Hydrology and Simulation of Ground-Water Flow in Kamas Valley, Summit County, Utah

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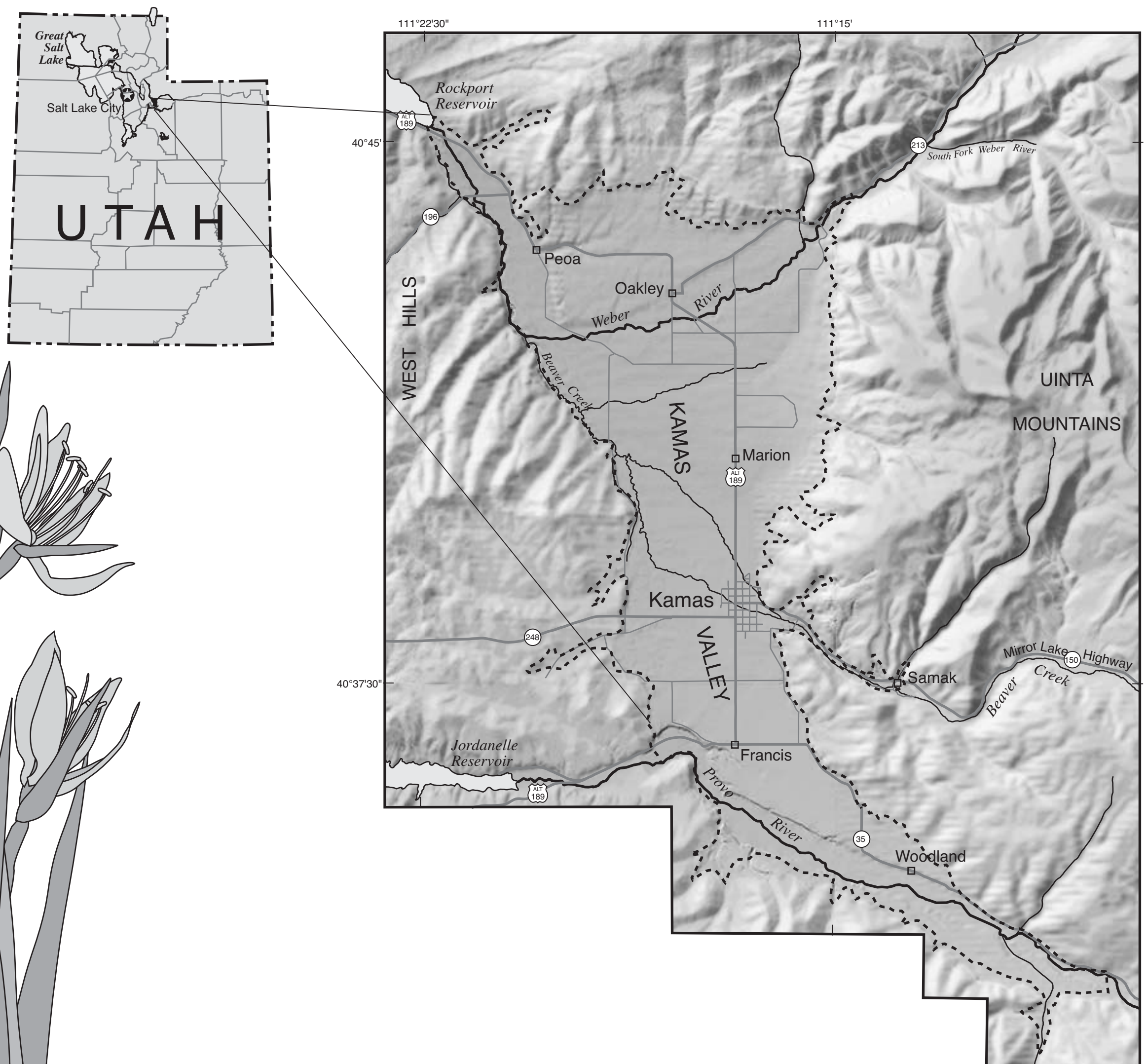

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HYDROLOGY AND SIMULATION OF GROUND-WATER FLOW IN KAMAS VALLEY, SUMMIT COUNTY, UTAH

By L.E. Brooks, B.J. Stolp, and L.E. Spangler

Prepared by the
United States Geological Survey
in cooperation with the
Utah Department of Natural Resources, Division of Water Rights;
Utah Department of Environmental Quality, Division of Water Quality;
Weber Basin Water Conservancy District;
Davis and Weber Counties Canal Company;
and Weber River Water Users Association

2003

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[Plate is in pocket]

TABLES

CONVERSION FACTORS, VERTICAL DATUM, AND ABBREVIATED WATER-QUALITY UNITS

Multiply	By	To obtain
acre	0.4047	square hectometer
	4,047	square meter
acre-foot (acre-ft)	0.0001233	cubic hectometer
	1,233	cubic meter
acre-foot per year (acre-ft/yr)	1,233	cubic meter per year
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
foot (ft)	0.3048	meter
foot per day (ft/d)	0.3048	meter per day
foot per year (ft/yr)	0.3048	meter per year
foot squared per day[1] (ft^2/d)	0.0929	meter squared per day
foot squared per day per foot squared ($ft^2/d/ft^2$)	1	meter squared per day per meter squared
gallon (gal)	3.785	liter
gallon per minute (gal/min)	0.06309	liter per second
inch (in.)	25.4	millimeter
mile (mi)	1.609	kilometer
square mile (mi^2)	259.0	hectare
	2.590	square kilometer

[1]An alternative way of expressing transmissivity is cubic foot per day per square foot times aquifer thickness, in feet [$ft^3/d/ft^2$]ft.

The unit cubic feet per second (ft^3/s) is used in this report and also can be expressed as 1 ft^3/s = 1.9835 acre-feet per day.

Water temperature is reported in degrees Celsius (°C), which can be converted to degrees Fahrenheit (°F) by using the following equation:

$$°F = 9/5(°C)+32.$$

Vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1929. Horizontal coordinate information is referenced to the North American Datum of 1927 (NAD 27).

Chemical concentration and water temperature are reported only in metric units. Chemical concentration in water is reported in milligrams per liter (mg/L) or micrograms per liter (µg/L), which express the solute mass per unit volume (liter) of water. One thousand micrograms per liter is equivalent to 1 milligram per liter. For concentrations less than 7,000 milligrams per liter, the numerical value is about the same as for concentrations in parts per million (ppm). Specific conductance is reported in microsiemens per centimeter at 25 degrees Celsius (µS/cm). Gross alpha and gross beta concentrations in water are reported as picocuries per liter (pCi/L).

Hydrology and Simulation of Ground-Water Flow in Kamas Valley, Summit County, Utah

By L.E. Brooks, B.J. Stolp, and L.E. Spangler

ABSTRACT

Kamas Valley, Utah, is located about 50 miles east of Salt Lake City and is undergoing residential development. The increasing number of wells and septic systems raised concerns of water managers and prompted this hydrologic study. About 350,000 acre-feet per year of surface water flows through Kamas Valley in the Weber River, Beaver Creek, and Provo River, which originate in the Uinta Mountains east of the study area. The ground-water system in this area consists of water in unconsolidated deposits and consolidated rock; water budgets indicate very little interaction between consolidated rock and unconsolidated deposits. Most recharge to consolidated rock occurs at higher altitudes in the mountains and discharges to streams and springs upgradient of Kamas Valley. About 38,000 acre-feet per year of water flows through the unconsolidated deposits in Kamas Valley. Most recharge is from irrigation and seepage from major streams; most discharge is to Beaver Creek in the middle part of the valley. Long-term water-level fluctuations range from about 3 to 17 feet. Seasonal fluctuations exceed 50 feet. Transmissivity varies over four orders of magnitude in both the unconsolidated deposits and consolidated rock and is typically 1,000 to 10,000 feet squared per day in unconsolidated deposits and 100 feet squared per day in consolidated rock as determined from specific capacity. Water samples collected from wells, streams, and springs had nitrate plus nitrite concentrations (as N) substantially less than 10 mg/L. Total and fecal coliform bacteria were detected in some surface-water samples and probably originate from livestock. Septic systems do not appear to be degrading water quality. A numerical ground-water flow model developed to test the conceptual understanding of the ground-water system adequately simulates water levels and flow in the unconsolidated deposits. Analyses of model fit and sensitivity were used to refine the conceptual and numerical models.

INTRODUCTION

Kamas Valley is located in north-central Utah in Summit County, about 50 mi east of Salt Lake City as shown in figure 1. The valley is surrounded on all sides by hills and mountains and is physiographically considered part of the Middle Rocky Mountain Province (Fenneman, 1931). Kamas Valley covers about 43 mi^2, has an average altitude of 6,500 ft, and contains the communities of Peoa, Oakley, Marion, Kamas, Francis, and Woodland. Surface water and ground water flow to the Weber and Provo Rivers. The Weber River flows across northern Kamas Valley, Beaver Creek flows northwestward across the central part of the valley and joins the Weber River, and the Provo River flows through the southern part of the valley.

Kamas Valley is undergoing residential development, in part the result of overflow from rapid growth in Park City and Snyderville Basin west of Kamas Valley. Consequently, land use is changing from alfalfa fields and pasture grass to ranchettes, large-lot subdivisions, and summer homes. Water needed to support new development is planned to come mainly from ground water, whereas agriculture has been and continues to be supported mainly from surface-water

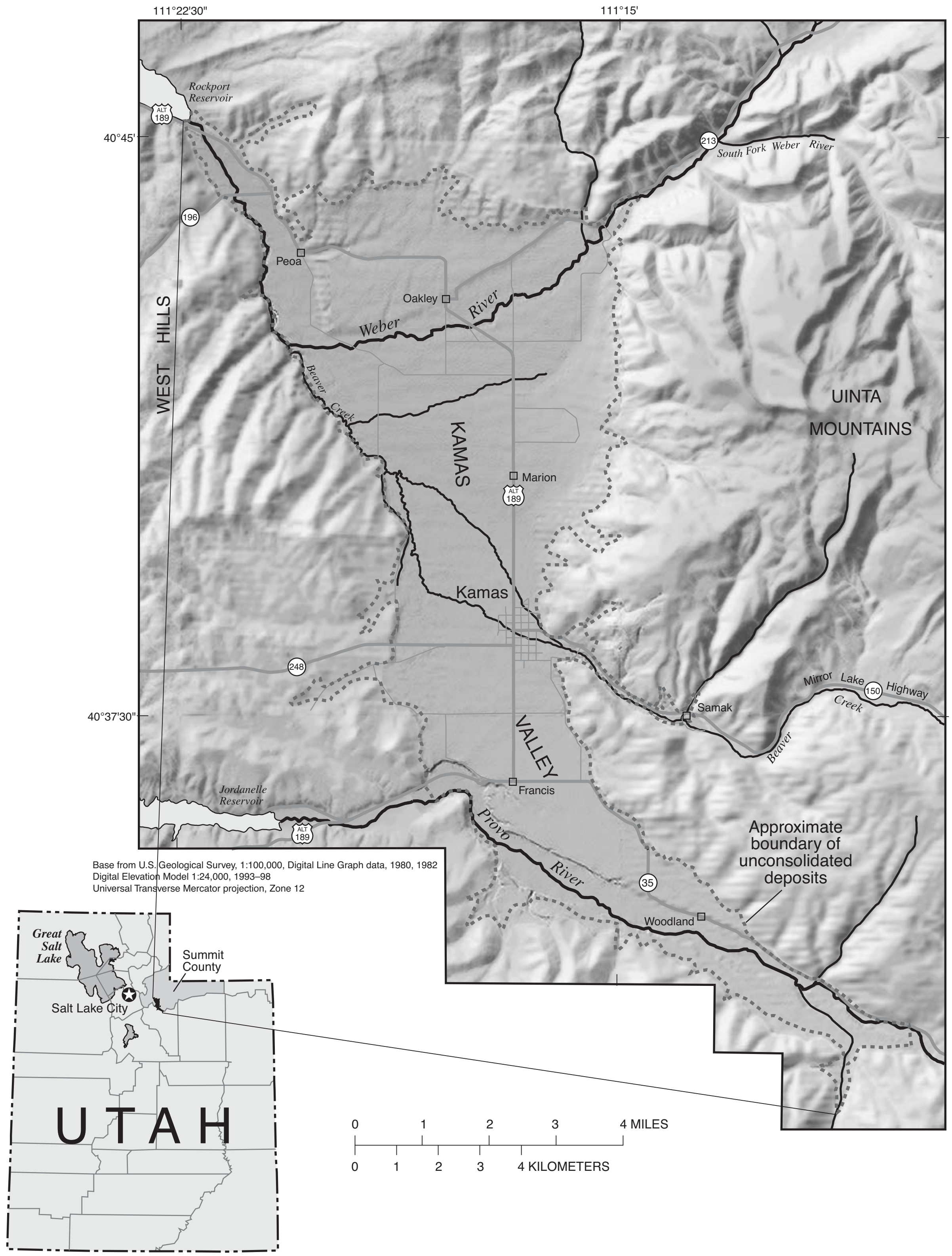


Figure 1. Location of Kamas Valley study area, Utah.

diversions out of local rivers and streams. Increased development has expanded the area and the number of domestic wells and septic systems in the valley. These activities raised concerns of local and State water managers and prompted a study to better characterize the hydrology of Kamas Valley. The U.S. Geological Survey, in cooperation with the Utah Department of Natural Resources, Division of Water Rights; Utah Department of Environmental Quality, Division of Water Quality; Weber Basin Water Conservancy District; Davis and Weber Counties Canal Company; and the Weber River Water Users Association, studied the hydrology of the area from 1997 to 2001. Specific issues that were investigated include recharge into, storage and movement within, and discharge from the unconsolidated deposits; aquifer characteristics of the unconsolidated deposits; the hydrologic connection between surface water and ground water; and water quality.

The purpose of the study was to better understand the water resources of Kamas Valley and the interaction between ground water and surface water. In Kamas Valley, this involved examination of aquifer characteristics, recharge amount and mechanisms, ground-water movement, discharge amount and mechanisms, and interaction of surface water and ground water. Monthly water levels were measured at a network of wells to better determine the sources and timing of ground-water recharge and discharge. A synoptic measurement of valley-wide water levels in monitoring wells was conducted in March and July of 1999 to define the direction of ground-water flow. A network of monthly flow-measurement sites was maintained to quantify ground-water discharge. Three separate seepage investigations were conducted to better identify areas and amounts of stream gains and losses. A baseline water-quality inventory also was conducted. Samples were collected from 63 surface- and ground-water sites and analyzed for major ions, trace metals, organic compounds, radionuclides, and fecal and total coliform bacteria. The location of selected hydrologic-data sites is shown on plate 1 and additional data sites are reported in Haraden and others (2001, pl. 1). The numbering system used for hydrologic-data sites in Utah is shown in figure 2.

The individual components of the Kamas Valley hydrologic system were compiled and synthesized into a numerical ground-water flow model. The model was used to increase conceptual understanding and determine the relative value of additional data-collection efforts. Integrated with this study, the Utah Geological Survey described the salient geologic features influencing ground-water occurrence and flow (Hurlow, 2002).

Purpose and Scope

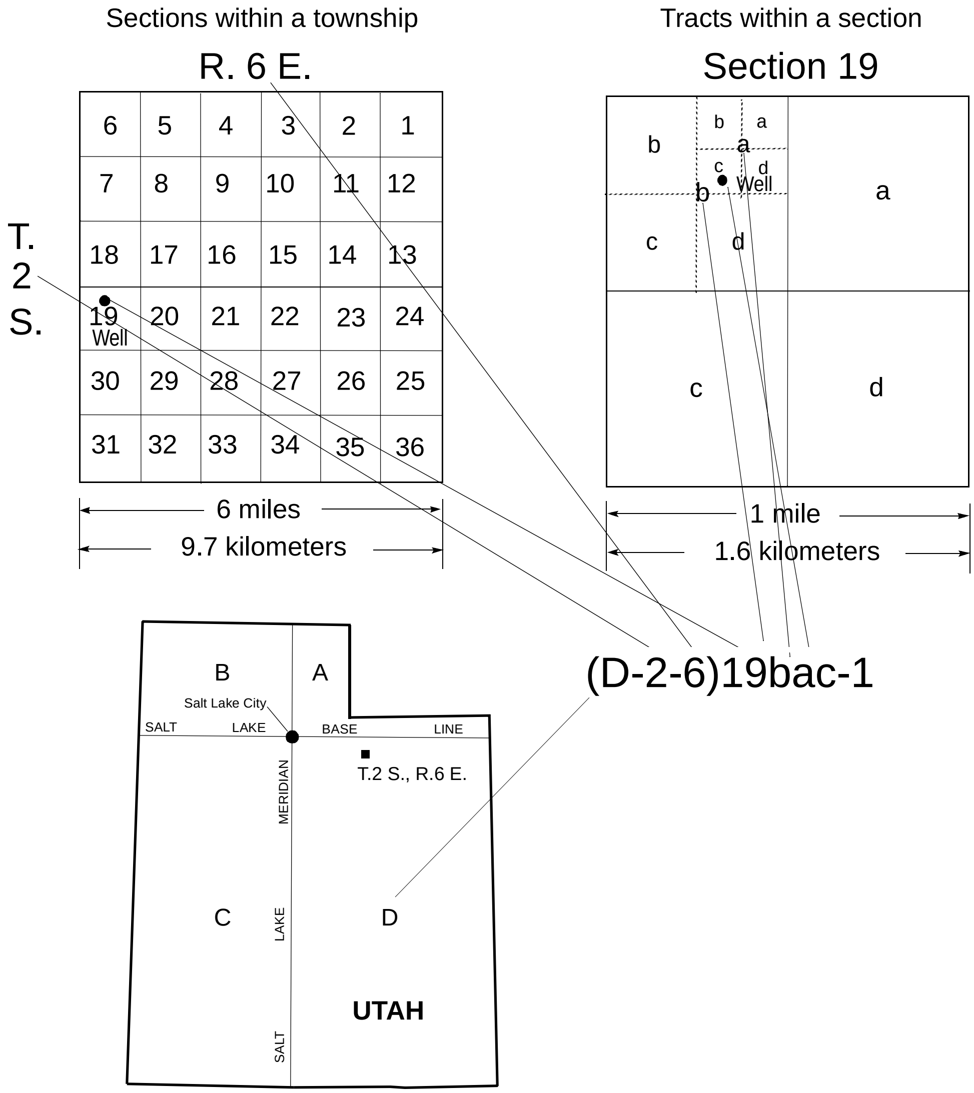
This report presents findings and results for the Kamas Valley hydrologic study. Included are a description of (1) surface-water resources, (2) areas and amounts of ground-water recharge and discharge, (3) ground-water levels and movement, and (4) aquifer characteristics. A summary of water quality is presented, a numerical computer model of the Kamas Valley ground-water system is described, and the results of simulating the conceptual ground-water budget are discussed.

Physiography and Geology

Kamas Valley is located between the Uinta Mountains on the east and the Wasatch Mountains on the west, in north-central Utah. Hoyt Peak, located directly to the east, rises to an altitude of 10,228 ft. The valley itself ranges in altitude from 7,500 ft along the eastern foothills to 6,000 ft near Rockport Reservoir. Eroded terraces step down from the valley surface to both the Weber and Provo Rivers. On the east side of the valley, alluvial fans and foothills gradually rise to meet the mountains. On the west, the mountains rise abruptly from the valley floor. A shallow topographic divide near Francis separates surface drainage between the Weber and Provo Rivers.

