.	<20	<.1	-	<30	<0.5	2.0	-	10.0	<2	20.0
1033ugs	3/14/05	BF	<1.0	<100.0	-	<1.0	<5.0	<12.0	-	<20.0	-	<0.2	<3.0	-	<5.0	1.1	<30.0
1048ctf	10/21/04	bdrx	0.6	46	-	<0.5	<5	<10	-	100	-	<0.5	<1	-	10.0	2.7	10.0
1057usgs	7/7/89	bdrx	-	69	-	1	5	10	0.6	7	-	-	10	240	1	-	22
1057ugs	8/4/05	bdrx	23.0	<100.0	329.0	<1.0	8.6	<12.0	-	<20.0	-	<0.2	<3.0	-	<5.0	1.9	<30.0
1128feltis	3/31/66	UK	-	-	1300.0	-	-	-	4.0	-	<mdl	-	-	-	-	-	-
1130ugs	2/3/05	UK	9.2	<100.0	-	<1.0	<10.0	<24.0	-	<20.0	-	<0.2	<3.0	-	<10.0	2.1	135.0
1140ctf	11/11/04	bdrx	<0.5	36	-	<0.5	<5	<10	-	50	-	<0.2	<1	-	<10	2.4	10.0
1141ctf	10/21/04	bdrx	0.7	54	-	-	<5	<10	-	140	-	-	-	-	10.0	-	10.0
1142ctf	11/11/04	bdrx	0.7	30	-	<0.5	<5	<10	-	4200	-	<0.2	<1	-	70.0	1.8	<10
1143ctf	11/11/04	bdrx	0.8	80	-	<0.5	<5	<10	-	410	-	<0.2	<1	-	10.0	2.5	<10

Table D-3 continued. *Minor constituent water chemistry from wells, springs, and surface water, Cedar Valley study area.*

Sample ID[1]	Sample Date	Geo-logy[2]	As (µg/L)	Ba (µg/L)	B (ug/L)	Cd (µg/L)	Cr (µg/L)	Cu (µg/L)	F (mg/L)	Fe, diss. (µg/L)	Fe, total (µg/L)	Hg (µg/L)	Pb (µg/L)	Li (µg/L)	Mn (µg/L)	Se (µg/L)	Zn (µg/L)
2009udeq	8/5/87	bdrx	<1.1	20	-	<1	<5.0	<20.0	0.1	-	<30	<0.1	<5.0	-	<10.0	<0.5	<10.0
2009ugs	5/6/05	bdrx	<1.0	<100.0	-	<1.0	<5.0	<12.0	-	<20.0	-	<0.2	<3.0	-	<5.0	1.3	<30.0
2011udeq	11/16/77	BF	0.0	17	80.0	0.0	-	0.0	0.1	149	<20	0	-	-	2.0	0.0	58.0
2011udeq	7/30/79	BF	<1.0	<50	50.0	<1	<20.0	<5.0	0.1	-	190	<0.1	<5.0	-	<5.0	<1.0	310.0
2011udeq	11/29/82	BF	1.0	<50	50.0	<1	<5	<10	0.1	-	40	<0.1	<5	-	<10	<.5	<5
2011udeq	6/13/88	BF	1.0	30	-	<1	<5.0	<20.0	0.1	-	70	<0.2	<5.0	-	<5.0	<0.5	<20
2011udeq	11/4/91	BF	<5.0	20	-	<1	<5.0	<20	0.2	-	<20	<0.2	<5.0	-	<5.0	<5.0	<20.0
2011ugs	2/1/05	BF	1.2	<100.0	-	<1.0	6.5	<12.0	-	<20.0	-	<0.2	<20.0	-	<5.0	2.1	<30.0
2012udeq	8/15/90	bdrx	<1.0	20	-	<1	<10	<10.0	0.1	-	<30	<0.4	<1.0	-	<10.0	<1.0	<10.0
2012ugs	5/6/05	bdrx	<1.0	<100.0	-	<1.0	<5.0	<12.0	-	<20.0	-	<0.2	<3.0	-	<5.0	1.8	<30.0
2014ugs	3/3/05	BF	<1.0	<100.0	-	<1.0	7.1	<12.0	-	1530	-	<0.2	<3.0	-	232.0	<1.0	<30.0
3001ugs	5/6/05	BF	<1.0	<100.0	-	<1.0	<5.0	<12.0	-	<20.0	-	<0.2	<3.0	-	<5.0	2.5	<30.0
3005udeq	7/21/04	BF	13.7	120	-	<0.5	<5	<10	-	779	-	0	5.0	-	34.0	3.0	24.5

Notes:
Analyses are on unfiltered samples except on the following samples: 1) those collected by UGS or USGS or 2) sample IDs 1015ctf, 1048ctf, 1140ctf, 1141ctf, 1142ctf, 1143ctf, 1018mont, or 985awal, which were filtered for "dissolved" constituents with a 0.45 µm filter prior to analysis for trace metals.

[1] Sample ID consists of the UGS well identification number followed by a data source code defined as:

awal	America West Analytical Laboratory report obtained from a private well owner.
byu	Brigham Young University Laboratory of Hydrogeochemistry analyses.
ctf	Chemtech-Ford Analytical Laboratory reports obtained from Eagle Mountain City, Barrick Mining Corporation, and private well owners.
dm	Reported in Dames & Moore, 1976, Ground water investigation—phase II, plant site, west shore of Utah Lake, for Ireco Chemicals: Salt Lake City, unpublished consultant's report, 5 p.
feltis	Reported in Feltis, R., 1967, Ground-water conditions in Cedar Valley, Utah County, Utah: Utah State Engineer Technical Publication 16, 31 p.
mont	Reported in Montgomery, S.B., 1995, Hydrogeologic study, John Walden well, water source protection report with delineation protection zones and management areas: Salt Lake City, unpublished consultant's report submitted to Sowby & Berg Consultants, American Fork, Utah, and Utah Department of Environmental Quality, Division of Drinking Water, 15 p.
udaf	Utah Department of Agriculture and Food analyses collected as part of their State Ground Water Plan and analyzed in-house.
udeq	Analyses compiled by the Utah Department of Environmental Quality, Division of Drinking Water. Analyses performed by either Chemtech-Ford or Utah Public Health laboratories.
ugs	Samples collected for this study. Inorganic chemistry analyzed by Utah Public Health laboratory and isotope chemistry by Brigham Young University Laboratory of Hydrogeochemistry.
usgs	Analyses reported in the U.S.Geological Survey's National Water Information System online data.

[2] Geology codes: well is open to this rock type based on geologic logs, geophysical logs, drillers' logs, or geologic maps.

BF	Basin fill
BFper	Perched, unconsolidated material in Cedar Pass area
bdrx	Bedrock, including Paleozoic sedimentary rock and Tertiary volcanic rock
bdrxp	Perched zone in volcanic or sedimentary bedrock
UK	Unknown lithology
X	Well is open across basin fill/bedrock contact

Table D-4. *Isotope water chemistry from wells, springs, and surface water, Cedar Valley study area.*

Sample ID[1]	Sample Date	Geo-logy[2]	$\delta^{18}O$ (‰)	+/- $\delta^{18}O$ (‰)	$\delta^{2}H$ (‰)	+/- $\delta^{2}H$ (‰)	3H (T.U.)	+/- ^{3}H (T.U.)	$\delta^{13}C$ (‰)	^{14}C (pmC)	+/- ^{14}C (pmC)	^{14}C age (yrs)	Age evaluation
8ugs	2/4/05	BF	-16.53	0.11	-124.4	1.0	0.3	0.1	-	-	-	-	modern component
18ugs	4/27/05	BF	-16.90	0.12	-126.2	1.0	<0.2	0.3	-	-	-	-	submodern
38ugs	1/31/05	BF	-16.70	0.11	-125.3	1.0	<0.2	0.2	-	-	-	-	submodern
49ugs	1/31/05	BF	-16.70	0.11	-125.7	1.0	0.5	0.2	-	-	-	-	modern component
50ugs	2/9/05	BF	-16.69	0.11	-125.1	1.0	<0.2	0.2	-	-	-	-	
53ugs	2/5/05	BF	-16.37	0.11	-122.7	1.0	2.9	0.3	-	-	-	-	modern
56usgs	6/26/81	X	-16.80	0.20	-126.0	2.0	-	-	-	-	-	-	
58byu	12/13/04	BF	-16.24	0.24	-121.4	1.0	<0.2	0.3	-	-	-	-	submodern
61ugs	1/31/05	BF	-16.66	0.11	-126.4	1.0	<0.2	0.2	-	-	-	-	submodern
63ugs	2/3/05	BF	-16.58	0.11	-127.2	1.0	<0.2	0.4	-	-	-	-	submodern
66ugs	2/1/05	bdrx	-16.10	0.11	-122.6	1.0	5.1	0.3	-	-	-	-	modern
68ugs	5/6/05	bdrx	-16.59	0.11	-125.4	1.0	0.4	0.2	-	-	-	-	modern component
74ugs	2/1/05	BF	-16.88	0.11	-125.1	1.0	0.6	0.2	-8.06	16.0	0.3	9000-10000	mixed modern/very old
80ugs	3/16/05	BF	-17.15	0.18	-128.9	1.0	<0.2	0.3	-6.26	15.7	0.4	7000-9500	very old
88ugs	5/23/07	BFper	-15.51	0.17	-118.6	1.0	0.4	0.3	-7.79	47.93	0.2	0-1000	young
93ugs	2/1/05	BFper	-15.94	0.11	-125.0	1.0	<0.2	0.2	-	-	-	-	submodern
98ugs	5/30/07	bdrxp	-16.85	0.17	-125.0	1.0	0.9	0.4	-9.20	33.90	0.2	4000	mixed modern/old
111ugs	5/30/07	bdrx	-16.86	0.17	-127.4	1.0	-	-	-	-	-	-	
119ugs	2/2/05	BF	-16.52	0.11	-124.7	1.0	<0.2	0.2	-	-	-	-	submodern
139ugs	3/16/05	UK	-17.37	0.18	-127.5	1.0	0.3	0.3	-4.96	11.1	0.3	18000	mixed modern/very old
141ugs	5/23/07	BFper	-15.60	0.17	-119.8	1.0	0.2	0.3	-9.12	56.40	0.2	0	young
145byu	11/22/04	bdrx	-16.45	0.11	-124.6	1.0	1.5	0.1	-5.95	41.2	0.5	2000	mixed modern/old
146usgs	6/4/03	BF	-15.90	0.20	-123.8	2.0	5.69	0.28	-	-	-	-	modern
156usgs	6/4/03	bdrx	-16.42	0.20	-125.0	2.0	0.5	-	-	-	-	-	see BYU sample
156byu	4/26/07	bdrx	-	-	-	-	1.2	0.3	-3.49	3.68	0.1	13000	mixed modern/very old
159ugs	5/31/07	bdrx	-16.55	0.17	-124.8	1.0	2.5	0.3	-3.51	7.45	0.1	7000	mixed modern/very old
831ugs	5/6/05	BF	-17.48	0.12	-131.6	1.0	0.3	0.2	-	-	-	-	modern component
832ugs	5/6/05	bdrx	-16.93	0.12	-128.2	1.0	<0.2	0.2	-5.71	18.1	0.3	5000-9000	very old
836ugs	5/30/07	bdrx	-17.52	0.40	-129.7	1.0	0.3	0.2	-7.50	5.40	0.1	18500	mixed modern/very old
839byu	11/22/04	X	-16.57	0.11	-125.5	1.0	0.2	0.2	-5.78	34.5	0.4	3200	mixed modern/old
859ugs	2/2/05	bdrx	-12.47	0.11	-107.1	1.0	0.2	0.3	-7.18	25.8	0.4	4000-6000	mixed modern/old
867ugs	8/4/05	UK	-16.22	0.15	-122.9	1.0	<0.2	0.2	-8.62	42.9	0.5	1300	old
902ugs	2/1/07	bdrxp	-17.31	0.20	-131.7	1.0	0.4	0.2	-	-	-	-	modern component
903ugs	2/3/07	bdrx	-16.63	0.20	-128.6	1.0	-	-	-	-	-	-	
985awal	9/20/07	bdrx	-7.75	0.30	-126.3	1.0	-	-	-	-	-	-	
987ugs	1/28/07	bdrx	-17.62	0.20	-135.9	1.0	0.2	0.2	-	-	-	-	modern component
992ctf	12/16/04	bdrx	-16.49	0.14	-125.2	1.0	<0.2	0.1	-	-	-	-	
992ugs	5/30/07	bdrx	-16.70	0.17	-125.9	1.0	-	-	-8.80	24.59	0.2	6000	old
1005ugs	5/23/07	BFper	-16.52	0.17	-125.2	1.0	-	-	-	-	-	-	
1018ugs	3/16/05	X	-17.30	0.18	-126.3	1.0	<0.2	0.7	-	-	-	-	submodern
1033ugs	3/14/05	BF	-16.92	0.18	-124.8	1.0	1.3	0.3	-	-	-	-	modern component
1057ugs	8/4/05	bdrx	-16.10	0.15	-124.3	1.0	0.3	0.2	-4.75	33.6	0.4	3300	mixed modern/old
1130ugs	2/3/05	UK	-16.22	0.11	-124.9	1.0	<0.2	0.2	-	-	-	-	submodern
2009ugs	5/6/05	bdrx	-16.29	0.12	-122.3	1.0	7.9	0.4	-	-	-	-	modern
2010ugs	4/27/05	BF	-15.87	0.12	-119.5	1.0	4.7	0.4	-	-	-	-	modern

Table D-4 continued. *Isotope water chemistry from wells, springs, and surface water, Cedar Valley study area.*

Sample ID[1]	Sample Date	Geo-logy[2]	$\delta^{18}O$ (‰)	+/- $\delta^{18}O$ (‰)	$\delta^{2}H$ (‰)	+/- $\delta^{2}H$ (‰)	3H (T.U.)	+/- ^{3}H (T.U.)	$\delta^{13}C$ (‰)	^{14}C (pmC)	+/- ^{14}C (pmC)	^{14}C age (yrs)	Age evaluation
2011ugs	2/1/05	BF	-16.68	0.11	-124.9	1.0	1.8	0.2	-	-	-	-	modern component
2012ugs	5/6/05	bdrx	-16.27	0.12	-122.4	1.0	5.3	0.4	-	-	-	-	modern
2014ugs	3/3/05	BF	-15.47	0.31	-122.6	1.0	<0.2	0.3	-	-	-	-	submodern
2015ugs	5/6/05	bdrx	-15.21	0.12	-115.9	1.0	-	-	-	-	-	-	
2016ugs	5/6/05	bdrx	-15.59	0.18	-116.9	1.0	7.8	0.4	-	-	-	-	modern
3001ugs	5/6/05	BF	-15.66	0.12	-119.5	1.0	6.3	0.4	-	-	-	-	modern

Isotope compositions are reported as the permil (‰) difference of the sample relative to Vienna Standard Mean Oceanic Water for $\delta^{2}H$ and $\delta^{18}O$ and the Pee Dee Formation belemnite for $\delta^{13}C$. ^{14}C values are reported relative to percent modern carbon (pmC). ^{3}H values are reported in tritium units (T.U.).

[1] Sample ID consists of the UGS well identification number followed by a data source code defined as:

awal	America West Analytical Laboratory report obtained from a private well owner.
byu	Brigham Young University Laboratory of Hydrogeochemistry analyses.
ctf	Chemtech-Ford Analytical Lab reports obtained from Eagle Mountain City, Barrick Mining Corp., and private owners.
ugs	Samples collected for this study. Inorganic chemistry analyzed by Utah Public Health laboratory and isotope chemistry by Brigham Young University Laboratory of Hydrogeochemistry.
usgs	Analyses reported in the U.S.Geological Survey's National Water Information System online data.

[2] Geology codes: well is open to this rock type based on geologic logs, geophysical logs, drillers' logs, or geologic maps.

BF	Basin fill
BFper	Perched, unconsolidated material in Cedar Pass area
bdrx	Bedrock, including Paleozoic sedimentary rock and Tertiary volcanic rock
bdrxp	Perched zone in volcanic or sedimentary bedrock
UK	Unknown lithology
X	Well is open across basin fill/bedrock contact

Table D-5. *Analytical methods used on UGS- and UDAF-collected samples.*

	Method used by UPHL[1] on UGS samples		Method used on UDAF[3] samples
Analyte	**Method No.[2]**	**Method Description**	**Method Description**
Alkalinity	310.1	Titration	na
Aluminum	200.8	ICP-MS[4]	ICP
Arsenic	200.8	ICP-MS	ICP
Barium	200.8	ICP-MS	ICP
Berylium	na	na	ICP
Bicarbonate	310.1	Titration and calculation	Field (HACH kit)
Boron	200.7	ICP[5]	ICP
Cadmium	200.8	ICP-MS	ICP
Calcium	200.7	ICP	ICP
Carbon Dioxide	310.1	Titration and calculation	na
Carbonate	310.1	Titration and calculation	Field (HACH kit)
Carbonate Solids	310.1	Titration and calculation	na
Chloride	325.2	Flow injection colorimetry	Field (HACH kit)
Chromium	200.8	ICP-MS	ICP
Conductance	120.1	Conductivity meter	Conductivity meter
Cobalt	na	na	ICP
Copper	200.8	ICP-MS	ICP
Coliform bacteria	na	na	IDEXX Colilert MUG field kit
E-coli	na	na	IDEXX Colilert MUG field kit
Hardness	na	Calculation based on Ca + Mg	Calculation based on Ca + Mg
Hydroxide	310.1	Titration and calculation	na
Iron	200.7	ICP	ICP
Lead	200.8	ICP-MS	ICP
Lithium	na	na	ICP
Magnesium	200.7	ICP	ICP
Manganese	200.8	ICP-MS	ICP
Mercury	245.1	Cold Vapor Atomic Absorption	na
Molebdenum	na	na	ICP
Nickel	200.8	ICP-MS	ICP
Nitrate+Nitrite as N	353.2	Colorimetric	na
Nitrate	na	na	Field (HACH kit)
pH	150.1	pH-Electrometric, field	pH-Electrometric
Phosphate, total	na	na	Converted from P
Phosphorus	na	na	ICP
Potassium	200.7	ICP	ICP
Selenium	200.8	ICP-MS	ICP
Silica	370.1	Colorimetric	na
Silver	200.8	ICP-MS	na
Sodium	200.7	ICP	ICP
Sodium adsorption ratio	na	na	Calculation
Sulfate	375.2	Colorimetric, automated	Converted from sulfur
Sulfur	na	na	ICP
Temperature	170.1	Thermometric, field	Thermometric, field
Total Dissolved Solids	160.1	Residue at 180 C, filterable	Conductivity * 0.6
Total Suspended Solids	160.2	Residue at 180 C, non-filterable	na
Turbidity	180.1	Turbidity nephelometric	na
Vanadium	na	na	ICP
Zinc	200.8	ICP-MS	ICP

[1] Utah Public Health Laboratory
[2] Environmental Protection Agency method numbers
[3] Utah Department of Agriculture and Food
[4] Inductively Coupled Plasma - Mass Spectrometry
[5] Inductively Coupled Plasma - Atomic Emission Spectrometry
na - not applicable, no analyses

Table D-6. *Quality control results for duplicate water-quality samples.*

Sample/Well ID	**1130**	**duplicate**		**18**	**duplicate**	
Sample Date	**2/3/2005**	**2/3/2005**	**%Difference***	**4/27/2005**	**4/27/2005**	**%Difference***
Aluminum, dissolved (µg/L)	<30.0	<30.0	**0**	<30.0	<30.0	**0**
Arsenic, dissolved (µg/L)	9.18	9.07	**-1.2**	<1.0	<1.0	**0**
Barium, dissolved (µg/L)	<100.0	<100.0	**0**	<100.0	<100.0	**0**
Bicarbonate (mg/L)	218	222	**1.8**	262	260	**-0.8**
Cadmium, dissolved (µg/L)	<1.0	<1.0	**0**	<1.0	<1.0	**0**
Calcium, dissolved (mg/L)	23.6	23.3	**-1.3**	73.3	70.3	**-4.2**
Carbon dioxide (mg/L)	4	9	**76.9**	5	4	**-22.2**
Carbonate (mg/L)	0	0	**0**	0	0	**0**
Carbonate Solids (mg/L)	107	109	**1.9**	129	128	**-0.8**
Chloride (mg/L)	78.9	78.3	**-0.8**	38.2	38.2	**0**
Chromium, dissolved (µg/L)	<10.0	<10.0	**0**	<5.0	<5.0	**0**
Copper, dissolved (µg/L)	<24.0	<24.0	**0**	<12.0	<12.0	**0**
Hydroxide (mg/L)	0	0	**0**	0	0	**0**
Iron, dissolved (µg/L)	<20.0	<20.0	**0**	32.6	32	**-1.9**
Lead, dissolved (µg/L)	<3.0	<3.0	**0**	<3.0	<3.0	**0.0**
Magnesium, dissolved (mg/L)	16.7	16.6	**-0.6**	15	13.8	**-8.3**
Manganese, dissolved (µg/L)	<10.0	<10.0	**0**	16.7	17	**1.8**
Mercury, dissolved (µg/L)	<0.2	<0.2	**0**	<0.2	<0.2	**0**
Nitrogen (NO_2 + NO^3) (mg/L)	0.74	0.75	**1.3**	0.74	0.75	**1.3**
pH, Field	7.9	NA		7.3	NA	
pH, Lab	7.96	7.61	**-4.5**	7.96	7.99	**0.4**
Potassium, dissolved (mg/L)	5.12	4.95	**-3.4**	1.42	1.47	**3.5**
Selenium, dissolved (µg/L)	2.08	1.99	**-4.4**	1.8	7.82	**125.2**
Silica (mg/L)	44.8	44.5	**-0.7**	10.3	31	**100.2**
Silver, dissolved (µg/L)	<2.0	<2.0	**0**	<2.0	<2.0	**0**
Sodium, dissolved (mg/L)	98.8	99.0	**0.2**	24.6	24.3	**-1.2**
Specific Cond., Field (µmhos)	634	NA		595	NA	
Specific Cond., Lab (µmhos)	720	719	**-0.1**	587	586	**-0.2**
Sulfate (mg/L)	65.6	67.9	**3.4**	34.9	34.7	**-0.6**
Total Alkalinity (mg/L)	179	182	**1.7**	215	213	**-0.9**
Total Dissolved Solids, (mg/L)	434	430	**-0.9**	334	338	**1.2**
Total Hardness as $CaCO_3$ (mg/L)	127.6	126.4	**-0.9**	244.6	232.2	**-5.2**
Total Suspended Solids (mg/L)	<4.0	<4.0	**0**	<4.0	<4.0	**0**
Turbidity (NTU)	<0.1	<0.1	**0**	1.19	3.04	**87.5**
Zinc, dissolved (µg/L)	135	130	**-3.8**	88.3	89.9	**1.8**
Tritium (T.U.)	<0.2	<0.2	**0**	<0.2	<0.2	**0**
$\delta^{18}O$ (per mil)	-16.22	-16.20	**-0.1**	-16.9	-16.91	**0.1**
$\delta^{2}H$ (per mil)	-124.9	-124.5	**-0.3**	-126.19	-126.5	**0.2**

* Percent Difference is calculated as the difference between the sample and the duplicate divided by the average of the two samples, multiplied by 100.

APPENDIX E

CALCULATIONS FOR RECHARGE FROM PRECIPITATION, STREAM AND CANAL SEEPAGE, UNUSED IRRIGATION, AND SEWAGE TREATMENT FACILITIES

Table E-1. *Estimated PRISM precipitation, Maxey-Eakin recharge, and geology-refined recharge for eight recharge zones in the Cedar Valley hydrologic basin, with emphasis on the four regions that contribute recharge to the groundwater system shown in blue shading.*

Recharge Regions: **WCD** = West Canyon drainage, **OQM** = Oquirrh Mountains, **TTH** = Thorpe and Topliff Hills, **ETM** = East Tintic Mountains, **VF** = valley floor, **CP** = Cedar Pass, **LM** = Lake Mountains, **MH** = Mosida Hills.