Kamas Valley is a depositional basin that is bounded on the west and east by normal faults (Hurlow, 2002, p. 1). The valley is filled with unconsolidated Quaternary-age deposits and Tertiary-age volcanics, and the surrounding consolidated rocks range in age from Proterozoic to Tertiary (Bryant, 1990). Unconsolidated deposits consist of alluvial- and debris-fan deposits (old and young), terrace gravels, alluvium, glacial outwash deposits, and landslide deposits. Delineations are shown on figure 3 and represent a generalization of work by Hurlow (2002, pl. 1). The unconsolidated deposits originate from the erosion of the surrounding mountains and are typically 200-300 ft thick. Near Marion, however, the unconsolidated

The system of numbering wells and springs in Utah is based on the cadastral land-survey system of the U.S. Government. The number, in addition to designating the well or spring, describes its position in the land net. The land-survey system divides the State into four quadrants separated by the Salt Lake Base Line and the Salt Lake Meridian. These quadrants are designated by the uppercase letters A, B, C, and D, indicating the northeast, northwest, southwest, and southeast quadrants, respectively. Numbers designating the township and range, in that order, follow the quadrant letter, and all three are enclosed in parentheses. The number after the parentheses indicates the section and is followed by three letters indicating the quarter section, the quarter-quarter section, and the quarter-quarter-quarter section—generally 10 acres for a regular section[1]. The lowercase letters a, b, c, and d indicate, respectively, the northeast, northwest, southwest, and southeast quarters of each subdivision. The number after the letters is the serial number of the well or spring within the 10-acre tract. When the serial number is not preceded by a letter, the number designates a well. When the serial number is preceded by an "S," the number designates a spring. A number having all three quarter designations but no serial number indicates a miscellaneous data site other than a well or spring, such as a location for a surface-water measurement site or tunnel portal. Thus, (D-2-6)19bac-1 designates the first well constructed or visited in the southwest 1/4 of the northeast 1/4 of the northwest 1/4 of section 19, T. 2 S., R. 6 E.



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[1]Although the basic land unit, the section, is theoretically 1 square mile, many sections are irregular in size and shape. Such sections are subdivided into 10-acre tracts, generally beginning at the southeast corner, and the surplus or shortage is taken up in the tracts along the north and west sides of the section.

Figure 2. Numbering system used for hydrologic-data sites in Utah.

deposits may be as much as to 1,100 ft thick (Hurlow, 2002, pl. 4). Excluding stream deposits, which are generally well sorted, the unconsolidated deposits are highly variable in composition (varying from boulders to clay) and sorting. Analysis of drillers' logs (Haraden and others, 2001, table 2) indicates little evidence of clay layers within the unconsolidated deposits. Lenses and layers of gravel, sand, silt, and clay are documented but do not appear continuous across even small areas. Tertiary-age Keetley Volcanics underlie most of the unconsolidated deposits and consist of andesitic to dacitic volcanic breccia, flow, tuff, and shallow intrusives (Bryant, 1990). The volcanics likely erupted from a source directly west of Kamas Valley in the West Hills (fig. 3).

Land Use and Irrigation

Most of Kamas Valley is developed, consisting mainly of irrigated pasture and grass hay, irrigated alfalfa, and residential areas. The surrounding mountains and hills are mostly undeveloped. At higher altitudes on the east side, the mountains are covered with aspen and conifers. Vegetation on the eastern foothills and lower altitude western hills is predominantly sagebrush and perennial grass. Major uses of the developed land in Kamas Valley and major vegetation on the surrounding undeveloped land that drains into the Weber River near Peoa, Utah (near Rockport Reservoir), or the Provo River near Hailstone, Utah (near Jordanelle Reservoir), are listed in table 1.

Irrigated cropland and irrigated residential areas cover about 20,000 acres of the 28,000-acre Kamas Valley. All of this land is irrigated by about 65,000 acre-ft/yr of surface water from the Weber River, Beaver Creek, Provo River, and small streams through a large network of mostly unlined canals and ditches. About 99 percent of the irrigated land is flood irrigated. Major canals divert water to the north and east benches from the Weber River where it enters the valley, one major canal diverts water to the area east of Francis from the Provo River near Woodland, and almost all of Beaver Creek is diverted for irrigation. Roadside ditches are prevalent, and the low-altitude parts of the valley have myriad natural drains. In general, surface water is highly visible throughout the valley.

Climate

The average annual temperature in Kamas Valley is 44^{o}F. Summers are typically moderate, with average daytime temperatures in the mid-70s ^{o}F. The growing season for alfalfa and pasture in Kamas Valley starts in late April and lasts through mid-September (Utah State University, 1994, p. 106). Winters in the valley are fairly cold, and by the middle of November snow is usually on the ground and typically remains through March. It is not uncommon, however, to have winter thaws that last from several days to a week. Average winter temperature in the valley is 28^{o}F. A breeze or wind blows in the valley on most days, often from the south.

Average annual precipitation in Kamas Valley is slightly greater than 17 in. This is nearly equivalent to precipitation in Salt Lake Valley, which is west of and about 1,600 ft lower than Kamas Valley. Low precipitation is caused by the rain-shadow effect of the Wasatch Mountains. June, July, and August are typically the driest months. Generally, precipitation in Kamas Valley and the surrounding mountains was near normal during 1997-99 and below normal in 2000. Precipitation in Kamas Valley in 2000 was about 30 percent below the long-term average. Snowpack in the Weber River drainage basin during the winter of 2000-01 was about 45 percent below normal, and in the Provo River drainage basin, about 20 percent below normal.

Previous Investigations

A description of the Kamas Valley hydrologic system was completed by Baker (1970) as part of a study that also included Heber Valley and areas around Park City. A reconnaissance of water quality in the Weber River drainage was carried out by Thompson (1983). Well information, water levels, surface-water measurements, and water-quality data were collected from 1997 to 2000 as part of this study (Haraden and others, 2001). Additional water-quality information also has been collected by the Utah Department of Agriculture and Food (Mark Quilter, oral commun., 2001). The geology of Kamas Valley and surrounding areas is described by Bryant (1990) and Hurlow (2002). Hurlow (2002) emphasizes the geometry of the unconsolidated deposits in Kamas Valley and fracturing of the surrounding consolidated rock.

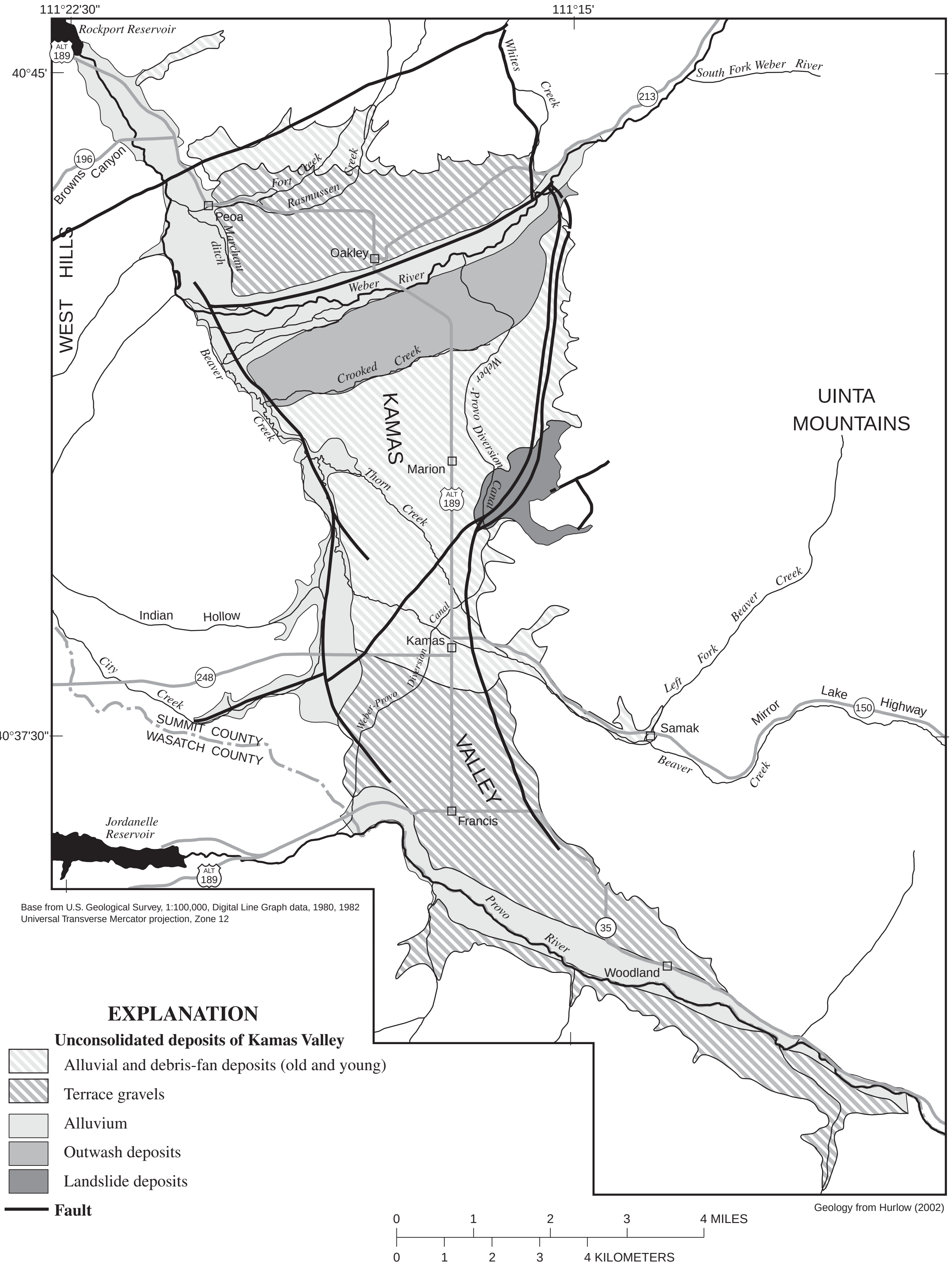

Figure 3. Generalized geology of the unconsolidated deposits, Kamas Valley, Utah.

Table 1. Major land use or type of vegetation, area, and estimated consumptive use of water, Kamas Valley and vicinity, Utah

Land use or type of vegetation	Area (acres)	Estimated consumptive use (feet per year)	References for water use
Developed land			
Irrigated pasture	10,000	1.7	Utah State University, 1994, p. 234
Irrigated grass hay	5,500	1.8	Utah State University, 1994, p. 234
Irrigated alfalfa	2,100	2.0	Utah State University, 1994, p. 234
Residential and other[1]	2,000	1.5	Utah State University, 1994, p. 235
Wet nonirrigated pasture[2]	240	1.7	Utah State University, 1994, p. 234
Irrigated grain	150	1.7	Utah State University, 1994, p. 234
Nonirrigated pasture	140	1.7	Utah State University, 1994, p. 234
Open water	40	2.9	Utah State University, 1994, p. 235
Nonirrigated alfalfa	30	2.0	Utah State University, 1994, p. 234
Commercial	30	.1	Estimated
Total area of developed land (rounded)	**20,200**		
Undeveloped land			
Aspen	128,800	1.7	Croft and Monninger, 1953, table 9
			Brown and Thompson, 1965, table 3
			American Society of Civil Engineers, 1989, p. 17
Lodgepole pine	51,300	1.1	Kaufmann, 1984, table 2
Sagebrush and perennial grasses	49,100	[3]1.0	Wight and others, 1986, table 2
			Tomlinson, 1996b, p. 63
Spruce-Fir and Ponderosa pine	40,000	1.2	Brown and Thompson, 1965, table 3
			Kaufmann, 1984, table 2
Gambel oak	11,300	1.2	American Society of Civil Engineers, 1989, p. 19
Alpine (barren rock)	8,700	.1	Estimated
Dry meadow	6,900	1.4	Tomlinson, 1996a, table 5
Mountain shrub	5,600	.8	Branson and others, 1970, figure 14
Pinyon-Juniper	2,600	1.7	American Society of Civil Engineers, 1989, p. 20
Riparian	2,300	2.4	Tomlinson, 1996a, table 5
Total area of undeveloped land (rounded)	**306,600**		

[1]Reported as idle, excavated, farmstead, and other (Utah Department of Natural Resources, Division of Water Resources, 1992).
[2]Assumed to use ground water.
[3]Reported to use all precipitation in the referenced reports; precipitation averaged about 1 foot per year.

Acknowledgments

Without the willing cooperation of individual well owners, this study would not have been possible. They deserve special acknowledgment for allowing their wells to be pumped, sampled, and monitored. Sharing of data by canal and irrigation company officials provided the framework for describing the pattern and distribution of surface-water use in the valley. Officials of Oakley, Marion, and Kamas allowed for access to municipal wells. The Utah Division of Water Rights provided assistance with streamflow monitoring, access to drillers' logs, and information concerning water rights. The Utah Division of Drinking Water provided water-quality data, and the Utah State Health Laboratory analyzed water-quality samples for coliform bacteria.

SURFACE-WATER HYDROLOGY

The major sources of water in Kamas Valley are the Weber River, Provo River, and Beaver Creek. Most streamflow in the study area originates in the Uinta Mountains on the eastern border and leaves the area through canyons on the northwestern and southwestern borders. Some streamflow originates on the low-altitude western and southern hills, and may be significant locally, but is insignificant in comparison to flow in the three major streams. As streamflow enters Kamas Valley, some is diverted near the canyon mouths for irrigation and some seeps into the ground near the canyon mouths, contributing recharge to the ground-water system. As the streams flow across the valley, additional streamflow is derived from irrigation return flow, tributary inflow, and ground-water discharge in the lower parts of the study area. Ground-water discharge is particularly evident between Marion and the West Hills and on the benches near Peoa and Francis. Water from the three major streams becomes mixed in Kamas Valley, with the Weber-Provo Diversion Canal moving water from the Weber River and Beaver Creek to the Provo River, and irrigation return flow from both the Weber and Provo Rivers contributing flow to Beaver Creek. The U.S. Geological Survey; the Provo River Water Users Association; and the Utah Department of Natural Resources, Division of Water Rights have operated surface-water gaging stations on Weber River, Beaver Creek, Provo River, Weber-Provo Diversion Canal and other locations during various years as listed in table 2.

The Weber River begins in the Uinta Mountains at an altitude of about 10,200 ft, receives water from snowmelt, rainfall, springs, and contributing streams, and enters Kamas Valley northeast of Oakley. Irrigation canals and the Weber-Provo Diversion Canal near Oakley at times divert almost all flow from the Weber River (Thompson, 1983, p. 15). As the river flows west from Oakley and north near Peoa, it gains additional water from irrigation return flow, tributary inflow, and ground-water discharge.

Beaver Creek begins in the Uinta Mountains at an altitude of about 9,900 ft, receives water from snowmelt, rainfall, springs, and contributing streams through Samak and enters the valley at Kamas. Streamflow is diverted to irrigation canals and the Weber-Provo Diversion Canal. Downstream from Kamas, Beaver Creek is entirely diverted to irrigation canals and a main channel is not evident. Irrigation return flow, ground-water discharge, and tributary inflow combine on the west side of the valley to again form Beaver Creek. Beaver Creek flows north along the western edge of the valley and flows into the Weber River south of Peoa.

The Provo River, which flows through the southern part of Kamas Valley, originates in the Uinta Mountains south of the headwaters of the Weber River at an altitude of about 10,200 ft and receives water from snowmelt, rainfall, and contributing streams. The Provo River enters Kamas Valley near Woodland where a small percentage of the water is diverted to one major irrigation canal. The Provo River then flows northwest, remaining in an incised channel south of Francis, and leaves Kamas Valley west of Francis.

The Weber-Provo Diversion Canal transfers water from the Weber River to the Provo River, generally from late fall through spring. Water is also diverted from Beaver Creek to the Provo River via the Weber-Provo Diversion Canal. The canal is not used for irrigation diversions within Kamas Valley. The canal is lined with concrete for a few short sections near the headgate at the Weber River, near Kamas, at check dams, and near the Provo River. Check dams on the canal are operated to keep the water level close to land surface to alleviate local concerns that the canal would decrease ground-water levels.

Average annual water budgets were determined for the Weber River, Beaver Creek, and Provo River through Kamas Valley and are listed in table 3. The budgets describe flow rates for all known components of the hydrologic system that interact with the major streams. In this report, each surface-water budget starts at a gaging station near where the stream enters Kamas Valley, constitutes all outflow and inflow occurring in the valley, and ends at a gaging station near where the stream leaves Kamas Valley or enters another stream. All the components are measured or estimated independently from the available data. Data used to compute the budgets were derived from some of the surface-water gaging sites (table 2); surface-water measurements on the Weber River, Beaver Creek, the Weber-Provo Diversion Canal, and other sites around the valley (Haraden and others, 2001, tables 5-12); estimates of the flow in ungaged perennial and ephemeral streams; and reported canal diversions (Utah Department of Natural Resources, Division of Water Rights, 2001). The water budgets for the three major streams are not independent of each other; some

Table 2. Location, period of record, average annual flow, and drainage area of surface-water gaging stations, Kamas Valley and vicinity, Utah

[na, not applicable to controlled diversions; —, no data]

Location: See figure 2 for an explanation of the numbering system used for hydrologic-data sites in Utah.
Site ID: A unique number identifying a site in the U.S. Geological Survey database.
Operating agency: USGS, U.S. Geological Survey; PRWUA, Provo River Water Users Association; UDWR, Utah Department of Natural Resources, Division of Water Rights.
Percent average at Oakley: Percent of flow in the Weber River near Oakley for the period of record for each gage as compared to the 1905-2000 average annual flow of the Weber River near Oakley, Utah. The 1998-2000 average annual flow in the Weber River near Oakley was 102 percent of the 1905-2000 average annual flow; therefore, all measured streamflow in Kamas Valley for 1998-2000 was assumed to be 102 percent of the long-term annual flow.
Adjusted annual flow: Average annual flow for period of record divided by percent average at Oakley multiplied by 100.

Gaging station	Location	Site ID	Period of record (water year)	Average annual flow for period of record (acre-feet)	Drainage area (square miles)	Operating agency	Percent average at Oakley	Adjusted annual flow (acre-feet)
Weber River drainage								
Weber River near Oakley, Utah	(D-1-6)15adb	10128500	1905-2000	159,000	162	USGS	—	—
Weber Provo Diversion Canal at Oakley, Utah	(D-1-6)21cca	10129000	1939-69 1990-99	37,000 35,000	na	USGS PRWUA	na	na
Marchant ditch near Peoa, Utah[1]	(D-1-5)23aca	404319111203501	1998-2000	5,000	1	USGS	102	4,900
Weber River near Peoa, Utah	(D-1-5)10bdb	10129300	1957-77	128,000	296	USGS	93	138,000
Beaver Creek drainage								
Beaver Creek at Lind Bridge near Kamas, Utah	(D-2-6)22dca	non-USGS site	1997-2000	27,000	45.5	UDWR	108	25,000
Beaver Creek at Grist Mill near Kamas, Utah	(D-2-6)21aaa	non-USGS site	1997-2000	25,000	46.4	UDWR	108	23,000
Beaver Creek at Weber-Provo Diversion Canal in Kamas, Utah	(D-2-6)17dac	non-USGS site	1997-2000	10,000	50.00	UDWR	108	9,000
Beaver Creek Diversion to Weber-Provo Diversion Canal in Kamas, Utah	(D-2-6)17dac	non-USGS site	1997-99	5,000	na	UDWR	na	na
City Creek near Kamas, Utah[1]	(D-2-5)24cbd	403746111200401	1998-2000	300	1.7	USGS	102	300
Indian Hollow near Kamas, Utah	(D-2-5)13dba	403846111192601	1998-2000	600	4.2	USGS	102	600
Beaver Creek at Rocky Point	(D-2-5)1aad	non-USGS site	1999-2000	37,000	68.0	UDWR	92	40,000
Provo River drainage								
Provo River near Woodland, Utah	(D-3-7)17dba	10154200	1963-2000	161,000	162	USGS	100	161,000
Weber-Provo Diversion Canal near Woodland, Utah	(D-2-6)30dca	10154500	partial 1932-69 1989-90 partial 1991-98	[2]40,000	na	USGS	na	na
Provo River near Hailstone, Utah	(D-2-5)36cac	10155000	1950-2000	202,000	219	USGS	98	206,000

[1] Estimated from monthly measurements.
[2] Estimated from partial records.

streamflow is accounted in more than one of the budgets. For instance, flow in Beaver Creek is in both the Beaver Creek budget and the Weber River budget, and irrigation water returns to streams other than those from which it was diverted. Because of this, the three stream budgets cannot be added to determine a surface-water budget for the entire valley.