Year	Estimated precipitation from PRISM data (acre-ft/yr)										Estimated Maxey-Eakin recharge (acre-ft/yr)									Estimated geology-refined recharge (acre-ft/yr)									
	WCD	OQM	TTH	ETM	VF	CP	LM	MH	Total	Contributing Areas Total	WCD	OQM	TTH	ETM	VF	CP	LM	MH	Total	WCD	OQM	TTH	ETM	VF	CP	LM	MH	Total	Contributing Areas Total
1969	53,054	78,534	14,802	32,862	104,272	20,616	9423	5690	**319,252**	**268,721**	12,896	18,649	1341	7239	7639	1414	283	171	**49,631**	8752	13,446	961	5128	4326	1192	190	64	**34,058**	**31,652**
1970	59,788	85,260	14,198	30,397	107,639	23,295	9891	5582	**336,051**	**283,085**	14,947	20,324	994	4527	8575	2715	297	167	**52,546**	10,178	14,656	720	3229	5600	2247	200	62	**36,893**	**33,664**
1971	57,475	90,400	16,777	31,639	129,303	23,695	12,037	6791	**368,116**	**308,817**	13,971	21,914	2516	4709	15,027	3482	843	475	**62,937**	9476	15,831	1830	3360	6954	2941	565	176	**41,133**	**35,621**
1972	48,446	68,025	10,556	24,239	80,034	18,068	7103	4218	**260,688**	**220,743**	11,801	16,130	317	1684	3844	953	152	127	**35,007**	7999	11,570	229	1201	2375	788	97	47	**24,307**	**23,146**
1973	58,346	85,497	15,533	33,187	113,755	23,252	10,050	6032	**345,652**	**290,785**	14,185	20,350	1397	7308	10,266	2699	418	422	**57,045**	9624	14,665	1003	5176	5539	2235	271	157	**38,669**	**35,003**
1974	38,557	57,426	9862	19,907	80,251	15,958	7575	3885	**233,420**	**196,140**	9154	13,457	296	1156	2569	479	227	27	**27,365**	6181	9672	215	816	1269	403	153	7	**18,718**	**17,939**
1975	59,213	89,485	14,718	29,735	115,363	23,840	10,573	5565	**348,492**	**293,796**	14,803	21,662	1323	4412	11,371	3504	740	217	**58,031**	10,090	15,671	951	3150	6926	2954	500	75	**40,315**	**35,836**
1976	38,715	55,041	8709	20,598	62,396	13,442	5165	3013	**207,078**	**176,750**	9204	13,013	261	1426	1134	391	0	0	**25,429**	6215	9336	189	1018	888	330	0	0	**17,976**	**17,457**
1977	48,861	73,215	13,183	21,172	118,734	24,246	10,898	5523	**315,831**	**261,982**	12,215	17,582	731	1468	12,163	3535	641	218	**48,554**	8341	12,783	541	1048	6927	2984	420	75	**33,119**	**29,099**
1978	68,408	103,506	18,952	43,606	138,540	26,802	12,909	7322	**420,045**	**354,060**	17,102	25,153	2843	10,848	19,615	3934	1195	637	**81,327**	11,631	18,149	2059	7737	9389	3316	782	224	**53,287**	**46,906**
1979	37,013	57,642	11,146	21,550	82,577	14,351	7813	4514	**236,605**	**198,781**	8794	13,439	334	1496	2861	431	234	135	**27,724**	5938	9655	243	1067	1362	362	158	50	**18,834**	**18,022**
1980	65,399	98,223	16,847	33,857	130,991	25,531	11,525	6595	**388,968**	**328,470**	16,350	23,869	2527	7454	18,215	3751	807	462	**73,434**	11,135	17,268	1834	5279	9763	3161	544	172	**49,157**	**43,446**
1981	59,629	92,713	16,702	29,569	138,774	28,282	13,079	7050	**385,799**	**320,686**	14,907	22,476	1995	4397	20,036	4242	1525	617	**70,195**	10,165	16,292	1468	3137	10,552	3574	1033	216	**46,438**	**40,147**
1982	68,238	99,103	19,512	34,588	152,292	29,552	13,833	8354	**425,471**	**354,220**	17,059	23,980	2927	8589	27,309	6112	1775	1253	**89,004**	11,627	17,362	2128	6125	12,971	5086	1162	465	**56,925**	**48,084**
1983	80,765	119,106	24,828	44,871	198,584	37,075	18,622	10,692	**534,543**	**443,326**	20,191	29,777	6207	11,218	49,598	9269	4656	2673	**133,588**	13,754	21,742	4517	7988	20,617	7804	3131	991	**80,544**	**64,101**
1984	63,117	96,388	16,764	29,135	133,986	26,076	12,210	7108	**384,784**	**322,626**	15,779	23,398	2515	4331	17,131	3835	855	498	**68,340**	10,748	16,916	1829	3090	8687	3232	574	184	**45,260**	**39,441**
1985	53,475	77,665	16,314	29,606	128,353	23,370	11,482	6800	**347,064**	**289,098**	13,369	18,753	1944	4404	16,031	3403	680	476	**59,060**	9113	13,624	1429	3142	8267	2871	444	176	**39,067**	**34,146**
1986	63,688	88,465	16,130	28,776	130,430	25,997	12,176	6617	**372,279**	**311,359**	15,922	21,437	1923	4280	16,285	3820	852	463	**64,983**	10,836	15,516	1415	3054	8451	3218	574	171	**43,236**	**37,857**
1987	49,724	72,845	13,519	24,277	108,863	21,275	9882	5493	**305,878**	**255,709**	12,054	17,205	946	1684	8280	1457	296	165	**42,088**	8174	12,431	688	1202	4557	1229	200	61	**28,542**	**26,364**
1988	37,918	53,698	8170	18,372	61,778	13,242	5506	3344	**202,029**	**171,766**	9020	10,894	168	544	1039	385	0	0	**22,050**	6092	7734	116	388	808	325	0	0	**15,464**	**15,023**
1989	39,122	55,765	9122	17,322	71,615	13,653	6446	3631	**216,676**	**183,824**	9305	11,327	274	512	1924	396	58	25	**23,821**	6285	8056	199	366	1052	334	35	7	**16,332**	**15,758**
1990	44,430	65,368	11,371	23,206	82,021	16,924	7411	4334	**255,064**	**215,024**	10,585	15,437	462	1611	3174	490	160	130	**32,048**	7145	11,070	331	1149	1659	414	102	48	**21,918**	**21,024**
1991	59,729	88,666	16,383	27,445	138,333	26,813	12,951	6908	**377,227**	**314,172**	14,932	21,456	1968	4080	21,239	3937	1202	610	**69,425**	10,174	15,547	1449	2912	10,424	3321	785	213	**44,824**	**39,056**
1992	40,581	60,681	12,130	21,674	99,405	19,756	9677	5240	**269,145**	**222,341**	9822	14,267	542	1503	6580	1351	290	157	**34,512**	6661	10,303	404	1073	3715	1140	196	58	**23,550**	**21,752**
1993	55,210	82,562	15,602	29,228	124,970	24,332	11,654	6562	**350,119**	**291,970**	13,802	20,023	1854	4347	13,711	3572	816	459	**58,586**	9407	14,504	1360	3101	7522	3012	550	170	**39,626**	**34,534**
1994	48,641	70,940	13,911	25,223	105,399	19,300	9598	5615	**298,627**	**250,204**	11,829	16,730	974	3184	6338	1322	404	218	**41,001**	8015	12,075	707	2249	3416	1115	262	76	**27,914**	**25,755**
1995	63,244	91,953	16,320	29,555	126,679	26,061	11,497	6405	**371,715**	**311,432**	15,811	22,344	2448	4397	13,813	3834	805	448	**63,900**	10,762	16,160	1775	3137	7665	3234	542	167	**43,441**	**37,723**
1996	56,900	84,117	16,013	28,726	124,070	24,520	11,443	6449	**352,239**	**293,814**	14,225	20,381	1892	4273	13,446	3604	801	451	**59,073**	9686	14,781	1389	3048	7324	3041	539	168	**39,975**	**34,839**
1997	57,380	83,680	18,869	34,982	151,860	30,032	14,470	8150	**399,424**	**327,902**	14,345	20,152	2830	8688	27,819	6259	2170	1223	**83,487**	9808	14,625	2058	6195	13,292	5208	1463	452	**53,101**	**43,920**
1998	71,213	103,653	21,419	41,338	165,942	32,929	15,433	9089	**461,017**	**382,146**	17,803	25,913	5355	10,269	30,605	8108	2315	1363	**101,732**	12,160	18,837	3889	7323	14,847	6832	1557	506	**65,951**	**53,167**
1999	46,951	68,248	14,610	28,645	112,148	24,090	10,375	6062	**311,128**	**255,991**	11,738	16,095	1458	4262	11,364	3542	555	424	**49,438**	8027	11,626	1085	3041	6812	2988	376	158	**34,112**	**29,506**
2000	50,373	75,360	15,641	30,485	119,606	23,491	10,996	6509	**332,462**	**275,825**	12,593	18,221	1846	4535	12,894	3452	770	456	**54,767**	8603	13,173	1357	3236	7131	2910	518	169	**37,097**	**32,143**
2001	44,432	65,864	12,471	24,323	95,199	18,407	8416	5188	**274,300**	**229,819**	10,749	15,573	678	1688	5084	997	252	156	**35,176**	7306	11,210	499	1204	3033	823	169	58	**24,302**	**22,754**
2002	36,857	53,954	9359	18,663	71,524	15,766	6251	3761	**216,135**	**180,998**	8888	10,698	281	560	2132	458	0	0	**23,017**	6042	7622	204	399	1748	387	0	0	**16,402**	**15,811**
2003	45,311	66,730	13,666	27,103	104,883	22,740	9559	5689	**295,681**	**244,027**	11,328	15,701	957	4032	9201	2628	287	171	**44,304**	7747	11,323	696	2877	6015	2177	194	64	**31,091**	**27,961**
2004	50,107	72,209	15,164	30,192	116,238	23,744	10,791	6480	**324,925**	**268,745**	12,527	16,996	1061	4490	12,232	3458	631	454	**51,849**	8557	12,256	770	3203	6967	2917	413	169	**35,252**	**30,983**
2005	60,987	90,031	17,346	35,697	134,800	28,836	12,146	7016	**386,859**	**321,515**	15,247	21,802	2602	8873	17,492	5931	850	491	**73,289**	10,405	15,791	1891	6327	9895	4941	573	182	**50,006**	**42,418**
2006	49,252	72,707	14,008	28,828	108,861	23,287	9809	5666	**312,418**	**259,648**	12,313	17,151	981	4291	10,006	3394	294	170	**48,600**	8403	12,372	713	3061	6321	2865	198	63	**33,997**	**30,157**
2007	41,012	60,543	11,665	24,005	90,648	19,391	8168	4718	**260,149**	**216,208**	9914	14,091	350	1666	4980	1330	245	142	**32,718**	6730	10,144	254	1189	2975	1122	165	52	**22,631**	**21,037**
Minimum	36,857	53,698	8170	17,322	61,778	13,242	5165	3013	**202,029**	**171,766**	8794	10,698	168	512	1039	385	0	0	**22,050**	5938	7622	116	366	808	325	0	0	**15,464**	**15,023**
Maximum	80,765	119,106	24,828	44,871	198,584	37,075	18,622	10,692	**534,543**	**443,326**	20,191	29,777	6207	11,218	49,598	9269	4656	2673	**133,588**	13,754	21,742	4517	7988	20,617	7804	3131	991	**80,544**	**64,101**
Average	53,117	78,340	14,674	28,425	114,387	22,873	10,483	5991	**328,291**	**274,270**	13,115	18,662	1598	4370	12,642	3022	753	429	**54,592**	8923	13,482	1164	3113	6616	2539	503	158	**36,499**	**32,135**

Table E-2. *Estimation of seepage from West Canyon Wash and Cedar Fort Ditch, in acre-feet except where noted.*

Fractions of West Canyon flow estimated to be released to channel or diverted down ditch per month.

Month	Fraction of creek flow to wash	Fraction of wash flow seeping	Fraction of creek flow to ditch	Fraction of ditch flow seeping, pre-1975	Fraction of ditch flow seeping, post-1975	Fraction of ditch flow lost to evaporation	Comment
Jan	1	1	0	0	0	0	All flow goes down channel. Low ET.
Feb	1	1	0	0	0	0	All flow goes down channel. Low ET.
Mar	1	1	0	0	0	0	All flow goes down channel. Low ET.
Apr	0.666	1	0.334	0.15	0.15	0.05	Irrigation season starts April 20. Flow down channel for 2/3 of month.
May	0.1	0.5	0.9	0.15	0.15	0.05	10% of flow released down creek because too muddy or too much volume.
Jun	0	0.5	1	0.15	0.15	0.05	All water diverted to ditch. Seepage measured in seepage study.
Jul	0	0.5	1	0.15	0.01	0.05	All water diverted to ditch. Seepage measured in seepage study.
Aug	0	0.5	1	0.15	0.01	0.05	All water diverted to ditch. Seepage measured in seepage study.
Sep	0	0.5	1	0.15	0.01	0	All water diverted to ditch. Seepage measured in seepage study.
Oct	0.333	1	0.667	0.15	0.01	0	Irrigation season ends Oct 20. Flow down channel for 1/3 of month.
Nov	1	1	0	0	0	0	All flow goes down channel. Low ET.
Dec	1	1	0	0	0	0	All flow goes down channel. Low ET.

Monthly flow multiplied by above fractions unless monthly flow is >1190 acre-feet, in which case we assume the excess must be released down the wash because ditch capacity would be exceeded.

Month-year	Monthly avg. flow of creek at gage, in cfs	Monthly average flow	Sum per year	Est. amt. released to wash	Sum per year	Seepage from wash	Sum per year	Est. amt. diverted to ditch	Sum per year	Seepage from ditch	Sum per year	Est. amt. to fields	Sum per year
Jan-69	0.51	31		31		31		0		0		0	
Feb-69	0.76	42		42		42		0		0		0	
Mar-69	1.03	63		63		63		0		0		0	
Apr-69	17.4	1037		691		691		346		52		277	
May-69	32.5	2002		812		406		1190		179		952	
Jun-69	17.3	1031		0		0		1031		155		825	
Jul-69	6.31	389		0		0		389		58		311	
Aug-69	5	308		0		0		308		46		246	
Sep-69	2.46	147	5224	0	1761	0	1355	147	3463	22	519	125	2780
Oct-69	2.06	127		42		42		85		13		72	
Nov-69	1.73	103		103		103		0		0		0	
Dec-69	1.36	84		84		84		0		0		0	
Jan-70	0.86	53		53		53		0		0		0	
Feb-70	0.65	36		36		36		0		0		0	
Mar-70	0.61	38		38		38		0		0		0	
Apr-70	0.63	38		25		25		13		2		10	
May-70	7.3	450		45		22		405		61		324	
Jun-70	10	596		0		0		596		89		477	
Jul-70	4.04	249		0		0		249		37		199	
Aug-70	1.97	121		0		0		121		18		97	
Sep-70	1.59	95	1989	0	426	0	403	95	1563	14	234	81	1259
Oct-70	1.17	72		24		24		48		7		41	
Nov-70	0.8	48		48		48		0		0		0	
Dec-70	0.7	43		43		43		0		0		0	
Jan-71	0.66	41		41		41		0		0		0	
Feb-71	0.7	39		39		39		0		0		0	
Mar-71	2.21	136		136		136		0		0		0	
Apr-71	11.1	662		441		441		221		33		177	
May-71	15.6	961		96		48		865		130		692	
Jun-71	14.1	841		0		0		841		126		672	
Jul-71	5.07	312		0		0		312		47		250	
Aug-71	3.52	217		0		0		217		33		173	
Sep-71	1.19	71	3442	0	867	0	819	71	2574	11	386	60	2066
Oct-71	1.27	78		26		26		52		8		44	
Nov-71	1.29	77		77		77		0		0		0	
Dec-71	1.05	65		65		65		0		0		0	
Jan-72	0.92	57		57		57		0		0		0	
Feb-72	0.66	37		37		37		0		0		0	
Mar-72	2.69	166		166		166		0		0		0	
Apr-72	5.36	320		213		213		107		16		85	
May-72	8.92	549		55		27		495		74		396	
Jun-72	8.51	507		0		0		507		76		406	
Jul-72	2.7	166		0		0		166		25		133	
Aug-72	1.5	92		0		0		92		14		74	
Sep-72	1.13	67	2181	0	694	0	667	67	1487	10	223	57	1195
Oct-72	0.92	57		19		19		38		6		32	
Nov-72	0.67	40		40		40		0		0		0	
Dec-72	0.65	40		40		40		0		0		0	
Jan-73	0.67	41		41		41		0		0		0	
Feb-73	0.44	24		24		24		0		0		0	
Mar-73	0.47	29		29		29		0		0		0	
Apr-73	11.3	674		449		449		225		34		180	
May-73	44.2	2723		1533		766		1190		179		952	
Jun-73	26.1	1556		366		183		1190		179		952	
Jul-73	9.92	611		0		0		611		92		489	

Table E-2 continued. *Estimation of seepage from West Canyon Wash and Cedar Fort Ditch, in acre-feet except where noted.*

Month-year	Monthly avg. flow of creek at gage, in cfs	Monthly average flow	Sum per year	Est. amt. released to wash	Sum per year	Seepage from wash	Sum per year	Est. amt. diverted to ditch	Sum per year	Seepage from ditch	Sum per year	Est. amt. to fields	Sum per year
Aug-73	4.59	283		0		0		283		42		226	
Sep-73	3.27	195	6272	0	2541	0	1591	195	3731	29	560	166	2997
Oct-73	2.51	155		51		51		103		15		88	
Nov-73	1.78	106		106		106		0		0		0	
Dec-73	1.48	91		91		91		0		0		0	
Jan-74	0.91	56		56		56		0		0		0	
Feb-74	0.78	43		43		43		0		0		0	
Mar-74	0.7	43		43		43		0		0		0	
Apr-74	7.18	428		285		285		143		21		114	
May-74	17.5	1078		108		54		970		146		776	
Jun-74	12.2	727		0		0		727		109		582	
Jul-74	4.29	264		0		0		264		40		211	
Aug-74	2.33	144		0		0		144		22		115	
Sep-74	1.4	83	3219	0	784	0	730	83	2435	13	365	71	1957
Oct-74	1.08	67		22		22		44		7		38	
Nov-74	0.89	53		53		53		0		0		0	
Dec-74	0.7	43		43		43		0		0		0	
Jan-75	0.61	38		38		38		0		0		0	
Feb-75	0.63	35		35		35		0		0		0	
Mar-75	1.38	85		85		85		0		0		0	
Apr-75	0.87	52		35		35		17		3		14	
May-75	14.2	875		87		44		787		118		630	
Jun-75	27.6	1645		455		228		1190		179		952	
Jul-75	21.2	1306		116		58		1190		179		952	
Aug-75	8.9	548		0		0		548		82		439	
Sep-75	4.47	266	5013	0	969	0	640	266	4044	40	607	226	3250
Oct-86	3.67	226		75		75		151		2		149	
Nov-86	3	179		179		179		0		0		0	
Dec-86	1.35	83		83		83		0		0		0	
Jan-87	1.4	86		86		86		0		0		0	
Feb-87	1.56	87		87		87		0		0		0	
Mar-87	1.52	94		94		94		0		0		0	
Apr-87	5.58	333		222		222		111		17		89	
May-87	11.5	708		71		35		638		96		510	
Jun-87	5.83	348		0		0		348		52		278	
Jul-87	3.83	236		0		0		236		2		222	
Aug-87	2.04	126		0		0		126		1		118	
Sep-87	1.54	92	2597	0	896	0	861	92	1700	1	170	91	1457
Oct-87	1.12	69		23		23		46		0		46	
Nov-87	0.95	57		57		57		0		0		0	
Dec-87	0.6	37		37		37		0		0		0	
Jan-88	0.48	30		30		30		0		0		0	
Feb-88	0.53	29		29		29		0		0		0	
Mar-88	0.48	30		30		30		0		0		0	
Apr-88	0.69	41		27		27		14		2		11	
May-88	12.3	758		76		38		682		102		546	
Jun-88	3.48	207		0		0		207		31		166	
Jul-88	1.14	70		0		0		70		1		66	
Aug-88	0.77	47		0		0		47		0		45	
Sep-88	0.61	36	1411	0	308	0	270	36	1103	0	137	36	915
Oct-88	0.4	25		8		8		16		0		16	
Nov-88	0.35	21		21		21		0		0		0	
Dec-88	0.23	14		14		14		0		0		0	
Jan-89	0.18	11		11		11		0		0		0	
Feb-89	0.13	7		7		7		0		0		0	
Mar-89	0.14	9		9		9		0		0		0	
Apr-89	1.59	95		63		63		32		5		25	
May-89	5.19	320		32		16		288		43		230	
Jun-89	3.11	185		0		0		185		28		148	
Jul-89	1.04	64		0		0		64		1		60	
Aug-89	0.42	26		0		0		26		0		24	
Sep-89	0.21	13	789	0	165	0	149	13	624	0	77	12	517
Oct-89	0.25	15		5		5		10		0		10	
Nov-89	0.21	13		13		13		0		0		0	
Dec-89	0.17	10		10		10		0		0		0	
Jan-90	0.16	10		10		10		0		0		0	
Feb-90	0.14	8		8		8		0		0		0	
Mar-90	0.11	7		7		7		0		0		0	
Apr-90	0.22	13		9		9		4		1		4	
May-90	3.05	188		19		9		169		25		135	
Jun-90	6.01	358		0		0		358		54		287	
Jul-90	1.2	74		0		0		74		1		69	
Aug-90	0.38	23		0		0		23		0		22	
Sep-90	0.21	13	732	0	80	0	71	13	652	0	81	12	539
Oct-90	0.19	12		4		4		8		0		8	
Nov-90	0.17	10		10		10		0		0		0	

Table E-2 continued. *Estimation of seepage from West Canyon Wash and Cedar Fort Ditch, in acre-feet except where noted.*

Month-year	Monthly avg. flow of creek at gage, in cfs	Monthly average flow	Sum per year	Est. amt. released to wash	Sum per year	Seepage from wash	Sum per year	Est. amt. diverted to ditch	Sum per year	Seepage from ditch	Sum per year	Est. amt. to fields	Sum per year
Dec-90	0.11	7		7		7		0		0		0	
Jan-91	0.062	4		4		4		0		0		0	
Feb-91	0.057	3		3		3		0		0		0	
Mar-91	0.12	7		7		7		0		0		0	
Apr-91	0.11	7		4		4		2		0		2	
May-91	12.6	776		78		39		699		105		559	
Jun-91	13.2	787		0		0		787		118		629	
Jul-91	3.25	200		0		0		200		2		188	
Aug-91	1.95	120		0		0		120		1		113	
Sep-91	2.59	154	2087	0	117	0	78	154	1970	2	228	153	1652
Oct-91	0.47	29		10		10		19		0		19	
Nov-91	0.84	50		50		50		0		0		0	
Dec-91	0.6	37		37		37		0		0		0	
Jan-92	0.45	28		28		28		0		0		0	
Feb-92	0.36	20		20		20		0		0		0	
Mar-92	0.34	21		21		21		0		0		0	
Apr-92	0.98	58		39		39		20		3		16	
May-92	3.83	236		24		12		212		32		170	
Jun-92	1.63	97		0		0		97		15		78	
Jul-92	0.66	41		0		0		41		0		38	
Aug-92	0.26	16		0		0		16		0		15	
Sep-92	0.24	14	647	0	228	0	216	14	419	0	50	14	350
Oct-92	0.17	10		3		3		7		0		7	
Nov-92	0.27	16		16		16		0		0		0	
Dec-92	0.1	6		6		6		0		0		0	
Jan-93	0.11	7		7		7		0		0		0	
Feb-93	0.12	7		7		7		0		0		0	
Mar-93	1.41	87		87		87		0		0		0	
Apr-93	6.67	398		265		265		133		20		106	
May-93	25.7	1583		393		197		1190		179		952	
Jun-93	16.2	966		0		0		966		145		773	
Jul-93	7.75	477		0		0		477		5		449	
Aug-93	3.8	234		0		0		234		2		220	
Sep-93	1.62	97	3887	0	784	0	587	97	3103	1	351	96	2602
Oct-93	1.48	91		30		30		61		1		60	
Nov-93	1.33	79		79		79		0		0		0	
Dec-93	0.78	48		48		48		0		0		0	
Jan-94	0.69	43		43		43		0		0		0	
Feb-94	0.52	29		29		29		0		0		0	
Mar-94	0.43	26		26		26		0		0		0	
Apr-94	1.49	89		59		59		30		4		24	
May-94	4.49	277		28		14		249		37		199	
Jun-94	4.69	280		0		0		280		42		224	
Jul-94	1.46	90		0		0		90		1		85	
Aug-94	1.33	82		0		0		82		1		77	
Sep-94	0.67	40	1173	0	342	0	329	40	831	0	86	40	708
Oct-94	0.52	32		11		11		21		0		21	
Nov-94	0.64	38		38		38		0		0		0	
Dec-94	0.31	19		19		19		0		0		0	
Jan-95	0.25	15		15		15		0		0		0	
Feb-95	0.23	13		13		13		0		0		0	
Mar-95	3.37	208		208		208		0		0		0	
Apr-95	4.9	292		195		195		98		15		78	
May-95	20.5	1263		126		63		1136		170		909	
Jun-95	29	1729		539		269		1190		179		952	
Jul-95	12	739		0		0		739		7		695	
Aug-95	3.26	201		0		0		201		2		189	
Sep-95	2.06	123	4671	0	1163	0	831	123	3508	1	374	122	2966
Oct-95	4.16	256		85		85		171		2		169	
Nov-95	3.4	203		203		203		0		0		0	
Dec-95	2.05	126		126		126		0		0		0	
Jan-96	1.31	81		81		81		0		0		0	
Feb-96	1.47	82		82		82		0		0		0	
Mar-96	3.59	221		221		221		0		0		0	
Apr-96	9.12	544		362		362		182		27		145	
May-96	14.6	899		90		45		809		121		648	
Jun-96	11.1	662		0		0		662		99		529	
Jul-96	3.44	212		0		0		212		2		199	
Aug-96	2.05	126		0		0		126		1		119	
Sep-96	1.47	88	3499	0	1250	0	1205	88	2249	1	254	87	1896
Oct-96	1.17	72		24		24		48		0		48	
Nov-96	0.93	55		55		55		0		0		0	
Dec-96	0.68	42		42		42		0		0		0	
Jan-97	0.55	34		34		34		0		0		0	
Feb-97	0.62	34		34		34		0		0		0	
Mar-97	1.72	106		106		106		0		0		0	

Table E-2 continued. *Estimation of seepage from West Canyon Wash and Cedar Fort Ditch, in acre-feet except where noted.*

Month-year	Monthly avg. flow of creek at gage, in cfs	Monthly average flow	Sum per year	Est. amt. released to wash	Sum per year	Seepage from wash	Sum per year	Est. amt. diverted to ditch	Sum per year	Seepage from ditch	Sum per year	Est. amt. to fields	Sum per year
Apr-97	2.91	173		116		116		58		9		46	
May-97	15.8	973		97		49		876		131		701	
Jun-97	12.1	721		0		0		721		108		577	
Jul-97	4.59	283		0		0		283		3		266	
Aug-97	3.09	190		0		0		190		2		179	
Sep-97	1.37	82	2766	0	508	0	460	82	2258	1	254	81	1897
Oct-97	1.16	71		24		24		48		0		47	
Nov-97	1.14	68		68		68		0		0		0	
Dec-97	0.72	44		44		44		0		0		0	
Jan-98	0.48	30		30		30		0		0		0	
Feb-98	0.55	31		31		31		0		0		0	
Mar-98	1.49	92		92		92		0		0		0	
Apr-98	9.83	586		390		390		196		29		157	
May-98	24.6	1515		325		163		1190		179		952	
Jun-98	23.2	1383		193		96		1190		179		952	
Jul-98	14.5	893		0		0		893		9		840	
Aug-98	8.18	504		0		0		504		5		474	
Sep-98	3.51	209	5426	0	1197	0	937	209	4230	2	403	207	3628
Oct-98	3.42	211		70		70		141		1		139	
Nov-98	2.58	154		154		154		0		0		0	
Dec-98	1.82	112		112		112		0		0		0	
Jan-99	1.53	94		94		94		0		0		0	
Feb-99	1.45	81		81		81		0		0		0	
Mar-99	1.32	81		81		81		0		0		0	
Apr-99	3.36	200		133		133		67		10		54	
May-99	16.4	1010		101		51		909		136		727	
Jun-99	14.4	858		0		0		858		129		687	
Jul-99	7.35	453		0		0		453		5		426	
Aug-99	4.96	306		0		0		306		3		287	
Sep-99	2.67	159	3719	0	827	0	776	159	2892	2	286	158	2477
Oct-99	1.85	114		38		38		76		1		75	
Nov-99	2	119		119		119		0		0		0	
Dec-99	1.19	73		73		73		0		0		0	
Jan-00	1.09	67		67		67		0		0		0	
Feb-00	0.83	46		46		46		0		0		0	
Mar-00	0.69	43		43		43		0		0		0	
Apr-00	2.47	147		98		98		49		7		39	
May-00	7.52	463		46		23		417		63		334	
Jun-00	3.79	226		0		0		226		34		181	
Jul-00	2.31	142		0		0		142		1		134	
Aug-00	0.65	40		0		0		40		0		38	
Sep-00	0.64	38	1519	0	531	0	508	38	988	0	107	38	838
Oct-00	0.47	29		10		10		19		0		19	
Nov-00	0.43	26		26		26		0		0		0	
Dec-00	0.3	18		18		18		0		0		0	
Jan-01	0.32	20		20		20		0		0		0	
Feb-01	0.32	18		18		18		0		0		0	
Mar-01	0.24	15		15		15		0		0		0	
Apr-01	1.21	72		48		48		24		4		19	
May-01	7.6	468		47		23		421		63		337	
Jun-01	3.06	182		0		0		182		27		146	
Jul-01	2.05	126		0		0		126		1		119	
Aug-01	1.08	67		0		0		67		1		63	
Sep-01	0.62	37	1078	0	201	0	177	37	877	0	97	37	739
Oct-01	0.32	20		7		7		13		0		13	
Nov-01	0.31	18		18		18		0		0		0	
Dec-01	0.27	17		17		17		0		0		0	
Jan-02	0.2	12		12		12		0		0		0	
Feb-02	0.28	16		16		16		0		0		0	
Mar-02	0.13	8		8		8		0		0		0	
Apr-02	0.095	6		4		4		2		0		2	
May-02	3.91	241		24		12		217		33		173	
Jun-02	3.92	234		0		0		234		35		187	
Jul-02	1.77	109		0		0		109		1		102	
Aug-02	0.55	34		0		0		34		0		32	
Sep-02	0.36	21	735	0	105	0	93	21	630	0	70	21	530
Oct-02	0.41	25		8		8		17		0		17	
Nov-02	0.36	21		21		21		0		0		0	
Dec-02	0.2	12		12		12		0		0		0	
Jan-03	0.16	10		10		10		0		0		0	
Feb-03	0.22	12		12		12		0		0		0	
Mar-03	0.11	7		7		7		0		0		0	
Apr-03	0.078	5		3		3		2		0		1	
May-03	2.35	145		14		7		130		20		104	
Jun-03	1.95	116		0		0		116		17		93	
Jul-03	0.74	46		0		0		46		0		43	

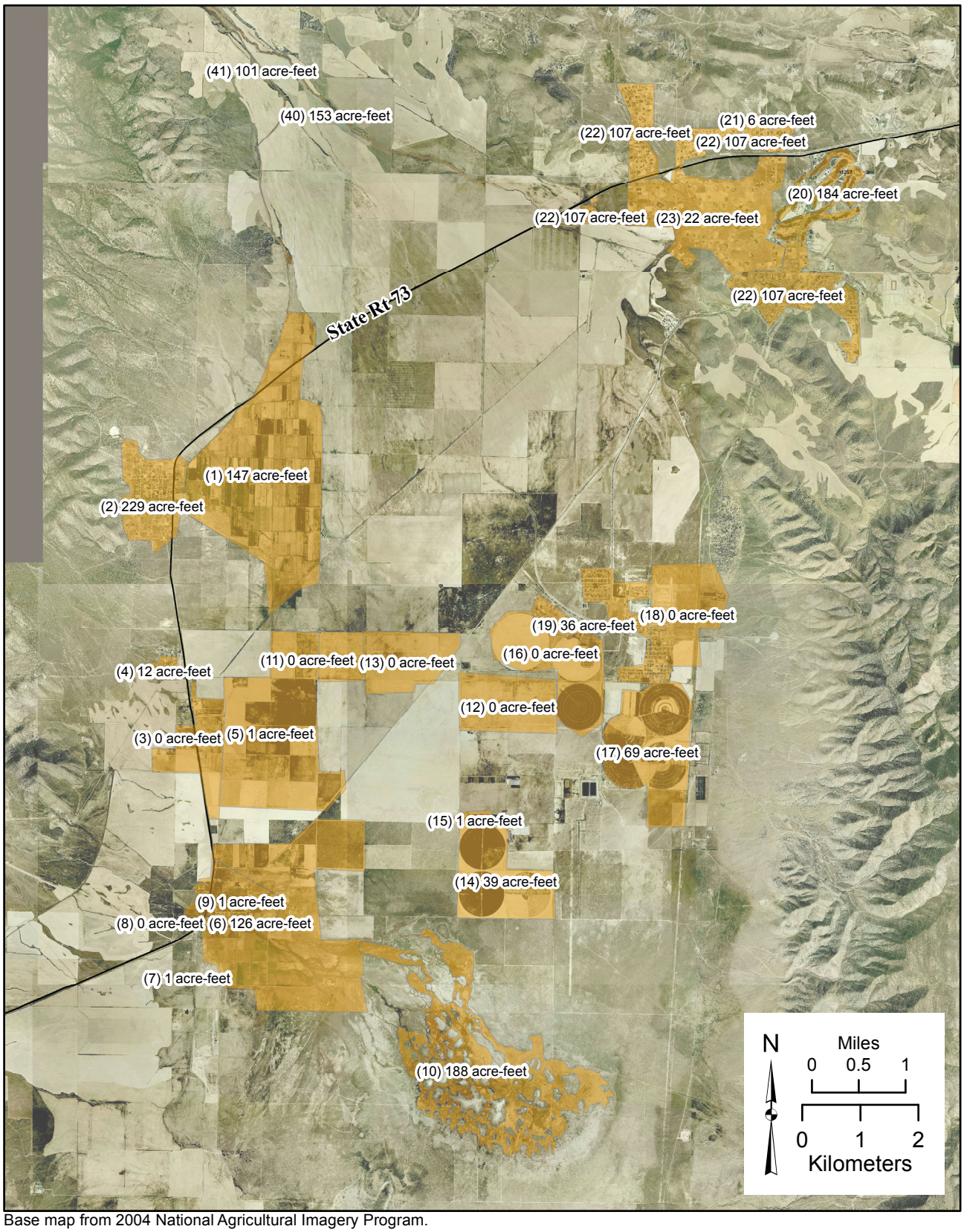
Table E-2 continued. *Estimation of seepage from West Canyon Wash and Cedar Fort Ditch, in acre-feet except where noted.*

Month-year	Monthly avg. flow of creek at gage, in cfs	Monthly average flow	Sum per year	Est. amt. released to wash	Sum per year	Seepage from wash	Sum per year	Est. amt. diverted to ditch	Sum per year	Seepage from ditch	Sum per year	Est. amt. to fields	Sum per year
Aug-03	0.45	28		0		0		28		0		26	
Sep-03	0.18	11	438	0	89	0	81	11	349	0	38	11	295
Oct-03	0.17	10		3		3		7		0		7	
Nov-03	0.13	8		8		8		0		0		0	
Dec-03	0.12	7		7		7		0		0		0	
Jan-04	0.17	10		10		10		0		0		0	
Feb-04	0.086	5		5		5		0		0		0	
Mar-04	0.071	4		4		4		0		0		0	
Apr-04	2.41	144		96		96		48		7		38	
May-04	6.07	374		37		19		337		50		269	
Jun-04	4.64	277		0		0		277		41		221	
Jul-04	1.96	121		0		0		121		1		113	
Aug-04	0.95	59		0		0		59		1		55	
Sep-04	0.54	32	1051	0	171	0	153	32	879	0	101	32	736

Table E-3. *Estimates of annual recharge from stream and canal seepage, unused irrigation water, and septic tank systems in Cedar Valley, in acre-ft/yr.*

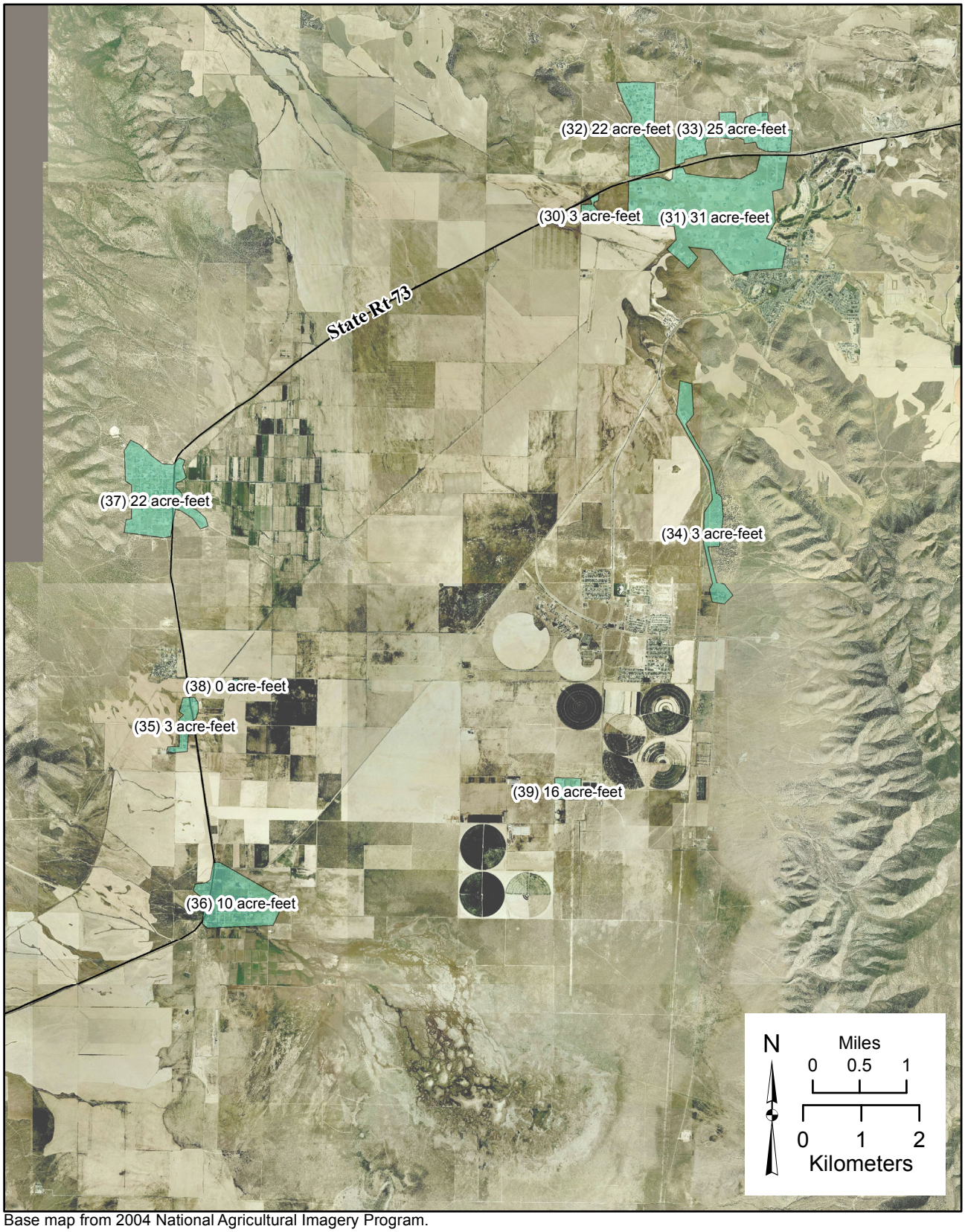
Map ID[1]	Recharge Area	Well ID or source	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	MIN.	AVG.	MAX.	RE[2]
	The following recharge sources are included in the total geology-refined Maxey-Eakin recharge estimate:																																									
	Stream and canal seepage																																									
40	West Canyon Wash seepage	W. Canyon Ck.	1355	403	819	667	1591	730	640	1120	1120	1120	1120	1120	1120	1560	1560	1120	1120	840	861	270	149	71	78	216	587	329	831	1205	460	937	776	508	177	93	81	153	71	747	1591	0.5-1.0
41	Cedar Fort Ditch seepage	W. Canyon Ck.	519	234	386	223	560	365	607	264	264	264	264	264	264	396	396	264	264	198	170	137	77	81	228	50	351	86	374	254	254	403	286	107	97	70	38	101	38	255	607	0.01-0.15
	Total		**1874**	**638**	**1205**	**890**	**2151**	**1095**	**1246**	**1384**	**1384**	**1384**	**1384**	**1384**	**1384**	**1956**	**1956**	**1384**	**1384**	**1038**	**1031**	**408**	**226**	**152**	**306**	**266**	**939**	**415**	**1205**	**1459**	**714**	**1340**	**1062**	**614**	**274**	**163**	**120**	**254**	**120**	**1002**	**2151**	
	Unused irrigation water seepage																																									
1	Cedar Fort Ditch irrigation	W. Canyon Ck.	556	252	413	239	599	391	650	403	403	403	403	403	403	605	605	403	403	302	291	183	103	108	330	70	520	142	593	379	379	726	495	168	148	106	59	147	59	355	726	0.20
2	CF springs & domestic wells irrigation	3 CF springs, sm. wells	569	230	230	230	230	230	230	230	230	230	230	230	230	230	230	230	230	230	230	230	230	230	230	230	230	229	228	228	227	227	228	228	228	229	229	229	227	239	569	0.30
3	Well 1033 irrigation	1033	0	0	2	0	89	195	195	185	222	211	236	172	56	121	66	4	4	12	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	49	236	0.25
4	White Hills municipal outdoor	1033	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	7	7	7	7	9	15	13	13	20	7	7	15	10	14	19	12	0	5	20	0.25
5	White wells irrigation	44, 1035	123	139	122	0	90	127	144	84	91	93	140	133	154	135	91	64	4	58	0	6	0	176	82	53	144	46	141	126	166	125	144	164	108	93	34	1	0	94	176	0.10
6	Fairfield Spring irrigation	Fairfield Spring, 1039	141	165	123	123	123	123	123	123	163	163	123	123	163	163	243	243	163	163	123	123	123	123	138	133	130	118	139	161	183	190	256	200	192	144	134	126	118	152	256	0.10
7	Cemetery	1131	4	3	3	3	3	5	3	5	5	6	5	0	1	1	1	3	2	1	4	4	4	3	2	1	1	1	1	1	1	2	2	1	0	1	1	1	0	2	6	0.15
8	Fairfield Park	22	1	1	1	1	1	2	1	2	2	2	2	0	0	0	0	1	1	0	1	1	1	1	1	0	0	0	0	0	0	1	1	0	0	0	0	0	0	1	2	0.05
9	Fairfield domestic wells	many sm. wells	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.05
11	Well 29 irrigation	29	0	0	0	0	0	6	6	5	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	6	0.10
12	Church farm east	134, 118, 1124, 1031	25	9	18	5	19	34	18	23	23	18	17	24	26	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	34	0.10
13	Church farm west	1120, 1121, 1122, 1123	37	37	37	37	37	40	27	36	24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	40	0.10
14	Utah Valley Turf Farm irrigation	4, 994	20	28	35	38	36	10	15	18	15	15	18	28	16	26	17	11	37	38	45	54	48	59	44	62	45	47	36	52	60	41	71	43	39	44	43	39	10	36	71	0.05
15	McLachlan mink farm	119	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	0	0	1	0.05
16	Well 1029 irrigation	1029	9	0	0	0	0	8	2	2	2	2	1	3	1	2	6	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	9	0.10
17	Ault turf farm	41, 56	0	0	0	0	0	25	32	38	40	65	72	72	72	31	11	21	59	42	45	40	36	65	40	37	29	36	46	54	51	41	45	45	49	73	66	69	0	40	73	0.05
18	Walden well irrigation	1018	0	0	0	0	0	0	0	0	0	0	0	0	81	72	76	75	0	0	0	0	0	0	0	0	0	0	88	97	108	104	98	169	0	0	0	0	0	27	169	0.10
19	E.M. Town Center municipal outdoor	156, 1018	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	6	9	12	15	18	22	24	27	36	0	5	36	0.10
20	Ranches Golf Course	156	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	120	184	184	0	14	184	0.20
21	Meadow Ranch East well	1003	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	6	0	0	6	0.20
22	Cedar Pass municipal outdoor	156, 1018	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	65	71	80	107	0	9	107	0.20
23	Cedar Pass domestic wells	many sm. wells	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	6	8	11	14	16	19	22	0	3	22	0.20
	Total		**1485**	**863**	**983**	**676**	**1227**	**1195**	**1446**	**1152**	**1219**	**1207**	**1247**	**1190**	**1203**	**1406**	**1347**	**1061**	**903**	**846**	**752**	**649**	**552**	**771**	**874**	**593**	**1110**	**635**	**1288**	**1118**	**1210**	**1482**	**1370**	**1063**	**877**	**937**	**901**	**980**	**552**	**1051**	**1485**	
10	**The Sinks**	Fairfield Spring	**211**	**247**	**184**	**184**	**184**	**184**	**184**	**184**	**244**	**244**	**184**	**184**	**244**	**244**	**364**	**364**	**244**	**244**	**184**	**184**	**184**	**184**	**207**	**199**	**195**	**177**	**208**	**242**	**275**	**285**	**383**	**299**	**288**	**216**	**201**	**188**	**177**	**228**	**383**	0.10
	Septic tank/waste water treatment seepage																																									
30	Sage Valley + Sage Hill		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	2	2	2	3	0	0	3	0.95
31	Cedar Pass Ranch		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	4	6	9	12	15	18	22	25	28	31	0	5	31	0.95
32	North Ranch		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	7	11	14	17	21	22	0	3	22	0.95
33	Meadow Ranch		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	2	2	6	9	13	17	21	25	25	0	3	25	0.95
34	Lake Mountain Road		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	2	2	2	2	2	2	2	3	3	0	1	3	0.95
35	White Hills septic (large lots S. of White Hills)		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	2	2	2	2	2	3	0	1	3	0.95
36	Fairfield		7	7	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	9	9	9	9	9	9	10	7	8	10	0.95
37	Cedar Fort		20	20	20	20	20	20	20	20	20	20	20	19	20	20	20	20	20	20	20	20	20	20	20	20	20	23	25	27	29	28	27	26	25	24	23	22	19	22	29	0.95
38	White Hills sewer		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.95
39	E.M. waste water treat. land app.		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0	16	0.95
	Total		**27**	**27**	**28**	**28**	**28**	**28**	**28**	**28**	**28**	**28**	**28**	**26**	**28**	**28**	**28**	**28**	**28**	**28**	**28**	**28**	**28**	**27**	**28**	**28**	**30**	**36**	**40**	**46**	**52**	**62**	**72**	**82**	**92**	**103**	**112**	**134**	**26**	**42**	**134**	
	Total recharge from indirect sources		***3598***	***1775***	***2400***	***1777***	***3590***	***2502***	***2904***	***2747***	***2874***	***2862***	***2843***	***2784***	***2859***	***3633***	***3694***	***2837***	***2559***	***2156***	***1994***	***1269***	***990***	***1134***	***1415***	***1087***	***2274***	***1263***	***2741***	***2865***	***2250***	***3169***	***2888***	***2059***	***1531***	***1418***	***1334***	***1556***	***990***	***2323***	***3694***	

[1] Map ID keyed to figures E-1 and E-2.
[2] RE = Recharge Efficiency. See table E-2 for details of West Canyon Wash and Cedar Fort Ditch recharge efficiency.



Base map from 2004 National Agricultural Imagery Program.

Figure E-1. Estimated surface water seepage and unused irrigation water recharge in 2004, Cedar Valley, Utah County. Each area is labeled with map ID in parentheses, keyed to table E-3, and estimated recharge in 2004, in acre-feet.



Base map from 2004 National Agricultural Imagery Program.

Figure E-2. Estimated recharge from septic tank and wastewater treatment facility seepage in 2004, Cedar Valley, Utah County. Each area is labeled with map ID in parentheses, keyed to table E-3, and seepage in 2004, in acre-feet.

Table E-4. *Cedar Valley water budget methods. Values in acre-ft/yr.*

RECHARGE	Min.	Avg. or Best	Max.	Comment
Direct recharge from precip and subsurface inflow				
MBR + direct precip on valley fill	13,753	29,889	60,407	Water balance method: total recharge minus all other forms of indirect recharge. A Darcy's calculation using the K values from bedrock aquifer tests and specific capacity tests suggests recharge from Oquirrh Mt. bedrock may be in the range of 46,000 to 1.4 million acre-ft/yr.
Subsurface inflow from Rush Valley	0	0	0	Darcy's calculation from Rush V. reconnaissance study (Hood and others, 1969, p. 23) = 5000 acre-feet.
West Canyon Creek Seepage	71	747	1591	Probably mostly a gaining stream in canyon and losing on alluvial fan. Estimate seepage to gw at 100% of non-irrigation season flow, 50% of May-Sept channel flow (very little water is released down the channel in these months). Made assumptions for each month of the year regarding how much water is released down W. Canyon Ck. channel vs. diverted to Cedar Fort Ditch (i.e. January 100% goes down channel, July 0%). Multiplied monthly flows for years 1966 through 2004 by specific month's fraction. Feltis (1967, p. 12) says recharge from W. Canyon Ck. = 1000 acre-ft/yr.
Cedar Fort Ditch Seepage	38	255	607	Seepage study summer 2006 determined up to 19% of the springtime flow is lost from the canal but mid-July seepage is minimal. Some of the lost water is ET. Before the buried pipe went in (pre-1975) estimate 15% of all ditch flow seeps to groundwater. After 1975 estimate 15% of May-June and 1% for July-Oct. ditch flow is seepage.
The Sinks Seepage	177	228	383	2 ways: (1) Mass balance on several ions between Fairfield Spring chemistry and Well 859. Initial volume = Fairfield Spring flow of 4 cfs for 6 mo. plus rainfall. Range 100-350 acre-ft/yr. (2) 10% of Fairfield Spring flow that goes to Sinks (which is 60% of flow). Range 177-383 acre-ft/yr.
Septic Tank & Wastewater Seepage	26	42	134	Septic: Main areas: Cedar Pass, Cedar Fort, Fairfield. ~30 acre-ft/yr 1950-1992. Then increase each yr. as Cedar Pass grows. Calculate from existing data on water use per capita, Municipal and Industrial Use reports, population data, city reports, and count number of residences on 4 years of air photos. Waste Water Treatment Plant: only since 2003 has Eagle Mountain land application been released, White Hills open sewer seepage is negligible (personal communication with residents and White Hills water manager).
Unused Irrigation Seepage	552	1051	1485	Other Utah studies have used various percentages. 25% of irrigation use per Stolp, 1994 cited in Tooele Valley model study. Brooks and Stolp (1995, p. 19) for southern Utah Valley used 7% of applied water and 1% of applied water in Goshen Valley. Cordova (1970, p. 25-28) used 30%.
Cedar Fort agriculture and residential				Add ditch application water, springs discharge, and 66% of the water right on domestic wells and subtract septic recharge. Recharge efficiency (RE) estimated fairly high because of underlying fan sediments and mix of sprinkler and flood. Feltis (1967, p. 17) est. 50% of springs + West Canyon flow is recharge.
White Hills agricultural and residential				Add municipal well and agricultural wells and subtract septic recharge. RE estimated at moderate because of underlying permeable fan sediments but exclusively sprinkler. Feltis (1967, p. 17) estimated 10% of well water applied is recharge except in sec. 17, T.6S., R.2W., SLB&M.
Fairfield agricultural and residential				Add 40% of Fairfield Spring discharge (6 mo. irrigation season but not all flow is applied to fields) and 66% of the water right on domestic wells and subtract septic recharge. RE is low because of fine-grained sediment but also use flood irrigation. Feltis (1967) est. 30% of Fairfield Spring is recharge.
Mid-valley agricultural well irrigation + Eagle Mtn. town center residential				Add wells in each irrigation area. RE estimated at lowest to almost lowest values, depending on the area, because of fine-grained sediments and mostly sprinkler irrigated with some areas flood irrigated in early days. Feltis (1967) est. 10% of well water applied is recharge except in sec. 17, T.6S., R.2W., SLB&M.
Cedar Pass residential and institutional				Include 66% of the water right on domestic wells in Cedar Pass Ranch area minus Cedar Pass septic tanks, half of Eagle Mtn. reported water use minus amount sold to golf course, and golf course use. RE set at moderate based on permeable sediments and dominant sprinkler use.
Total recharge for basin [1]	**15,023**	**32,135**	**64,101**	Maxey-Eakin (Eakin and Maxey, 1951) isohetal method calculated using original M-E REs, annual PRISM precipitation data, and a factor representing the formation's geologic suceptibility to recharge. Feltis (1967) used modified M-E REs and got 24,000 acre-feet. If use precip. map in Feltis (composite publication 1963) but with GIS (better area estimates) get 29,050 acre-feet. Preliminary data from USGS's Net Infiltration Model shows 37,900 acre-ft/yr using 1971 to 2000 average PRISM precip.

Table E-4 continuted. *Cedar Valley water budget methods. Values in acre-ft/yr.*

DISCHARGE	Min.	Avg. or Best	Max.	Comment
Well Withdrawal	1296	3563	6526	Variety of data sources including USGS estimates from power records, DWRi reported, summation of water rights, private records, interviews, and measured. These values represent only the wells within the model area.
Evapotranspiration	1648	3206	3995	Seasonal consumptive use-(applied irrigation*irrigation efficiency)-septic recharge-precipitation. ET from irrigated areas and unirrigated areas where groundwater can support or supplement irrigation to meet potential ET. About 1450 acres around Fairfield has depth to water <10 feet and phreatophyte vegetation. Feltis' (1967, p. 17) calculation not comparable to this calculation: Feltis estimated 50% of stream and Cedar Fort springs water, 70% of the Sinks water, and 90% of well water on fine-grained sediments goes to ET. Feltis total ET = 5100 acre-ft/yr. ET in this water budget comparable to Feltis' calculation is about 5200 to 13,300 with average 8400 acre-ft/yr.)
Fairfield Spring	2884	3775	6324	Measured by DWRi. Estimated based on precipitation trends for years without data.
All Other Springs	996	1029	2169	Discharge measurements from DWRi records, Cedar Fort Irrigation Co., and Feltis (1967).
Base Flow to West Canyon Creek	240	920	1800	Simple graphical separation of the spring runoff from base flow. Stream flow measured by USGS. Estimated based on precipitation trends for years without data.
Subsurface Outflow to Cedar Pass	7700	12,000	12,000	Minimum from Feltis' (1967) Darcy calculation divided into north and south flowing sections. Maximum from N. Utah Valley groundwater model. Based on high K values in aquifer tests, maximum is a better estimate. Feltis' (1967) water balance divided = 10,000.
Subsurface Outflow to Mosida Hills	2300	4000	9000	Best from Brooks and Stolp (1995, p. 17 & 63) who used 200 acre-ft/yr at injection wells in about 9 cells to represent Mosida Hills, but their model didn't extend northern to Lake Mts. Estimate another 4 cells in that area. 200 acre-ft/yr was the starting value and the calibrated value is not available. Minimum from Feltis' (1967) Darcy calculation divided into north and south flowing sections. Maximum from Feltis' water balance, divided.
Total discharge for basin [1]	**25,931**	**28,286**	**32,555**	

[1] Total recharge and discharge values are the minumum, average, or maximum of the annual sum of recharge or discharge components for each year, and therefore, the values on this table may not sum.

APPENDIX F

DISCHARGE: ET METHODS AND DISCHARGE FROM CREEKS, SPRINGS, AND WELLS

Method to calculate evapotranspiration in zone ET-10

We estimated evapotranspiration from groundwater (ETg) in the area around Fairfied where the water table is less than 10 feet below ground (zone ET-10) using methods similar to those used in hydrogeologic studies of Goshen and southern Utah Valleys (Cordova, 1970; Brooks and Stolp, 1995), Salt Lake Valley (Lambert, 1995), Sanpete Valley (Wilberg and Heilweil, 1995), and Cache Valley (Kariya and others, 1994). These studies generally attempt to estimate the area covered by phreatophytes, their water use, and the water available to them. We assumed vegetation will use the available precipitation and applied irrigation water sources to meet its water needs and take up groundwater from below only if those sources are not adequate. We chose 10 feet as the maximum depth to water that the alfalfa and pasture grasses growing around Fairfield could be taking up groundwater based on work by Hill (1998). On the groundwater potentiometric map (plate 2), the area where the water table is less than 10 feet below the land surface is roughly 1450 acres around Fairfield. To calculate how much groundwater discharge may be attributed to ET, we took the seasonal consumptive use (SCS) of the vegetation in this shallow-groundwater area and subtracted all other sources of water available to the vegetation, including applied irrigation, septic-tank recharge, and precipitation (equation 1).

$$ETg = SCS - (IE * [SPRING + WELLS] + SEPTIC + 0.8 * PRECIP) \qquad \textbf{\textit{Eqn. 1}}$$

Where:

ETg = Estimated groundwater discharge by evapotranspiration from the area having a shallow water table, in acre-ft/yr

SCS = Seasonal consumptive use of vegetation in the area of interest, in acre-ft/yr

IE = Irrigation efficiency

SPRING = 40% of the discharge from Fairfield Spring and artesian well 1039 was assumed to be applied to the fields and pastures, in acre-ft/yr

WELLS = 66% of the water right allowed to each domestic well in the Fairfield area was assumed to be used for lawn and garden watering, in acre-ft/yr

SEPTIC = volume of water calculated to be released by septic tank soil absorption systems in the Fairfield area, in acre-ft/yr, and

PRECIP = Precipitation at Fairfield Station multiplied by the area having shallow water table, in acre-ft/yr.

Hill (1998) estimated that the SCS of vegetation (alfalfa and pasture grass) around Fairfield, based on a calibrated Blaney-Criddle equation, is 31.23 inches per year. Over the estimated 1446 acres where the water table is less than 10 feet deep, the SCS amounts to 3764 acre-ft/yr. We used an irrigation efficiency factor of 65%, meaning 65% of the irrigation water applied is available for plant use, based on characteristics of the area (very level ground, flood irrigated, medium to heavy soils) (Hill, 1998, p. 129). All seepage from septic tanks was assumed to be available to vegetation. Only 80% of the annual precipitation was assumed to be available to plants (Kariya and others, 1994; Hill, 1998, p. 194). Our initial estimates for

evapotranspiration from groundwater in the area around Fairfied where the water table is less than 10 feet below ground using the above method ranged from 0 to 2350 acre-ft/yr, depending on the year (table G-3).