Because the streams have been gaged for different periods, it is not possible to use the average annual flow for the period of record for each stream to determine the surface-water budgets. Instead, the average annual flow in the Weber River near Oakley, Utah, for each period of record was compared to the 1905-2000 average annual flow of the Weber River near Oakley. The ratio of the short-term average annual flow to the long-term average annual flow was used to adjust the flow at the shorter-term gaging stations to the long-term annual flow (table 2) listed for the surface-water budgets.

Inflow to streams includes perennial streamflow entering the valley; irrigation return flow; ground-water discharge to streams; ungaged perennial, intermittent, and ephemeral streamflow; and runoff from precipitation in the valley. Discharge from municipal waste-water systems is insignificant. Outflow from streams includes streamflow leaving the valley, irrigation diversions, and ground-water recharge from streams. Additionally, the Weber-Provo Diversion Canal transfers water from the Weber River to the Provo River.

Probable ranges of error discussed for the budget components represent both measurement errors and estimate errors. Measurement errors represent the inability to perfectly measure budget components. Estimate errors represent the error associated with extending measurements to long-term annual flows and with estimating unmeasured components. These errors may not be absolute, but represent probable ranges of inflows and outflows given the known data and methodology. Appendix A contains error analyses of water-budget components.

Perennial Streams

Perennial streams contributing inflow to the surface-water budgets have been measured at Weber River near Oakley, Beaver Creek at Lind Bridge near Kamas, Indian Hollow, City Creek, and Provo River near Woodland. Because of long-term records (table 2), the error in the annual flow in the Weber River near Oakley and the Weber-Provo Diversion Canal at Oakley is probably less than 5 percent. Because of the limited data for Beaver Creek at Lind Bridge, Indian Hollow, and City Creek, the error in the annual flow is estimated to be as much as 20 percent. Error estimates are subjective and based on observations during the study period and other gaging stations in northern Utah. Some water from City Creek and Indian Hollow is diverted for irrigation, but because of the small amounts and the errors in the annual flow, the diversions are not accounted for in this budget. The 37-year record of Provo River near Woodland appears to be representative of long-term average flow (table 2), and the error in the annual flow is probably less than 5 percent.

Outflow from Beaver Creek and inflow to the Weber River is measured at Beaver Creek near Rocky Point. Because of the limited data for Beaver Creek at Rocky Point, the error in the annual flow is estimated to be as much as 20 percent. Other perennial streams removing water from the surface-water budgets have been measured at Weber River near Peoa and Provo River near Hailstone. Weber River near Peoa was measured during a period of below-normal flow (table 2), and the error in the annual flow is estimated to be as much as 10 percent. The 52-year record of Provo River near Hailstone indicates slightly less than long-term average flow (table 2), and the error in the annual flow is probably less than 5 percent. Because of the partial record of the Weber-Provo Diversion Canal near Woodland, the error in the annual flow is estimated to be as much as 10 percent.

Ungaged Streams

Ungaged surface water entering the valley includes water from small perennial streams and intermittent and ephemeral runoff. Annual streamflow from ungaged drainage basins was estimated from precipitation, consumptive use, and runoff from gaged drainage basins. Precipitation on each drainage basin was estimated from the 1961-90 normal precipitation (Utah Climate Center, 1996). Maps of vegetative cover (Utah Cooperative Fish and Wildlife Research Unit, 1995) and consumptive use estimates for each type of vegetation (table 1) were used to determine the amount of precipitation consumed by vegetation in each drainage basin.

Table 3. Annual water budget for the Weber River, Beaver Creek, and Provo River through Kamas Valley, Utah

[Amounts in acre-feet]

Weber River			
Inflow		**Outflow**	
Weber River near Oakley, Utah	159,000	Weber River near Peoa, Utah	138,000
Beaver Creek at Rocky Point	40,000	Diversion from Weber River to the Weber-Provo Diversion Canal	36,000
Irrigation return flow	12,000	Irrigation diversions from the Weber River	35,000
Ground-water discharge to Beaver Creek downstream from Rocky Point gage	7,000	Ground-water recharge from the Weber River	8,000
Runoff from precipitation in valley	3,000		
Ungaged streamflow	2,900		
Springs on bench near Peoa	2,500		
Springs near Fort Creek	1,000		
Ground-water discharge to Weber River near Oakley and Peoa	1,000		
Total inflow (rounded)	**228,000**	**Total outflow**	**217,000**
Residual			11,000

Beaver Creek			
Inflow		**Outflow**	
Beaver Creek at Lind Bridge near Kamas, Utah	25,000	Beaver Creek at Rocky Point	40,000
Irrigation return flow	25,000	Irrigation diversions from Beaver Creek	18,000
Ground-water discharge to Beaver Creek	15,000	Diversion to Weber-Provo Diversion Canal	5,000
Runoff from precipitation in valley	2,800	Ground-water recharge from Beaver Creek between Lind Bridge and Grist Mill	1,000
Ungaged streamflow	1,200	Ground-water recharge from City Creek and Indian Hollow	700
Indian Hollow and City Creek	900		
Total inflow (rounded)	**70,000**	**Total outflow (rounded)**	**65,000**
Residual			5,000

Provo River			
Inflow		**Outflow**	
Provo River near Woodland, Utah	161,000	Provo River near Hailstone, Utah	206,000
Weber-Provo Diversion Canal	40,000	Irrigation diversions from the Provo River	12,000
Ungaged streamflow	12,000		
Irrigation return flow	4,500		
Runoff from precipitation in valley	1,400		
Ground-water discharge to Provo River	1,000		
Springs on bench near Francis	1,000		
Total inflow (rounded)	**221,000**	**Total outflow**	**218,000**
Residual			3,000

Water remaining from precipitation that is not consumed becomes either surface-water runoff or recharge to consolidated rock within each drainage basin as listed in table 4. For the lower altitude western drainage basins, the maximum percentage of precipitation that becomes runoff to streams was estimated to be 15 percent. The annual streamflow in City Creek and Indian Hollow is about 15 percent of normal precipitation on those drainage basins. For the eastern, northern, and southern drainage basins, the maximum percentage of precipitation that becomes runoff to streams was assumed to be 20 or 25 percent. These drainage basins have higher altitudes and more precipitation than the western drainage basins, but lower altitudes and less precipitation than the Weber and Provo drainage basins, where estimated runoff is 35 percent of normal precipitation.

Much of the flow from ungaged drainage basins does not contribute flow directly to the Weber or Provo Rivers because it infiltrates the ground and becomes ground-water recharge as it flows across alluvial fans at canyon mouths or is diverted for irrigation. About 20 percent of the ungaged flow into Kamas Valley from the north and east is estimated to enter the Weber River, Beaver Creek, or Provo River, and 80 percent is estimated to recharge the ground-water system. This estimate is based on observations that indicate that many small streams have no stream channels across alluvial fans and landslide deposits. Ground-water recharge from ungaged runoff west of Kamas Valley into Beaver Creek or the Weber River and south of Kamas Valley into the Provo River is probably negligible because the ungaged runoff enters the valley at lower altitudes near the streams. Cumulative errors in precipitation, consumptive use by natural vegetation, and runoff cause the estimate error for the amount of surface-water inflow from ungaged streams to be as much as 70 percent as listed in table A-1. Because the amount of flow is small in relation to the flow in the Weber and Provo Rivers, the effect of the errors on the surface-water budget is not significant. The amount of ungaged streamflow diverted for irrigation is within the error and is not accounted for in these budgets.

Streamflow Gains and Losses

To determine the amount of streamflow that recharges the ground-water system and the amount of ground water that discharges to streams, streamflow measurements were made along the Weber River, Beaver Creek, and the Weber-Provo Diversion Canal. All inflows and outflows also were measured. The difference in flow between measurement locations that is not accounted for as inflow or outflow is assumed to be streamflow recharge to ground water or ground-water discharge to the stream.

The Weber River was measured at seven sites from 1 to 7 mi east of Oakley, Utah, in November 1998. Near Oakley and west of Oakley, the river has limited access and many small inflows and outflows. Measurements were not made in that area. The following table summarizes the location and rate of gain or loss based on measurements made during November 2-4, 1998. The measurements were repeated for 3 days and the gains and losses were averaged. Flow, water temperature, and specific conductance were reported by Haraden and others (2001, table 6).

Measurements indicate that the river gains flow in the canyon east of Oakley and loses flow in the valley east of Oakley. In the canyon, between site (A-1-7)31dcb and (D-1-6)15adb, water probably is discharging from consolidated rocks to the river. In the valley, between site (D-1-6)15adb and (D-1-6)21ccb, water from the river probably is recharging the ground-water system in the unconsolidated deposits. The loss of 10.5 ft^3/s measured in November 1998 is an estimate of annual ground-water recharge of about 8,000 acre-ft.

Upstream site	Downstream site	Distance (miles)	Gain or loss (-) (cubic feet per second)	Gain or loss (-) (percent of upstream flow)	Gain or loss (-) (cubic feet per second per mile)
(A-1-7)31dcb	(D-1-6)12bdd	2.3	5.8	9	2.5
(D-1-6)12bdd	(D-1-6)15adb	1.8	5.2	7	2.9
(D-1-6)15adb	(D-1-6)15cda	.6	-5.6	-6	-9.3
(D-1-6)15cda	(D-1-6)21ccb	2.1	-4.9	-6	-2.3

Table 4. Annual runoff and recharge from ungaged drainage basins surrounding Kamas Valley, Utah

[Amounts in acre-feet]

Runoff over unconsolidated deposits: Precipitation minus consumptive use, or 15 to 25 percent of precipitation.
Recharge to consolidated rock: Precipitation minus Consumptive use minus Runoff over unconsolidated deposits.
Recharge to unconsolidated deposits: Eighty percent of Runoff over unconsolidated deposits.
Runoff to surface water: Runoff over unconsolidated deposits minus Recharge to unconsolidated deposits.

Location of drainage basin	Area (acres)	Precipitation	Consumptive use	Runoff over unconsolidated deposits	Recharge to consolidated rock	Recharge to unconsolidated deposits	Runoff to surface water
Flow to Weber River							
West of valley	9,200	13,700	11,700	2,000	0	[1]0	2,000
North of valley	10,300	17,600	14,000	[2]3,500	100	2,800	700
East of valley	2,400	4,800	3,800	1,000	0	800	200
Total for Weber River	21,900	36,100	29,500	6,500	100	3,600	2,900
Flow to Beaver Creek							
West of valley	2,700	3,900	2,700	[3]600	600	[1]0	600
East of valley	6,200	12,200	9,300	2,900	0	2,300	600
Total for Beaver Creek	8,900	16,100	12,000	3,500	600	2,300	1,200
Flow to Provo River							
Southeast of valley	4,100	8,200	5,200	[4]2,000	1,000	1,600	400
South of valley	26,800	47,700	35,900	11,800	0	[1]0	11,800
Total for Provo River	30,900	55,900	41,100	13,800	1,000	1,600	12,200
Total (rounded)	**62,000**	**108,000**	**83,000**	**24,000**	**2,000**	**8,000**	**16,000**

[1] Runoff occurs near major streams and flow is assumed to contribute to surface water with little ground-water interaction.
[2] Maximum 20 percent runoff assumed.
[3] Maximum 15 percent runoff assumed.
[4] Maximum 25 percent runoff assumed.

Even though the measurements were repeated, all measurements occurred during the same time of year and the estimate error for annual recharge could be as much as 50 percent. Though the streamflow measurements indicate interaction with ground water, the gradient between consolidated rocks, unconsolidated deposits, and the stream can only be determined using monitoring wells located near the stream, which were not available during this study.

Beaver Creek was measured at eight sites from 2 mi upstream from Samak, Utah, to the Weber-Provo Diversion Canal in September 1999. Downstream from the Weber-Provo Diversion Canal, Beaver Creek is diverted into many channels and measurements were not made. The following table summarizes the location and rate of gain or loss for measurements made during September 21-23, 1999. Gains and losses in areas not listed were within measurement error, and ground-water recharge and discharge are considered negligible. Gains and losses are considered negligible from site (D-2-6)21aaa through Kamas to the Weber-Provo Diversion Canal. The measurements were repeated for 3 days, and the gains and losses were averaged. Flow, water temperature, and specific conductance were reported by Haraden and others (2001, table 6).

Upstream site	Downstream site	Distance (miles)	Gain or loss (-) (cubic feet per second)	Gain or loss (-) (percent of upstream flow)	Gain or loss (-) (cubic feet per second per mile)
(D-2-7)19cad	(D-2-6)25dbb	1.3	0.54	9	.42
(D-2-6)25dbb	(D-2-6)26abc	1.2	-.91	-15	-.76
(D-2-6)26abb	(D-2-6)26abb	.06	.76	8	12.6
(D-2-6)22dca	(D-2-6)21aaa	1.0	-1.8	-14	-1.8

Measurements indicate that Beaver Creek gains and loses water at several places along the measured reach. The gains and losses from site (D-2-7)19cad to (D-2-6)26abc represent interaction between consolidated rock, unconsolidated deposits, and Beaver Creek. Near the Utah Division of Wildlife Resources Fish Hatchery in Samak, Utah, water from springs in Left-hand Canyon enters Beaver Creek. The stream also gains water from additional ground-water discharge in this area in (D-2-6)26abb. The loss from site (D-2-6)22dca to (D-2-6)21aaa probably recharges the unconsolidated deposits and flows into Kamas Valley as ground water. Some of this recharge may be through the creek channel, and some may be from water that is diverted to a ditch and allowed to flood irrigate fields as it returns to Beaver Creek. Effective precipitation is about equal to consumptive use by pasture grass, so little of this irrigation water is consumed by plants. The 1.8 ft^3/s loss measured in September 1999 is an estimate of annual ground-water recharge of about 1,000 acre-ft. Even though the measurements were repeated, all measurements occurred during the same time of year and the estimate error for annual recharge could be as much as 50 percent. Though streamflow measurements indicate interaction with ground water, the gradient between consolidated rock, unconsolidated deposits, and Beaver Creek can only be determined using monitoring wells located near the creek, which were not available during this study.

The Provo River enters the valley in an incised channel. Because of this, little recharge probably occurs from the Provo River to the ground-water system in the unconsolidated deposits. Recharge may occur and flow along the river channel and then discharge back to the river.

In October 1999, the Provo River Water Users Association opened the check dams on the Weber-Provo Diversion Canal but did not divert water from the Weber River into the canal. This enabled the U.S. Geological Survey to measure the canal at seven sites and measure inflows and outflows (Haraden and others, 2001, table 6). The low flows make the calculation of any gain or loss more accurate. Little surface-water/ground-water interaction occurs upstream of Beaver Creek, but from Beaver Creek to near Francis, site (D-2-6)30aab, the canal gained about 2 ft^3/s, which is equivalent to an annual gain of about 1,500 acre-ft. During normal operation, however, the check dams on the canal remain closed to keep the water level in the canal at approximately land surface, and the canal probably gains little water.

In addition to ground-water discharge directly to streams, ground water also contributes streamflow through diffuse discharge to springs and natural drains in the lower altitude parts of the valley and along the benches near Peoa and Francis.

Ground-water discharge to creeks in the middle of the valley was estimated by measuring all surface-water flow across the roads surrounding the middle of the valley in October 1999 (Haraden and others, 2001, table 6 and pl. 1) in the area shown in figure 4. The measurements indicate a gain of about 25,000 acre-ft/yr in streams through this area. The October measurements, however, would include all discharge as discharge to streams; in the summer, about 3,000 acre-ft/yr would be discharged by evapotranspiration in the area (see “Evapotranspiration” section of this report), and the discharge to streams would be about 22,000 acre-ft/yr. About 15,000 acre-ft/yr of that discharge enters Beaver Creek upstream from the Rocky Point gaging station and is considered to be ground-water discharge to Beaver Creek. About 7,000 acre-ft/yr enters Beaver Creek downstream from the Rocky Point gaging station and is considered to be ground-water discharge to the Weber River. These measurements were made only once, and the error estimate for annual ground-water discharge could be as much as 50 percent.

Ground-water discharge from the bench near Peoa is partially consumed by the vegetation along the bench, but some of it flows into an unnamed stream known locally as Marchant ditch. Annual flow in the stream is about 5,000 acre-ft/yr (table 2) as determined from monthly flow measurements (Haraden and others, 2001, table 5); about 50 percent of that is estimated to be ground-water discharge. Because of the short duration and intermittent measurements of flow, the estimate error for ground-water discharge to Marchant ditch could be as much as 20 percent.

Ground-water discharge directly to the Weber River could not be estimated by surface-water measurements because of the braided channel and difficult access to the river below Oakley. Ground-water discharge is apparent in the area and is estimated to be 1,000 acre-ft/yr. Ground-water discharge that appears near the lower part of Fort Creek as diffuse seeps is estimated to be 1,000 acre-ft/yr. The error estimate for annual discharge in these areas is at least 50 percent.