References

Brooks, L.E., and Stolp, B.J., 1995, Hydrology and simulation of ground-water flow in southern Utah and Goshen Valleys, Utah: Utah Department of Natural Resources Technical Publication 111, 96 p., 2 plates.

Cordova, R.M., 1970, Ground-water conditions in southern Utah Valley and Goshen Valley, Utah: Utah Department of Natural Resources Technical Publication 28, 79 p., 4 plates.

Hill, R.W., 1998, Consumptive use of irrigated crops in Utah: Utah Agricultural Experiment Station Research Report 145, 361 p.

Kariya, K.A., Roark, D.M., and Hanson, K.M., 1994, Hydrology of Cache Valley, Cache County, Utah, and adjacent part of Idaho, with emphasis on simulation of ground-water flow: Utah Department of Natural Resources Technical Publication 108, 120 p., 2 pl.

Lambert, P.M., 1995, Numerical simulation of ground-water flow in basin-fill material in Salt Lake Valley, Utah: Utah Department of Natural Resources Technical Publication 110-B, 58 p.

Wilberg, D.E., and Heilweil, V.M., 1995, Hydrology of Sanpete Valley, Sanpete and Juab Counties, Utah, and simulation of ground-water flow in the valley-fill aquifer: Utah Department of Natural Resources Technical Publication 113, 121 p., 1 plate.

Table F-1. *Reported or estimated annual discharge from creeks and springs, 1963 to 2007, in acre-feet.*

Data Sources:
Estimated flow *(shown in italics)* based on nearby years' data.
Estimated flow (shown in ***bold italics***) based on relationship of annual precipitation at Fairfield to measured flow in Fairfield Spring and West Canyon Creek.
NE = not estimated

In model	Name/UGS ID	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	Min.	Avg.	Max.
	West Canyon Ck./3001	*1494*	*1494*	*1494*	1494	1920	2088	5224	1989	3442	2181	6272	3219	5013	***4000***	***4000***	***4000***	***4000***	***4000***	***4000***	***6000***	***6000***	***4000***	***4000***	***3000***	2597	1411	789	732	2087	647	3887	1173	4671	3499	2766	5426	3719	1519	1078	735	438	1051	NE	NE	NE	438	3127	6272
Y	Fairfield Spring/2011	2676	1970	2065	3093	3082	3298	3453	4052	***3000***	***3000***	***3000***	***3000***	***3000***	***3000***	***4000***	***4000***	***3000***	***3000***	***4000***	***4000***	***6000***	***6000***	***4000***	***4000***	***3000***	***3000***	***3000***	***3000***	3388	3259	3186	2884	3402	3971	4516	4681	6324	4924	4732	3532	3286	3074	3934	4253	4385	2884	3775	6324
	South Spring/2010	*158*	*158*	190	127	*158*	*158*	*158*	*158*	*158*	*158*	*158*	*158*	*158*	*158*	*158*	*158*	*158*	*158*	*158*	*158*	*158*	*158*	*158*	*158*	*158*	*158*	*158*	*158*	*158*	*158*	*158*	*158*	*158*	*158*	*158*	*158*	*158*	*158*	*158*	*158*	*158*	*158*	NE	NE	NE	158	158	158
	N. Spring Ck. Spr./2009	*455*	*455*	485	332	*455*	652	1304	*455*	*455*	*455*	*455*	*455*	*455*	*455*	*455*	*455*	*455*	*455*	*455*	*455*	*455*	*455*	*455*	*455*	*455*	*455*	*455*	*455*	*455*	455	*455*	*455*	*455*	*455*	*455*	*455*	*455*	*455*	*455*	*455*	*455*	*455*	NE	NE	NE	455	479	1304
	Tunnel Spring/2012	*152*	*152*	142	111	*152*	217	435	*152*	*152*	*152*	*152*	*152*	*152*	*152*	*152*	*152*	*152*	*152*	*152*	*152*	*152*	*152*	*152*	*152*	*152*	*152*	*152*	*152*	*152*	152	*152*	*152*	*152*	*152*	*152*	*152*	*152*	*152*	*152*	*152*	*152*	*152*	NE	NE	NE	152	160	435
	2001	*16*	*16*	*16*	16	*16*	*16*	*16*	*16*	*16*	*16*	*16*	*16*	*16*	*16*	*16*	*16*	*16*	*16*	*16*	*16*	*16*	*16*	*16*	*16*	*16*	*16*	*16*	*16*	*16*	*16*	*16*	*16*	*16*	*16*	*16*	*16*	*16*	*16*	*16*	*16*	*16*	*16*	NE	NE	NE	16	16	16
	2002	*25*	*25*	25	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	NE	NE	NE	25	25	25
	2003	*25*	*25*	25	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	NE	NE	NE	25	25	25
	2004	*25*	*25*	25	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	NE	NE	NE	25	25	25
	2005	*27*	*27*	27	*27*	*27*	*27*	*27*	*27*	*27*	*27*	*27*	*27*	*27*	*27*	*27*	*27*	*27*	*27*	*27*	*27*	*27*	*27*	*27*	*27*	*27*	*27*	*27*	*27*	*27*	*27*	*27*	*27*	*27*	*27*	*27*	*27*	*27*	*27*	*27*	*27*	*27*	*27*	NE	NE	NE	27	27	27
	2006	*1*	*1*	1	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	NE	NE	NE	1	1	1
	2007	*16*	*16*	16	*16*	*16*	*16*	*16*	*16*	*16*	*16*	*16*	*16*	*16*	*16*	*16*	*16*	*16*	*16*	*16*	*16*	*16*	*16*	*16*	*16*	*16*	*16*	*16*	*16*	*16*	*16*	*16*	*16*	*16*	*16*	*16*	*16*	*16*	*16*	*16*	*16*	*16*	*16*	NE	NE	NE	16	16	16
	2008	30	*40*	8	*40*	*40*	*40*	*40*	*40*	*40*	*40*	*40*	*40*	*40*	*40*	*40*	*40*	*40*	*40*	*40*	*40*	*40*	*40*	*40*	*40*	*40*	*40*	*40*	*40*	*40*	*40*	*40*	*40*	*40*	*40*	81	*40*	*40*	*40*	*40*	*40*	*40*	*40*	NE	NE	NE	40	41	81
	2013	*11*	*11*	11	*11*	*11*	*11*	*11*	*11*	*11*	*11*	*11*	*11*	*11*	*11*	*11*	*11*	*11*	*11*	*11*	*11*	*11*	*11*	*11*	*11*	*11*	*11*	*11*	*11*	*11*	*11*	*11*	*11*	*11*	*11*	*11*	*11*	*11*	*11*	*11*	*11*	*11*	*11*	NE	NE	NE	11	11	11
	2014	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	NE	NE	NE	1	1	1
	2015	*8*	*8*	*8*	*8*	*8*	*8*	*8*	*8*	*8*	*8*	*8*	*8*	*8*	*8*	*8*	*8*	*8*	*8*	*8*	*8*	*8*	*8*	*8*	*8*	*8*	*8*	*8*	*8*	*8*	*8*	*8*	*8*	*8*	*8*	*8*	*8*	*8*	*8*	*8*	*8*	*8*	*8*	NE	NE	NE	8	8	8
	2016	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	NE	NE	NE	25	25	25
	2017	11	*11*	*11*	*11*	*11*	*11*	*11*	*11*	*11*	*11*	*11*	*11*	*11*	*11*	*11*	*11*	*11*	*11*	*11*	*11*	*11*	*11*	*11*	*11*	*11*	*11*	*11*	*11*	*11*	*11*	*11*	*11*	*11*	*11*	*11*	*11*	*11*	*11*	*11*	*11*	*11*	*11*	NE	NE	NE	11	11	11
	Total surface water	5156	4460	4575	5388	5998	6644	10,804	7037	7438	6177	10,268	7215	9009	7996	8996	8996	7996	7996	8996	10,996	12,996	10,996	8996	7996	6593	5407	4785	4728	6471	4902	8069	5053	9069	8466	8319	11,103	11,039	7439	6806	5263	4720	5121	NE	NE	NE	4720	7896	12,996
	Total springs	3662	2966	3081	3894	4078	4556	5580	5048	3996	3996	3996	3996	3996	3996	4996	4996	3996	3996	4996	4996	6996	6996	4996	4996	3996	3996	3996	3996	4384	4255	4182	3880	4398	4967	5553	5677	7320	5920	5728	4528	4282	4070	NE	NE	NE	3880	4769	7320
	Fairfield precip. (in.)	12.14	14.24	11.58	9.07	12.02	14.81	10.30	11.49	15.69	8.04	12.51	10.09	11.73	6.03	13.24	15.79	9.90	14.37	15.10	18.02	24.07	15.78	16.16	15.41	11.88	6.57	8.30	8.62	15.92	11.09	13.50	12.43	13.61	14.45	14.64	17.35	9.89	12.76	10.51	6.78	9.99	10.91	NE	NE	NE	6.03	12.58	24.07

Table F-2. *Reported or estimated annual withdrawal from wells in the model and wells producing more than 10 acre-ft/yr, 1963 to 2007, in acre-feet.*

Data Sources:
Most pumpage data for large wells (shown in regular font) are calculated from power usage at each well for each calendar year by the USGS Utah Water Science Center.
USGS calculations for years 1964-1966 checked against reported use in Feltis, 1967. Wells 1118, 1120, 1121, 1123, 1124 and 1039 usage added based on Feltis, 1967 (shown in **bold underline** font).
Division of Water Rights municipal suppliers' reports data, accessed 4/3/06, 8/21/06, and 3/11/10 (http://waterrights.utah.gov/distinfo/wuse.asp) (shown in underlined text).
Division of Water Resources municipal and industrial use survey data (shown in ***bold italic*** font) (Hansen, Allen & Luce, Inc., 2000).
Written or personal communication with individual water purveyors or well owners (shown in **bold** font).
Well 22 at Fairfield Stagecoach Inn State Park irrigates roughly the same area as the Camp Floyd Cemetery well and is operated by the same entity so we assume the same usage (shown in *underlined italics*).
Full water right used for some smaller wells (shown in outlined boxes).
Estimated flow *(shown in italics)* based on nearby years' data or extrapolated based on flowing rate for wells 1039 and 1132.
Geo Unit: 1 = clay unit, 2 = basin-fill aquifer, 3 = bedrock aquifers.

ID	Geo unit	Model layer	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	Min.	Avg.	Max.
4	2	1	704	200	440	754	585	613	398	558	709	759	725	207	308	355	300	303	350	556	256	410	330	164	550	593	699	918	744	930	643	868	628	618	427	710	921	596	982	579	494	282	275	325	559	559	559	164	541	982
18	2	1	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
22	1	1	24	18	24	31	30	32	26	19	18	20	20	35	20	33	31	38	36	2	9	9	5	22	10	6	24	29	25	20	12	9	7	8	6	6	6	12	11	8	3	6	7	8	8	7	7	2	16	38
29	2	1	134	93	0	0	0	0	0	0	0	0	0	56	60	51	0	0	0	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	60
39	3	2																																			4	4	4	4	4	4	4	4	4	4	4	4.0	4.0	4.0
41	2	1												176	305	355	279	578	612	482	487	296	206	322	503	291	263	175	0	0	0	0	0	0	0	0	0	0	1	3	2	4	4	1	**0**	300	300	0	172	612
44	2	1	255	1590	0	370	288	644	1230	1387	1219	0	818	1120	1169	381	0	0	300	650	514	629	308	538	0	354	0	0	0	751	385	248	1286	261	588	166	1130	576	987	1015	400	688	267	11	360.5	360.5	977	0	538	1387
56	3	2												326	333	399	520	718	824	950	945	326	23	96	680	542	632	626	714	1294	805	733	571	717	914	1070	1020	827	892	890	969	1462	1323	1388	1391	1391	1391	23	759	1462
62	3	2																																	2.85	2.85	2.85	2.85	2.85	2.85	2.85	2.85	2.85	2.85	2.85	2.85	2.85	2.85	2.9	2.9	2.9
67	3	2																																				1.73	1.73	1.73	1.73	1.73	1.73	1.73	1.73	1.73	1.73	1.7	1.7	1.7
68	3	2																																			1.73	1.73	1.73	1.73	1.73	1.73	1.73	1.73	1.73	1.73	1.73	1.7	1.7	1.7
75	3	2																																						1.81	1.81	1.81	1.81	1.81	1.81	1.81	1.81	1.81	1.8	1.8	1.8
119	2	1																																	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
131	2	1																																			16	16	16	16	16	16	16	16	16	16	16	16	16	16	16
134	2	1	346	250	337	386	282	180	155	34	123	0	139	285	126	169	176	155	147	218	240	183	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	**0**	**0**	0	60	285
145	3	2																																					2	2	2	2	2	2	2	2	2	2.0	2.0	2.0
156	3																																							243.8	982	1306	1872	1180	623.9	1086		244	1101	1872
832	3																																												0	0		0	0	0
833	3	2																																									2	2	2	2		2.0	2.0	2.0
839	2-3														0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
847	3	2																																								**5**	**5**	**5**	5	5	5	5.0	5.0	5.0
854	2	1	7.644	7.644	7.644	7.644	7.644	7.644	7.644	7.644	7.644	7.644	7.644	7.644	7.644	7.644	7.644	7.644	7.644	7.644	7.644	7.644	7.644	7.644	7.644	7.644	7.644	7.644	7.644	7.644	7.644	7.644	7.644	7.644	7.644	7.644	7.644	7.644	7.644	7.644	7.644	7.644	7.644	7.644	7.644	7.644	7.644	7.6	7.6	7.6
983	3																																													0	0		0
984	3																																													0	0		0
992	3																																										0	123.6	1080	1465	0	0	0
994	2	1																		8	64	106	17	50	193	166	198	171	215	245	237	371	278	331	286	332	285	230	435	281	293	604	580	457	457	457	457	8	257	604
997	3																																												**1075**	**1075**	0	0	0
1003	3																																										**20.2**	**28.1**	24	24	24	20	24	28
1018	3	2																			809	721	761	752	4	0	0	0	0	0	0	0	0	0	938	1090	1263	1275	1277	2047	849.3	823.6	994.1	880.5	714.6	958.1	867	0	604	2047
1029	2	1	80	145	134	225	162	128	91	0	0	0	0	75	23	17	16	17	6	28	11	15	59	61	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	1	0	0	**0**	**0**	**0**	0	12	91
1031	2	1	118	32	188	184	147	130	21	0	0	0	0	4	3	3	3	5	6	3	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	0	3	21
1033	2	1									8	0	354	778	778	738	888	842	945	688	222	482	265	14	14	48	50	50	50	50	50	50	70	110	98	100	150	***55***	55	112	**79**	104.3	**138**	**86**	**79**	89	97	0	251	945
1035	2	1	285	841	0	0	0	0	0	0	0	0	80	148	268	456	906	930	1100	682	1026	721	599	100	44	222	0	62	0	1009	434	278	156	197	817	1090	532	671	456	629	681	246	72	0	360.5	1000	1696	0	406	1100
1039	2	1		**300**	65	65	65	65	65	65	65	65	65	65	65	65	65	65	65	65	65	65	65	65	65	65	65	65	65	65	65	65	65	65	65	65	65	65	65	65	65	65	65	65	65	65	65	65	65	65
1118	2	1	0	**35**	**70**	**35**	35	35	35	35	35	35	35	35	35	35	35																										0	0	**0**	**0**	**0**	0	29	35
1120	2	1	135	**130**	**270**	**135**	135	135	135	135	135	135	135	135	135	135	135																										0	0	**0**	**0**	**0**	0	110	135
1121	2	1	130	**125**	**260**	**130**	130	130	130	130	130	130	135	160	35	125	6	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	**0**	**0**	0	27	160
1122	2		35																																								0	0	**0**	**0**	**0**	0	0	0
1123	2	1	100	**100**	**200**	**100**	100	100	100	100	100	100	100	100	100	100	100																										0	0	**0**	**0**	**0**	0	82	100
1124	2	1	36	36	**36**	36	36	36	36	18	18	18	18	18	18	18	18	18	18	18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	**0**	**0**	0	8	36
1131	1	1	24	18	24	31	30	32	26	19	18	20	20	35	20	33	31	38	36	2	9	9	5	22	10	6	24	29	25	20	12	9	7	8	6	6	6	12	11	8	3	6	7	8	7	7	7	2	16	38
1132	2	1	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.5	1.5	1.5
Total annual withdrawal all large and model wells			2420	3927	2062	2496	2039	2274	2462	2514	2592	1296	2658	3772	3815	3482	3523	3721	4463	4380	4691	4006	2659	2222	2089	2309	1971	2141	1854	4400	2659	2647	3084	2331	4214	4704	5468	4411	5264	5734	4180	5375	5159	5232	5431	8099	10,176	1296	3876	10,176

Flow from model area wells summed by layer																																																		
Total annual withdrawal model layer 1									2462	2514	2592	1296	2658	3446	3482	3083	3003	3003	3639	3430	2937	2959	1875	1374	1405	1767	1339	1515	1140	3106	1854	1914	2513	1614	2359	2541	3177	2299	3085	2783	2104	2088	1497	1043	1978	2926	4247	1043	2411	4247
Total annual withdrawal model layer 2									0	0	0	0	0	326	333	399	520	718	824	950	1754	1047	784	848	684	542	632	626	714	1294	805	733	571	717	1855	2163	2292	2112	2179	2951	1832	2305	2336	2290	2127	2370	2279	0	1152	2951
Total annual withdrawal all model area wells									2462	2514	2592	1296	2658	3772	3815	3482	3523	3721	4463	4380	4691	4006	2659	2222	2089	2309	1971	2141	1854	4400	2659	2647	3084	2331	4214	4704	5468	4411	5264	5734	3936	4393	3833	3332	4104	5296	6526	1296	3563	6526

Flow from large and model wells summed by area																																																		
Area																																																		
Western alluvial fans + Fairfield	597	2776	122	506	422	782	1356	1499	1337	114	1366	2190	2329	1715	1930	1922	2491	2098	1854	1924	1256	770	152	710	172	244	174	1924	967	668	1600	658	1589	1442	1898	1400	1594	1846	1240	1124	565	187	889	1538	2858	114	1286	2491
Central agricultural region	1818	1146	1935	1985	1612	1487	1101	1010	1250	1177	1287	1075	843	1008	789	498	531	845	591	734	408	277	745	761	899	1091	961	1177	882	1241	908	951	765	1094	1274	894	1485	929	857	955	923	850	1084	1084	1084	277	918	1485
Eastern valley margin	0	0	0	0	0	0	0	0	0	0	0	502	638	754	799	1296	1436	1432	2241	1343	990	1170	1187	833	895	801	714	1294	805	733	571	717	1855	2163	2290	2109	2177	2949	1829	2298	2330	2278	2114	2658	2567	0	1206	2949
Cedar Pass	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	248	987	1331	1904	1332	2807	3655	5	128	1904
Western bedrock	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	3	3	5	5	10	10	12	12	12	12	0	1	12
Total	2420	3927	2062	2496	2039	2274	2462	2514	2592	1296	2658	3772	3815	3482	3523	3721	4463	4380	4691	4006	2659	2222	2089	2309	1971	2141	1854	4400	2659	2647	3084	2331	4214	4704	5468	4411	5264	5734	4180	5375	5159	5232	5431	8099	10,176	1296	3876	10,176

Total small wells (Table F-3)	15	15	15	18	21	21	21	21	21	22	22	24	25	25	30	30	30	31	33	38	39	42	44	72	74	78	80	89	91	103	109	115	133	206	233	244	257	270	244	254	278	282	300	300	300	21	118	300
Total annual withdrawal all we	**2435**	**3942**	**2077**	**2514**	**2060**	**2295**	**2483**	**2535**	**2613**	**1318**	**2680**	**3796**	**3840**	**3507**	**3553**	**3751**	**4493**	**4411**	**4724**	**4043**	**2698**	**2264**	**2133**	**2381**	**2045**	**2218**	**1933**	**4489**	**2749**	**2750**	**3193**	**2446**	**4347**	**4909**	**5702**	**4655**	**5521**	**6004**	**4424**	**5629**	**5438**	**5513**	**5731**	**8399**	**10,476**	**1318**	**3995**	**10,476**

Table F-3. *Reported or estimated annual withdrawal from small wells (<10 acre-ft/yr) 1963 to 2007, in acre-feet.*
Data Sources:
Pumpage data taken as full water right since completion date of the well (shown in regular font) on record with the Utah Division of Water Rights.
Pumpage data estimated as a smaller portion of the water right based on interviews with well owners, water rights file information, or field observations (shown in bold font).
Geo Unit: 1 = clay unit, 2 = basin-fill aquifer, 3 = bedrock aquifers, 4 = Cedar Pass perched unconsolidated

ID	Geo Unit	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	Min.	Avg.	Max.
2	3																															1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.5	1.5	1.5
5	2																						1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.5	1.5	1.5
7	3																													1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.5	1.5	1.5
8	2													1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.5	1.5	1.5
9	2																						1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.5	1.5	1.5
10	2																																			1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.5	1.5	1.5
11	2																				0.906	0.906	0.906	0.906	0.906	0.906	0.906	0.906	0.906	0.906	0.906	0.906	0.906	0.906	0.906	0.906	0.906	0.906	0.906	0.906	0.906	0.906	0.906	0.906	0.906	0.906	0.9	0.9	0.9
12	3																							1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.5	1.5	1.5
13	2																											1.73	1.73	1.73	1.73	1.73	1.73	1.73	1.73	1.73	1.73	1.73	1.73	1.73	1.73	1.73	1.73	1.73	1.73	1.73	1.7	1.7	1.7
14	2																				1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.5	1.5	1.5
15	2																															1.62	1.62	1.62	1.62	1.62	1.62	1.62	1.62	1.62	1.62	1.62	1.62	1.62	1.62	1.62	1.6	1.6	1.6
16	2	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.5	1.5	1.5
17	2																															1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.5	1.5	1.5
20	2																														1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.5	1.5	1.5
21	2																												0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.6	0.6	0.6
23	2					1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.5	1.5	1.5
24	2															1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.5	1.5	1.5
25	2																										2.414	2.414	2.414	2.414	2.414	2.414	2.414	2.414	2.414	2.414	2.414	2.414	2.414	2.414	2.414	2.414	2.414	2.414	2.414	2.414	2.4	2.4	2.4
26	3																																			1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.5	1.5	1.5
27	2	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.5	1.5	1.5
28	2	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.5	1.5	1.5
30	2																																1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.5	1.5	1.5
31	2																																		1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.5	1.5	1.5
32	2																																0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.8	0.8	0.8
34	2																																		2.15	2.15	2.15	2.15	2.15	2.15	2.15	2.15	2.15	2.15	2.15	2.15	2.2	2.2	2.2
36	2															1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.5	1.5	1.5
37	1-2												1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.5	1.5	1.5
38	2					1.288	1.288	1.288	1.288	1.288	1.288	1.288	1.288	1.288	1.288	1.288	1.288	1.288	1.288	1.288	1.288	1.288	1.288	1.288	1.288	1.288	1.288	1.288	1.288	1.288	1.288	1.288	1.288	1.288	1.288	1.288	1.288	1.288	1.288	1.288	1.288	1.288	1.288	1.288	1.288	1.288	1.3	1.3	1.3
43	3																														1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.5	1.5	1.5
46	2																																					1.59	1.59	1.59	1.59	1.59	1.59	1.59	1.59	1.59	1.6	1.6	1.6
49	2															1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.5	1.5	1.5
50	2																														1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.5	1.5	1.5
51	2																																						1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.5	1.5	1.5
52	2																																			1.59	1.59	1.59	1.59	1.59	1.59	1.59	1.59	1.59	1.59	1.59	1.6	1.6	1.6
53	2																																						1.562	1.562	1.562	1.562	1.562	1.562	1.562	1.562	1.6	1.6	1.6
55	3																																				1.562	1.562	1.562	1.562	1.562	1.562	1.562	1.562	1.562	1.562	1.6	1.6	1.6
57	2																															1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.5	1.5	1.5
58	2																																	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.5	1.5	1.5
59	3																																		1.87	1.87	1.87	1.87	1.87	1.87	1.87	1.87	1.87	1.87	1.87	1.87	1.9	1.9	1.9
60	2																																			1.53	1.53	1.53	1.53	1.53	1.53	1.53	1.53	1.53	1.53	1.53	1.5	1.5	1.5
61	2																																	2.85	2.85	2.85	2.85	2.85	2.85	2.85	2.85	2.85	2.85	2.85	2.85	2.85	2.9	2.9	2.9
63	2																																	3	3	3	3	3	3	3	3	3	3	3	3	3	3.0	3.0	3.0
64	4																																		1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.5	1.5	1.5
65	2																														1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.7	1.7	1.7
66	3																																		0.734	0.734	0.734	0.734	0.734	0.734	0.734	0.734	0.734	0.734	0.734	0.734	0.7	0.7	0.7
69	2																																					2.01	2.01	2.01	2.01	2.01	2.01	2.01	2.01	2.01	2.0	2.0	2.0
70	2																																				2.01	2.01	2.01	2.01	2.01	2.01	2.01	2.01	2.01	2.01	2.0	2.0	2.0
71	2																																					0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.3	0.3	0.3
72	2																																		2.15	2.15	2.15	2.15	2.15	2.15	2.15	2.15	2.15	2.15	2.15	2.15	2.2	2.2	2.2
73	2																																					1.126	1.126	1.126	1.126	1.126	1.126	1.126	1.126	1.126	1.1	1.1	1.1
74	2																																	2.29	2.29	2.29	2.29	2.29	2.29	2.29	2.29	2.29	2.29	2.29	2.29	2.29	2.3	2.3	2.3
76	2																				1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1.0	1.0	1.0
77	2-3																																		1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.5	1.5	1.5
78	2																																				1.73	1.73	1.73	1.73	1.73	1.73	1.73	1.73	1.73	1.73	1.7	1.7	1.7
79	2																																1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.7	1.7	1.7
80	2																																		3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
82	2																														1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.7	1.7	1.7
83	2																														1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.7	1.7	1.7
84	2																														1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.7	1.7	1.7
85	3																																1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.5	1.5	1.5
86	3																																		1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.5	1.5	1.5
87	2																																0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.5	0.5	0.5
88	4																																		1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.5	1.5	1.5
89	4																																		1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.5	1.5	1.5
90	4																																		1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.5	1.5	1.5
91	4																																		1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.5	1.5	1.5
92	4																																			1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.5	1.5	1.5
93	4																																						1	1	1	1	1	1	1	1	1.0	1.0	1.0
94	4																																		1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.5	1.5	1.5
95	4																																			1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.5	1.5	1.5
96	3																																			1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.5	1.5	1.5
97	3																																		1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.5	1.5	1.5
98	3																																		1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.5	1.5	1.5
99	3																																			1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.5	1.5	1.5
100	3																																		1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.5	1.5	1.5
101	3																																		1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.5	1.5	1.5
102	3																																		1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.5	1.5	1.5
103	3																																						1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.5	1.5	1.5
104	3																																			1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.5	1.5	1.5
105	3																																		1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.5	1.5	1.5
106	3																																			1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.5	1.5	1.5
107	3																																		1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.5	1.5	1.5
108	3																																		1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.5	1.5	1.5
109	3																																		1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.5	1.5	1.5
110	3																																		1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.5	1.5	1.5
111	3																																			1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.5	1.5	1.5
112	4																																		1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.5	1.5	1.5
113	4																																		1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.5	1.5	1.5
114	4																																			1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.5	1.5	1.5
115	4																																		1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.5	1.5	1.5
116	4																																		1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.5	1.5	1.5
117	2																																	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
118	2																																	**3.5**	**3.5**	**3.5**	**3.5**	**3.5**	**3.5**	**3.5**	**3.5**	**3.5**					3.5	3.5	3.5
120	3																																		1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.5	1.5	1.5
121	3																																			1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.5	1.5	1.5
122	3																																		1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.5	1.5	1.5
123	3																																			1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.5	1.5	1.5
124	3																																			1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.5	1.5	1.5
125	3																																			1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.5	1.5	1.5
126	3																																			1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.5	1.5	1.5
127	3																																		1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.5	1.5	1.5
128	2																																			1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.5	1.5	1.5
129	2-3																																				1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.5	1.5	1.5
130	2																																						1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.7	1.7	1.7
132	2																																					2.29	2.29	2.29	2.29	2.29	2.29	2.29	2.29	2.29	2.3	2.3	2.3
133	2																																				3.62	3.62	3.62	3.62	3.62	3.62	3.62	3.62	3.62	3.62	3.6	3.6	3.6
135	2																																					1.56	1.56	1.56	1.56	1.56	1.56	1.56	1.56	1.56	1.6	1.6	1.6
136	4																																					1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.5	1.5	1.5
137	3																																		3	3	3	3	3	3	3	3	3	3	3	3	3.0	3.0	3.0
138	2																																					0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
139	3																																		**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	10.0	10.0	10.0
141	4																																			0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.5	0.5	0.5
142	4-3																																		1	1	1	1	1	1	1	1	1	1	1	1	1.0	1.0	1.0
143	3																																						1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.1	1.1	1.1
144	2																																						2.85	2.85	2.85	2.85	2.85	2.85	2.85	2.85	2.9	2.9	2.9
160	3																																		1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.5	1.5	1.5
161	3																																		1.5065	1.5065	1.5065	1.5065	1.5065	1.5065	1.5065	1.5065	1.5065	1.5065	1.5065	1.5065	1.5	1.5	1.5
162	3																																						1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.5	1.5	1.5

Table F-3 continuted. *Reported or estimated annual withdrawal from small wells (<10 acre-ft/yr) 1963 to 2007, in acre-feet.*

ID	Geo Unit	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	Min.	Avg.	Max.
175	2	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.5	1.5	1.5
790	3																																											0.768	0.768	0.768	0.0	0.0	0.0
791	2																																											1.506	1.506	1.506	0.0	0.0	0.0
804	4																																	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.5	1.5	1.5
805	3																																									1.506	1.506	1.506	1.506	1.506	1.5	1.5	1.5
806	3																																									1.506	1.506	1.506	1.506	1.506	1.5	1.5	1.5
807	3																																										1.506	1.506	1.506	1.506	1.5	1.5	1.5
829	3																																									1.506	1.506	1.506	1.506	1.506	1.5	1.5	1.5
830	3																																									1.506	1.506	1.506	1.506	1.506	1.5	1.5	1.5
831	2																										1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.5	1.5	1.5
836	3																																									1	1	1	1	1	1.0	1.0	1.0
840	2																																						1	1	1	1	1	1	1	1	1.0	1.0	1.0
841	2																																								1.03	1.03	1.03	1.03	1.03	1.03	1.0	1.0	1.0
842	3																																									1.506	1.506	1.506	1.506	1.506	1.5	1.5	1.5
843	3																																							1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.5	1.5	1.5
844	3																					1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.5	1.5	1.5
845	2																																									1	1	1	1	1	1.0	1.0	1.0
846	2																																									2.15	2.15	2.15	2.15	2.15	2.2	2.2	2.2
850	2																																								8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4
857	2																																					2	2	2	2	2	2	2	2	2	2.0	2.0	2.0
859	3																																									1.73	1.73	1.73	1.73	1.73	1.7	1.7	1.7
861	2																																									10	10	10	10	10	10.0	10.0	10.0
863	3																																									1.506	1.506	1.506	1.506	1.506	1.5	1.5	1.5
864	2																																									2	2	2	2	2	2.0	2.0	2.0
877	2				1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.5	1.5	1.5
880	2				1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.5	1.5	1.5
881	2	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.5	1.5	1.5
883	2	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.5	1.5	1.5
898	4																																		1	1	1	1	1	1	1	1	1	1	1	1	1.0	1.0	1.0
991	2																																										15.89	15.89	15.89	15.89	0.0	0.0	0.0
995	2																																									3	3	3	3	3	3.0	3.0	3.0
998	2																																									0.45	0.45	0.45	0.45	0.45	0.5	0.5	0.5
1000	4																																		1.45	1.45	1.45	1.45	1.45	1.45	1.45	1.45	1.45	1.45	1.45	1.45	1.5	1.5	1.5
1005	4																																		1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.5	1.5	1.5
1006	3																																		1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.5	1.5	1.5
1010	3																																	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.5	1.5	1.5
1013	3																												1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.5	1.5	1.5
1014	3																												1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.5	1.5	1.5
1015	3																												1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.5	1.5	1.5
1019	3																		1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.5	1.5	1.5
1023	3	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.5	1.5	1.5
1026	2																				1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.5	1.5	1.5
1028	3																									1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.5	1.5	1.5
1046	3																												1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.5	1.5	1.5
1047	3																								1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.5	1.5	1.5
1048	3																						1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.5	1.5	1.5
1049	3																						1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.5	1.5	1.5
1050	3																			1.5	1.5	1.5	1.5	1.5	**30**	**30**	**30**	**30**	**30**	**30**	**30**	**30**	**30**	**30**	**30**	**30**	**30**	**30**	**30**	**2**	**2**	**2**	**2**	**2**	**2**	1.5	19.4	30.0
1053	2	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506														1.5	1.5	1.5
1054	2	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.5	1.5	1.5
1119	3										1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.5	1.5	1.5
1130	2	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.5	1.5	1.5
Small wells		15	15	15	18	21	21	21	21	21	22	22	24	25	25	30	30	30	31	33	38	39	42	44	72	74	78	80	89	91	103	109	115	133	206	233	244	257	270	244	254	278	282	300	300	300	21	118	300
Large and model wells		2420	3927	2062	2496	2039	2274	2462	2514	2592	1296	2658	3772	3815	3482	3523	3721	4463	4380	4691	4006	2659	2222	2089	2309	1971	2141	1854	4400	2659	2647	3084	2331	4214	4704	5468	4411	5264	5734	4180	5375	5159	5232	5431	8099	10,176	1296	3876	10176
All wells		2435	3942	2077	2514	2060	2295	2483	2535	2613	1318	2680	3796	3840	3507	3553	3751	4493	4411	4724	4043	2698	2264	2133	2381	2045	2218	1933	4489	2749	2750	3193	2446	4347	4909	5702	4655	5521	6004	4424	5629	5438	5513	5731	8399	10,476	1318	3995	10476
Small well % of total		1%	0%	1%	1%	1%	1%	1%	1%	1%	2%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	2%	2%	3%	4%	4%	4%	2%	3%	4%	3%	5%	3%	4%	4%	5%	5%	5%	6%	5%	5%	5%	5%	4%	3%			
Total discharge: wells, springs, and ck.		***7591***	***8402***	***6652***	***7902***	***8058***	***8939***	***13,287***	***9572***	***10,051***	***7495***	***12,948***	***11,011***	***12,849***	***11,503***	***12,549***	***12,747***	***12,489***	***12,407***	***13,720***	***15,039***	***15,694***	***13,260***	***11,129***	***10,377***	***8638***	***7625***	***6718***	***9217***	***9220***	***7652***	***11,262***	***7499***	***13,416***	***13,375***	***14,021***	***15,758***	***16,560***	***13,443***	***11,230***	***10,892***	***10,158***	***10,634***						***11,891***

APPENDIX G

NUMERICAL GROUNDWATER FLOW MODEL INPUT AND OUTPUT DATA TABLES

Table G-1. *List of parameter keys, names, initial values, range of values, and final calibrated values used in the Parameter Estimation (PEST) for automatic inverse calibration of steady-state and transient groundwater flow models.*

Definitions	
Key	Negative key value assigned to parameter
Name	Parameter name in inverse mode
Initial Value	Initial value assigned to the parameter
Minimum Value	Lower bound of the parameter value
Maximum Value	Upper bound of the parameter value
Final Value	Final calibrated value of the parameter
DRN_1	Drain conductance simulating Fairfield Spring outflow (ft^2/day)
DRN_2	Drain conductance simulating Cedar Pass outflow (ft^2/day)
DRN_3	Drain conductance simulating Mosida Hills outflow (ft^2/day)
WELL_4	Well parameter simulating inflow from West Canyon drainage (ft^3/day)
WELL_5	Well parameter simulating inflow from Oquirrh Mtns (ft^3/day)
WELL_6	Well parameter simulating inflow from East Tintic Mtns (ft^3/day)
ET_10	Evapotranspiration parameter for the 10-ft extinction depth (ft/day)
ET_35	Evapotranspiration parameter for the 35-ft extinction depth (ft/day)
ET_50	Evapotranspiration parameter for the 50-ft extinction depth (ft/day)
RCH_##	Recharge (ft^3/day). Last 2 digits of name are zone ID, shown on figure 45.
HK_1## or HK_2##	Horizontal hydraulic conductivity (ft/day). Last two digits of name are zone ID, see figure 41. Parameter keys in the -100s are layer 1 and -200s are layer 2.
VANI_11## or VANI_22##	Vertical anisotropy (ratio). Last two digits of name are zone ID, see figure 42. Parameter keys in the -1100s are layer 1 and -2200s are layer 2.
SY_111##	Specific yield (unitless). Last two digits of name are zone ID, location shown on figure 43.
SS_222##	Specific storage (1/ft). Last two digits of name are zone ID, location shown on figure 43.

HK, VANI, SY, SS, and DRN are time-independent parameters used in steady-state and transient models. WELL, RCH, and ET are time-dependent parameters used in the inverse mode in the steady-state model.

Key	Name	Initial Value	Minimum Value	Maximum Value	Final Value
-1	DRN_1	5,000	1,000	10,000	7,000
-2	DRN_2	20	10	100	16.41
-3	DRN_3	20	10	100	11.09
-4	WELL_4	1,044,492	500,000	1,500,000	530,108
-5	WELL_5	1,604,647	1,000,000	2,000,000	1,998,056
-6	WELL_6	611,969	100,000	800,000	202,205
-10	ET_10	0.002948	1.0E-06	5.0E-03	0.004007
-35	ET_35	0.001000	1.0E-06	5.0E-03	0.001383
-50	ET_50	1.0E-09	1.0E-10	1.0E-06	2.2E-09

Key	Name	Initial Value	Minimum Value	Maximum Value	Final Value
-9	RCH_09	0.001243	0	0.004	0.000414
-11	RCH_11	0.000473	0	0.004	0.000414
-13	RCH_13	0.001791	0	0.004	0.000101
-19	RCH_19	0.001072	0	0.004	0.000247
-20	RCH_20	0.001161	0	0.004	0.000139
-21	RCH_21	0.001377	0	0.004	0.000150
-22	RCH_22	0.001358	0	0.004	0.000035
-26	RCH_26	0.000159	0	0.004	0.000433
-27	RCH_27	0.000155	0	0.004	0.000083
-28	RCH_28	0.000163	0	0.004	0.000018
-29	RCH_29	0.000167	0	0.004	0.000020
-33	RCH_33	0.000476	0	0.004	0.000108
-34	RCH_34	0.000315	0	0.004	0.000082
-35	RCH_35	0.000175	0	0.004	0.000017
-36	RCH_36	0.000141	0	0.004	0.000026
-39	RCH_39	0.000895	0	0.004	0.000034
-40	RCH_40	0.000801	0	0.004	0.000093
-41	RCH_41	0.000787	0	0.004	0.000050
-42	RCH_42	0.000797	0	0.004	0.000013
-45	RCH_45	0.000099	0	0.004	0.000099
-46	RCH_46	0.000097	0	0.004	0.000008
-47	RCH_47	0.000879	0	0.004	0.000023
-48	RCH_48	0.000732	0	0.004	0.000016
-51	RCH_51	0.000604	0	0.004	0.000026
-52	RCH_52	0.000218	0	0.004	0.000005
-53	RCH_53	0.000585	0	0.004	0.000005
-54	RCH_54	0.000497	0	0.004	0.000010
-56	RCH_56	0.000046	0	0.004	0.000018
-57	RCH_57	0.000475	0	0.004	0.000006
-58	RCH_58	0.000322	0	0.004	0.000010
-59	RCH_59	0.000020	0	0.004	0.000012
-61	RCH_61	0.000365	0	0.004	0.000023
-62	RCH_62	0.000070	0	0.004	0.000018
-63	RCH_63	0.000007	0	0.004	0.000051
-66	RCH_66	0.000011	0	0.004	0.000135
-67	RCH_67	0.000008	0	0.004	0.000208
-68	RCH_68	0.000024	0	0.004	0.000135
-69	RCH_69	0.000151	0	0.004	0.000046

Table G-1 continued. *List of parameter key names, initial values, and final calibrated values used in the Parameter Estimation (PEST) for automatic inverse calibration of steady-state and transient groundwater flow models.*

Key	Name	Initial Value	Minimum Value	Maximum Value	Final Value	Key	Name	Initial Value	Minimum Value	Maximum Value	Final Value
-101	HK_101	15	1.0E-06	150	0.002	-201	HK_201	12.5	1.0E-06	150	0.262
-102	HK_102	15	1.0E-06	150	0.088	-202	HK_202	12.5	1.0E-06	150	3.878
-103	HK_103	15	1.0E-06	150	1.197	-203	HK_203	12.5	1.0E-06	150	0.050
-104	HK_104	15	1.0E-06	150	150.0	-204	HK_204	47.5	1.0E-06	150	1.204
-105	HK_105	15	1.0E-06	150	0.779	-205	HK_205	47.5	1.0E-06	150	150.0
-106	HK_106	15	1.0E-06	150	0.019	-206	HK_206	47.5	1.0E-06	150	98.3
-107	HK_107	15	1.0E-06	150	0.017	-207	HK_207	47.5	1.0E-06	150	0.302
-108	HK_108	15	1.0E-06	150	5.090	-208	HK_208	47.5	1.0E-06	150	0.023
-109	HK_109	15	1.0E-06	150	0.354	-209	HK_209	47.5	1.0E-06	150	0.028
-110	HK_110	15	1.0E-06	150	150.0	-210	HK_210	47.5	1.0E-06	150	0.581
-111	HK_111	15	1.0E-06	150	0.057	-211	HK_211	12.5	1.0E-06	150	5.116
-112	HK_112	15	1.0E-06	150	0.006	-212	HK_212	12.5	1.0E-06	150	0.695
-113	HK_113	15	1.0E-06	150	0.145	-213	HK_213	47.5	1.0E-06	150	0.165
-114	HK_114	15	1.0E-06	150	0.554	-214	HK_214	12.5	1.0E-06	150	0.046
-115	HK_115	2.5	1.0E-06	150	3.537	-215	HK_215	12.5	1.0E-06	150	11.5
-116	HK_116	15	1.0E-06	150	0.388	-216	HK_216	47.5	1.0E-06	150	9.407
-117	HK_117	15	1.0E-06	150	0.214	-217	HK_217	47.5	1.0E-06	150	2.473
-118	HK_118	2.5	1.0E-06	150	1.997	-218	HK_218	47.5	1.0E-06	150	34.6
-119	HK_119	15	1.0E-06	150	2.191	-219	HK_219	47.5	1.0E-06	150	0.906
-120	HK_120	15	1.0E-06	150	2.368	-220	HK_220	47.5	1.0E-06	150	0.009
-121	HK_121	15	1.0E-06	150	1.110	-221	HK_221	47.5	1.0E-06	150	150.0
-122	HK_122	15	1.0E-06	150	0.025	-222	HK_222	47.5	1.0E-06	150	86.6
-123	HK_123	15	1.0E-06	150	0.799	-223	HK_223	47.5	1.0E-06	150	0.010
-124	HK_124	15	1.0E-06	150	1.890	-224	HK_224	47.5	1.0E-06	150	0.367
-125	HK_125	15	1.0E-06	150	25.2	-225	HK_225	47.5	1.0E-06	150	0.091
-126	HK_126	15	1.0E-06	150	2.394	-226	HK_226	12.5	1.0E-06	150	0.391
-127	HK_127	15	1.0E-06	150	30.1	-227	HK_227	12.5	1.0E-06	150	2.872
-128	HK_128	15	1.0E-06	150	150.0	-228	HK_228	12.5	1.0E-06	150	40.9
-129	HK_129	15	1.0E-06	150	0.036	-229	HK_229	12.5	1.0E-06	150	0.916
-130	HK_130	15	1.0E-06	150	3.943	-230	HK_230	12.5	1.0E-06	150	1.344
-131	HK_131	15	1.0E-06	150	0.511	-231	HK_231	12.5	1.0E-06	150	0.008
-132	HK_132	15	1.0E-06	150	0.047	-232	HK_232	12.5	1.0E-06	150	0.050
-133	HK_133	15	1.0E-06	150	0.007	-233	HK_233	12.5	1.0E-06	150	0.015
-134	HK_134	2.5	1.0E-06	150	27.8	-234	HK_234	12.5	1.0E-06	150	0.004
-135	HK_135	2.5	1.0E-06	150	0.164	-235	HK_235	12.5	1.0E-06	150	6.519
-136	HK_136	2.5	1.0E-06	150	0.784	-236	HK_236	12.5	1.0E-06	150	91.4
-137	HK_137	2.5	1.0E-06	150	3.8	-237	HK_237	12.5	1.0E-06	150	54.8
-138	HK_138	2.5	1.0E-06	150	7.6	-238	HK_238	12.5	1.0E-06	150	0.501

Table G-1 continued. *List of parameter key names, initial values, and final calibrated values used in the Parameter Estimation (PEST) for automatic inverse calibration of steady-state and transient groundwater flow models.*

Key	Name	Initial Value	Minimum Value	Maximum Value	Final Value	Key	Name	Initial Value	Minimum Value	Maximum Value	Final Value
-1101	VANI_1101	4	1	10	1.00	-2201	VANI_2201	4	1	10	1.68
-1102	VANI_1102	4	1	10	1.24	-2202	VANI_2202	4	1	10	7.71
-1103	VANI_1103	4	1	10	3.41	-2203	VANI_2203	4	1	10	1.03
-1104	VANI_1104	4	1	10	1.80	-2204	VANI_2204	4	1	10	5.29
-1105	VANI_1105	4	1	10	2.27	-2205	VANI_2205	4	1	10	4.52
-1106	VANI_1106	4	1	10	8.49	-2206	VANI_2206	4	1	10	6.80
-1107	VANI_1107	4	1	10	4.39	-2207	VANI_2207	4	1	10	3.13
-1108	VANI_1108	4	1	10	2.03	-2208	VANI_2208	4	1	10	1.20
-1109	VANI_1109	4	1	10	7.88	-2209	VANI_2209	4	1	10	2.13
-1110	VANI_1110	4	1	10	3.84	-2210	VANI_2210	4	1	10	2.46
-1111	VANI_1111	4	1	10	3.28	-2211	VANI_2211	4	1	10	6.57
-1112	VANI_1112	4	1	10	1.00	-2212	VANI_2212	4	1	10	4.60
-1113	VANI_1113	4	1	10	4.62	-2213	VANI_2213	4	1	10	7.08
-1114	VANI_1114	4	1	10	1.41	-2214	VANI_2214	4	1	10	3.83
-1115	VANI_1115	4	1	10	3.04	-2215	VANI_2215	4	1	10	2.31
-1116	VANI_1116	4	1	10	3.94	-2216	VANI_2216	4	1	10	7.36
-1117	VANI_1117	4	1	10	3.06	-2217	VANI_2217	4	1	10	2.73
-1118	VANI_1118	4	1	10	4.63	-2218	VANI_2218	4	1	10	3.37
-1119	VANI_1119	4	1	10	4.90	-2219	VANI_2219	4	1	10	3.62
-1120	VANI_1120	4	1	10	9.02	-2220	VANI_2220	4	1	10	4.23
-1121	VANI_1121	4	1	10	5.59	-2221	VANI_2221	4	1	10	1.58
-1122	VANI_1122	4	1	10	7.51	-2222	VANI_2222	4	1	10	3.94
-1123	VANI_1123	4	1	10	1.00	-2223	VANI_2223	4	1	10	4.02
-1124	VANI_1124	4	1	10	2.30	-2224	VANI_2224	4	1	10	2.46
-1125	VANI_1125	4	1	10	7.99	-2225	VANI_2225	4	1	10	3.99
-1126	VANI_1126	4	1	10	3.24	-2226	VANI_2226	4	1	10	2.63
-1127	VANI_1127	4	1	10	4.17	-2227	VANI_2227	4	1	10	2.13
-1128	VANI_1128	4	1	10	1.00	-2228	VANI_2228	4	1	10	1.56
-1129	VANI_1129	4	1	10	5.13	-2229	VANI_2229	4	1	10	2.55
-1130	VANI_1130	4	1	10	2.52	-2230	VANI_2230	4	1	10	1.26
-1131	VANI_1131	4	1	10	2.01	-2231	VANI_2231	4	1	10	4.23
-1132	VANI_1132	4	1	10	2.68	-2232	VANI_2232	4	1	10	4.20
-1133	VANI_1133	4	1	10	8.60	-2233	VANI_2233	4	1	10	2.46
-1134	VANI_1134	4	1	10	3.53	-2234	VANI_2234	4	1	10	3.82
-1135	VANI_1135	4	1	10	3.31	-2235	VANI_2235	4	1	10	2.95
-1136	VANI_1136	4	1	10	2.91	-2236	VANI_2236	4	1	10	1.46
-1137	VANI_1137	4	1	10	3.45	-2237	VANI_2237	4	1	10	1.60
-1138	VANI_1138	4	1	10	7.74	-2238	VANI_2238	4	1	10	2.36

Table G-1 continued. *List of parameter key names, initial values, and final calibrated values used in the Parameter Estimation (PEST) for automatic inverse calibration of steady-state and transient groundwater flow models.*

Key	Name	Initial Value	Minimum Value	Maximum Value	Final Value	Key	Name	Initial Value	Minimum Value	Maximum Value	Final Value
-11101	SY_11101	0.11	1.0E-04	0.22	0.012	-22201	SS_22201	1.1E-05	1.0E-09	1.0E-04	5.0E-06
-11102	SY_11102	0.11	1.0E-04	0.22	0.047	-22202	SS_22202	1.1E-05	1.0E-09	1.0E-04	4.3E-07
-11103	SY_11103	0.11	1.0E-04	0.22	0.028	-22203	SS_22203	1.1E-05	1.0E-09	1.0E-04	5.9E-07
-11104	SY_11104	0.11	1.0E-04	0.22	0.167	-22204	SS_22204	1.1E-05	1.0E-09	1.0E-04	4.1E-06
-11105	SY_11105	0.11	1.0E-04	0.22	0.096	-22205	SS_22205	1.1E-05	1.0E-09	1.0E-04	5.7E-06
-11106	SY_11106	0.11	1.0E-04	0.22	0.056	-22206	SS_22206	1.1E-05	1.0E-09	1.0E-04	1.2E-05
-11107	SY_11107	0.11	1.0E-04	0.22	0.037	-22207	SS_22207	1.1E-05	1.0E-09	1.0E-04	3.9E-07
-11108	SY_11108	0.11	1.0E-04	0.22	0.017	-22208	SS_22208	1.1E-05	1.0E-09	1.0E-04	1.0E-05
-11109	SY_11109	0.11	1.0E-04	0.22	0.025	-22209	SS_22209	1.1E-05	1.0E-09	1.0E-04	1.8E-06
-11110	SY_11110	0.11	1.0E-04	0.22	0.080	-22210	SS_22210	1.1E-05	1.0E-09	1.0E-04	7.4E-06
-11111	SY_11111	0.11	1.0E-04	0.22	0.102	-22211	SS_22211	1.1E-05	1.0E-09	1.0E-04	4.7E-06
-11112	SY_11112	0.11	1.0E-04	0.22	0.010	-22212	SS_22212	1.1E-05	1.0E-09	1.0E-04	9.0E-06
-11113	SY_11113	0.11	1.0E-04	0.22	0.023	-22213	SS_22213	1.1E-05	1.0E-09	1.0E-04	2.5E-05
-11114	SY_11114	0.11	1.0E-04	0.22	0.014	-22214	SS_22214	1.1E-05	1.0E-09	1.0E-04	4.9E-06
-11115	SY_11115	0.11	1.0E-04	0.22	0.017	-22215	SS_22215	1.1E-05	1.0E-09	1.0E-04	4.0E-06
-11116	SY_11116	0.11	1.0E-04	0.22	0.012	-22216	SS_22216	1.1E-05	1.0E-09	1.0E-04	4.6E-06
-11117	SY_11117	0.11	1.0E-04	0.22	0.023	-22217	SS_22217	1.1E-05	1.0E-09	1.0E-04	4.7E-08
-11118	SY_11118	0.11	1.0E-04	0.22	0.023	-22218	SS_22218	1.1E-05	1.0E-09	1.0E-04	1.1E-05
-11119	SY_11119	0.11	1.0E-04	0.22	0.014	-22219	SS_22219	1.1E-05	1.0E-09	1.0E-04	8.9E-07
-11120	SY_11120	0.11	1.0E-04	0.22	0.052	-22220	SS_22220	1.1E-05	1.0E-09	1.0E-04	2.6E-05
-11121	SY_11121	0.11	1.0E-04	0.22	0.044	-22221	SS_22221	1.1E-05	1.0E-09	1.0E-04	2.6E-06
-11122	SY_11122	0.11	1.0E-04	0.22	0.060	-22222	SS_22222	1.1E-05	1.0E-09	1.0E-04	2.3E-05
-11123	SY_11123	0.11	1.0E-04	0.22	0.034	-22223	SS_22223	1.1E-05	1.0E-09	1.0E-04	9.7E-07
-11124	SY_11124	0.11	1.0E-04	0.22	0.013	-22224	SS_22224	1.1E-05	1.0E-09	1.0E-04	3.4E-06
-11125	SY_11125	0.11	1.0E-04	0.22	0.016	-22225	SS_22225	1.1E-05	1.0E-09	1.0E-04	4.4E-06
-11126	SY_11126	0.11	1.0E-04	0.22	0.001	-22226	SS_22226	1.1E-05	1.0E-09	1.0E-04	1.4E-05
-11127	SY_11127	0.11	1.0E-04	0.22	0.053	-22227	SS_22227	1.1E-05	1.0E-09	1.0E-04	8.1E-07
-11128	SY_11128	0.11	1.0E-04	0.22	0.005	-22228	SS_22228	1.1E-05	1.0E-09	1.0E-04	2.2E-06
-11129	SY_11129	0.11	1.0E-04	0.22	0.034	-22229	SS_22229	1.1E-05	1.0E-09	1.0E-04	1.7E-07
-11130	SY_11130	0.11	1.0E-04	0.22	0.166	-22230	SS_22230	1.1E-05	1.0E-09	1.0E-04	7.0E-06
-11131	SY_11131	0.11	1.0E-04	0.22	0.007	-22231	SS_22231	1.1E-05	1.0E-09	1.0E-04	1.4E-07
-11132	SY_11132	0.11	1.0E-04	0.22	0.023	-22232	SS_22232	1.1E-05	1.0E-09	1.0E-04	8.8E-06
-11133	SY_11133	0.11	1.0E-04	0.22	0.077	-22233	SS_22233	1.1E-05	1.0E-09	1.0E-04	1.3E-05
-11134	SY_11134	0.11	1.0E-04	0.22	0.035	-22234	SS_22234	1.1E-05	1.0E-09	1.0E-04	8.3E-06
-11135	SY_11135	0.11	1.0E-04	0.22	0.050	-22235	SS_22235	1.1E-05	1.0E-09	1.0E-04	8.4E-07
-11136	SY_11136	0.11	1.0E-04	0.22	0.041	-22236	SS_22236	1.1E-05	1.0E-09	1.0E-04	1.3E-05
-11137	SY_11137	0.11	1.0E-04	0.22	0.007	-22237	SS_22237	1.1E-05	1.0E-09	1.0E-04	5.9E-06
-11138	SY_11138	0.11	1.0E-04	0.22	0.024	-22238	SS_22238	1.1E-05	1.0E-09	1.0E-04	3.7E-06