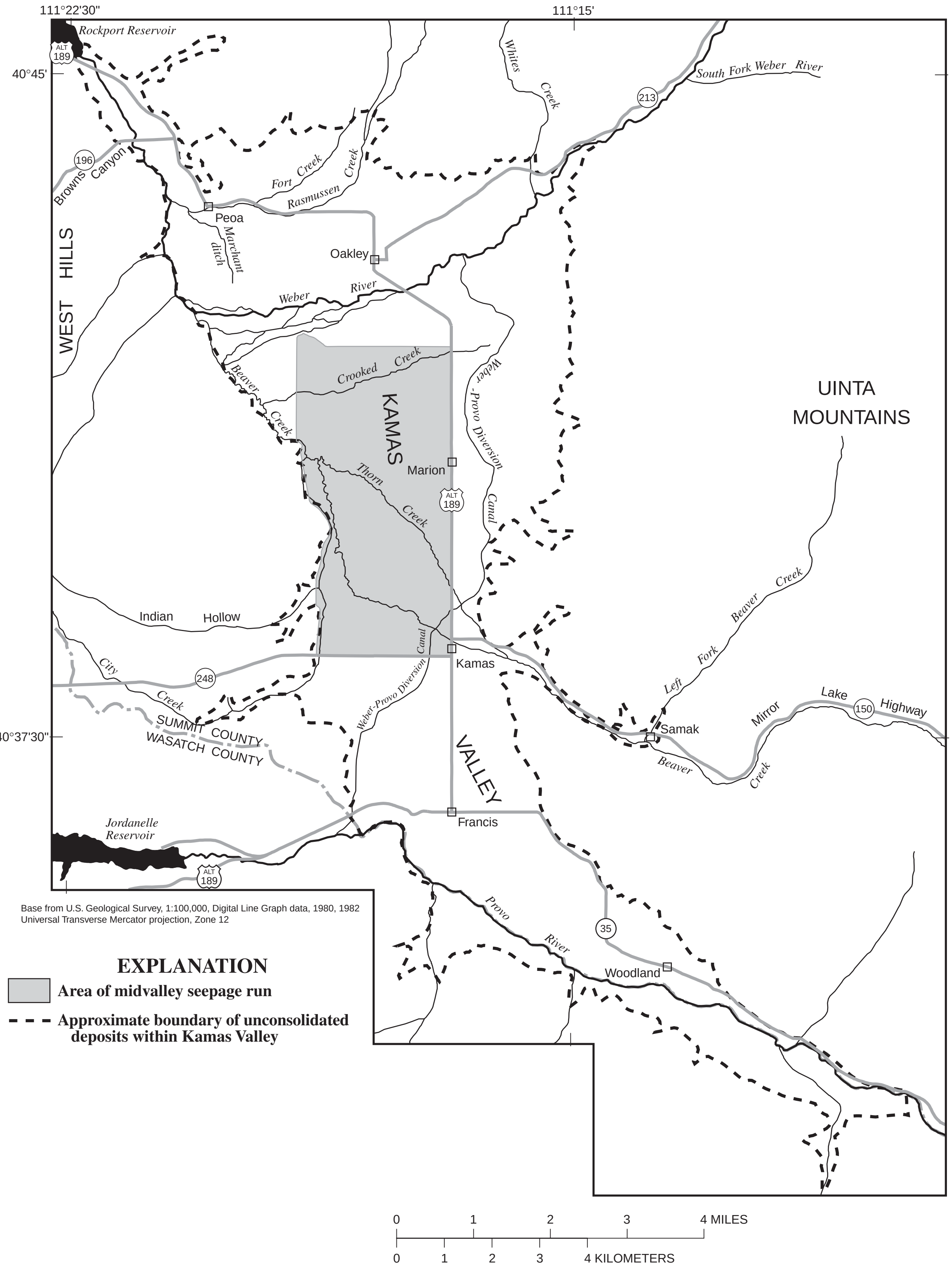

Figure 4. Area of midvalley seepage run, Kamas Valley, Utah, October 1999.

Ground-water discharge to the Provo River and the bench below Francis was not estimated by surface-water measurements because of the difficult access and many diversions and returns. Ground-water discharge is apparent near Provo River and along the bench, and is estimated to be 1,000 acre-ft/yr to the Provo River and an additional 1,000 acre-ft/yr to the springs along the bench. None of this ground-water discharge was measured and does not significantly affect the surface-water budget of the Provo River; values were assumed that allow for the small discharge noted during field reconnaissance. The error estimate for annual discharge is at least 50 percent.

Irrigation

Irrigation diversions and irrigation return flow are major components of the surface-water budget in Kamas Valley. An average of 35,000 acre-ft/yr are diverted from the Weber River and 12,000 acre-ft/yr from the Provo River for irrigation in Kamas Valley. This was determined by examining the diversion data for 13 years with different flows in the Weber River (Utah Department of Natural Resources, Division of Water Rights, 2001). For those years (1960-69, 1971, 1996, and 1997), average annual flow in the Weber River was 159,000 acre-ft, the same as the average annual flow for the period of record, and it is assumed that the 13-year average of the diversions approximates the long-term average of the diversions. Given the uncertainties in diversions, including flume accuracy and measurements during only the summer months even though some canals flow year round, a more detailed estimate of average diversions was not warranted. The average diversion from the Provo River was estimated for the same 13 years. Diversions from Beaver Creek were not measured, but all flow in Beaver Creek is diverted to canals and small ditches. For an adjusted annual flow of 23,000 acre-ft at Grist Mill and an annual diversion of 5,000 acre-ft from Beaver Creek to the Weber-Provo Diversion Canal (table 2), 18,000 acre-ft would be diverted for irrigation annually. The annual diversions have estimate errors of 10 percent for Weber and Provo Rivers and 20 percent for Beaver Creek. This error, however, is probably small in comparison with other assumptions about conveyance loss and irrigation efficiency and does not significantly affect the surface-water budgets determined in this report.

To route the water through the valley and estimate irrigation return flow, the valley was divided into unofficial irrigation areas as shown in figure 5. The unofficial name of irrigation areas, amount diverted, return flow, and amount applied are listed in table 5. The irrigation areas were determined from field observation of areas of service for major canals and estimated depth to ground water. Throughout much of the valley, ground water is close to land surface; recharge is less in these areas and surface-water runoff is greater. The approximate boundaries of areas where ground water is estimated to be within 5 ft of land surface are shown in figure 6. Some of this boundary was determined not by measured water levels, but from field observations of ground-water discharge such as springs and gaining ditches.

Field observations indicate that not all diverted water is applied to fields and that some water remains in canals and ditches and flows directly to a stream. This direct return flow was not measured, but is estimated to be 10 percent of the diversions; it could, however, range from 5 to 20 percent.

The Utah Department of Natural Resources, Division of Water Resources (1996, p. 29) estimates that canal conveyance efficiency is 85 percent. Canals and ditches are not lined with concrete. In this report, it is assumed that canals on the benches contribute 15 percent of their flow to the ground-water system and that canals in the lower parts of the valley (fig. 6) contribute negligible recharge to the ground-water system. It is possible that canal loss ranges from 0 to 15 percent of diversions. A small amount of canal loss is used by vegetation along canals, but the amount is negligible because of the limited area of this vegetation.

An infiltration rate of 80 percent of applied water is assumed for parts of Kamas Valley where ground-water levels are more than about 5 ft below land surface (fig. 6). In southern Utah Valley, which is also mostly flood irrigated, Mizue (1968, p. 51) reported infiltration of applied water of 75 to 85 percent. In the areas of ground-water levels within 5 ft of the land surface, it is assumed that all applied irrigation water runs off the fields and crop demand is satisfied by precipitation and evapotranspiration from ground water. It is possible that bench areas have an infiltration rate from 50 to 85 percent and that lower altitude areas have an infiltration rate from 0 to 50 percent. Infiltration rate has a significant effect on the surface-water budgets presented in this report.

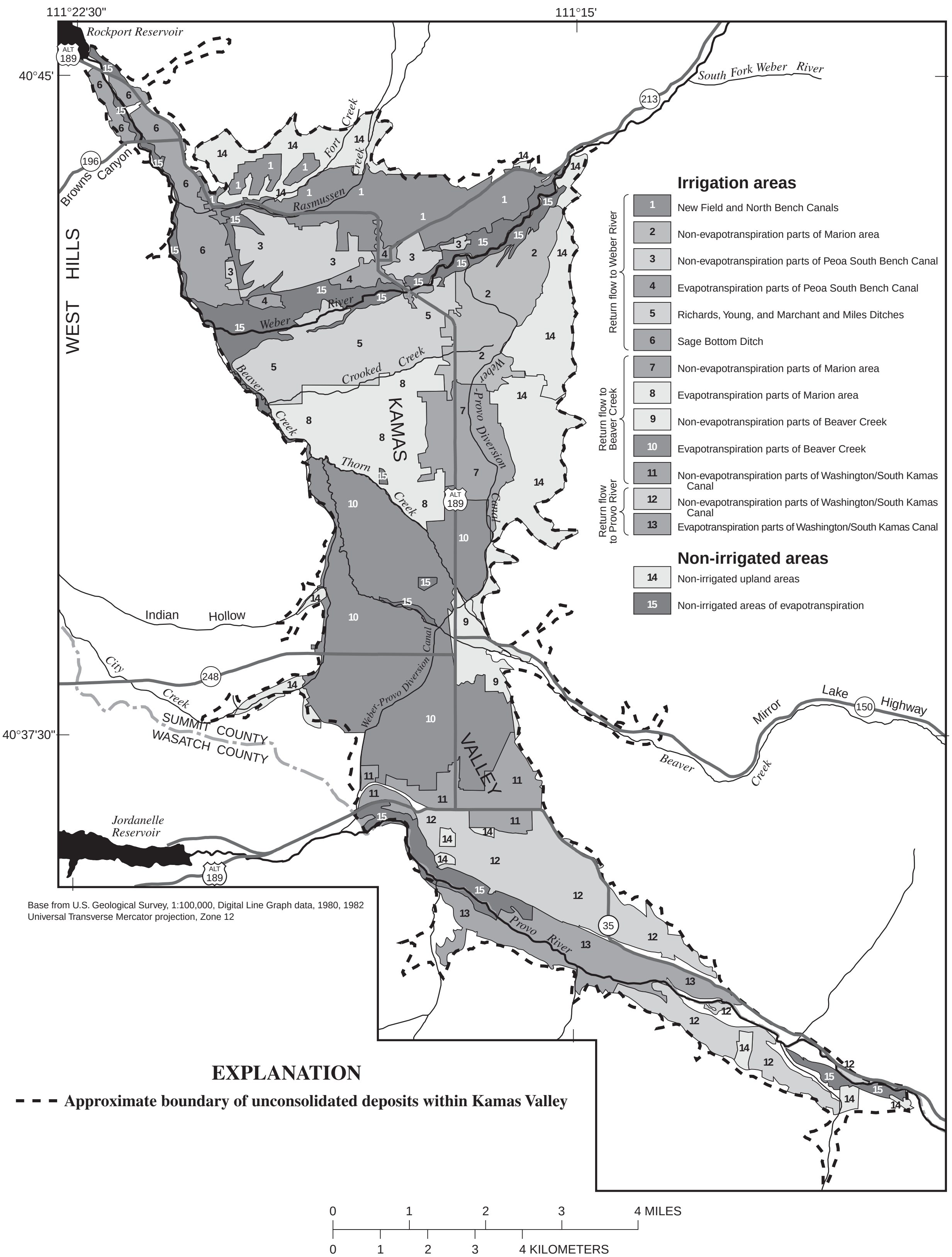

Figure 5. Irrigation areas, Kamas Valley, Utah.

Table 5. Annual irrigation water budget for Kamas Valley, Utah

[Amounts in acre-feet, rounded; ET, evapotranspiration; —, not applicable]

Amount diverted: Estimated long-term average (Utah Department of Natural Resources, Division of Water Rights, 2001).
Direct return flow: Ten percent of amount diverted is estimated to remain in ditches and reenter a stream.
Ground-water recharge from canals: 0 or 15 percent.
Amount applied: Amount diverted minus direct return flow minus ground-water recharge from canals.
Runoff from fields: Twenty or 100 percent of amount applied is estimated to run off fields and reenter a stream.
Amount effectively applied: Amount applied minus runoff from fields.

Unofficial name of irrigation area	Amount diverted	Direct return flow	Ground-water recharge from canals	Amount applied	Runoff from fields	Amount effectively applied
Diverted from Weber River, return flow to Weber River						
New Field and North Bench Canals	8,000	800	1,200	6,000	1,200	4,800
Non-ET parts of Marion area[1]	5,000	500	800	3,700	700	3,000
Non-ET parts of Peoa South Bench Canal	4,000	400	600	3,000	600	2,400
ET parts of Peoa South Bench Canal	1,000	100	0	900	900	0
Richards, Young, and Marchant and Miles Ditches	5,000	500	0	4,500	4,500	0
Sage Bottom Ditch	2,000	200	0	1,800	1,800	0
Total return flow to Weber River	—	2,500	—	—	9,700	—
Diverted from Weber River, return flow to Beaver Creek at Rocky Point						
Non-ET parts of Marion area[1]	4,000	400	600	3,000	600	2,400
ET parts of Marion area[1]	6,000	600	0	5,400	5,400	0
Diverted from Beaver Creek, return flow to Beaver Creek at Rocky Point						
Non-ET parts of Beaver Creek	1,000	100	200	700	100	600
ET parts of Beaver Creek	17,000	1,700	0	15,300	15,300	0
Diverted from Provo River, return flow to Beaver Creek at Rocky Point						
Non-ET parts of Washington/South Kamas Canal	3,000	300	400	2,300	500	1,800
Total return flow to Beaver Creek	—	3,100	—	—	21,900	—
Diverted from Provo River, return flow to Provo River						
Non-ET parts of Washington/South Kamas Canal	6,000	600	900	4,500	900	3,600
ET parts of Washington/South Kamas Canal	3,000	300	0	2,700	2,700	0
Total return flow to Provo River	—	900	—	—	3,600	—
Total (rounded)	**65,000**	**6,000**	**5,000**	**54,000**	**35,000**	**19,000**

[1]Marion area includes all areas estimated to be irrigated by Upper Marion Ditch, Lower Marion Ditch, Gibbons Ditch, and Boulderville Ditches.

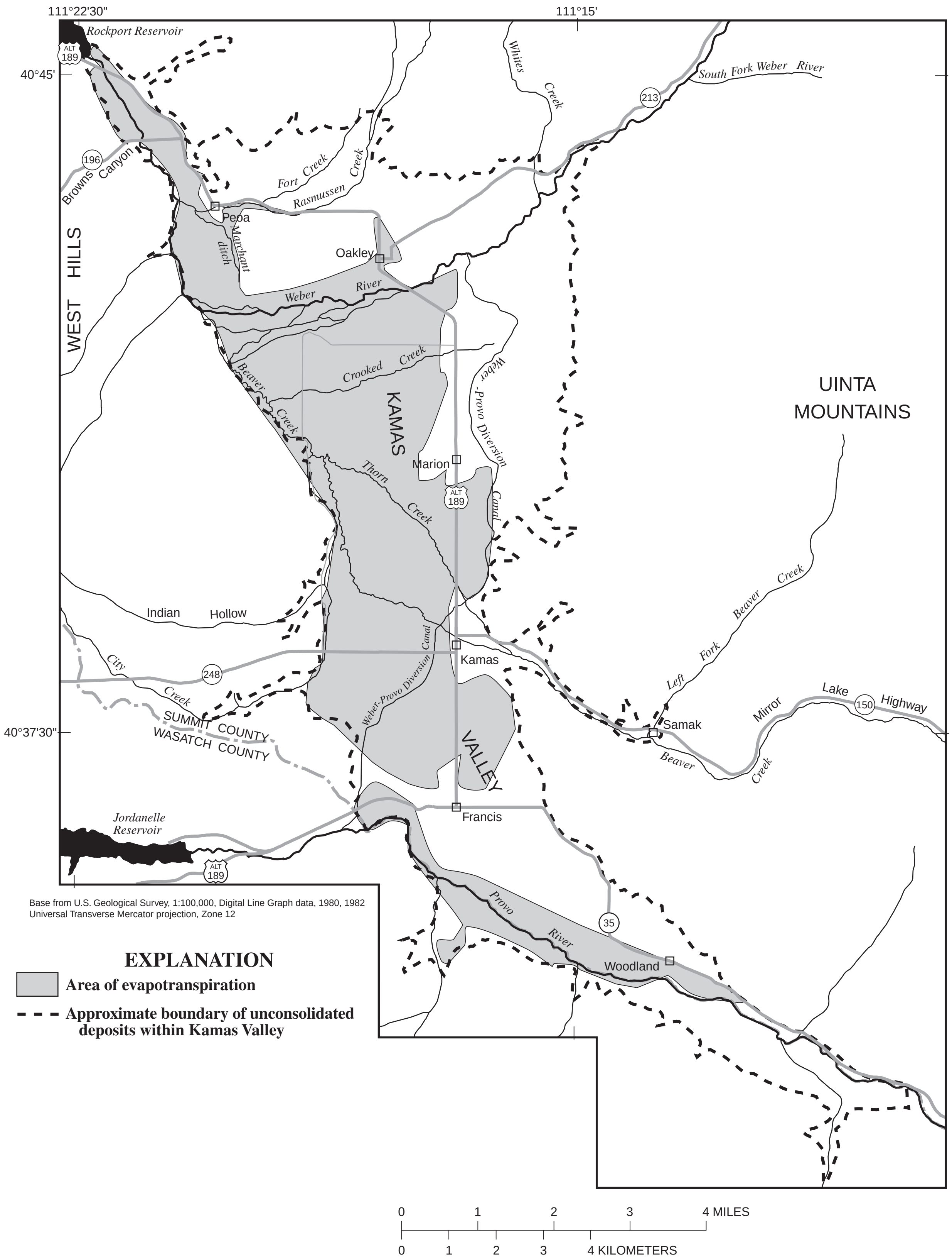

Figure 6. Areas of evapotranspiration, ground-water levels within about 5 feet of land surface, and little ground-water recharge, Kamas Valley, Utah.

Cumulative errors of diversions, direct return in canals, canal loss to ground water, and runoff from fields cause the estimate error for irrigation return flow to be as much as 60 percent as listed in table A-2.

Precipitation

Precipitation on the valley also contributes to streamflow leaving Kamas Valley. Precipitation on the valley was determined for each irrigation area by summing the 1961-90 normal precipitation in the area (Utah Climate Center, 1996). The Utah Department of Natural Resources, Division of Water Resources (1996, p. 29) assumes that 80 percent of annual precipitation is available for consumptive use of crops (80 percent effective). Monthly effective precipitation that exceeds monthly consumptive use contributes to soil moisture. Ground-water recharge is assumed to occur if annual effective precipitation plus effectively applied irrigation water exceeds annual consumptive use. This report assumes that 20 percent of precipitation becomes runoff to streams, either as direct overland flow or through storm drain systems. The precipitation estimate could have a 10 percent error, and runoff from precipitation could range from 10 to 30 percent. The error analysis for runoff from precipitation is presented in table A-3.

Residual and Error Analysis

The surface-water budgets indicate greater inflow than outflow (table 3). Because the budgets represent long-term averages and no storage is available within the surface-water system in Kamas Valley, in reality, inflow to the streams should equal outflow. The discrepancies in the budgets could indicate several things. First, measurement errors were made at gaging stations and during other stream measurements. Second, errors were made in the estimates of long-term flows and in the estimates of irrigation return flow. Third, a method of outflow exists that was not determined in this study. Because the residuals are within 10 percent of the respective budgets, inflow and outflow appear to be equal within measurement error and it is unlikely another method of significant outflow exists.

The ranges of budget components with the estimate errors described in the previous sections are listed in table A-4. In general, surface-water outflow is better measured and defined than surface-water inflow. The uncertainties in irrigation return flow, ungaged runoff, and ground-water discharge to streams cause the uncertainty in surface-water inflow to be greater than the uncertainty in surface-water outflow.

GROUND-WATER HYDROLOGY

The ground-water system in Kamas Valley consists of water in unconsolidated deposits and water in consolidated rock. Most municipal wells are completed in unconsolidated deposits or Weber Sandstone east of the valley; one municipal well is completed in the Humbug Formation east of the valley. Most domestic wells are completed in the unconsolidated deposits or in the Keetley Volcanics underlying the unconsolidated deposits and west of the valley. Domestic wells also are completed in Weber Sandstone east of Francis, in several consolidated rock formations north of Oakley, in the canyon along the Weber River east of Oakley, and near Samak. Withdrawal from wells in consolidated rock and unconsolidated deposits does not significantly affect the entire ground-water system but could affect conditions locally. The degree of interaction between ground water in consolidated rock and unconsolidated deposits is not known but is considered to be small. Water budgets indicate little flow from consolidated rock to the unconsolidated deposits.

Consolidated Rock

Recharge to consolidated rock occurs mostly from precipitation at the higher altitudes where rock is exposed or covered by a thin veneer of unconsolidated deposits. Discharge from consolidated rock occurs mostly to springs and streams upgradient from Kamas Valley. Most municipal water systems in Kamas Valley use water from springs in consolidated rock and use a total of about 2,000 acre-ft/yr. Municipal wells withdraw about 300 acre-ft/yr from consolidated rock around Kamas Valley. Domestic wells withdraw an estimated 500 acre-ft/yr from consolidated rock around Kamas Valley. These rates are determined from population (Utah Governor's Office of Planning and Budget, written commun., 1998), an average use of 1 acre-ft/yr for a household of four people, and an estimated even distribution of wells between consolidated rock and unconsolidated deposits.

Potential discharge from consolidated rock to unconsolidated deposits in Kamas Valley was estimated by an analysis of precipitation, consumptive use, and outflow for gaged streams around Kamas Valley. The methods of analysis are explained in the “Surface-water hydrology” section of this report. The values listed in table 6 indicate that most recharge to consolidated rock in the Uinta Mountains discharges to streams east of Kamas Valley. Discharge from consolidated rock to the Weber River east of Kamas Valley was substantiated by measurements on the Weber River (see the “Surface-water hydrology” section of this report). West of Kamas Valley, some water may be available in areas underlain by Keetley Volcanics in Indian Hollow and City Creek drainage basins to discharge to Kamas Valley. Similar analyses of ungaged drainage basins around Kamas Valley indicate some recharge to consolidated rock in areas underlain by Keetley Volcanics west of the valley and Keetley Volcanics and Weber Sandstone east of Francis (table 4); if this recharge occurs, the water may be available to discharge from consolidated rock to unconsolidated deposits. This analysis is very rough and the error estimate could exceed 100 percent, but it does indicate that little water is available in the consolidated rock to recharge the unconsolidated deposits in Kamas Valley.

The ground-water system in consolidated rock is estimated to be in a long-term steady-state condition. Seasonal and yearly water-level fluctuations occur with precipitation, but withdrawal from wells has been relatively insignificant. As withdrawal from wells increases, however, the ground-water system will be affected. All water withdrawn from wells must be balanced by loss of storage in the ground-water system, decrease in natural discharge, increase in natural recharge, or a combination of these. Loss of storage results in declining ground-water levels and continues until the decrease in natural discharge and increase in recharge equal the amount withdrawn by wells. Decreasing natural discharge would include decreasing discharge to streams, springs, and evapotranspiration. It is possible that well withdrawal would decrease flow to springs currently used for municipal supply. Because of the magnitude of streamflow, the decrease in discharge to streams probably could not be measured. Recharge would be increased if ground-water levels decreased to below the level of streams, thereby causing the stream to lose water to the ground-water system. This may also be too small to measure. In areas of low transmissivity, it is possible that water levels in wells could decline below the pumps before enough discharge could be captured to stop water-level declines.

Table 6. Annual precipitation, consumptive use, outflow, and potential discharge from consolidated rock to Kamas Valley for gaged drainage basins surrounding Kamas Valley, Utah

[Amounts in acre-feet]

Potential discharge from consolidated rock to Kamas Valley: Precipitation minus consumptive use minus gaged outflow.

Stream	Drainage area (acres)	Precipitation	Consumptive use	Gaged outflow	Potential discharge from consolidated rock to Kamas Valley
East side of Kamas Valley					
Weber River near Oakley, Utah	104,000	312,000	135,000	159,000	18,000
Beaver Creek at Lind Bridge	23,000	54,000	34,000	27,000	-7,000
Provo River near Woodland, Utah	110,000	294,000	146,000	161,000	-13,000
Total	**237,000**	**660,000**	**315,000**	**347,000**	**-2,000**
West side of Kamas Valley					
Indian Hollow near Kamas, Utah	2,700	4,100	2,900	400	800
City Creek near Kamas, Utah	1,100	1,600	1,100	300	200
Total	**3,800**	**5,700**	**4,000**	**700**	**1,000**

Interaction Between Consolidated Rock and Unconsolidated Deposits

Although water budgets indicate little interaction between consolidated rock and unconsolidated deposits, this does not mean that unconsolidated deposits are hydrologically separate from consolidated rock. Very little geologic or hydrologic data exist to substantiate a connection or separation. East of Francis, water levels in well (D-2-6)28aab-3 (pl. 1), completed in Weber Sandstone, indicate recharge from irrigation on nearby unconsolidated deposits (see the "Water-level fluctuations" section of this report). Data collected from well (D-2-6)29bcb-1, however, indicate little connection between unconsolidated deposits and the underlying Keetley Volcanics. Well (D-2-6)29bcb-1 was originally drilled 84 ft deep in unconsolidated deposits and had a water level of about 4 ft below land surface. The well was then deepened to 290 ft and completed in unconsolidated deposits and Keetley Volcanics; with this completion the water level was about 25 ft below land surface (Haraden and others, 2001, table 3). Hydrologic connectivity could best be determined by aquifer tests involving enough withdrawal to stress the system and monitoring wells in consolidated rock and unconsolidated deposits. During this study, not enough suitable wells could be found to conduct this testing.

As water levels in well (D-2-6)28aab-3 indicate, wells completed in consolidated rock should not be considered isolated from water in unconsolidated deposits. As municipal and domestic withdrawal from consolidated rock increases, it is possible that flow will be induced from unconsolidated deposits above or adjacent to the wells.

The East Kamas Valley fault zone (fig. 3) may inhibit ground-water flow, especially north of Kamas (Hurlow, 2002, p. 27). Oakley City uses water from springs in consolidated rock near the fault zone just south of the Weber River. Additional small springs near the fault zone north of Kamas may indicate flow along the fault zone or some barrier to flow across the fault zone. Wells (D-2-6)4dac-1, (D-2-6)4dad-1, and (D-2-6)4dda-1 (pl. 1) are located near the fault zone; the water-level altitude in well (D-2-6)4dac-1 (the westernmost well) is about 130 ft lower than the water-level altitude in the other two wells (Haraden and others, 2001, table 1). The fault zone may add to the complexity and discontinuity of the landslide deposits in this area.

Unconsolidated Deposits

The ground-water budget presented in table 7 is for ground water in the unconsolidated deposits. One reason for this emphasis is that increased residential development will affect ground water in the unconsolidated deposits in more complex ways than in the consolidated rocks. In consolidated rocks, increasing development will generally result in more withdrawal from wells, which may affect water levels but should not significantly affect recharge. In the unconsolidated deposits, several changes are possible. Recharge may change as flood-irrigated fields are replaced by residential use; septic tank use may increase as development increases or may decrease as more waste-water systems are constructed because of increased residential density; the use of scattered domestic wells may increase, or some domestic wells may be replaced by larger municipal wells.

Table 7. Annual ground-water budget for the unconsolidated deposits in Kamas Valley, Utah

[Amounts in acre-feet]

Budget component	Flow
Recharge	
Precipitation and irrigation	15,000
Weber River	8,000
Ungaged streamflow	8,000
Canals	5,000
Beaver Creek	1,000
City Creek and Indian Hollow	700
Total recharge (rounded)	**38,000**
Discharge	
Beaver Creek	22,000
Evapotranspiration from crop areas	5,700
Springs on bench near Peoa, Utah	2,500
Evapotranspiration from riparian area along Weber and Provo Rivers	2,300
Springs near Fort Creek	1,000
Weber River near Oakley and Peoa	1,000
Provo River	1,000
Springs on bench near Francis	1,000
Wells	1,000
Total discharge (rounded)	**38,000**

A ground-water budget attempts to identify and estimate all sources of recharge and discharge. Because withdrawal from wells is still small in Kamas Valley, the ground-water system in the unconsolidated deposits is assumed to be in a long-term steady-state condition. This means that average annual recharge equals average annual discharge and long-term water-level fluctuations do not occur. Water levels in March are similar from year to year (pl. 1). Withdrawal from wells has not been substantial enough to remove measurable quantities of water from storage.

Probable ranges of error discussed for the budget components represent both measurement errors and estimate errors. Measurement errors represent the inability to perfectly measure budget components. Estimate errors represent the error associated with extending measurements to average annual flows and with estimating unmeasured components. These errors may not be absolute, but represent probable ranges of inflows and outflows given the known data and methodology (appendix A).

Recharge

Recharge to the unconsolidated deposits is from infiltration of irrigation water, precipitation, streams, and canals (table 7). This is more recharge than the estimated minimum recharge of 22,000 acre-ft/yr reported by Baker (1970, p. 37), which was based on water-level fluctuations of about 10 wells. Data collected during this study from more wells (Haraden and others, 2001, table 3) indicate larger water-level fluctuations than reported by Baker (1970, p. 37).

Irrigation and Precipitation

Applied irrigation water and precipitation contribute recharge to the ground-water system in the unconsolidated deposits. The location of irrigated crops, nonirrigated crops, and municipal areas was determined from digital land-use information (Utah Department of Natural Resources, Division of Water Resources, 1992). The location of nonirrigated areas underlain by unconsolidated deposits (Utah Cooperative Fish and Wildlife Research Unit, 1995) were added to this information. Each crop area was assigned an irrigation area (fig. 5) and a consumptive use (table 1). Most residential irrigation is from small ditches that are used to flood lawns and gardens; therefore, municipal and residential areas also were assigned to an irrigation area. The amount of applied irrigation water, precipitation, consumptive use, ground-water recharge from irrigation and precipitation, and evapotranspiration for each irrigation area is listed in table 8.

The amount of surface water effectively applied to each irrigation area was determined as explained in the “Surface-water hydrology” section of this report. Because several assumptions about irrigation efficiency are made, the effective applied irrigation could range from 8,000 to 46,000 acre-ft/yr (table A-2) but is estimated to be 19,000 acre-ft/yr (table 5). Precipitation was determined for each 1961-90 normal precipitation contour (Utah Climate Center, 1996) and summed to estimate total precipitation for each irrigation area. The estimate error is assumed to be 10 percent. Eighty percent of the precipitation is assumed to reach the root zone and to be available for plant use (Utah Department of Natural Resources, Division of Water Resources, 1996, p. 29), but this could range from 70 to 90 percent. Consumptive use was determined for each crop type (table 1) within an irrigation area and summed to estimate the total consumptive use for each area. The estimate error of consumptive use is 10 percent. Recharge from each irrigation area is calculated by the following equation:

$$\textit{Recharge} = \textit{Surface water effectively applied} + 0.8 \times \textit{annual precipitation} - \textit{consumptive use}. \qquad (1)$$

In some areas where consumptive use exceeds effective irrigation and precipitation, crops are assumed to get enough water to meet consumptive use by evapotranspiration from ground water. Because estimate errors for irrigation and precipitation components are additive, ground-water recharge from irrigation and precipitation could range from 1,000 to 47,000 acre-ft/yr as listed in table A-5, but is estimated to be 15,000 acre-ft/yr (table 8).

Significant irrigation from wells is not known to occur in Kamas Valley, but some wells are used to supplement lawn and garden watering. This is considered to be a negligible portion of the ground-water budget. Small streams are also diverted for irrigation. These include City Creek and Indian Hollow on the west side of the valley, and small streams on the north and east sides of the valley. The combined area irrigated from these sources is about 700 acres. In this report, irrigation from these sources is not included,

Table 8. Irrigation areas and annual applied irrigation water, precipitation, consumptive use, recharge from irrigation and precipitation, and evapotranspiration from ground water, Kamas Valley, Utah

[—, no data available; ET, evapotranspiration; na, evapotranspiration from ground water not applicable to these areas]

Amount of surface water effectively applied: See table 5.
Precipitation: 1961-1990 normal precipitation (Utah Climate Center, 1996).
Consumptive use: Area-weighted average consumptive use of crops within area (table 1).
Recharge: Surface water effectively applied plus 80 percent of precipitation minus consumptive use.
Evapotranspiration from ground water: Use of ground water to satisfy consumptive use demand. Consumptive use minus 80 percent of precipitation.

Unofficial name of irrigation area	Estimated area (acres)	Surface water effectively applied (acre-feet)	Precipitation (acre-feet)	Consumptive use (acre-feet)	Recharge (acre-feet)	Evapotrans-piration from ground water (acre-feet)
Kamas Valley						
New Field and North Bench Canals	1,900	4,800	2,700	3,300	3,700	na
Non-ET parts of Marion area[1]	2,100	5,400	3,200	3,400	4,600	na
ET parts of Marion area[1]	1,600	[2]0	2,400	2,800	0	900
Non-ET parts of Peoa South Bench Canal	1,000	2,400	1,400	1,800	1,700	na
ET parts of Peoa South Bench Canal	300	[2]0	200	300	0	100
Richards, Young, and Marchant and Miles Ditches	1,600	[2]0	2,300	2,800	0	1,000
Sage Bottom Ditch	1,000	[2]0	1,400	1,700	0	600
Non-ET parts of Beaver Creek	400	600	300	300	500	na
ET parts of Beaver Creek	4,800	[2]0	7,100	8,400	0	2,700
Non-ET parts of Washington/South Kamas Canal	3,100	5,400	4,800	5,100	4,100	na
ET parts of Washington/South Kamas Canal	1,300	[2]0	1,900	1,900	0	400
Small streams	500	—	600	800	—[3]	na
Nonirrigated sage and other dry areas	2,700	0	4,200	2,700	700	na
Nonirrigated crop and riparian areas	2,100	0	3,200	4,900	0	2,300
Total (rounded)	**24,000**	**19,000**	**36,000**	**40,000**	**15,000**	**8,000**

[1] Includes all areas estimated to be irrigated by Upper Marion Ditch, Lower Marion Ditch, Gibbons Ditch, and Boulderville Ditches.
[2] High ground-water levels in this area prevent infiltration of irrigation water.
[3] Recharge from streams included in stream loss. Recharge from precipitation is negligible.

but loss from the streams is included as recharge from streams.

Infiltration from Streams and Canals

On the basis of streamflow measurements in the Weber River and Beaver Creek, streams lose water near canyon mouths. This water is assumed to recharge the ground-water system in the unconsolidated deposits in Kamas Valley. The methods to determine the amount of infiltration are explained in the "Surface-water hydrology" section of this report. The estimate error for ground-water recharge from the Weber River and Beaver Creek could be as much as 50 percent. The estimate error for recharge from ungaged streams is about 80 percent.

Irrigation canals may lose water as they flow across parts of the unconsolidated deposits. The assumptions of canal loss are explained in the "Surface-water hydrology" section of this report. The estimate error for ground-water recharge from canals is about 100 percent.

Discharge

Discharge from the ground-water system occurs as seepage to streams, springs, and canals; evapotranspiration; and withdrawal from wells. Most discharge occurs in the lower altitude parts of the valley.

Discharge to Streams and Springs

Discharge to streams occurs in the lower altitude parts of the valley. Discharge occurs to Beaver Creek, the Weber River, and the Provo River as explained in the "Surface-water hydrology" section of this report. The estimate error for ground-water discharge to Beaver Creek could be as much as 50 percent. The estimate error for discharge to the Weber River and Provo River is at least 50 percent. Discharge to springs occurs along benches near Peoa and Francis as explained in the "Surface-water hydrology" section of this report. The estimate error for discharge to springs from Peoa South Bench into Marchant ditch is about 20 percent. The estimate error for discharge to springs north of Fort Creek near Peoa and south of Francis is at least 50 percent. No measurements were made; the estimate is based on field reconnaissance noting wet areas, small channels, vegetation, and other signs of ground-water discharge.

Evapotranspiration

Discharge to evapotranspiration occurs in crop areas in lower altitude parts of the valley (fig. 6) and in riparian areas along the Weber and Provo Rivers. Evapotranspiration from ground water in crop areas was estimated to be the difference between effective precipitation and consumptive use of the crops (table 8). This method assumes that ground-water levels are close enough to land surface to fully supply consumptive use of the crops and that all applied surface water becomes irrigation return flow in these areas. The estimate of 8,000 acre-ft/yr is similar to the 10,000 acre-ft/yr reported by Baker (1970, p. 41). Because of cumulative error in estimating applied water, precipitation, and consumptive use, the estimate error for evapotranspiration could be as much as 80 percent (table A-5).

Wells

Discharge to wells has been an insignificant part of the ground-water system in the unconsolidated deposits of Kamas Valley. On the basis of population (Utah Governor's Office of Planning and Budget, written commun., 1998), domestic wells are estimated to withdraw about 500 acre-ft/yr from the unconsolidated deposits in Kamas Valley. Municipal wells withdraw about 100 acre-ft/yr from the unconsolidated deposits. Wells are scattered throughout the valley and though they may affect water levels locally, they have not affected water levels over wide areas.

As withdrawal from wells increases, however, the ground-water system will be affected. All water withdrawn from wells must be balanced by loss of storage in the ground-water system, decrease in natural discharge, increase in natural recharge, or a combination of these. Loss of storage results in declining ground-water levels and continues until the decrease in natural discharge and increase in recharge equal the rate withdrawn by wells. Decreasing natural discharge would include decreasing discharge to streams, springs, and evapotranspiration. Because of the magnitude of streamflow, the decrease in discharge to streams probably could not be measured. Recharge would be increased if ground-water levels decreased to below the level of streams, thereby causing the streams to lose water to the ground-water system. This may also be too small to measure.

Residual and Error Analysis

The probable ranges of ground-water budget components are listed in table A-6. Recharge from irrigation, recharge from ungaged streamflow, and discharge to Beaver Creek contribute the most uncertainty in the ground-water budget. Just as surface-water outflow is better defined than surface-water inflow, ground-water discharge is better defined than ground-water recharge.

Water-Level Fluctuations

Water-level fluctuations are caused by changes in recharge to and discharge from the ground-water system. The magnitude and timing of fluctuations depend on the amount of recharge and discharge, the amount of ground water that can be stored in the aquifer, and the distances from recharge and discharge areas. Water levels typically fluctuate less in areas where interaction occurs between the aquifer and nearby surface water. Monthly and annual water levels (Haraden and others, 2001, table 3) were examined at wells throughout the study area and are shown on plate 1.

Long-term water-level fluctuations indicate changes in the amount of water that is entering and leaving the aquifer on a multi-year time scale. Water levels have been measured annually in either March or April since 1938 at wells (D-2-6)20ccc-1 and (D-2-6)20dcc-1. The wells are within half a mile of each other and located in the area between Kamas and Francis (pl. 1). Since 1938, March/April water levels have fluctuated less than 3.5 ft. Since 1949, annual precipitation at Kamas has fluctuated from 8.80 in. in 1976 to 24.88 in. in 1983. Water-level stability in the area of the wells may reflect surface-water influences from Weber-Provo Diversion Canal. Surface water in the canal is held near land surface during summer and winter by means of check dams.

Annual water levels since 1988 have also been measured at well (D-2-6)6bcc-1, located at the western edge of Kamas Valley, south of Peoa and adjacent to the West Hills (pl. 1). Here, as in the area between Kamas and Francis, annual water levels have fluctuated less than 3.5 ft. For the area near the well, the lack of water-level fluctuations indicates that not much ground-water recharge occurs to the West Hills and moves as subsurface flow into Kamas Valley. Water-level fluctuations at this well also may be moderated by proximity to Beaver Creek. For water levels in this area and between Kamas and Francis to change dramatically would require large, probably long-term changes in precipitation and/or water-use and irrigation practices.