Table G-2. *Simulated drain flow discharge from Fairfield Spring, Cedar Pass, and Mosida Hills.*

Year	Fairfield Spring discharge		Residual	Mosida Hills Drain Flow	Cedar Pass Drain Flow	Total Simulated Drain Flow	Q_{MH}/Total	Q_{CP}/Total
	Conceptual [1]	Simulated						
	acre-ft/yr	acre-ft/yr	acre-ft/yr	acre-ft/yr	acre-ft/yr	acre-ft/yr		
1969	3453	3539	86	4579	10,810	15,389	30%	70%
1970	4052	3539	513	4587	10,821	15,408	30%	70%
1971	*3000*	3668	668	4590	10,828	15,419	30%	70%
1972	*3000*	3494	494	4586	10,826	15,412	30%	70%
1973	*3000*	3337	337	4572	10,736	15,308	30%	70%
1974	*3000*	3161	161	4551	10,570	15,121	30%	70%
1975	*3000*	3076	76	4527	10,420	14,948	30%	70%
1976	*3000*	2982	18	4498	10,284	14,782	30%	70%
1977	*4000*	2800	1200	4492	10,131	14,623	31%	69%
1978	*4000*	3273	727	4492	9943	14,435	31%	69%
1979	*3000*	3308	308	4492	9799	14,291	31%	69%
1980	*3000*	3232	232	4511	9601	14,112	32%	68%
1981	*4000*	3684	316	4558	9544	14,102	32%	68%
1982	*4000*	4157	157	4663	9837	14,500	32%	68%
1983	*6000*	5031	969	4769	10,143	14,912	32%	68%
1984	*6000*	5454	546	4827	10,330	15,157	32%	68%
1985	*4000*	5054	1054	4873	10,554	15,427	32%	68%
1986	*4000*	4946	946	4902	10,766	15,668	31%	69%
1987	*3000*	4662	1662	4898	10,892	15,790	31%	69%
1988	*3000*	3835	835	4863	10,953	15,816	31%	69%
1989	*3000*	3217	217	4813	10,850	15,662	31%	69%
1990	*3000*	2944	56	4775	10,745	15,519	31%	69%
1991	3388	3198	190	4745	10,743	15,488	31%	69%
1992	3259	3345	86	4719	10,739	15,458	31%	69%
1993	3186	3297	111	4696	10,705	15,401	30%	70%
1994	2884	3324	440	4679	10,443	15,122	31%	69%
1995	3402	3395	7	4676	10,063	14,739	32%	68%
1996	3971	3648	323	4698	9820	14,517	32%	68%
1997	4516	3977	539	4755	9760	14,515	33%	67%
1998	4681	4680	1	4806	9766	14,572	33%	67%
1999	6324	4794	1530	4831	9623	14,454	33%	67%
2000	4924	4354	570	4836	9603	14,439	33%	67%
2001	4732	3959	773	4812	9666	14,478	33%	67%
2002	3532	3379	153	4776	9571	14,347	33%	67%
2003	3286	3139	147	4748	9492	14,240	33%	67%
2004	3074	3264	190	4744	9466	14,210	33%	67%
2005	3934	3598	336	4758	9388	14,146	34%	66%
2006	4253	3953	300	4776	9263	14,038	34%	66%
2007	4385	3900	485	4789	9192	13,981	34%	66%
Minimum	**2884**	**2800**	**1**	**4492**	**9192**	**13,981**	**30%**	**66%**
Maximum	**6324**	**5454**	**1662**	**4902**	**10,953**	**15,816**	**34%**	**70%**
Average	**3775**	**3733**	**455**	**4699**	**10,171**	**14,870**	**32%**	**68%**

[1] Conceptual Fairfield Spring discharge for the years 1971-1989 (in italic font) is an estimate of spring flow based on the annual precipitation at Fairfield. Our calibration target of +/-1000 acre-ft/yr does not apply.

Residual is the absolute value of the difference between simulated and observed flow discharge from Fairfield Spring.

Q_{MH}/Total is the percentage of drain flow through Mosida Hills divided by the total combined drain flow through Mosida Hills and Cedar Pass.

Q_{CP}/Total is the percentage of drain flow through Cedar Pass divided by the total combined drain flow through Mosida Hills and Cedar Pass.

Table G-3. *Comparison of conceptual (initial) to simulated (final) annual evapotranspiration.*

Year	ET rate in ft/day						Volume of ET per zone in acre-ft/yr						Total (acre-ft/yr)		Diff-erence
	ET-10		ET-35		ET-50		ET-10		ET-35		ET-50				
	Initial	Final	Initial	Final	Initial	Final	Initial	Final	Initial	Final	Initial	Final	Initial	Final	
1969	0.003452	0.004100	0.0010	0.001400	1.00E-09	2.20E-09	1823	855	1413	1648	0.030	0.0700	**3236**	**2503**	**-733**
1970	0.002948	0.004007	0.0014	0.001383	2.20E-09	2.20E-09	1557	914	1648	1803	0.070	0.0011	**3205**	**2717**	**-495**
1971	0.002700	0.004035	0.0014	0.001393	2.20E-09	3.22E-09	1426	2010	1648	694	0.07	0.0016	**3074**	**2704**	**-370**
1972	0.004094	0.003695	0.0014	0.001275	2.20E-09	2.95E-09	2162	2298	1648	793	0.07	0.0018	**3810**	**3091**	**-719**
1973	0.003277	0.005602	0.0014	0.001934	2.20E-09	4.47E-09	1731	2335	1648	806	0.07	0.0019	**3379**	**3140**	**-238**
1974	0.003700	0.004485	0.0014	0.001548	2.20E-09	3.58E-09	1954	2045	1648	706	0.07	0.0016	**3602**	**2750**	**-852**
1975	0.003419	0.005063	0.0014	0.001748	2.20E-09	4.04E-09	1806	1951	1648	674	0.07	0.0016	**3454**	**2625**	**-829**
1976	0.004444	0.004680	0.0014	0.001615	2.20E-09	3.74E-09	2347	1978	1648	683	0.07	0.0016	**3995**	**2660**	**-1334**
1977	0.002637	0.006082	0.0014	0.002099	2.20E-09	4.86E-09	1393	1631	1648	563	0.07	0.0013	**3041**	**2194**	**-847**
1978	0.002164	0.003610	0.0014	0.001246	2.20E-09	2.88E-09	1143	1328	1648	458	0.07	0.0011	**2791**	**1787**	**-1004**
1979	0.003734	0.002962	0.0014	0.001022	2.20E-09	2.37E-09	1972	1675	1648	578	0.07	0.0013	**3620**	**2253**	**-1367**
1980	0.002959	0.005110	0.0014	0.001764	2.20E-09	4.08E-09	1563	1815	1648	627	0.07	0.0014	**3211**	**2442**	**-769**
1981	0.002325	0.004050	0.0014	0.001398	2.20E-09	3.23E-09	1228	1691	1648	584	0.07	0.0013	**2876**	**2274**	**-602**
1982	0.001793	0.003182	0.0014	0.001098	2.20E-09	2.54E-09	947	1605	1648	554	0.07	0.0013	**2595**	**2158**	**-437**
1983	0	0.002454	0.0014	0.000847	2.20E-09	1.96E-09	0	2319	1648	800	0.07	0.0019	**1648**	**3119**	**1471**
1984	0.001200	0.003966	0.0014	0.001369	2.20E-09	3.22E-09	634	2402	1648	829	0.07	0.0019	**2282**	**3230**	**949**
1985	0.002132	0.001643	0.0014	0.000567	2.20E-09	1.31E-09	1126	2066	1648	713	0.07	0.0016	**2774**	**2779**	**5**
1986	0.002272	0.002918	0.0014	0.001007	2.20E-09	2.33E-09	1200	2754	1648	950	0.07	0.0022	**2848**	**3704**	**856**
1987	0.003387	0.003109	0.0014	0.001073	2.20E-09	2.48E-09	1789	3422	1648	1181	0.07	0.0027	**3437**	**4603**	**1166**
1988	0.004351	0.004636	0.0014	0.001600	2.20E-09	3.70E-09	2298	3907	1648	1348	0.07	0.0031	**3946**	**5255**	**1309**
1989	0.004039	0.005955	0.0014	0.002055	2.20E-09	4.76E-09	2133	3383	1648	1167	0.07	0.0027	**3781**	**4550**	**769**
1990	0.003987	0.005527	0.0014	0.001908	2.20E-09	4.41E-09	2106	2671	1648	922	0.07	0.0021	**3754**	**3593**	**-161**
1991	0.002473	0.005457	0.0014	0.001884	2.20E-09	4.36E-09	1306	2143	1648	740	0.07	0.0017	**2954**	**2883**	**-71**
1992	0.003423	0.003384	0.0014	0.001168	2.20E-09	2.70E-09	1808	1994	1648	688	0.07	0.0016	**3456**	**2682**	**-774**
1993	0.003020	0.004685	0.0014	0.001617	2.20E-09	3.74E-09	1595	2072	1648	715	0.07	0.0017	**3243**	**2787**	**-456**
1994	0.003363	0.004133	0.0014	0.001426	2.20E-09	3.30E-09	1776	2023	1648	698	0.07	0.0016	**3424**	**2721**	**-703**
1995	0.002895	0.004602	0.0014	0.001588	2.20E-09	3.68E-09	1529	2011	1648	694	0.07	0.0016	**3177**	**2704**	**-473**
1996	0.002461	0.003962	0.0014	0.001367	2.20E-09	3.16E-09	1300	1859	1648	642	0.07	0.0015	**2948**	**2501**	**-447**
1997	0.002158	0.003369	0.0014	0.001163	2.20E-09	2.69E-09	1140	1794	1648	619	0.07	0.0014	**2788**	**2414**	**-374**
1998	0.001573	0.002954	0.0014	0.001020	2.20E-09	2.36E-09	831	1792	1648	619	0.07	0.0014	**2479**	**2411**	**-67**
1999	0.002128	0.002153	0.0014	0.000743	2.20E-09	1.72E-09	1124	1947	1648	672	0.07	0.0016	**2772**	**2619**	**-153**
2000	0.002297	0.002913	0.0014	0.001005	2.20E-09	2.33E-09	1213	2254	1648	778	0.07	0.0018	**2861**	**3032**	**171**
2001	0.002808	0.003143	0.0014	0.001085	2.20E-09	2.51E-09	1483	2422	1648	836	0.07	0.0019	**3131**	**3258**	**127**
2002	0.004076	0.003843	0.0014	0.001326	2.20E-09	3.07E-09	2153	2686	1648	927	0.07	0.0021	**3801**	**3612**	**-189**
2003	0.003609	0.005579	0.0014	0.001926	2.20E-09	4.46E-09	1906	2562	1648	885	0.07	0.0020	**3554**	**3447**	**-107**
2004	0.003543	0.004939	0.0014	0.001705	2.20E-09	3.94E-09	1871	2353	1648	812	0.07	0.0019	**3519**	**3166**	**-353**
2005	0.003022	0.004848	0.0014	0.001673	2.20E-09	3.87E-09	1596	2804	1648	968	0.07	0.0022	**3244**	**3772**	**527**
2006	0.003022	0.006097	0.0014	0.002104	2.20E-09	4.87E-09	1596	3036	1648	1048	0.07	0.0024	**3244**	**4084**	**840**
2007	0.003022	0.004906	0.0014	0.001693	2.20E-09	3.92E-09	1596	2550	1648	880	0.07	0.0020	**3244**	**3430**	**185**
Minimum	0.000000	0.001643	0.001000	0.000567	1.00E-09	1.31E-09	0	855	1413	458	0.03	0.0011	**1648**	**1787**	**-1367**
Maximum	0.004444	0.006097	0.001400	0.002104	2.20E-09	4.87E-09	2347	3907	1648	1803	0.07	0.0700	**3995**	**5255**	**1471**
Average	0.002921	0.004150	0.001390	0.001432	2.17E-09	3.26E-09	1543	2189	1642	828	0.07	0.0035	**3184**	**3017**	**-168**

Table G-4. *Comparison of conceptual to simulated recharge from surface and subsurface sources, in acre-ft/yr.*

Year	Recharge from surface sources (Layer 1; basin-fill aquifer)			Recharge from subsurface sources (Layer 2; bedrock aquifer)			Combined recharge		
	Conceptual	Simulated	Residual[1]	Conceptual	Simulated	Residual[1]	Conceptual	Simulated	Residual[1]
1969	4326	1182	3145	27,326	22,951	4375	31,652	24,132	7519
1970	5600	1489	4111	28,064	25,316	2747	33,664	26,805	6859
1971	6954	1319	5636	28,667	20,701	7965	35,621	22,020	13,601
1972	2375	1161	1214	20,771	19,681	1090	23,146	20,842	2304
1973	5539	1300	4239	29,464	17,666	11,798	35,003	18,966	16,037
1974	1269	1261	9	16,670	18,585	-1915	17,939	19,846	-1907
1975	6926	1175	5751	28,910	18,391	10,519	35,836	19,566	16,270
1976	888	1238	-350	16,569	15,595	974	17,457	16,833	624
1977	6927	2037	4890	22,172	27,793	-5621	29,099	29,830	-731
1978	9389	1774	7615	37,517	23,206	14,311	46,906	24,981	21,925
1979	1362	1535	-173	16,660	21,371	-4712	18,022	22,906	-4885
1980	9763	2171	7593	33,683	30,915	2768	43,446	33,085	10,361
1981	10,552	2756	7796	29,594	33,531	-3936	40,147	36,287	3860
1982	12,971	4621	8350	35,113	43,796	-8682	48,084	48,417	-333
1983	20,617	4098	16,519	43,484	39,913	3571	64,101	44,011	20,090
1984	8687	1934	6753	30,755	26,609	4146	39,441	28,543	10,898
1985	8267	1605	6662	25,879	28,672	-2793	34,146	30,277	3869
1986	8451	1205	7246	29,406	25,529	3877	37,857	26,734	11,123
1987	4557	694	3863	21,807	13,728	8079	26,364	14,422	11,942
1988	808	404	404	14,214	9719	4495	15,023	10,124	4899
1989	1052	511	541	14,707	11,885	2822	15,758	12,395	3363
1990	1659	1297	362	19,365	21,524	-2160	21,024	22,822	-1798
1991	10,424	1350	9074	28,632	22,040	6593	39,056	23,390	15,667
1992	3715	1178	2538	18,037	20,038	-2001	21,752	21,215	537
1993	7522	1225	6297	27,012	21,385	5628	34,534	22,610	11,924
1994	3416	1248	2168	22,339	22,703	-363	25,755	23,951	1805
1995	7665	1710	5955	30,059	26,703	3355	37,723	28,413	9310
1996	7324	2506	4818	27,515	29,729	-2214	34,839	32,235	2604
1997	13,292	3431	9861	30,627	38,192	-7564	43,920	41,623	2297
1998	14,847	2582	12,265	38,320	32,104	6216	53,167	34,686	18,481
1999	6812	1569	5243	22,694	22,716	-22	29,506	24,285	5221
2000	7131	1194	5937	25,012	19,523	5489	32,143	20,718	11,425
2001	3033	649	2385	19,720	12,983	6737	22,754	13,632	9122
2002	1748	642	1106	14,063	15,307	-1244	15,811	15,949	-138
2003	6015	982	5032	21,947	21,506	440	27,961	22,488	5473
2004	6967	1305	5662	24,016	29,728	-5712	30,983	31,033	-51
2005	9895	1310	8584	32,523	33,070	-547	42,418	34,381	8037
2006	6321	1075	5246	23,836	27,300	-3464	30,157	28,375	1782
2007	2975	983	1992	18,062	25,028	-6966	21,037	26,011	-4974
Minimum	**808**	**404**	**-350**	**14,063**	**9719**	**-8682**	**15,023**	**10,124**	**-4974**
Maximum	**20,617**	**4621**	**16,519**	**43,484**	**43,796**	**14,311**	**64,101**	**48,417**	**21,925**
Average	**6616**	**1582**	**5034**	**25,518**	**24,029**	**1489**	**32,135**	**25,611**	**6523**

[1] Residual is calculated by subtracting simulated recharge from conceptual recharge.

Table G-5. *Simulated versus observed water-level elevations for the 24 head observation locations, in feet.*

Year	TS	Well 4 water-level elevation (ft)			Well 41 water-level elevation (ft)			Well 44 water-level elevation (ft)			Well 45 water-level elevation (ft)			Well 118 water-level elevation (ft)			Well 134 water-level elevation (ft)			Well 852 water-level elevation (ft)			Well 877 water-level elevation (ft)		
		Simulated	Observed	Residual *	Simulated	Observed	Residual	Simulated	Observed	Residual	Simulated	Observed	Residual	Simulated	Observed	Residual	Simulated	Observed	Residual	Simulated	Observed	Residual	Simulated	Observed	Residual
1969	**1**	4795	4787	8.2	4677	4664	13.3	4893	4896	3.0	4818	4811	7.1	4728	4727	1.0	4772	4768	4.1	4847	4843	3.8	4774	4771	3.4
1970	**2**	4793	4786	6.9	4677	4663	14.4	4894	4899	5.0	4818	4812	6.1	4728	4728	0.0	4772	4770	2.3	4847	4844	3.4	4774	4770	4.2
1971	**3**	4791	4788	2.8	4677	4662	15.4	4897	4900	2.6	4817	4811	6.2	4728	4721	7.0	4772	4769	3.3	4846	4845	1.5	4774	4768	5.7
1972	**4**	4790	4786	4.1	4677	4665	12.4	4899	4901	2.4	4816	4813	3.4	4728	4727	1.0	4772	4769	3.1	4846	4846	0.3	4773	4768	5.3
1973	**5**	4794	4786	7.8	4674	4663	10.9	4893	4897	3.5	4816	4813	3.4	4728	4727	1.0	4771	4768	3.0	4845	4846	0.9	4773	4768	5.3
1974	**6**	4797	4786	10.8	4668	4664	3.7	4888	4904	16.1	4816	4813	3.4	4728	4727	1.0	4771	4763	7.5	4844	4848	3.7	4773	4768	5.4
1975	**7**	4795	4785	10.0	4664	4660	3.5	4885	4901	16.3	4815	4814	1.4	4728	4727	1.0	4770	4768	2.0	4843	4848	5.2	4773	4767	6.0
1976	**8**	4794	4788	6.3	4663	4661	2.2	4882	4905	22.6	4814	4815	0.5	4728	4727	1.0	4769	4769	0.0	4842	4849	7.2	4772	4768	4.4
1977	**9**	4795	4789	6.4	4659	4660	1.3	4884	4902	17.8	4816	4816	0.2	4728	4728	0.0	4770	4767	2.5	4844	4850	5.8	4773	4768	4.5
1978	**10**	4795	4790	5.4	4652	4656	4.2	4884	4899	14.7	4816	4817	0.8	4728	4728	0.1	4770	4771	1.0	4844	4850	5.6	4773	4769	3.5
1979	**11**	4793	4790	2.9	4653	4656	3.5	4883	4903	20.3	4815	4818	2.7	4728	4728	0.1	4769	4771	1.6	4844	4850	6.5	4772	4769	3.0
1980	**12**	4794	4790	3.8	4654	4660	6.1	4885	4904	18.8	4816	4819	2.6	4728	4728	0.1	4769	4772	2.7	4845	4854	8.6	4772	4768	3.9
1981	**13**	4796	4789	7.3	4657	4660	2.9	4891	4906	14.9	4819	4820	1.1	4728	4728	0.2	4771	4772	1.5	4849	4853	4.0	4773	4768	4.7
1982	**14**	4799	4789	10.4	4664	4660	3.6	4905	4902	2.7	4823	4821	2.0	4728	4728	0.5	4774	4773	1.2	4854	4854	0.2	4775	4768	6.7
1983	**15**	4806	4792	14.1	4665	4662	2.6	4921	4905	16.3	4828	4822	6.4	4729	4729	0.3	4779	4774	5.0	4862	4859	2.6	4778	4769	8.9
1984	**16**	4807	4794	12.6	4660	4664	4.1	4933	4920	12.7	4831	4826	4.7	4729	4729	0.2	4782	4777	5.1	4866	4861	4.9	4780	4770	10.2
1985	**17**	4804	4796	7.8	4661	4675	14.0	4938	4921	17.3	4831	4829	1.6	4729	4729	0.2	4784	4778	5.8	4865	4856	8.6	4781	4772	9.2
1986	**18**	4802	4796	6.2	4666	4680	14.0	4939	4918	20.8	4829	4831	1.8	4729	4729	0.2	4784	4779	5.5	4861	4859	1.7	4781	4773	8.5
1987	**19**	4797	4797	0.2	4669	4685	16.3	4932	4918	14.2	4825	4831	5.8	4729	4729	0.2	4783	4778	5.3	4855	4855	0.3	4780	4774	6.4
1988	**20**	4794	4797	3.0	4674	4686	12.3	4922	4912	9.9	4822	4830	8.2	4729	4729	0.3	4781	4781	0.3	4851	4855	4.1	4779	4775	3.8
1989	**21**	4791	4796	5.1	4677	4688	11.3	4908	4906	1.6	4819	4828	9.1	4729	4730	1.3	4779	4781	2.2	4848	4853	5.2	4777	4776	0.9
1990	**22**	4790	4796	5.8	4677	4686	9.5	4900	4902	2.5	4818	4826	8.1	4729	4731	2.3	4777	4781	3.9	4847	4851	3.8	4776	4776	-0.4
1991	**23**	4789	4795	5.6	4677	4684	7.4	4900	4899	0.9	4817	4824	6.6	4729	4730	1.2	4776	4781	5.0	4847	4850	2.7	4775	4777	-2.4
1992	**24**	4788	4796	7.5	4677	4683	6.3	4897	4898	0.9	4817	4824	7.5	4729	4730	1.2	4775	4781	5.9	4846	4850	3.6	4774	4778	-4.2
1993	**25**	4790	4795	4.8	4677	4682	5.4	4896	4897	1.1	4816	4822	5.5	4729	4730	1.2	4775	4781	6.3	4846	4851	5.0	4773	4778	-4.5
1994	**26**	4792	4796	4.3	4676	4677	1.4	4896	4901	5.2	4817	4822	5.3	4729	4730	1.2	4775	4781	6.5	4846	4849	2.8	4773	4779	-5.6
1995	**27**	4791	4794	2.7	4674	4680	6.0	4895	4900	4.6	4817	4821	3.7	4729	4730	1.1	4774	4780	5.7	4848	4849	1.5	4773	4779	-5.8
1996	**28**	4788	4795	7.1	4673	4676	3.0	4897	4906	8.5	4818	4821	3.3	4729	4730	1.0	4774	4779	4.9	4849	4849	0.3	4773	4779	-6.1
1997	**29**	4791	4795	3.8	4673	4673	0.3	4905	4905	0.1	4821	4821	0.1	4729	4730	0.9	4775	4780	4.5	4854	4853	1.0	4774	4779	-5.3
1998	**30**	4792	4796	4.1	4673	4672	0.5	4912	4906	6.4	4823	4822	0.8	4729	4731	1.8	4777	4781	4.2	4857	4854	2.7	4775	4779	-4.4
1999	**31**	4792	4797	5.1	4672	4674	2.2	4912	4913	1.0	4822	4824	1.6	4729	4730	0.7	4777	4782	4.9	4855	4854	1.1	4775	4780	-5.0
2000	**32**	4796	4797	0.8	4672	4674	2.4	4909	4909	0.5	4822	4825	2.6	4729	4730	0.7	4777	4782	4.6	4853	4855	2.0	4776	4780	-4.3
2001	**33**	4796	4799	3.2	4672	4674	2.1	4904	4905	0.6	4820	4825	4.9	4729	4730	0.7	4777	4782	5.5	4849	4855	5.7	4775	4780	-4.7
2002	**34**	4795	4797	2.4	4672	4671	0.5	4901	4902	1.3	4818	4824	6.1	4729	4729	0.3	4775	4783	7.8	4847	4854	7.3	4774	4780	-5.8
2003	**35**	4794	4798	4.0	4671	4666	5.3	4902	4899	3.1	4817	4824	6.7	4729	4729	0.3	4775	4783	8.5	4846	4853	6.6	4773	4780	-6.5
2004	**36**	4792	4796	4.1	4671	4663	8.3	4905	4897	7.7	4817	4823	5.9	4729	4728	1.4	4774	4783	8.9	4847	4851	4.2	4773	4780	-7.2
2005	**37**	4790	4798	8.1	4666	4660	5.8	4906	4899	6.8	4817	4822	4.8	4729	4729	0.4	4774	4779	5.2	4848	4851	3.2	4772	4782	-9.9
2006	**38**	4790	4801	11.2	4660	4663	3.4	4901	4905	3.9	4817	4822	4.6	4729	4729	0.4	4773	4781	7.6	4848	4851	2.6	4772	4782	-10.3
2007	**39**	4789	4801	11.6	4659	4661	2.1	4894	4908	13.9	4817	4822	4.9	4729	4728	1.4	4773	4778	5.4	4848	4851	3.2	4771	4783	-11.7
Minimum		**4788**	**4785**	**0.2**	**4652**	**4656**	**0.3**	**4882**	**4896**	**0.1**	**4814**	**4811**	**0.1**	**4728**	**4721**	**0.0**	**4769**	**4763**	**0.0**	**4842**	**4843**	**0.2**	**4771**	**4767**	**-11.7**
Maximum		**4807**	**4801**	**14.1**	**4677**	**4688**	**16.3**	**4939**	**4921**	**22.6**	**4831**	**4831**	**9.1**	**4729**	**4731**	**7.0**	**4784**	**4783**	**8.9**	**4866**	**4861**	**8.6**	**4781**	**4783**	**10.2**
Average		**4794**	**4793**	**6.1**	**4669**	**4670**	**6.2**	**4902**	**4904**	**8.3**	**4819**	**4821**	**4.1**	**4729**	**4729**	**0.9**	**4775**	**4776**	**4.4**	**4849**	**4852**	**3.7**	**4775**	**4774**	**0.2**

* Residual is the absolute value of the difference between the simulated water-level elevation and the observed water-level elevation

Table G-5 continued. *Simulated versus observed water-level elevations for the 24 head observation locations, in feet.*