There is one additional well, located in Francis at (D-2-6)28ccc-3 (Haraden and others, 2001, table 3), for which long-term water-level data exist. The March/April water levels are somewhat erratic and may be showing the effects of early season irrigation rather than multi-year processes. The mid-winter (December and January) water levels are a better indicator of long-term fluctuations; they fluctuated about 5.5 ft during 1938-2000.

Seasonally, water levels in Kamas Valley rise in spring and early summer and decline during winter (pl. 1). This pattern indicates the dominance of surface water on the hydrologic system. Water-level rises begin in April as ephemeral streams begin to carry snowmelt runoff and early season irrigation begins in the valley. Larger rises in May and June are a response to the major diversions of surface water onto croplands during the prime growing season. Water levels decline in fall and winter when irrigation stops and ground water continues to drain into creeks and streams. These patterns indicate a direct correlation between surface water and recharge to ground water. Any change toward decreased or more efficient irrigation will likely cause water-level declines in the valley.

Although the pattern of seasonal fluctuations is fairly consistent in Kamas Valley, the magnitude of fluctuations is highly variable. In the northern parts of Kamas Valley, at wells (D-1-5)10dda-1, along the Weber River and near Browns Canyon and (D-1-6)15acd-2, near where the Weber River enters the valley, seasonal fluctuations are minor (pl. 1). Both wells are completed into consolidated rock and this might be the reason for moderated fluctuations. More likely, it is because the wells are not located in areas of large-scale surface-water irrigation. North of Oakley at wells (D-1-6)16dbc-1 and (D-1-6)20bcb-1 (pl. 1), seasonal water levels fluctuate in excess of 50 ft. Water levels slowly begin to rise in March and April, likely as a result of snowmelt and ephemeral streamflow in Rasmussen and Fort Creeks. Water levels rise rapidly in May in reaction to irrigation from surface-water diversions out of Weber River. Declines in August and September correspond to the end of the irrigation season. Within this area of large water-level change, limited data at well (D-1-6)17cdc-1 (pl. 1) shows less than 10 ft of seasonal change. This well is completed in volcanics and the moderated fluctuations point toward a poor hydraulic connection between unconsolidated deposits and underlying volcanics in the vicinity of the well.

South of the Weber River and east of Marion, water levels start rising in mid-March and continue to rise into June (wells (D-1-6)22bdc-1 and (D-1-6)22cbb-1, pl. 1). The early season water-level rises indicate that this area is influenced by mountain snowmelt and ephemeral streamflow, although irrigation from Weber River also contributes. Water levels fluctuate almost identically in well (D-1-6)22bdc-1, completed in consolidated rock, and well (D-1-6)22cbb-1, completed in unconsolidated deposits, which may indicate a localized hydraulic connection between unconsolidated deposits and nearby consolidated rock. Farther south and directly east of Marion at well (D-1-6)33dcc-1, the same pattern of water-level rises occurs. However, peak water levels declined during 1998-2000. This is likely a result of changing amounts of surface water applied for irrigation. The area is irrigated with surface water flowing from Hoyt Canyon; virtually the entire stream is diverted for this purpose. Quantitative streamflow data for Hoyt Canyon are not available; however, on the basis of streamflow data in the Weber and Provo Rivers and annual precipitation at Kamas (1998-17.84 in.; 1999-15.70 in.; 2000-15.13 in.)(Western Regional Climate Center, 2002), it is reasonable to assume that irrigation from Hoyt Canyon decreased during 1998-2000. This trend is not seen in areas serviced by the Weber and Provo Rivers, where diversion amounts are not as dependent on streamflow. At well (D-2-6)4dda-1, which is closer to the foothills, water levels are stable and do not fluctuate seasonally. This illustrates that near this well and in the nearby foothills, recharge to the unconsolidated deposits is minimal.

In the Kamas and Samak areas, water levels in two wells, completed in consolidated rock, were measured monthly. Water-level rises at both wells began in March, which is characteristic of recharge from snowmelt. Seasonal fluctuation at well (D-2-6)16cda-1 is about 10 ft; water levels slowly rise in spring and slowly decline in fall. At well (D-2-6)26bad-2, located on the hillside south of Samak, water-level rise and decline is more rapid. The extent of decline, which did not exceed about 120 ft below land surface, is probably controlled by the altitude of Beaver Creek. Although precipitation was below normal in 2000, it is not clear why water levels at the hillside well did not rise at all in 2000.

Only minor water-level fluctuations, (wells (D-2-6)20dcc-1 and (D-2-6)29bcb-1, pl. 1) occur in the area between Kamas and Francis near U.S. Highway Alt 189. The small magnitude of change makes it difficult to accurately determine the cause of fluctuations. Along the eastern margin in this same area, continuous water levels were recorded at well (D-2-6)28aab-3 (pl. 1), which is completed in consolidated rock. Water levels in this well undergo about 10 to 15 ft of seasonal change; the same pattern of fluctuation occurs in nearby well (D-2-6)21cdd-1, completed in unconsolidated deposits, but the magnitude of change is much less. The March/April water-level rises in consolidated rock likely reflect recharge from melting snow. Superimposed on the natural recharge/discharge cycle at well (D-2-6)28aab-3 is recharge from some type of rapid and very localized recharge, likely irrigation in an adjacent field. At well (D-2-6)21ddb-1, completed in consolidated rock (Haraden and others, 2001, fig. 2) and located about half a mile to the north, there is no superimposed recharge. At well (D-2-6)20dcc-1, previously discussed in connection with long-term fluctuations, monthly water levels show a slight (less than 1.5 ft) decline during the summer. This is a contrast to most areas of Kamas Valley and may indicate that evapotranspiration of ground water near the well exceeds irrigation.

Water levels between Francis and Woodland are remarkably dynamic; seasonal changes range from 50 to 60 ft throughout a large part of this area. Water levels typically begin rising in late April/early May in response to surface-water irrigation from the Provo River (wells (D-2-6)33cbb-1, (D-2-6)34cbc-2, (D-2-6)34dcc-1, and (D-3-6)3bdb-1, pl. 1). The pattern and magnitude of fluctuations in all of these wells are similar. Water levels begin declining in mid-August and approach equilibrium during late winter/early spring, just before the next irrigation cycle begins. Wells near Francis and along State Highway 35 show the same pattern; however, the magnitude of the fluctuations is attenuated (wells (D-2-6)28ccc-3, (D-2-6)29dcd-1, (D-2-6)33abb-1 and (D-2-6)33ada-1, pl. 1). Water levels in the consolidated rock along the eastern margin of the valley (well (D-2-6)34acc-1, pl. 1) also follow this pattern, indicating localized connection with the unconsolidated deposits.

In the West Hills at Indian Hollow, water levels indicate that recharge to consolidated rock occurs, but that discharge from the consolidated rock to Kamas Valley is minor. At well (D-2-5)11bcd-1, the highest altitude well monitored in Indian Hollow (pl. 1), rapid water-level rises in March indicate recharge from snowmelt and correspond with spring runoff in the creek in Indian Hollow (Haraden and others, 2001, fig. 4). The magnitude of water-level rise decreased dramatically from 1999 to 2000, as did streamflow in the creek. Although precipitation at Kamas was only slightly less in 2000 than in 1999, the decline in water levels might reflect the effects of a second year of less-than-normal precipitation. At the intermediate-altitude well in Indian Hollow, (D-2-5)14daa-1, water-level rises are about one-half the rises at the highest altitude well. At the lowest altitude well, (D-2-5)13adc-1, water levels fluctuate even less. Although the pattern of fluctuation is not identical in the three wells, there is a clear attenuation in magnitude. Ground water recharged in March through May in the upper part of Indian Hollow likely discharges to the creek in the lower areas, resulting in only limited amounts of water leaving the area as subsurface flow to Kamas Valley.

Movement

Ground water generally moves from recharge areas on the benches to discharge areas near Beaver Creek and the Weber River (pl. 1). Ground-water levels and surface-water measurements indicate that most discharge occurs to Beaver Creek. Ground-water discharge to Beaver Creek downstream from the Rocky Point gaging station was not measured during this study, but water-level contours indicate that discharge occurs in this area. A ground-water divide near Francis causes some water to move toward the Provo River, which is deeply incised south and west of Francis. The ground-water divide is more pronounced during July than during March, and the location of the divide may depend on local irrigation practices. Hydraulic gradients and local ground-water movement north of Oakley are not well understood. Many of the observation wells in that area are completed in consolidated rock (pl. 1; Haraden and others, 2001, table 1) because few wells were available for measurement of water levels in unconsolidated deposits. Several of the wells completed in consolidated rock, however, have water-level fluctuations similar to those of wells completed in unconsolidated deposits (pl. 1), and measured water levels are assumed to approximate general flow patterns in the unconsolidated deposits. Hydraulic gradient and direction of flow in the unconsolidated deposits on the bench east of Peoa and north of Fort Creek are not known because observation wells were not available.

Ground-water flow in the Keetley Volcanics near Indian Hollow is from areas of higher altitude toward Kamas Valley (pl. 1). A hydrogeological barrier is not known to prevent this water from flowing into the unconsolidated deposits of Kamas Valley, but the amount of flow is estimated to be small. Water-level fluctuations in the Keetley Volcanics near the valley are small, indicating that little seasonal recharge remains in the Keetley Volcanics near the valley. Limited water-level data indicate that ground water discharges to the creek in Indian Hollow (pl. 1). The steep hydraulic gradient in the area is consistent with the typically low transmissivity values determined by specific capacity (see “Aquifer characteristics” section of this report).

Aquifer Characteristics

Ground water in the unconsolidated deposits of Kamas Valley exists under unconfined conditions. The movement and amount of ground water is described by two important aquifer characteristics, hydraulic conductivity and specific yield. Ground water moves through the interconnected void space of the unconsolidated deposits; hydraulic conductivity is a measure of how easily it moves through the voids. Specific yield describes the amount of water yielded by gravity drainage out of the interconnected void space. Aquifer characteristics are determined by the depositional history, which controls the type, grain-size distribution, and sorting of the unconsolidated deposits. Hydraulic conductivity and specific yield generally increase as sorting and grain size increase. Aquifer characteristics of the unconsolidated deposits were examined on the basis of depositional history and specific-capacity data.

The depositional history of Kamas Valley is complex, ranging from glacial outwash to debris-fan deposits. On the basis of geologic mapping by Bryant (1990) and Hurlow (2002, pl. 1) the unconsolidated deposits on the valley have been generalized into five categories: (1) alluvium, (2) terrace gravels, (3) alluvial-fan and debris-fan deposits, (4) outwash deposits, and (5) landslide deposits (fig. 3). Alluvium, terrace gravels, and outwash deposits consist, in part, of moderate to well-sorted boulders, gravels, and sands (larger grain size material). Despite a silt and clay matrix, sorting and the larger grain size will result in relatively higher hydraulic conductivities (Fetter, 1994, p. 99). Alluvial- and debris-fan deposits are less sorted and weakly layered, resulting in generally lower conductivity values (Fetter, 1994, p. 99). Using these depositional inferences, on the eastern edges of the valley where alluvial and debris fans predominate, hydraulic-conductivity values are generally expected to be lower (Hurlow, 2002, p. 22). On the western side of the valley where alluvium predominates, hydraulic-conductivity values are likely to be higher. For the entire valley, hydraulic conductivity probably decreases with depth as a result of increased clay content and compaction (Hurlow, 2002, p. 22).

Depositional history can give a general sense of the gross spatial distribution of aquifer characteristics. Actual quantification of aquifer characteristics involves measuring ground-water withdrawals and resultant water-level changes. This provides point-specific values. For this study, specific-capacity data offers a practical method of broadly surveying aquifer characteristics within order-of-magnitude accuracy (table 9). Specific capacity is the ratio of discharge from a well per unit drawdown and is presented as gal/min per foot of drawdown. The Cooper and Jacob (1946) approximation of the Theis equation can be rearranged to equate specific capacity to a function of transmissivity and specific yield (Lohman, 1972, p. 52). The equation can be solved iteratively if you assume a value for specific yield and assume that drawdown in a well represents drawdown in the aquifer at a distance of the well radius (Bradbury and Rothschild, 1985). Hydraulic conductivity can then be determined by dividing transmissivity by the saturated thickness of the water-bearing material.

The Theis equation assumes confined aquifer conditions, which do not exist in Kamas Valley. However, the method described can be applied to unconfined conditions as long as drawdowns are small with respect to total saturated thickness of the aquifer. This criteria was not met at all wells completed in unconsolidated deposits. Aquifer geometry and saturated thickness is not known for the consolidated rock. Although the question of saturated thickness is important, it was not considered critical for this order-of-magnitude analysis.

On the basis of information reported on drillers' logs and gathered during the study (Haraden and others, 2001, table 4), specific capacity and transmissivity were determined for wells completed in both unconsolidated deposits and consolidated rock (fig. 7, table 9). Transmissivities for the unconsolidated deposits are corrected for the fact that the wells do not draw water from the entire saturated thickness (partial penetration). Because of limited data and fracture-flow characteristics, consolidated-rock wells were not corrected for partial penetration. None of the wells were corrected for head loss that may occur as water enters the well from the surrounding deposits. No direct data exists to determine specific-yield values in Kamas Valley so an assumed value of 0.15 was used to determine transmissivity. Lohman (1972, p. 8) states that specific yield averages about 0.2; Fetter (1994, table 4.4) lists average values ranging from 0.02 to 0.27. Because of the numerous simplifications and additional assumptions that (1) wells are usually constructed to draw water from zones of relatively higher productivity, and (2) ground water removed during pumping is instantaneously released from storage, transmissivity values are only considered accurate to the nearest order of magnitude.

Transmissivity of the unconsolidated deposits shows a high degree of variability that ranges over four orders of magnitude (fig. 8). This is partially a result of inconsistencies in testing methods; however, values determined from more controlled field measurements (drawdown reported to an accuracy of 0.01 ft in table 9) still show a variability of three orders of magnitude. Because of inherent assumptions and varied degrees of reporting accuracy, transmissivity values should be considered as a rough estimate rather than a definitive value for a specific area. The most common transmissivities are 1,000 and 10,000 ft^2/d (table 9, fig. 8). Some average of these values is a reasonable estimate of the transmissivity of the unconsolidated deposits in Kamas Valley. This leads to an average hydraulic conductivity of about 50 ft/d for the unconsolidated deposits. Hydraulic conductivity was calculated by using wells with transmissivity values of either 1,000 or 10,000 ft^2/d and dividing by 50 percent of the saturated thickness listed in table 9. The unconsolidated deposits are heterogeneous and the assumption was made that observed transmissivity is derived from one half of the thickness of the aquifer. This assumption also tries to compensate for the fact that most water wells are typically constructed to draw water from the more productive zones of the aquifer.

Transmissivity of the consolidated rock shows the same degree of variability as the unconsolidated deposits (four orders of magnitude, table 9), but the most common transmissivity is 100 ft^2/d. Generally, consolidated rock will not yield as much water as unconsolidated deposits. However, the aquifer characteristics of consolidated rock can be extremely variable and it is possible that a well completed in a highly fractured zone can yield large amounts of water. Because of heterogeneity and the complexity of correcting for the structural geometry of consolidated rock, it is difficult to estimate saturated thickness with any degree of confidence and hydraulic conductivity cannot be determined.

Table 9. Specific capacity and transmissivity values at selected wells, Kamas Valley, Utah

[—, no data]

Saturated thickness: Determined by subtracting the static water level from the thickness of the unconsolidated deposits as determined from Hurlow (2002, pl. 4).

Open interval: Determined from drillers' logs; if the casing is not perforated, an open interval of 5 feet was assumed.

Transmissivity: Calculated on the basis of specific capacity with a method described by Bradbury and Rothschild (1985). Because of assumptions made in the calculation, transmissivity values are only accurate to the nearest order of magnitude. Transmissivity values were calculated with a specific-yield value of 0.15. Transmissivity values increase by about 10 percent if a specific-yield value of 0.05 is used; this is not significant enough to change the order-of-magnitude estimates. Wells are only open to a part of the saturated thickness of the unconsolidated deposits and this partial penetration can cause specific capacity to be anomalously low. Therefore, transmissivity values are corrected by using a function based on saturated thickness divided by open interval (Bradbury and Rothschild, 1985). Saturated thickness values used for the correction are one half of the listed values. This was done because water wells typically draw from the most productive parts of the saturated deposits. In Kamas Valley, 50 percent of the total saturated thickness is assumed to have a comparable permeability. Because of the unknowns associated with consolidated rock, no correction was made for partial penetration for wells completed in consolidated rock. Well loss was assumed to be negligible.

Local well number (fig. 2)	Diameter (inches)	Drawdown (feet)	Time (hours)	Discharge (gallons per minute)	Saturated thickness (feet)	Open interval (feet)	Specific capacity (gallons per minute per foot of drawdown)	Transmissivity (feet squared per day)
Unconsolidated deposits								
(D-1-5)15aad-1	8	12	1	20	146	13	2	1,000
(D-1-5)25bdc-1	6	21	3	30	182	5	1	1,000
(D-1-5)25dbc-1	6	30	4	30	192	15	1	1,000
(D-1-6)21cbb-1	8	1	2	30	130	5	30	10,000
(D-1-6)21ddd-1	6	6	1	40	286	5	7	10,000
(D-1-6)27bcb-1	5	5	4	12	400	20	2	1,000
(D-1-6)28	6	10	2	15	840	5	2	10,000
(D-1-6)28cba-1	5	5.34	4	15	884	20	3	10,000
(D-1-6)29cbd-1	8	15	5	20	586	5	1	10,000
(D-1-6)29ccc-1	6	21.89	1.4	11	588	5	1	1,000
(D-1-6)34cca-1	6	30	1	20	1,056	5	1	10,000
[1](D-2-6)4cbc-1	8	10	1	20	—	—	2	100
(D-2-6)5ada-1	8	1.30	3.2	35	1,068	20	27	100,000
(D-2-6)5dab-1	5	1.13	1.8	15	1,082	20	13	100,000
(D-2-6)19bac-1	12	10	8	60	192	10	6	10,000
(D-2-6)21cdd-1	6	6	1	37	134	5	6	10,000
(D-2-6)21dcc-2	4.5	4.04	.6	16	116	20	4	1,000
(D-2-6)21ddc-1	5	30	4	20	120	60	1	100
(D-2-6)28cda-1	8	2	8	100	196	5	50	100,000
[2](D-2-6)29bcb-1	8	5	2	100	210	9	20	10,000
(D-2-6)29bcc-1	8	10	3	30	210	5	3	10,000
(D-2-6)29cbb-1	6	42	1	30	156	39	1	100
(D-2-6)30aaa-1	6	125	3	10	200	20	0	10
(D-2-6)30aad-2	8	57	1	20	100	20	0	100
(D-2-6)33abb-1	6	40	4	6	230	5	0	100
Consolidated rock								
(D-1-5)13dba-1	5	33	1	20	—	—	1	100
(D-1-5)13dcb-1	8	117	1	100	—	—	1	100
(D-1-5)15acb-1	6	90	10	35	—	—	0	100
(D-1-6)15acc-1	5.5	20	24	37	—	—	2	100
(D-1-6)17cca-2	6	6	13	11	—	—	2	100

Table 9. Specific capacity and transmissivity values at selected wells, Kamas Valley, Utah—Continued

Local well number (fig. 2)	Diameter (inches)	Drawdown (feet)	Time (hours)	Discharge (gallons per minute)	Saturated thickness (feet)	Open interval (feet)	Specific capacity (gallons per minute per foot of drawdown)	Transmissivity (feet squared per day)
Consolidated rock-Continued								
(D-1-6)19bbc-1	8	5	4	12	—	—	2	100
(D-1-6)19caa-1	4.5	5.51	2	18	—	—	3	100
(D-1-6)20bcb-1	6	100	4	3	—	—	0	1
(D-1-6)22bdc-1	16	100	35	240	—	—	2	100
(D-1-6)22dbc-1	6	300	72	650	—	—	2	100
(D-1-6)34ccc-1	8	60	6	30	—	—	1	100
(D-2-5)13aaa-1	5	20	2	15	—	—	1	100
(D-2-5)13adc-1	5	40	2	15	—	—	0	10
(D-2-6)3cbc-1	5.5	90	2	50	—	—	1	100
[1](D-2-6)4cbc-1	8	10	1	20	—	—	2	100
(D-2-6)16cda-1	12	30.01	20	1,300	—	—	43	10,000
(D-2-6)21acd-1	5	100	2	60	—	—	1	100
(D-2-6)21dbc-1	6	20	4	18	—	—	1	100
(D-2-6)25dba-1	5	6.51	1.7	10	—	—	2	100
(D-2-6)26aba-1	6	9	24	33	—	—	4	1,000
(D-2-6)26abc-1	12	105	48	125	—	—	1	100
(D-2-6)27ccd-1	8	67	8	219	—	—	3	1,000
(D-2-6)28add-1	4.5	65	1	30	—	—	0	10
[2](D-2-6)29bcb-1	6	30.09	2.5	36	—	—	1	100
(D-2-6)30aad-1	6	100	1	40	—	—	0	10
(D-2-6)32dba-1	5	60	1	15	—	—	0	10
(D-2-6)34acc-1	5	20	1	15	—	—	1	100
(D-2-6)34dcd-1	6.6	10.17	2	27	—	—	3	100

[1]Well is completed in unconsolidated deposits; formation is incorrect in table 4 of Haraden and others (2001).
[2]Well originally completed in unconsolidated deposits; well deepened in November 2000 and completed in alluvium and volcanics.