Year	TS	Well 879 water-level elevation (ft)			Well 880 water-level elevation (ft)			Well 883 water-level elevation (ft)			Well 884 water-level elevation (ft)			Well 1029 water-level elevation (ft)			Well 1031 water-level elevation (ft)			Well 1037 water-level elevation (ft)			Well 1040 water-level elevation (ft)		
		Simulated	Observed	Residual *	Simulated	Observed	Residual	Simulated	Observed	Residual	Simulated	Observed	Residual	Simulated	Observed	Residual	Simulated	Observed	Residual	Simulated	Observed	Residual	Simulated	Observed	Residual
1969	**1**	4898	4891	7.1	4887	4889	2.0	4689	4690	0.9	4682	4682	0.0	4741	4738	3.3	4772	4763	8.9	4898	4899	1.4	4825	4814	11.0
1970	**2**	4899	4900	1.0	4889	4892	2.7	4689	4690	0.7	4682	4682	0.1	4742	4738	4.1	4772	4763	9.1	4898	4899	0.5	4825	4816	9.1
1971	**3**	4899	4899	0.4	4886	4892	5.8	4689	4685	4.3	4682	4682	0.2	4742	4740	2.3	4772	4770	2.2	4898	4899	1.4	4824	4817	7.2
1972	**4**	4897	4897	0.4	4883	4890	6.7	4689	4690	0.9	4682	4682	0.2	4742	4739	3.2	4772	4770	2.0	4896	4895	1.1	4823	4818	5.3
1973	**5**	4895	4897	2.3	4880	4890	9.9	4689	4690	1.1	4682	4682	0.2	4741	4739	2.1	4771	4769	2.0	4895	4895	0.3	4823	4817	6.1
1974	**6**	4892	4901	9.4	4879	4893	14.5	4689	4690	1.4	4682	4682	0.0	4740	4737	3.3	4770	4765	5.4	4893	4898	4.5	4823	4817	5.9
1975	**7**	4888	4898	9.8	4877	4891	14.3	4688	4690	1.7	4682	4683	1.3	4740	4736	4.1	4770	4765	4.8	4892	4895	3.3	4822	4822	0.1
1976	**8**	4884	4903	19.1	4873	4893	19.5	4688	4690	2.1	4682	4683	1.5	4739	4737	2.4	4769	4767	1.8	4889	4898	8.7	4821	4818	3.1
1977	**9**	4885	4899	14.3	4882	4893	11.1	4688	4690	1.9	4682	4683	1.2	4739	4735	4.3	4769	4766	3.4	4891	4897	5.6	4823	4819	3.6
1978	**10**	4886	4898	12.5	4883	4890	7.4	4688	4692	3.9	4682	4683	1.2	4739	4737	2.3	4770	4768	1.9	4893	4894	1.2	4823	4820	2.8
1979	**11**	4885	4897	11.5	4881	4892	10.7	4688	4691	2.9	4682	4683	1.4	4739	4736	2.8	4769	4769	0.5	4893	4897	4.1	4822	4820	2.1
1980	**12**	4889	4899	9.6	4889	4893	3.6	4688	4690	1.5	4682	4683	1.3	4739	4736	2.5	4769	4770	0.5	4896	4899	3.2	4823	4820	3.4
1981	**13**	4896	4904	7.8	4898	4894	4.2	4689	4689	0.2	4682	4683	0.7	4739	4736	3.1	4771	4767	3.7	4901	4900	0.8	4826	4821	5.0
1982	**14**	4909	4898	11.1	4914	4892	22.1	4691	4691	0.1	4684	4683	1.0	4741	4737	3.8	4774	4771	3.2	4908	4896	11.6	4830	4822	7.9
1983	**15**	4922	4901	20.9	4922	4894	28.2	4692	4691	1.4	4685	4683	2.4	4743	4738	5.3	4779	4773	5.9	4913	4899	14.4	4835	4823	11.9
1984	**16**	4927	4916	11.3	4916	4898	17.5	4693	4691	2.0	4686	4683	2.7	4746	4738	8.0	4782	4775	7.1	4914	4911	3.0	4837	4831	6.1
1985	**17**	4931	4973	41.8	4913	4900	13.4	4694	4691	2.5	4686	4684	1.9	4748	4737	11.3	4784	4777	7.1	4913	4915	2.0	4837	4839	2.0
1986	**18**	4933	4965	32.5	4908	4905	3.0	4694	4689	4.8	4686	4684	2.1	4749	4740	9.4	4785	4778	6.9	4911	4913	1.9	4836	4841	5.4
1987	**19**	4927	4929	1.8	4893	4907	14.2	4693	4692	1.4	4686	4684	2.1	4749	4742	7.4	4784	4779	4.9	4906	4913	7.0	4831	4840	8.5
1988	**20**	4918	4917	0.9	4882	4900	18.4	4693	4692	0.7	4686	4685	0.9	4749	4743	5.7	4782	4780	1.9	4900	4907	6.7	4828	4839	10.9
1989	**21**	4908	4909	0.6	4876	4896	19.5	4692	4692	0.0	4686	4686	0.3	4747	4743	4.4	4779	4780	0.6	4896	4902	6.2	4825	4836	10.6
1990	**22**	4903	4903	0.4	4881	4893	12.2	4692	4692	0.1	4686	4686	0.2	4746	4744	2.1	4777	4780	2.5	4895	4898	3.0	4825	4830	5.3
1991	**23**	4901	4898	2.9	4883	4890	6.6	4692	4692	0.3	4686	4685	0.8	4745	4745	0.3	4776	4779	2.5	4895	4895	0.1	4824	4828	3.7
1992	**24**	4899	4896	2.7	4883	4890	7.4	4692	4693	1.5	4686	4686	0.5	4745	4745	0.4	4776	4780	4.5	4895	4894	0.8	4823	4827	3.6
1993	**25**	4897	4893	4.4	4883	4890	7.0	4691	4692	0.7	4685	4685	0.3	4744	4746	1.9	4775	4779	4.0	4895	4893	1.7	4823	4826	2.7
1994	**26**	4897	4893	4.0	4884	4891	6.7	4691	4693	1.8	4685	4685	0.1	4744	4747	3.3	4775	4779	4.2	4895	4896	1.0	4823	4825	1.5
1995	**27**	4899	4894	4.8	4889	4890	1.1	4691	4693	1.7	4685	4686	1.0	4743	4746	2.8	4775	4778	3.4	4897	4895	2.1	4824	4825	0.8
1996	**28**	4902	4895	7.4	4895	4892	3.0	4692	4693	1.3	4685	4686	0.7	4743	4749	6.2	4774	4777	2.6	4901	4899	1.5	4825	4825	0.0
1997	**29**	4911	4897	13.8	4908	4892	15.9	4693	4693	0.4	4686	4686	0.1	4743	4750	6.8	4776	4778	2.2	4906	4898	8.0	4828	4826	2.3
1998	**30**	4918	4902	15.6	4910	4892	18.3	4693	4693	0.3	4686	4686	0.5	4744	4751	7.1	4777	4778	0.8	4909	4900	9.2	4830	4827	3.2
1999	**31**	4918	4903	15.4	4902	4894	8.4	4693	4694	0.6	4686	4686	0.4	4744	4752	8.0	4778	4779	1.4	4908	4905	3.1	4830	4832	2.2
2000	**32**	4916	4903	12.6	4895	4893	2.2	4693	4694	0.8	4686	4687	0.7	4744	4753	8.9	4778	4779	1.3	4906	4902	3.6	4829	4830	0.6
2001	**33**	4909	4907	1.9	4885	4892	7.5	4693	4693	0.4	4686	4686	0.0	4744	4753	9.2	4777	4780	3.2	4901	4898	2.9	4827	4829	2.0
2002	**34**	4902	4899	3.3	4880	4891	11.1	4692	4693	0.9	4686	4687	1.3	4743	4754	10.9	4775	4780	4.5	4897	4896	0.9	4825	4827	2.3
2003	**35**	4899	4895	4.1	4882	4889	7.1	4692	4693	1.2	4686	4687	1.4	4743	4755	12.5	4775	4781	6.2	4895	4894	1.3	4824	4826	1.9
2004	**36**	4901	4893	8.1	4889	4888	0.9	4692	4693	0.9	4686	4687	1.4	4742	4755	12.9	4774	4780	5.5	4897	4893	3.8	4824	4825	1.1
2005	**37**	4906	4895	11.1	4896	4889	7.0	4692	4693	0.5	4686	4687	1.3	4742	4756	14.3	4774	4780	5.7	4900	4893	7.2	4824	4824	0.2
2006	**38**	4909	4902	6.7	4896	4892	4.3	4693	4693	0.4	4686	4686	0.2	4741	4757	15.8	4774	4779	5.2	4902	4901	0.8	4825	4825	0.4
2007	**39**	4909	4900	8.8	4895	4892	2.8	4693	4693	0.3	4686	4687	1.0	4741	4759	18.4	4773	4779	6.0	4902	4900	2.1	4824	4825	0.5
Minimum		**4884**	**4891**	**0.4**	**4873**	**4888**	**0.9**	**4688**	**4685**	**0.0**	**4682**	**4682**	**0.0**	**4739**	**4735**	**0.3**	**4769**	**4763**	**0.5**	**4889**	**4893**	**0.1**	**4821**	**4814**	**0.0**
Maximum		**4933**	**4973**	**41.8**	**4922**	**4907**	**28.2**	**4694**	**4694**	**4.8**	**4686**	**4687**	**2.7**	**4749**	**4759**	**18.4**	**4785**	**4781**	**9.1**	**4914**	**4915**	**14.4**	**4837**	**4841**	**11.9**
Average		**4904**	**4904**	**9.1**	**4891**	**4893**	**9.7**	**4691**	**4692**	**1.3**	**4684**	**4685**	**0.9**	**4743**	**4744**	**6.1**	**4775**	**4775**	**3.8**	**4900**	**4899**	**3.6**	**4826**	**4825**	**4.2**

* Residual is the absolute value of the difference between the simulated water level elevation and the observed water level elevation

Table G-5 continued. *Simulated versus observed water-level elevations for the 24 head observation locations, in feet.*

Year	TS	Well 1041 water-level elevation (ft)			Well 1054 water-level elevation (ft)			Well 1118 water-level elevation (ft)			Well 1120 water-level elevation (ft)			Well 1121 water-level elevation (ft)			Well 1122 water-level elevation (ft)			Well 1123 water-level elevation (ft)			Well 1124 water-level elevation (ft)		
		Simulated	Observed	Residual *	Simulated	Observed	Residual	Simulated	Observed	Residual	Simulated	Observed	Residual	Simulated	Observed	Residual	Simulated	Observed	Residual	Simulated	Observed	Residual	Simulated	Observed	Residual
1969	**1**	4728	4711	16.6	4675	4676	0.9	4768	4762	5.7	4775	4756	18.6	4797	4792	4.6	4760	4739	21.5	4783	4779	4.3	4744	4746	2.0
1970	**2**	4728	4714	13.7	4675	4676	0.7	4768	4763	4.9	4775	4759	15.8	4797	4795	1.9	4761	4749	11.6	4784	4782	1.6	4746	4747	0.6
1971	**3**	4728	4715	12.7	4675	4676	0.7	4768	4762	6.0	4775	4764	11.0	4797	4798	0.6	4761	4754	6.7	4784	4787	3.1	4748	4748	0.4
1972	**4**	4728	4716	11.7	4675	4676	0.8	4768	4763	4.8	4775	4767	8.1	4797	4800	2.6	4761	4753	7.7	4784	4790	6.0	4748	4748	0.2
1973	**5**	4728	4718	9.5	4675	4676	0.9	4767	4763	3.8	4774	4770	4.2	4795	4802	6.7	4760	4757	3.0	4783	4792	9.3	4748	4748	0.3
1974	**6**	4727	4719	8.2	4675	4676	1.1	4766	4762	4.2	4773	4772	1.1	4797	4800	3.4	4759	4756	3.5	4782	4792	9.7	4748	4747	1.1
1975	**7**	4727	4720	6.7	4675	4676	1.3	4766	4762	3.7	4772	4774	2.1	4796	4804	7.7	4759	4757	1.8	4781	4794	12.7	4748	4748	0.1
1976	**8**	4726	4721	5.1	4674	4676	1.6	4765	4763	1.8	4771	4776	5.0	4796	4806	10.2	4758	4759	1.1	4780	4797	16.5	4747	4748	0.6
1977	**9**	4726	4722	3.6	4674	4676	1.6	4765	4761	4.3	4776	4778	2.0	4802	4806	4.1	4759	4760	1.3	4787	4797	10.3	4747	4748	0.6
1978	**10**	4725	4723	2.3	4674	4676	1.6	4766	4764	1.9	4781	4778	3.2	4805	4807	2.5	4760	4761	1.4	4792	4798	5.7	4747	4749	1.5
1979	**11**	4725	4723	1.9	4674	4676	1.6	4765	4764	1.4	4782	4778	3.6	4804	4807	2.6	4759	4762	2.6	4793	4798	5.4	4747	4749	1.6
1980	**12**	4725	4723	1.7	4675	4676	1.4	4765	4765	0.3	4782	4779	3.0	4805	4808	2.9	4759	4763	3.5	4793	4799	5.9	4747	4749	1.6
1981	**13**	4725	4723	1.8	4675	4676	1.0	4766	4766	0.4	4783	4781	2.5	4807	4809	1.6	4760	4765	4.6	4795	4801	6.1	4748	4750	2.2
1982	**14**	4726	4724	1.8	4676	4676	0.2	4770	4767	2.7	4787	4781	6.3	4813	4810	3.0	4763	4765	1.8	4800	4801	1.5	4752	4750	1.7
1983	**15**	4727	4725	2.4	4677	4676	1.4	4774	4768	6.2	4792	4782	10.3	4820	4811	9.1	4767	4766	1.0	4806	4802	3.5	4757	4751	6.4
1984	**16**	4729	4726	2.9	4678	4676	1.9	4777	4771	6.3	4796	4786	10.5	4825	4814	11.3	4770	4769	0.8	4810	4805	5.2	4761	4753	8.0
1985	**17**	4731	4730	0.5	4678	4676	2.4	4779	4772	7.2	4800	4791	8.6	4828	4816	12.5	4772	4771	0.9	4813	4809	4.4	4764	4754	9.6
1986	**18**	4732	4734	2.1	4679	4676	2.8	4780	4773	7.0	4801	4793	8.3	4830	4818	11.6	4773	4775	1.8	4815	4810	4.8	4765	4755	10.4
1987	**19**	4733	4737	4.1	4679	4676	2.7	4779	4774	5.0	4801	4796	4.8	4827	4819	8.4	4773	4777	4.1	4813	4812	1.5	4766	4756	10.3
1988	**20**	4733	4740	6.8	4678	4676	2.5	4777	4775	2.2	4799	4795	3.7	4823	4818	5.5	4772	4779	7.4	4811	4811	0.5	4766	4757	9.4
1989	**21**	4733	4741	8.0	4678	4676	2.1	4775	4775	0.1	4795	4794	1.5	4819	4816	2.6	4770	4778	8.4	4807	4810	3.5	4766	4758	7.9
1990	**22**	4732	4740	7.6	4678	4676	1.9	4773	4775	1.8	4793	4791	1.8	4815	4815	0.1	4768	4777	9.0	4803	4808	4.5	4765	4759	6.2
1991	**23**	4732	4739	7.2	4678	4676	1.8	4772	4775	2.9	4791	4789	2.1	4814	4813	0.7	4767	4776	9.1	4802	4806	4.1	4765	4759	5.7
1992	**24**	4731	4738	6.8	4678	4677	0.6	4771	4775	3.8	4790	4787	2.9	4812	4812	0.4	4766	4775	9.0	4801	4805	4.4	4764	4760	4.1
1993	**25**	4731	4737	6.4	4677	4676	1.4	4771	4775	4.2	4789	4784	5.0	4812	4810	1.5	4765	4773	7.6	4800	4803	3.3	4764	4760	3.6
1994	**26**	4730	4735	5.1	4677	4676	1.2	4771	4775	4.5	4788	4783	5.4	4811	4810	1.2	4765	4771	6.1	4799	4802	2.7	4763	4760	3.1
1995	**27**	4729	4734	4.7	4677	4677	0.2	4770	4775	4.7	4788	4782	6.2	4811	4809	2.2	4765	4771	6.4	4799	4801	1.8	4763	4760	2.8
1996	**28**	4729	4733	4.2	4677	4676	1.4	4770	4775	4.9	4788	4781	7.4	4812	4810	1.8	4764	4770	5.5	4800	4801	1.4	4763	4760	2.8
1997	**29**	4729	4732	3.1	4678	4677	1.1	4771	4775	3.7	4790	4781	9.1	4815	4811	3.7	4766	4770	4.4	4802	4802	0.2	4763	4760	3.4
1998	**30**	4729	4731	1.9	4679	4677	1.5	4773	4775	2.4	4792	4782	10.0	4818	4812	5.5	4767	4770	3.3	4804	4803	1.1	4764	4760	3.9
1999	**31**	4729	4732	2.7	4679	4677	1.7	4773	4775	2.1	4793	4783	9.7	4818	4814	4.2	4767	4771	4.0	4805	4804	0.9	4764	4761	3.1
2000	**32**	4729	4732	2.7	4679	4677	1.7	4773	4776	2.9	4793	4785	7.6	4818	4815	2.6	4767	4771	3.9	4805	4805	0.4	4764	4761	3.2
2001	**33**	4729	4733	3.8	4678	4677	1.4	4772	4776	3.7	4791	4786	5.5	4815	4816	0.5	4766	4772	5.7	4803	4807	4.1	4764	4761	2.9
2002	**34**	4729	4733	4.3	4678	4677	1.1	4771	4777	5.9	4790	4786	3.9	4813	4816	2.7	4765	4773	7.8	4801	4806	5.0	4763	4762	1.4
2003	**35**	4728	4732	3.8	4678	4677	0.9	4770	4777	6.6	4789	4785	3.9	4812	4815	2.5	4765	4772	7.5	4800	4806	5.8	4763	4762	0.9
2004	**36**	4728	4731	3.2	4678	4677	0.9	4770	4777	7.0	4789	4783	5.7	4813	4813	0.2	4764	4771	6.8	4800	4804	3.8	4763	4762	0.6
2005	**37**	4727	4730	2.5	4678	4677	1.1	4770	4777	7.3	4789	4781	7.9	4813	4811	2.3	4764	4770	5.9	4801	4802	1.5	4762	4762	0.2
2006	**38**	4727	4729	1.8	4678	4677	1.2	4769	4777	7.7	4788	4780	8.4	4813	4811	1.5	4764	4769	5.3	4800	4801	1.1	4762	4762	0.1
2007	**39**	4727	4728	1.0	4678	4677	1.3	4769	4776	7.5	4787	4781	6.3	4811	4811	0.4	4763	4768	5.0	4798	4801	2.5	4761	4762	0.6
Minimum		**4725**	**4711**	**0.5**	**4674**	**4676**	**0.2**	**4765**	**4761**	**0.1**	**4771**	**4756**	**1.1**	**4795**	**4792**	**0.1**	**4758**	**4739**	**0.8**	**4780**	**4779**	**0.2**	**4744**	**4746**	**0.1**
Maximum		**4733**	**4741**	**16.6**	**4679**	**4677**	**2.8**	**4780**	**4777**	**7.7**	**4801**	**4796**	**18.6**	**4830**	**4819**	**12.5**	**4773**	**4779**	**21.5**	**4815**	**4812**	**16.5**	**4766**	**4762**	**10.4**
Average		**4729**	**4728**	**5.1**	**4677**	**4676**	**1.4**	**4771**	**4771**	**4.2**	**4787**	**4781**	**6.2**	**4811**	**4810**	**3.8**	**4764**	**4767**	**5.4**	**4798**	**4801**	**4.4**	**4758**	**4755**	**3.2**

* Residual is the absolute value of the difference between the simulated water level elevation and the observed water level elevation

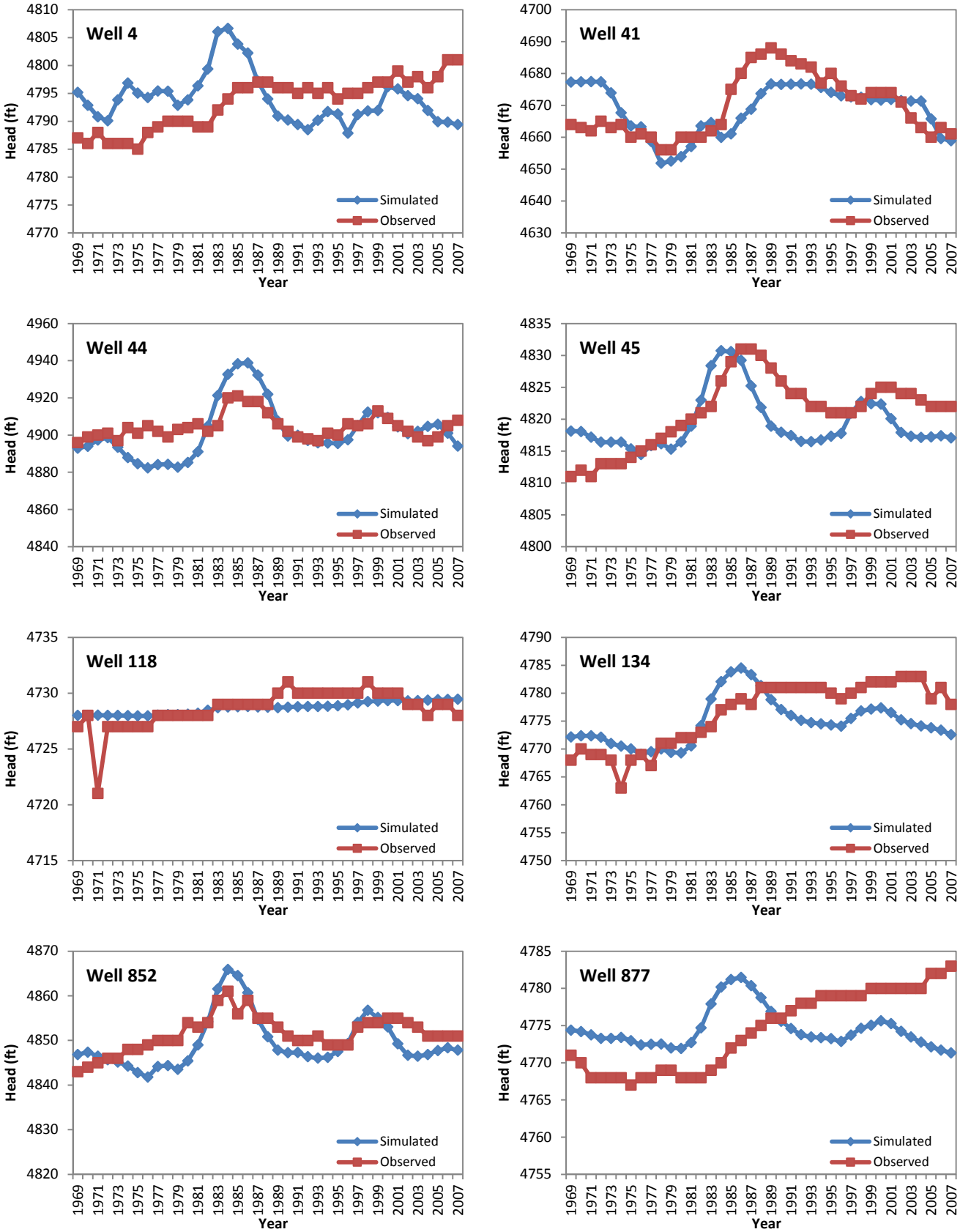


Figure G-1. *Hydrographs of simulated versus observed heads over time for 24 observation wells for the calibrated transient model.*

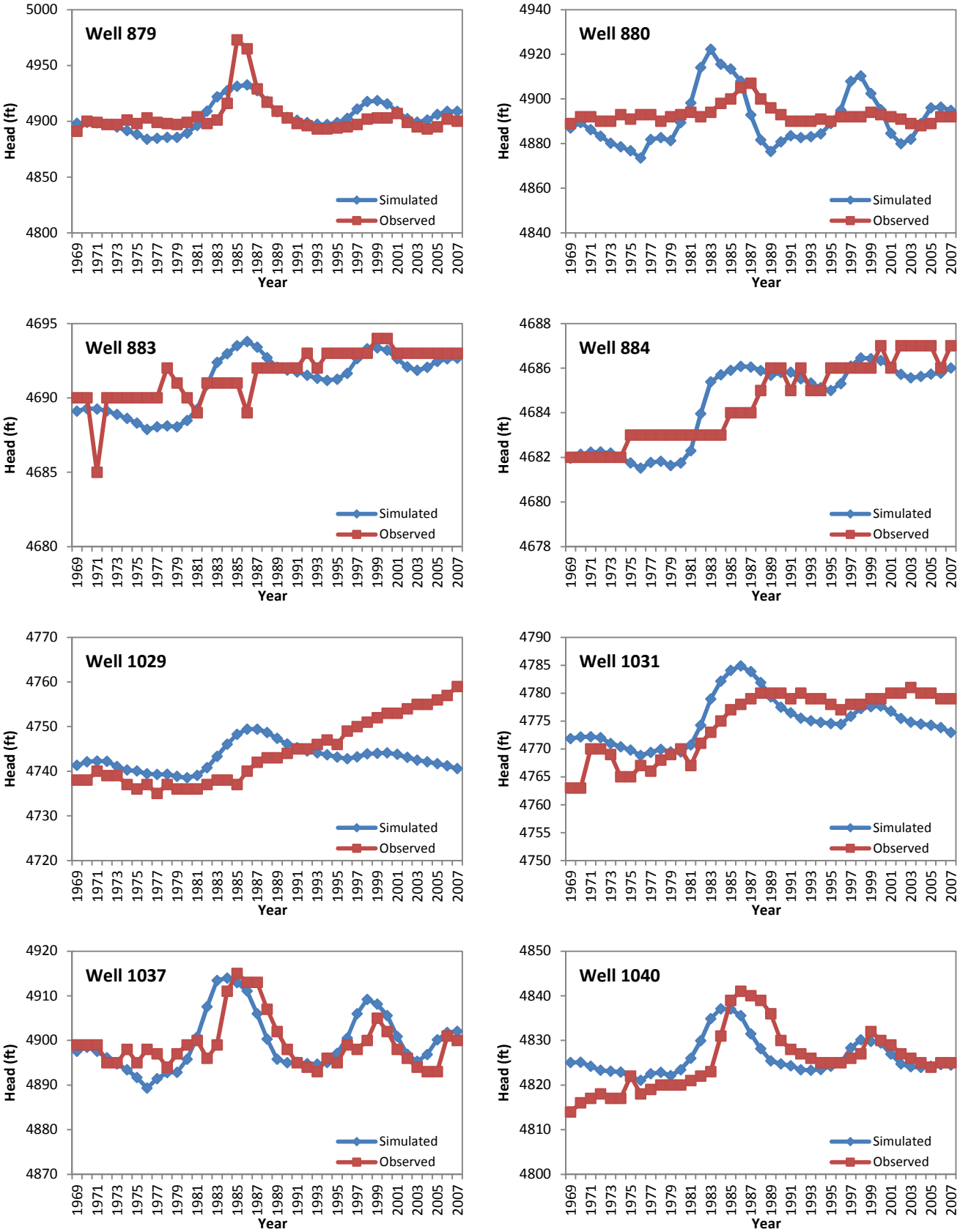


Figure G-1 continued. *Hydrographs of simulated versus observed heads over time for 24 observation wells for the calibrated transient model.*