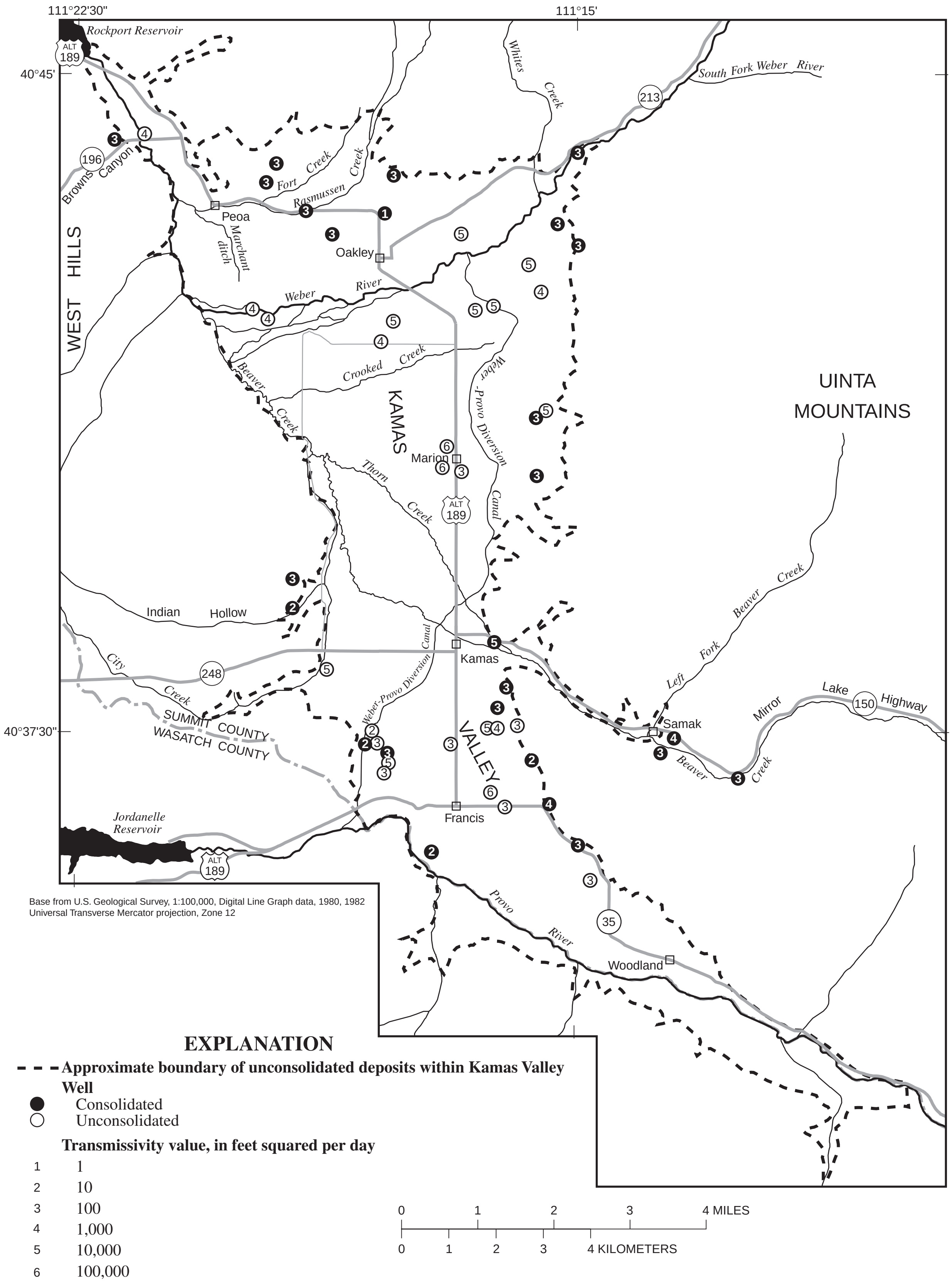

Figure 7. Transmissivity values at selected wells in Kamas Valley, Utah.

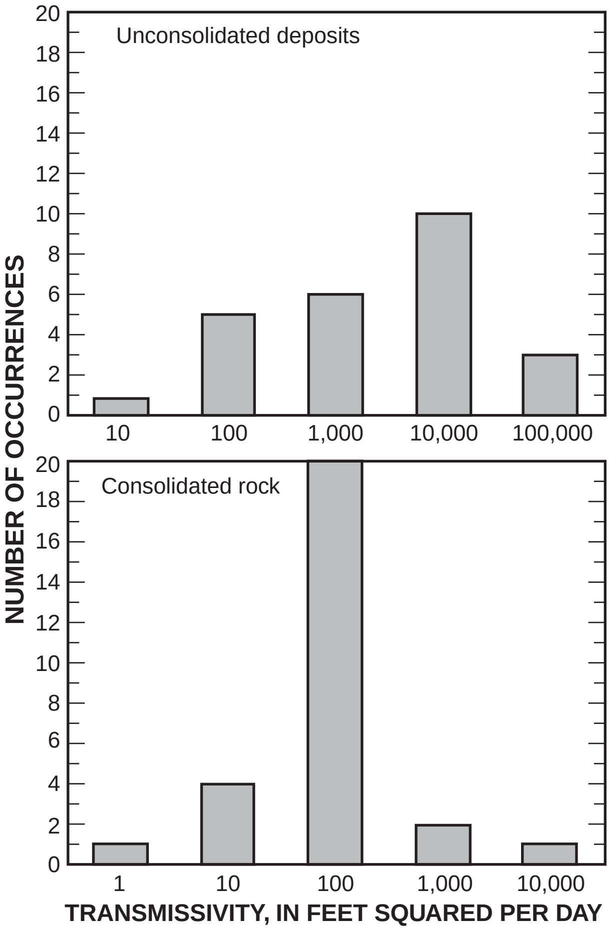

Figure 8. Histogram of transmissivity values in unconsolidated deposits and consolidated rock, Kamas Valley, Utah.

Well Interference

Water-level declines occur in response to the withdrawal of ground water. In the large-scale context, water levels decline when ground-water pumping creates an imbalance between regional recharge and discharge. At the scale of individual wells, pumping creates a localized water-level decline, referred to as a cone of depression. It is this decline that induces ground-water flow toward a pumping well. Interference among closely spaced wells happens when the cone of depression at one well extends to and creates a water-level decline in neighboring wells. Well interference is examined from the viewpoint of these short-term interactions among closely spaced wells.

Ground water in Kamas Valley is generally unconfined and ground water that flows to a pumping well comes from gravity drainage of the pore space within the unconsolidated deposits. Under these conditions the cone of depression is generally not laterally extensive. The Theis equation (Theis, 1935) is used to determine the degree of interference resulting from short-term ground-water withdrawals at closely spaced wells. This mathematical solution assumes that the source of water to the well is storage, that the cone of depression does not intercept hydrologic boundaries, and that the aquifer is confined. The solution does not account for the long-term effects of changing the balance between regional recharge and discharge. Since ground water in Kamas Valley is unconfined, aquifer transmissivity will decrease within the cone of depression. The effect is that the Theis solution will over-estimate the lateral extent of the cone of depression and under-estimate drawdown at the pumping well.

To quantify the potential for interference among wells the following assumptions are made: (1) aquifer transmissivity is equal to 1,000 ft^2/d, (2) pumping of nearby wells totals 250 gal/min, and (3) specific yield of the aquifer is 0.05. With these values, well interference (or drawdown) at a distance of 300 ft after 1 day of pumping is less than 1 ft. This illustrates that average aquifer characteristics of Kamas Valley are such that closely spaced domestic wells turning on and off in response to daily water needs will not interfere with one another.

Transmissivity and specific-yield values used in this analysis represent the low end of likely values (see “Aquifer characteristics” section of this report). If transmissivity is increased, the lateral extent of the cone of depression will be greater and interference could increase. This is offset by the fact that drawdown at the pumping well is less. If specific yield is increased, chances of interference will decrease. To place the interference analysis into perspective, consider that the average domestic well is sized to deliver 25 gal/min. Because a 300-ft radius circle is equivalent to about 7 acres, density is 1 well per 0.7 acres. Calculated drawdown is for a single unpumped well surrounded by 10 wells pumping at full capacity for an entire day.

QUALITY OF WATER

Water samples were collected from surface- and ground-water sites throughout Kamas Valley and vicinity to establish baseline water-quality conditions and to evaluate potential effects on water quality from increasing residential development, septic systems, and agricultural practices. Water samples were collected from 39 wells and springs, and 24 surface-water sites, in Kamas Valley and along Beaver Creek and the Weber River from 1997 to 2000. Constituents sampled for each site are listed in table 10 and were selected to characterize general water quality, allow classification of ground water, and target potential contaminants. These include physical properties (water temperature, pH, and specific conductance), major ions, dissolved-solids concentration, nutrients, selected trace elements, radionuclides (gross alpha and beta), dissolved organic carbon, methylene blue active substances or surfactants (MBAS), pesticides, and total and fecal coliform bacteria. Nutrients analyzed included nitrogen (ammonia, nitrate, and nitrite) and phosphorus (total and orthophosphate). Trace elements were selected to correspond with the suite of metals established for ground-water quality protection by the State of Utah (Department of Environmental Quality, Division of Water Quality, 1995) and include aluminum, arsenic, barium, cadmium, chromium, copper, lead, selenium, silver, and zinc. In addition, boron, bromide, iron, and manganese were analyzed in water from almost all ground- and surface-water sites sampled. Physical properties measured and results of analyses for all ground- and surface-water samples are published in Haraden and others (2001) and are discussed below.

Methods

All water samples collected during this study except total and fecal coliform bacteria were analyzed at the U.S. Geological Survey National Water Quality Laboratory (NWQL) in Denver, Colorado. Total and fecal coliform bacteria were analyzed at the Utah State Health Laboratory in Salt Lake City, Utah. Analytical methodology used at the NWQL is described in Fishman and Friedman (1989).

Water samples collected for analysis of major and minor ions, trace elements, dissolved-solids concentration, and gross alpha/beta were filtered on-site (0.45-micron capsule filter) and collected in opaque polyethylene bottles. Nutrient samples were filtered and collected in brown polyethylene bottles. Samples for dissolved organic carbon also were filtered on-site (0.45-micron silver membrane filter) and collected in brown, baked glass bottles. Samples for pesticides were obtained directly from the well (whole water) or stream (filtered) and also collected in brown, baked glass bottles. Water samples collected for analysis of physical properties, MBAS, and total and fecal coliform bacteria were collected directly from the well and submitted as whole water (unfiltered) samples. Samples collected for total and fecal coliform bacteria were collected in 50 ml clear plastic bottles provided by the Utah State Health Laboratory. Samples collected for analysis of cations, trace metals, and gross alpha/beta were stabilized with nitric acid to a pH of less than 2 to prevent precipitation of dissolved constituents between field collection and laboratory analysis. Water samples collected for analysis of nutrients, dissolved organic carbon, MBAS, pesticides, and total and fecal coliform bacteria were chilled on ice from time of collection to laboratory analysis to inhibit growth of microorganisms or degradation of organic material. Total and fecal coliform bacteria samples were delivered to the Utah State Health Laboratory within 24 hours of sample collection.

To obtain representative ground-water samples, water samples were collected after the well had been purged for about 1.5 hours and when water temperature, pH, and specific conductance were stable. In most cases, this time frame was sufficient to evacuate the equivalent of three casing volumes from the well. Surface-water samples were collected mid-stream as grab samples or composited by using either equal width increment (EWI) or equal discharge increment (EDI) techniques. Water temperature, pH, specific conductance, and total alkalinity were determined in the field at the time of sample collection. Temperature of water from wells was measured at the discharge point (usually a tap on or near the well) to the nearest 0.5 degree Celsius. Specific conductance and pH values were determined after calibration with standards in the range of the water-sample values. Calculated values for total alkalinity, and bicarbonate and carbonate concentrations, were determined by titration. Specific conductance, pH, and alkalinity also were determined in the laboratory. Procedures for collection of water-quality samples and determination of field parameters are outlined in Wilde and others (1998-99).

Table 10. Physical properties measured and chemical constituents sampled at selected ground- and surface-water sites, Kamas Valley and vicinity, Utah, 1997-2000

[X, data available; —, no data]

Location: See figure 2 for an explanation of the numbering system used for hydrologic-data sites in Utah.
Source of water: ALVM, unconsolidated deposits; CONR, consolidated rock.
Physical properties: Water temperature, pH, specific conductance.

Location	Source of water	Date sampled	Physical properties	Major ions	Trace elements	Nutrients	Dissolved organic carbon	Methylene blue active substances	Pesticides	Radionuclides	Total and fecal coliform bacteria
				Ground-water sites							
(A-1-8)36bba-1	ALVM	09-21-2000	X	X	—	X	X	X	—	—	X
(D-1-5)13cdb-1	ALVM	07-27-2000	X	X	—	X	X	X	—	—	X
(D-1-5)15acb-1	CONR	07-20-2000	X	X	X	X	X	X	—	X	X
(D-1-5)23dda-1	ALVM	05-30-2000	X	X	X	X	X	X	X	—	X
(D-1-5)25dbb-1	CONR	09-06-2000	X	X	—	X	X	X	—	X	X
(D-1-6)15acc-1	CONR	08-21-1998	X	X	—	—	—	—	—	—	—
		05-31-2000	X	X	X	X	X	X	—	—	X
(D-1-6)16dbc-1	CONR	07-26-2000	X	X	X	X	X	X	—	X	X
(D-1-6)18ddb-1	ALVM	09-13-2000	X	X	—	X	X	X	—	—	X
(D-1-6)19dbd-1	CONR	08-24-2000	X	X	—	X	X	X	—	—	X
(D-1-6)21cbb-1	ALVM	06-01-2000	X	X	—	X	X	X	—	—	X
(D-1-6)22cbb-1	ALVM	08-31-2000	X	X	—	X	X	X	—	—	X
(D-1-6)28cbc-1	ALVM	06-14-2000	X	X	X	X	X	X	X	X	X
(D-1-6)29ccc-1	ALVM	08-21-2000	X	X	—	X	X	X	—	—	X
(D-1-6)32daa-1	ALVM	09-11-2000	X	X	—	X	X	X	—	—	X
(D-2-5)11dcc-1	CONR	09-28-2000	X	X	—	X	X	X	—	—	X
(D-2-5)13cad-1	CONR	06-13-2000	X	X	X	X	X	X	—	X	X
(D-2-5)24ada-1	ALVM	05-15-2000	X	X	—	X	X	X	X	—	X
(D-2-5)24cbb-S1	CONR	08-15-2000	X	X	—	X	—	—	—	—	X
(D-2-6)3bac-1	ALVM	11-30-1998	X	X	—	X	—	—	—	—	—
		05-18-2000	X	X	—	X	X	X	—	—	X
(D-2-6)4dac-1	ALVM	08-28-2000	X	X	X	X	X	X	—	X	X
(D-2-6)4dad-1	ALVM	09-09-1997	X	X	—	X	—	—	—	—	—
(D-2-6)6bcc-1	CONR	05-24-2000	X	X	X	X	X	X	—	—	X
(D-2-6)8ddd-1	ALVM	08-22-2000	X	X	—	X	X	X	—	—	X
(D-2-6)9bbb-1	ALVM	05-22-2000	X	X	X	X	X	X	X	—	X
(D-2-6)21ddb-1	CONR	08-03-2000	X	X	X	X	X	X	—	X	X
(D-2-6)23adc-S1	CONR	10-27-1999	X	—	—	X	—	—	—	—	—
(D-2-6)23ccd-1	CONR	08-31-2000	X	X	—	X	X	—	—	—	X
(D-2-6)25aad-1	CONR	09-27-2000	X	X	—	X	X	X	—	—	X
(D-2-6)25caa-1	ALVM	09-28-2000	X	X	—	X	X	X	—	—	X
(D-2-6)25dba-1	CONR	08-29-2000	X	X	—	X	X	X	—	—	X
(D-2-6)26aad-1	ALVM	11-02-2000	X	X	—	X	X	X	—	—	X
(D-2-6)26abb-1	CONR	10-03-2000	X	X	—	X	X	X	—	—	X
(D-2-6)27ccc-1	ALVM	08-29-2000	X	X	—	X	X	X	—	—	X
(D-2-6)29ada-1	ALVM	08-16-2000	X	X	—	X	X	X	X	—	X
(D-2-6)29bcb-1	ALVM	06-21-2000	X	X	X	X	X	X	—	X	—
	ALVM/CONR	11-28-2000	X	X	—	X	—	—	—	X	X
(D-2-6)33cab-1	ALVM	09-12-2000	X	X	—	X	X	X	—	—	X
(D-2-6)34dcd-1	ALVM/CONR	07-25-2000	X	X	X	X	X	X	X	X	X

Table 10. Physical properties measured and chemical constituents sampled at selected ground- and surface-water sites, Kamas Valley and vicinity, Utah, 1997-2000—Continued