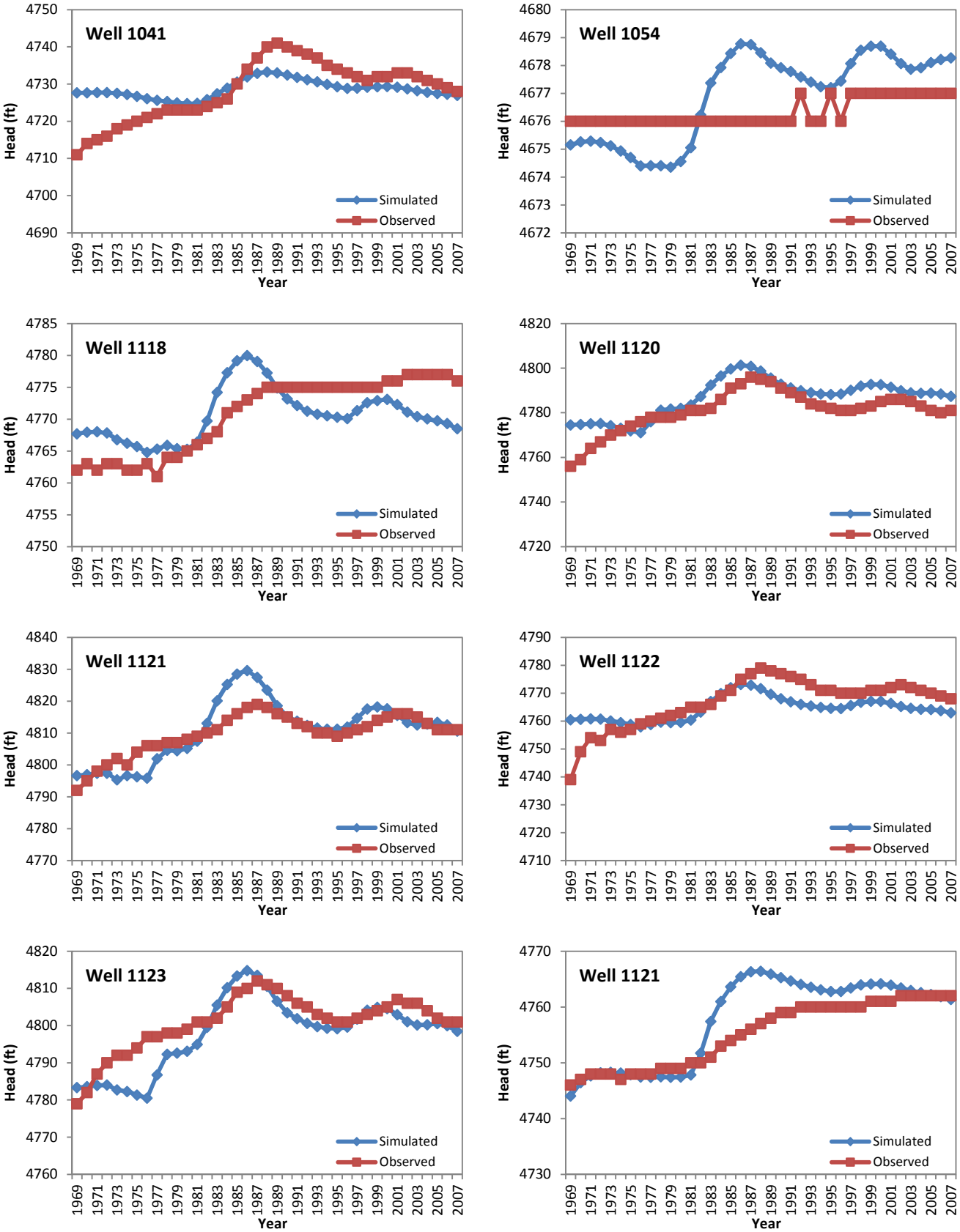


Figure G-1 continued. *Hydrographs of simulated versus observed heads over time for 24 observation wells for the calibrated transient model.*

Table G-6. *Statistical error analysis of head and flow for calibrated steady-state (SS) and transient groundwater flow models.*

		Head (ft)			Spring discharge (acre-ft/yr)		
Year	**Timestep**	**Mean error**	**Mean absolute error**	**Root mean squared error**	**Error**	**Absolute error**	**Root mean squared error**
SS		2.4	5.8	7.8	-220	220	220
1969	1	5.5	6.4	8.6	-86	86	86
1970	2	4.1	5.0	6.9	513	513	513
1971	3	3.3	4.6	6.0	-668	668	668
1972	4	2.3	3.9	5.2	-494	494	494
1973	5	1.2	4.1	5.2	-337	337	337
1974	6	0.0	5.3	6.8	-161	161	161
1975	7	-1.3	5.0	6.7	-76	76	76
1976	8	-3.7	6.0	8.9	18	18	18
1977	9	-1.9	4.7	6.4	1200	1200	1200
1978	10	-1.7	3.7	5.1	727	727	727
1979	11	-2.5	4.1	5.9	-308	308	308
1980	12	-2.3	3.9	5.5	-232	232	232
1981	13	-0.6	3.4	4.7	316	316	316
1982	14	4.2	4.5	6.7	-157	157	157
1983	15	7.8	7.8	10.3	969	969	969
1984	16	6.3	6.6	7.9	546	546	546
1985	17	3.0	8.0	11.7	-1054	1054	1054
1986	18	2.3	7.2	10.1	-946	946	946
1987	19	0.5	5.7	7.2	-1662	1662	1662
1988	20	-1.3	5.2	6.9	-835	835	835
1989	21	-3.0	4.7	6.6	-217	217	217
1990	22	-2.9	4.0	5.1	56	56	56
1991	23	-2.2	3.4	4.3	190	190	190
1992	24	-2.8	3.8	4.6	-86	86	86
1993	25	-2.2	3.7	4.3	-111	111	111
1994	26	-2.3	3.5	4.0	-440	440	440
1995	27	-1.7	3.2	3.8	7	7	7
1996	28	-1.5	3.6	4.4	323	323	323
1997	29	0.9	3.9	5.7	539	539	539
1998	30	2.1	4.6	6.5	1	1	1
1999	31	0.3	3.7	5.1	1530	1530	1530
2000	32	-0.2	3.1	4.2	570	570	570
2001	33	-2.2	3.4	4.1	773	773	773
2002	34	-3.2	4.1	5.2	153	153	153
2003	35	-2.9	4.5	5.4	147	147	147
2004	36	-1.5	4.8	5.9	-190	190	190
2005	37	-0.7	5.2	6.5	336	336	336
2006	38	-2.3	4.9	6.5	300	300	300
2007	39	-3.1	5.8	7.8	485	485	485
Minimum		**-3.7**	**3.1**	**3.8**	**-1662**	**1**	**1**
Maximum		**7.8**	**8.0**	**11.7**	**1530**	**1662**	**1662**
Average		**-0.1**	**4.7**	**6.3**	**36**	**449**	**449**

Table G-7. *Simulated volume from and to aquifer storage, in acre-feet.*

Year	Basin fill (Layer 1)			Bedrock (Layer 2)			Total (basin fill and bedrock)		
	From storage	To storage	Net[1]	From storage	To storage	Net[1]	From storage	To storage	Net[1]
1969	0	0	**0**	0	0	**0**	0	0	**0**
1970	23	973	**950**	2	1523	**1521**	25	2496	**2472**
1971	705	378	**-326**	1640	39	**-1601**	2344	417	**-1928**
1972	1313	141	**-1172**	1859	6	**-1853**	3172	148	**-3025**
1973	2496	37	**-2459**	3012	3	**-3008**	5507	40	**-5467**
1974	2543	18	**-2525**	2247	3	**-2244**	4790	21	**-4770**
1975	2521	0	**-2521**	2152	0	**-2151**	4673	1	**-4672**
1976	2881	12	**-2869**	3577	0	**-3577**	6457	12	**-6446**
1977	349	2240	**1891**	266	4902	**4636**	616	7142	**6526**
1978	353	728	**375**	276	794	**518**	630	1522	**893**
1979	786	35	**-750**	783	54	**-729**	1568	89	**-1479**
1980	223	3157	**2934**	203	5747	**5545**	426	8905	**8479**
1981	41	5116	**5075**	62	6507	**6445**	104	11,623	**11,520**
1982	0	9858	**9858**	3	12,579	**12,576**	3	22,437	**22,434**
1983	0	9466	**9466**	0	8507	**8506**	0	17,973	**17,973**
1984	456	4864	**4408**	2974	1962	**-1012**	3430	6826	**3396**
1985	180	3159	**2979**	387	1408	**1021**	568	4567	**3999**
1986	697	1514	**817**	1865	706	**-1159**	2562	2220	**-342**
1987	4503	511	**-3992**	8759	234	**-8525**	13,262	745	**-12517**
1988	6374	188	**-6186**	9378	103	**-9274**	15,752	292	**-15460**
1989	6389	15	**-6374**	6586	27	**-6559**	12,975	41	**-12934**
1990	3111	492	**-2619**	1492	1800	**308**	4602	2292	**-2310**
1991	1488	382	**-1106**	691	1016	**325**	2179	1398	**-780**
1992	1933	28	**-1905**	1324	34	**-1290**	3257	62	**-3195**
1993	1279	76	**-1203**	551	208	**-343**	1831	284	**-1547**
1994	921	208	**-713**	511	701	**189**	1433	909	**-524**
1995	579	1285	**707**	423	2825	**2402**	1002	4110	**3109**
1996	367	2736	**2369**	240	4161	**3922**	607	6897	**6291**
1997	49	6242	**6193**	73	9013	**8941**	121	15,255	**15,133**
1998	33	4341	**4308**	25	3637	**3612**	58	7978	**7920**
1999	892	905	**13**	3563	553	**-3010**	4454	1458	**-2997**
2000	1848	197	**-1651**	4186	120	**-4066**	6034	317	**-5717**
2001	4660	29	**-4631**	7408	94	**-7314**	12,068	123	**-11945**
2002	4427	1	**-4426**	4624	11	**-4613**	9051	12	**-9039**
2003	2003	287	**-1716**	1056	1066	**10**	3059	1353	**-1706**
2004	683	1609	**926**	170	4959	**4789**	853	6568	**5716**
2005	371	2260	**1890**	105	5646	**5541**	476	7906	**7430**
2006	694	981	**287**	452	1133	**682**	1146	2114	**968**
2007	1118	394	**-723**	1107	322	**-785**	2224	716	**-1509**
Minimum	**0**	**0**	**-6374**	**0**	**0**	**-9274**	**0**	**0**	**-15460**
Maximum	**6389**	**9858**	**9858**	**9378**	**12,579**	**12,576**	**15,752**	**22,437**	**22,434**
39-yr Average	**1520**	**1663**	**143**	**1898**	**2113**	**215**	**3418**	**3776**	**358**
Total	**59,287**	**64,864**	**5577**	**74,030**	**82,403**	**8373**	**133,317**	**147,268**	**13,951**

[1] *Net volume of storage is the difference between volume put into storage and volume released from storage.*
Positive values indicate that water is put into storage, and negative values indicates that water is released from storage.

Table G-8. *Summary of simulated flow budget for the steady-state model and the last time step of the transient model.*

Flow Budget for Layer 1 (Steady State Model; 1969)		
IN:	**ft^3/day**	**acre-ft/yr**
Storage	NA	NA
Constant heads	0	0
Drains	0	0
Wells	0	0
Recharge	141,007	1182
Evapotranspiration	0	0
Layer 2 to Layer 1	2,229,023	18,678
Total IN	**2,370,029**	**19,859**
OUT:	**ft^3/day**	**acre-ft/yr**
Storage	NA	NA
Constant heads	0	0
Drains	422,321	3539
Wells	296,882	2488
Recharge	0	0
Evapotranspiration	324,252	2717
Layer 1 to Layer 2	1,326,572	11,116
Total OUT	**2,370,027**	**19,859**

Flow Budget for Layer 1 (Transient Model; 2007; Time Step 39)		
IN:	**ft^3/day**	**acre-ft/yr**
Storage	133,390	1118
Constant heads	0	0
Drains	0	0
Wells	0	0
Recharge	117,340	983
Evapotranspiration	0	0
Layer 2 to Layer 1	2,510,851	21,039
Total IN	**2,761,581**	**23,140**
OUT:	**ft^3/day**	**acre-ft/yr**
Storage	47,047	394
Constant heads	0	0
Drains	473,776	3970
Wells	500,491	4194
Recharge	0	0
Evapotranspiration	367,669	3081
Layer 1 to Layer 2	1,372,611	11,501
Total OUT	**2,761,593**	**23,140**

Flow Budget for Layer 2 (Steady State Model; 1969)		
IN:	**ft^3/day**	**acre-ft/yr**
Storage	NA	NA
Constant heads	0	0
Drains	0	0
Wells	2,739,022	22,951
Recharge	0	0
Evapotranspiration	0	0
Layer 1 to Layer 2	1,326,572	11,116
Total IN	**4,065,593**	**34,067**
OUT:	**ft^3/day**	**acre-ft/yr**
Storage	NA	NA
Constant heads	0	0
Drains	1,836,569	15,389
Wells	0	0
Recharge	0	0
Evapotranspiration	0	0
Layer 2 to Layer 1	2,229,023	18,678
Total OUT	**4,065,592**	**34,067**

Flow Budget for Layer 2 (Transient Model; 2007; Time Step 39)		
IN:	**ft^3/day**	**acre-ft/yr**
Storage	132,078	1107
Constant heads	0	0
Drains	0	0
Wells	2,986,895	25,028
Recharge	0	0
Evapotranspiration	0	0
Layer 1 to Layer 2	1,372,611	11,501
Total IN	**4,491,584**	**37,636**
OUT:	**ft^3/day**	**acre-ft/yr**
Storage	38,383	322
Constant heads	0	0
Drains	1,668,504	13,981
Wells	273,845	2295
Recharge	0	0
Evapotranspiration	0	0
Layer 2 to Layer 1	2,510,851	21,039
Total OUT	**4,491,582**	**37,636**

Flow Budget for Layers 1 and 2 (Steady State Model; 1969)		
IN:	**ft^3/day**	**acre-ft/yr**
Storage	NA	NA
Constant heads	0	0
Drains	0	0
Wells	2,739,022	22,951
Recharge	141,007	1182
Evapotranspiration	0	0
Layer 2 to Layer 1		
Total IN	**2,880,028**	**24,132**
OUT:	**ft^3/day**	**acre-ft/yr**
Storage	NA	NA
Constant heads	0	0
Drains	2,258,890	18,928
Wells	296,882	2488
Recharge	0	0
Evapotranspiration	324,252	2717
Layer 1 to Layer 2		
Total OUT	**2,880,025**	**24,132**

Flow Budget for Layers 1 and 2 (Transient Model; 2007; Time Step 39)		
IN:	**ft^3/day**	**acre-ft/yr**
Storage	265,468	2224
Constant heads	0	0
Drains	0	0
Wells	2,986,895	25,028
Recharge	117,340	983
Evapotranspiration	0	0
Layer 1 to Layer 2		0
Total IN	**3,369,703**	**28,236**
OUT:	**ft^3/day**	**acre-ft/yr**
Storage	85,429	716
Constant heads	0	0
Drains	2,142,280	17,951
Wells	774,336	6488
Recharge	0	0
Evapotranspiration	367,669	3081
Layer 2 to Layer 1		0
Total OUT	**3,369,714**	**28,236**

Interflow between model layers	acre-ft/yr
Steady state net flow from layer 2 to layer 1	**7562**
Transient (2007) net flow from layer 2 to layer 1	**9538**

Storage component	acre-ft/yr
Net flow from storage into layer 1	**723**
Net flow from storage into layer 2	**785**
Net flow from storage into both model layers	**1508**

Table G-9. *Projected water-level elevations at six selected observation wells for eight projection scenarios, in feet.*

Year	Simulated head at observation well 4								Simulated head at observation well 44								Simulated head at observation well 134							
	S1	S2	S3	S4	S5	S6	S7	S8	S1	S2	S3	S4	S5	S6	S7	S8	S1	S2	S3	S4	S5	S6	S7	S8
2007	4791	4791	4791	4791	4791	4791	4791	4791	4659	4659	4659	4659	4659	4659	4659	4659	4776	4776	4776	4776	4776	4776	4776	4776
2008	4790	4788	4786	4789	4790	4790	4788	4788	4658	4656	4654	4656	4657	4656	4656	4656	4775	4774	4774	4768	4774	4769	4774	4774
2009	4789	4784	4780	4785	4788	4787	4784	4784	4657	4652	4648	4653	4655	4653	4652	4652	4773	4772	4770	4757	4772	4759	4772	4772
2010	4788	4783	4778	4782	4786	4784	4783	4783	4656	4651	4645	4652	4653	4651	4651	4651	4772	4770	4767	4752	4770	4753	4770	4770
2011	4787	4781	4776	4779	4785	4781	4781	4781	4656	4650	4644	4650	4652	4649	4650	4650	4771	4768	4765	4748	4768	4749	4768	4768
2012	4786	4780	4774	4777	4783	4779	4780	4780	4655	4649	4642	4649	4651	4648	4649	4649	4770	4766	4763	4745	4766	4746	4766	4766
2013	4785	4779	4779	4775	4782	4777	4779	4779	4655	4648	4641	4648	4650	4647	4648	4648	4769	4765	4761	4743	4764	4744	4765	4765
2014	4784	4778	4771	4774	4781	4775	4778	4778	4655	4648	4640	4647	4650	4646	4648	4648	4768	4764	4759	4741	4763	4741	4764	4764
2015	4784	4777	4770	4773	4780	4773	4777	4777	4655	4647	4640	4647	4649	4645	4647	4647	4767	4763	4758	4740	4761	4739	4763	4763
2016	4783	4776	4769	4772	4779	4772	4776	4776	4654	4647	4639	4646	4648	4644	4647	4647	4767	4762	4756	4739	4760	4738	4762	4762
2017	4783	4776	4768	4771	4778	4771	4776	4776	4654	4646	4638	4645	4648	4643	4646	4646	4766	4761	4755	4737	4759	4736	4761	4761
2018	4783	4775	4767	4770	4777	4770	4775	4775	4654	4646	4638	4645	4647	4642	4646	4646	4766	4760	4754	4737	4758	4735	4760	4760
2019	4782	4775	4766	4770	4776	4769	4774	4774	4654	4646	4637	4645	4647	4642	4646	4646	4766	4760	4753	4736	4757	4734	4760	4759
2020	4782	4774	4766	4769	4776	4768	4774	4773	4654	4645	4637	4644	4646	4641	4645	4645	4765	4759	4753	4735	4756	4733	4759	4758
2021	4782	4774	4765	4769	4775	4767	4773	4772	4654	4645	4636	4644	4646	4641	4645	4645	4765	4759	4752	4735	4756	4732	4758	4757
2022	4782	4773	4765	4768	4774	4766	4772	4771	4653	4645	4636	4644	4646	4640	4645	4644	4765	4758	4751	4734	4755	4731	4757	4756
2023	4782	4773	4764	4768	4774	4766	4771	4770	4653	4645	4636	4643	4645	4640	4644	4644	4765	4758	4751	4734	4754	4730	4756	4754
2024	4781	4773	4764	4767	4773	4765	4770	4768	4653	4644	4635	4643	4645	4639	4644	4644	4764	4757	4750	4733	4754	4729	4755	4753
2025	4781	4773	4764	4767	4773	4765	4769	4767	4653	4644	4635	4643	4645	4639	4643	4643	4764	4757	4750	4733	4753	4729	4754	4752
2026	4781	4772	4763	4767	4773	4764	4768	4766	4653	4644	4635	4643	4644	4639	4643	4643	4764	4757	4749	4732	4753	4728	4753	4751
2027	4781	4772	4763	4767	4772	4764	4768	4765	4653	4644	4634	4643	4644	4639	4643	4642	4764	4757	4749	4732	4752	4728	4752	4749
2028	4781	4772	4763	4767	4772	4764	4767	4764	4653	4644	4634	4643	4644	4638	4642	4642	4764	4756	4748	4732	4752	4727	4751	4748
2029	4781	4772	4762	4766	4772	4763	4767	4764	4653	4644	4634	4642	4644	4638	4642	4641	4764	4756	4748	4732	4751	4727	4751	4747
2030	4781	4772	4762	4766	4772	4763	4767	4763	4653	4643	4634	4642	4644	4638	4642	4641	4764	4756	4748	4732	4751	4726	4750	4747
2031	4781	4772	4762	4766	4771	4763	4767	4764	4653	4643	4634	4642	4643	4638	4642	4640	4764	4756	4747	4731	4751	4726	4750	4747
2032	4781	4772	4762	4766	4771	4762	4767	4764	4653	4643	4633	4642	4643	4637	4642	4640	4764	4756	4747	4731	4750	4726	4750	4747
2033	4781	4771	4761	4766	4771	4762	4767	4764	4653	4643	4633	4642	4643	4637	4641	4640	4764	4756	4747	4731	4750	4725	4751	4747
2034	4781	4771	4761	4766	4771	4762	4767	4765	4653	4643	4633	4642	4643	4637	4641	4640	4763	4755	4747	4731	4750	4725	4751	4748
2035	4781	4771	4761	4766	4770	4762	4768	4765	4653	4643	4633	4642	4643	4637	4641	4640	4763	4755	4746	4731	4750	4725	4751	4748
2036	4781	4771	4761	4766	4770	4762	4768	4765	4653	4643	4633	4642	4643	4637	4641	4640	4763	4755	4746	4731	4750	4725	4751	4748
2037	4781	4771	4761	4766	4770	4762	4768	4765	4653	4643	4633	4642	4643	4637	4641	4640	4763	4755	4746	4731	4750	4725	4751	4748
Drawdown	**10**	**20**	**30**	**25**	**21**	**29**	**23**	**26**	**6**	**16**	**26**	**17**	**16**	**22**	**18**	**19**	**12**	**21**	**30**	**45**	**26**	**51**	**24**	**28**

S1 through S8 indicate Scenario 1 through Scenario 8.

Drawdown was estimated at the end of the 30-year projection period by subtracting head in 2037 from head in 2007.

Yellow shading denotes water level at steady state, defined here as less than 1 ft of water-level change over 2 or more consecutive years.

Table G-9 continued. *Projected water-level elevations at six selected observation wells for eight projection scenarios, in feet.*

Year	Simulated head at observation well 880								Simulated head at observation well 883								Simulated head at observation well 1120							
	S1	S2	S3	S4	S5	S6	S7	S8	S1	S2	S3	S4	S5	S6	S7	S8	S1	S2	S3	S4	S5	S6	S7	S8
2007	4898	4898	4898	4898	4898	4898	4898	4898	4695	4695	4695	4695	4695	4695	4695	4695	4794	4794	4794	4794	4794	4794	4794	4794
2008	4894	4894	4894	4891	4894	4891	4894	4894	4695	4695	4695	4695	4695	4695	4695	4695	4792	4792	4791	4775	4792	4777	4792	4792
2009	4892	4892	4891	4885	4891	4885	4892	4892	4696	4696	4696	4696	4696	4696	4696	4696	4790	4789	4788	4751	4789	4755	4789	4789
2010	4890	4890	4889	4882	4888	4882	4890	4890	4696	4696	4696	4696	4696	4696	4696	4696	4789	4787	4785	4742	4786	4747	4787	4787
2011	4889	4889	4888	4881	4886	4879	4889	4889	4696	4696	4696	4696	4696	4696	4696	4696	4787	4784	4781	4738	4783	4742	4784	4784
2012	4888	4887	4887	4880	4885	4878	4887	4887	4696	4696	4696	4696	4696	4696	4696	4696	4786	4782	4779	4735	4781	4738	4782	4782
2013	4888	4887	4886	4879	4883	4876	4887	4887	4697	4697	4697	4696	4696	4696	4697	4697	4785	4781	4776	4732	4778	4735	4781	4781
2014	4887	4886	4885	4878	4882	4875	4886	4886	4697	4697	4697	4696	4697	4696	4697	4697	4784	4779	4774	4730	4776	4732	4779	4779
2015	4887	4885	4884	4877	4882	4874	4885	4885	4697	4697	4697	4697	4697	4696	4697	4697	4783	4778	4772	4729	4774	4729	4778	4778
2016	4886	4885	4884	4877	4881	4873	4885	4885	4697	4697	4697	4697	4697	4696	4697	4697	4782	4776	4771	4727	4772	4727	4776	4776
2017	4886	4885	4883	4876	4880	4873	4885	4885	4697	4697	4697	4697	4697	4696	4697	4697	4781	4775	4769	4726	4771	4725	4775	4775
2018	4886	4884	4883	4876	4880	4872	4884	4884	4697	4697	4697	4697	4697	4696	4697	4697	4781	4775	4768	4725	4770	4723	4775	4775
2019	4885	4884	4882	4876	4879	4871	4882	4881	4698	4697	4697	4697	4697	4696	4697	4697	4780	4774	4767	4724	4768	4722	4774	4774
2020	4885	4884	4882	4875	4879	4871	4879	4877	4698	4697	4697	4697	4697	4696	4697	4697	4780	4773	4766	4723	4767	4721	4772	4772
2021	4885	4883	4882	4875	4878	4871	4877	4874	4698	4698	4697	4697	4697	4696	4697	4697	4780	4772	4765	4722	4766	4719	4771	4770
2022	4885	4883	4881	4875	4878	4870	4876	4872	4698	4698	4697	4697	4697	4696	4697	4696	4779	4772	4764	4722	4765	4718	4770	4769
2023	4885	4883	4881	4875	4878	4870	4875	4870	4698	4698	4697	4697	4697	4696	4697	4696	4779	4771	4763	4721	4764	4717	4768	4767
2024	4885	4883	4881	4875	4877	4870	4874	4869	4698	4698	4697	4697	4697	4696	4696	4696	4779	4771	4763	4721	4764	4716	4767	4765
2025	4885	4883	4881	4874	4877	4869	4873	4868	4698	4698	4698	4697	4697	4696	4696	4695	4779	4771	4762	4720	4763	4716	4766	4763
2026	4885	4883	4881	4874	4877	4869	4872	4867	4698	4698	4698	4697	4697	4696	4696	4695	4778	4770	4761	4720	4762	4715	4765	4761
2027	4885	4883	4881	4874	4877	4869	4872	4866	4698	4698	4698	4697	4697	4696	4696	4695	4778	4770	4761	4719	4762	4714	4764	4760
2028	4885	4883	4880	4874	4877	4869	4871	4865	4698	4698	4698	4697	4697	4696	4696	4694	4778	4770	4760	4719	4761	4714	4763	4758
2029	4885	4883	4880	4874	4876	4868	4872	4867	4698	4698	4698	4697	4697	4696	4696	4694	4778	4769	4760	4719	4761	4713	4762	4757
2030	4884	4882	4880	4874	4876	4868	4875	4871	4698	4698	4698	4697	4697	4696	4696	4694	4778	4769	4760	4719	4760	4712	4761	4757
2031	4884	4882	4880	4874	4876	4868	4877	4873	4698	4698	4698	4697	4697	4696	4696	4694	4778	4769	4759	4718	4760	4712	4761	4756
2032	4884	4882	4880	4874	4876	4868	4878	4875	4698	4698	4698	4697	4697	4696	4696	4694	4778	4769	4759	4718	4759	4712	4761	4757
2033	4884	4882	4880	4874	4876	4868	4878	4876	4698	4698	4698	4697	4697	4696	4696	4694	4778	4769	4758	4718	4759	4711	4762	4757
2034	4884	4882	4880	4874	4876	4868	4879	4876	4698	4698	4698	4697	4697	4696	4696	4694	4778	4768	4758	4718	4759	4711	4762	4757
2035	4884	4882	4880	4874	4876	4868	4879	4877	4698	4698	4698	4697	4697	4696	4696	4694	4778	4768	4758	4718	4758	4711	4762	4758
2036	4884	4882	4880	4874	4876	4868	4880	4878	4698	4698	4698	4697	4697	4696	4696	4694	4778	4768	4758	4718	4758	4710	4763	4759
2037	4884	4882	4880	4874	4876	4868	4880	4878	4698	4698	4698	4697	4697	4696	4696	4694	4778	4768	4758	4718	4758	4710	4763	4759
Drawdown	**13**	**16**	**18**	**24**	**22**	**30**	**18**	**20**	**-4**	**-3**	**-3**	**-2**	**-2**	**-1**	**-1**	**0**	**16**	**26**	**36**	**76**	**36**	**84**	**31**	**35**

S1 through S8 indicate Scenario 1 through Scenario 8.

Drawdown was estimated at the end of the 30-year projection period by subtracting head in 2037 from head in 2007.

Yellow shading denotes water level at steady state, defined here as less than 1 ft of water-level change over 2 or more consecutive years.