Location	Source of water	Date sampled	Physical properties	Major ions	Trace elements	Nutrients	Dissolved organic carbon	Methylene blue active substances	Pesticides	Radionuclides	Total and fecal coliform bacteria
Ground-water sites—Continued											
(D-3-6)2dbb-1	ALVM	09-07-2000	X	X	—	X	X	X	—	—	X
(D-3-6)4aad-1	ALVM	08-21-2000	X	X	—	X	X	X	—	—	X
Surface-water sites											
(A-1-7)27ddd	Weber River above Smith and Morehouse Creek	10-26-1999	X	—	—	X	—	—	—	—	—
(A-1-7)31dcb	Weber River at Weber Canyon Road	10-26-1999	X	—	—	X	—	—	—	—	—
(A-1-7)33aba	Smith and Morehouse Creek at Weber River	10-26-1999	X	—	—	X	—	—	—	—	—
(A-1-7)33baa	Weber River below Smith and Morehouse Creek	08-14-2000	X	—	X	X	—	—	—	—	—
(A-1-7)35aaa	Smith and Morehouse Creek below reservoir	10-26-1999	X	—	—	X	—	—	—	—	—
(A-1-8)25cbc	Weber River at Dry Fork	10-26-1999	X	—	—	X	—	—	—	—	—
(A-1-8)25ccb	Holiday Park Spring at junction with Weber River	10-26-1999	X	—	—	X	—	—	—	—	—
(A-1-8)26daa	Weber River at Holiday Park	09-21-2000	X	X	—	X	X	X	—	—	X
(D-1-5)10bdb	Weber River near Peoa	08-14-2000	X	X	X	X	X	—	X	—	—
(D-1-5)23aca	Marchant ditch	09-01-2000	X	X	—	X	X	X	X	—	X
(D-1-6)12bdd	Weber River at South Fork	10-26-1999	X	—	—	X	—	—	—	—	—
(D-1-6)12bdd	South Fork at Weber River	10-26-1999	X	—	—	X	—	—	—	—	—
(D-1-6)15adb	Weber River near Oakley	08-11-2000	X	X	X	X	X	—	X	—	—
(D-2-5)1aad	Beaver Creek at Rocky Point	10-27-1999	X	—	—	X	—	—	—	—	—
(D-2-5)13dba	Indian Hollow	10-27-1999	X	—	—	X	—	—	—	—	—
(D-2-5)24cbd	City Creek	10-27-1999	X	—	—	X	—	—	—	—	—
(D-2-6)17dac	Beaver Creek at Weber-Provo Diversion Canal	10-27-1999	X	—	—	X	—	—	—	—	—
(D-2-6)21aaa	Beaver Creek at Grist Mill	03-12-2000	X	X	X	X	X	—	—	—	—
		08-11-2000	X	X	X	X	X	—	X	—	—
(D-2-6)22dca	Beaver Creek at Lind Bridge	09-07-2000	X	X	—	X	X	X	—	—	X
(D-2-6)23cdd	Inflow from Left-Hand Canyon below Samak Road	10-27-1999	X	—	—	X	—	—	—	—	—
(D-2-6)25dbb	Beaver Creek 1 mile above Samak hatchery	10-27-1999	X	—	—	X	—	—	—	—	—
(D-2-6)26abb	Beaver Creek below Samak fish hatchery	10-27-1999	X	—	—	X	—	—	—	—	—
(D-2-6)26baa	Inflow from Willow Spring	10-27-1999	X	—	—	X	—	—	—	—	—
(D-2-7)19cad	Beaver Creek 2 miles above Samak hatchery	10-27-1999	X	—	—	X	—	—	—	—	—

Four quality-assurance water samples were collected, processed, and submitted to the NWQL, along with environmental water-quality samples collected during the study. These included three inorganic blank samples and a duplicate sample. Inorganic blank water with very low (trace) concentrations of major ions, selected trace elements, and nutrients was used to assess contamination among samples during processing of water samples. After an environmental water sample from a well was processed, the sample container and filtration apparatus were cleaned with deionized water and a 5-percent solution of hydrochloric acid. The inorganic blank water was then processed through the same equipment, collected, and analyzed. A field duplicate was collected to evaluate consistency in the methods used to collect and analyze water samples, and to evaluate laboratory analytical precision. The duplicate sample was collected and processed immediately after the routine water sample, using the same techniques. Results of analysis for blank and duplicate samples are summarized in Haraden and others (2001, table 19).

Surface Water

Physical properties, major ions, dissolved-solids concentration, nutrients, and dissolved organic carbon were analyzed in water from seven surface-water sites along the Weber River, Beaver Creek, and Marchant ditch. Physical properties and nitrate were analyzed at an additional 17 sites along these streams as well as in City Creek and Indian Hollow. Specific conductance of water from selected sites along the Weber River ranged from 91 to 360 µS/cm at 25°C, and in water from Beaver Creek from 82 to 420 µS/cm. Low conductance values are from the headwaters or upstream areas of these drainage basins, where streamflow originates directly from precipitation, residence times are short, and/or water has had minimal contact with unconsolidated deposits or consolidated rock. Generally, water increases in specific conductance downstream as inflow from tributaries and ground water with higher conductance mixes with surface water. During August 11-14, 2000, specific conductance of water from the Weber River below Smith and Morehouse Creek was 190 µS/cm, water from the Weber River near Oakley was 240 µS/cm, and water from the Weber River near Peoa was 335 µS/cm. Specific-conductance values generally are dependent upon discharge; with increasing discharge, conductance typically decreases from dilution. Surface streams that originate from springflow however, generally show considerably less fluctuation with discharge. Flow in Marchant ditch varied from 3.4 to 15 ft^3/s during 1998 to 2000, but specific conductance varied only from 410 to 495 µS/cm. Because dissolved-solids concentration is typically about 65 percent of measured specific-conductance values, dissolved-solids concentration in surface streams in the study area generally is less than 300 mg/L. Hydrogen-ion concentrations (pH) in surface water ranged from 7.6 to 8.7.

Nitrate plus nitrite (as N) concentrations in surface water from seven sites in the study area ranged from less than 0.050 to 0.37 mg/L. Nitrate (as N) concentrations in whole water (unfiltered) samples from 17 additional sites were determined by photometric analysis (CHEMetrics vacu-vials) and ranged from 0.23 to 0.68 mg/L. These values are substantially below the State of Utah drinking-water standard of 10 mg/L for nitrate (Utah Department of Environmental Quality, Division of Drinking Water, 2001). Concentrations of orthophosphorus (as P) in water from selected sites along the Weber River, Beaver Creek, and Marchant ditch also were very low, ranging from less than 0.010 to 0.028 mg/L.

Total and fecal coliform bacteria were detected in water from selected sites along the Weber River, Beaver Creek, and Marchant ditch. The maximum total coliform count was 640 in 100 milliliters of water from Beaver Creek. Further, water samples from selected sites along Beaver Creek above, near, and below Samak during fall 2000, when discharge was low, showed increasing levels of total coliform bacteria downstream. Total and fecal coliform counts in surface water initially may be higher after storms, as overland runoff containing bacteria enters streams. Coliform bacteria in surface water throughout the study area probably originate from livestock and domestic animals rather than septic systems, because concentrations of nitrate, MBAS, and coliform bacteria in ground water are very low or absent.

Selected trace elements were analyzed for in water from four surface-water sites along the Weber River and Beaver Creek. Results of analysis indicate very low concentrations of these constituents, and in many cases, less than laboratory reporting levels. No constituent was present in concentrations that exceeded the State of Utah drinking-water standards (Utah

Department of Environmental Quality, Division of Drinking Water, 2001).

Pesticides were analyzed for in water from four sites along the Weber River, Beaver Creek, and Marchant ditch. Diazinon, P P' DDE, and trifluralin were detected in very low (trace) concentrations in water from the Weber River near Peoa (above Rockport Reservoir). Atrazine, deethylatrazine, and simazine also were detected in very low concentrations in water from Marchant ditch. Concentrations of these constituents did not exceed 0.005 µg/L and may originate from agricultural activities.

Ground Water

Thirty-seven wells were sampled from 1997 to 2000, of which 22 are completed in unconsolidated deposits and 15 are completed in consolidated rock (table 10). At least two of the wells completed in consolidated rock also are open to the overlying unconsolidated deposits. Well (D-2-6)29bcb-1 initially was completed in unconsolidated deposits and subsequently drilled deeper and completed in both unconsolidated deposits and Keetley Volcanics. Well depths throughout the study area range from 10 ft (hand dug) to 450 ft. Most of the wells sampled are used for domestic purposes, with a lesser number used for irrigation and stock purposes. Two springs discharging from consolidated rock also were sampled.

Physical properties, major ions, dissolved-solids concentration, nutrients, dissolved organic carbon, MBAS, and total and fecal coliform bacteria were analyzed for in water from all or most of the wells sampled. Water temperature from wells ranged from 7.0 to 12.0^{o}C. Because temperature was generally measured in water discharging from a tap near the well, values higher than about 9.5^{o}C probably do not represent actual ground-water temperatures. Hydrogen-ion concentration (pH) of water from wells ranged from 6.2 to 7.9. Values less than 7.0 were from areas near the Provo River and in the headwaters of the upper Weber River, where ground water also contains the lowest dissolved-solids concentrations. Calculated hardness of water from wells ranged from 12 mg/L to as much as 440 mg/L, with an average of about 215 mg/L. Water with hardness values greater than 180 mg/L is considered very hard (Durfor and Becker, 1964).

Dissolved-solids concentration in water from wells completed in unconsolidated deposits in Kamas Valley and along Beaver Creek ranged from 124 to 517 mg/L, with a mean of about 265 mg/L. Dissolved-solids concentration in water from wells completed in consolidated rock in this area ranged from 183 to 656 mg/L, with a mean of about 320 mg/L. Water from only four wells and one spring exceeded a dissolved-solids concentration of 450 mg/L. As a result, on the basis of dissolved-solids concentrations, most ground water in the Kamas Valley area could be classified as Class 1A - Pristine Ground Water (Utah Department of Environmental Quality, Division of Water Quality, 1995).

Some of the lowest dissolved-solids concentrations (less than 150 mg/L) in the study area were in water from wells near the Provo River. Lower concentrations in this area are probably related to the effects of using water from the Provo River for irrigation. Hydrographs for selected wells in this area (pl. 1) indicate a substantial rise in water levels during the summer when water from the river is diverted to canals and ditches and applied to fields. On the basis of specific-conductance values, dissolved-solids concentrations in water from the Provo River are typically less than 200 mg/L (ReMillard and others, 1991). Mixing of downward moving irrigation water with ground water that has a higher dissolved-solids concentration could result in the relatively low concentrations observed in well water.

Other possible explanations for low dissolved-solids concentrations in ground water in this area and in several other wells in the study area include proximity of the wells to a river (surface-water/ground-water interaction), the location of the wells in upgradient areas of the ground-water flow system (generally lower concentrations than in downgradient areas), or more permeable zones of better quality water. Water from well (A-1-8)36bba-1, adjacent to a headwater tributary of the Weber River, contained a dissolved-solids concentration of only 29 mg/L. The specific conductance of water in the tributary, however, was about the same as that of the well water, indicating a probable hydraulic connection. Water from the Keetley Volcanics and Weber Sandstone also tends to contain low dissolved-solids concentrations.

Results of analysis for major-ion chemistry in water samples from wells in unconsolidated deposits indicate that water in the Kamas Valley area is generally a calcium-bicarbonate type (fig. 9). Water

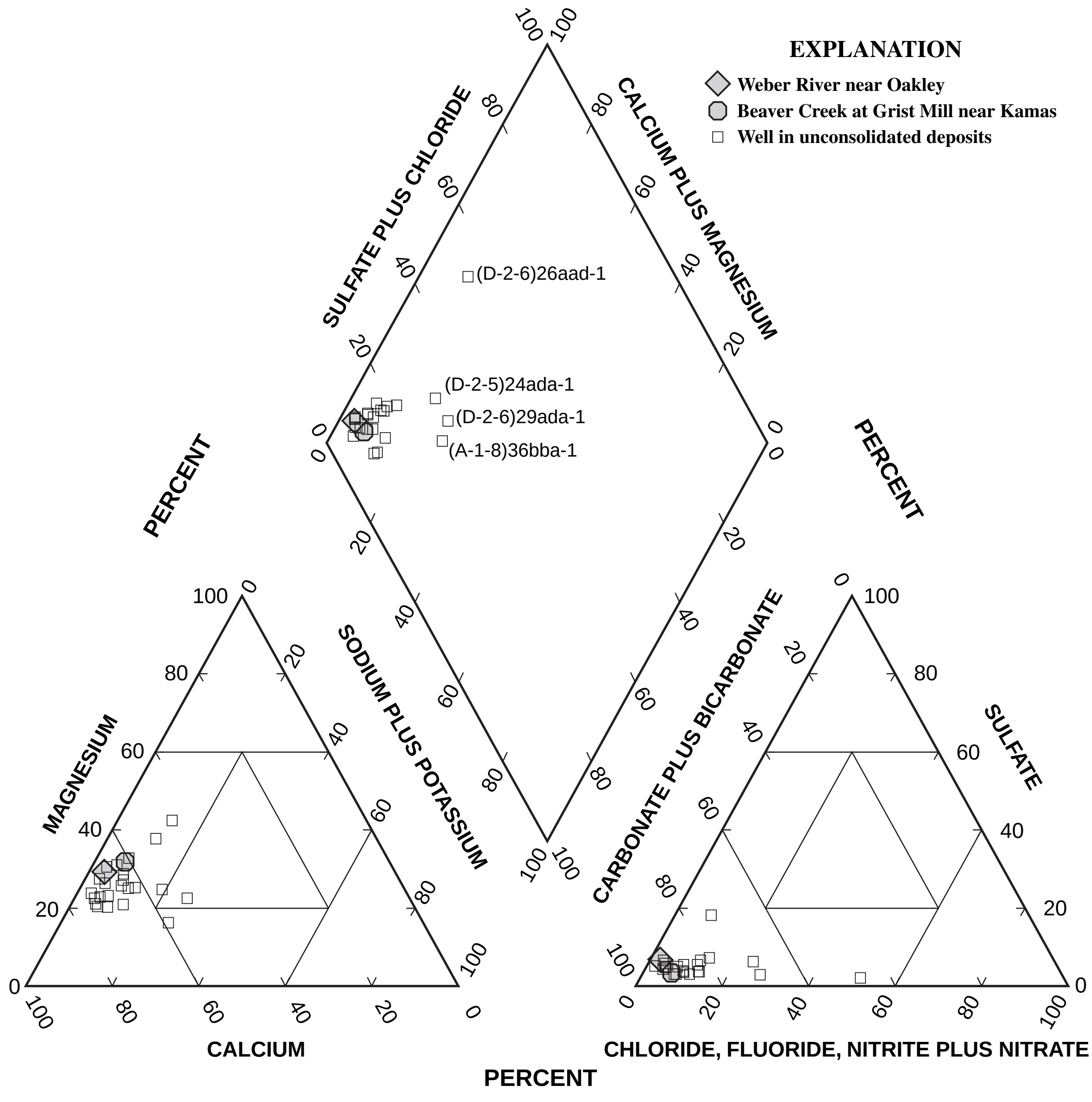

Figure 9. Chemical composition of water from unconsolidated deposits and surface water, Kamas Valley and vicinity, Utah.

from the Weber River and Beaver Creek is also a calcium-bicarbonate type (fig. 9). Water from most of the wells completed in unconsolidated deposits has very similar chemistry, regardless of well location, implying a common source of water or similar hydrogeologic conditions along the ground-water flowpath (pl. 1). Slight differences in water chemistry in several wells can be attributed to local geology, geochemical interactions, and/or possible mixing with different sources of water. Water from well (D-2-6)26aad-1, along Beaver Creek near Samak, shows a substantial concentration of chloride relative to bicarbonate (fig. 9). Sources for the high chloride concentration in water from this shallow well may include road salt runoff from the nearby highway. Water from this well also contains the highest dissolved-solids concentration (517 mg/L) of any well completed in unconsolidated deposits.

Water from consolidated rock shows a greater variation in major-ion chemistry than water from unconsolidated deposits (fig. 10). These differences can be attributed in large part to geologic variations inherent in at least seven different formations in which the wells are completed. Nonetheless, the water is generally a calcium-bicarbonate type. Water from well (D-1-5)15acb-1 contains the highest dissolved-solids concentration of any well sampled (656 mg/L), which is in large part because of alkalinity (calcium bicarbonate). This well is probably completed in the Kelvin Formation, which consists of shaly, conglomeratic sandstones. Water from well (D-2-6)25aad-1, along Beaver Creek, and spring (D-2-5)24cbb-S1, near City Creek, also contains anomalous concentrations of chloride that are not present in the formations from which the water is derived. Because of the proximity of these sites to highways, the chloride may be derived from road salt used for winter de-icing.

Nutrients, MBAS, dissolved organic carbon, boron, bromide, and coliform bacteria were analyzed for in water from almost all wells sampled to assess potential contamination of ground water from septic systems. Nitrate plus nitrite (as N) concentrations in well water throughout the Kamas Valley area ranged from 0.021 to 3.43 mg/L, substantially below the State of Utah drinking-water maximum of 10 mg/L (Utah Department of Environmental Quality, Division of Drinking Water, 2001). Concentrations of orthophosphorus (as P) in water from wells ranged from less than 0.010 to 0.12 mg/L. MBAS concentrations were less than 0.02 mg/L in water from virtually all wells sampled. Concentrations of dissolved organic carbon in well water ranged from 0.26 to 4.3 mg/L. Boron concentrations ranged from 7.6 to 226 µg/L, and bromide concentrations ranged from less than 0.010 to 0.093 µg/L. Results of analysis for total and fecal coliform bacteria in water from wells ranged from less than 2 to less than 50 counts in 100 milliliters of sample. Low concentrations of nutrients and related anthropogenic constituents, in addition to the absence of coliform bacteria in well water from the study area, indicate no degradation of water quality from septic systems.

Trace metals were analyzed for in water from 12 wells throughout the study area. Results of analysis indicate that concentrations of these constituents are very low, and in many cases, less than laboratory reporting levels. No constituent was present in concentrations that exceed the State of Utah primary drinking-water standards (Utah Department of Environmental Quality, Division of Drinking Water, 2001). The highest concentration of arsenic was 7 µg/L, below the current (October 2001) drinking-water standard of 10 µg/L (U.S. Environmental Protection Agency, 2001). An iron concentration of 3,700 µg/L was detected in water from well (D-2-6)23ccd-1 along Beaver Creek in Samak. This flowing artesian well yields water from Paleozoic-age carbonate rock at a depth of 323 ft. Concentrations of 542 µg/L iron and 557 µg/L manganese also were detected in water from well (D-2-6)29ada-1 in Kamas Valley. Anomalous concentrations of iron and manganese may indicate chemically reducing conditions in the aquifer or well. These concentrations exceed the State of Utah secondary drinking-water standards for these metals (Utah Department of Environmental Quality, Division of Drinking Water, 2001). Several wells also contained water with zinc concentrations exceeding 100 µg/L. Higher concentrations of zinc can be derived from galvanized surfaces in storage tanks or distribution systems rather than actually present in ground water.

Radionuclides (gross alpha and beta) were analyzed for in water from nine wells. Results of analysis indicate that concentrations of these constituents were generally less than laboratory reporting levels. The highest gross beta concentration in water was 12 pCi/L from well (D-1-5)15acb-1 in Browns Canyon. Although this well is probably completed in the conglomeratic Kelvin Formation, elevated concentrations of barium (294 µg/L) and boron (226 µg/L) in water from this well, along with

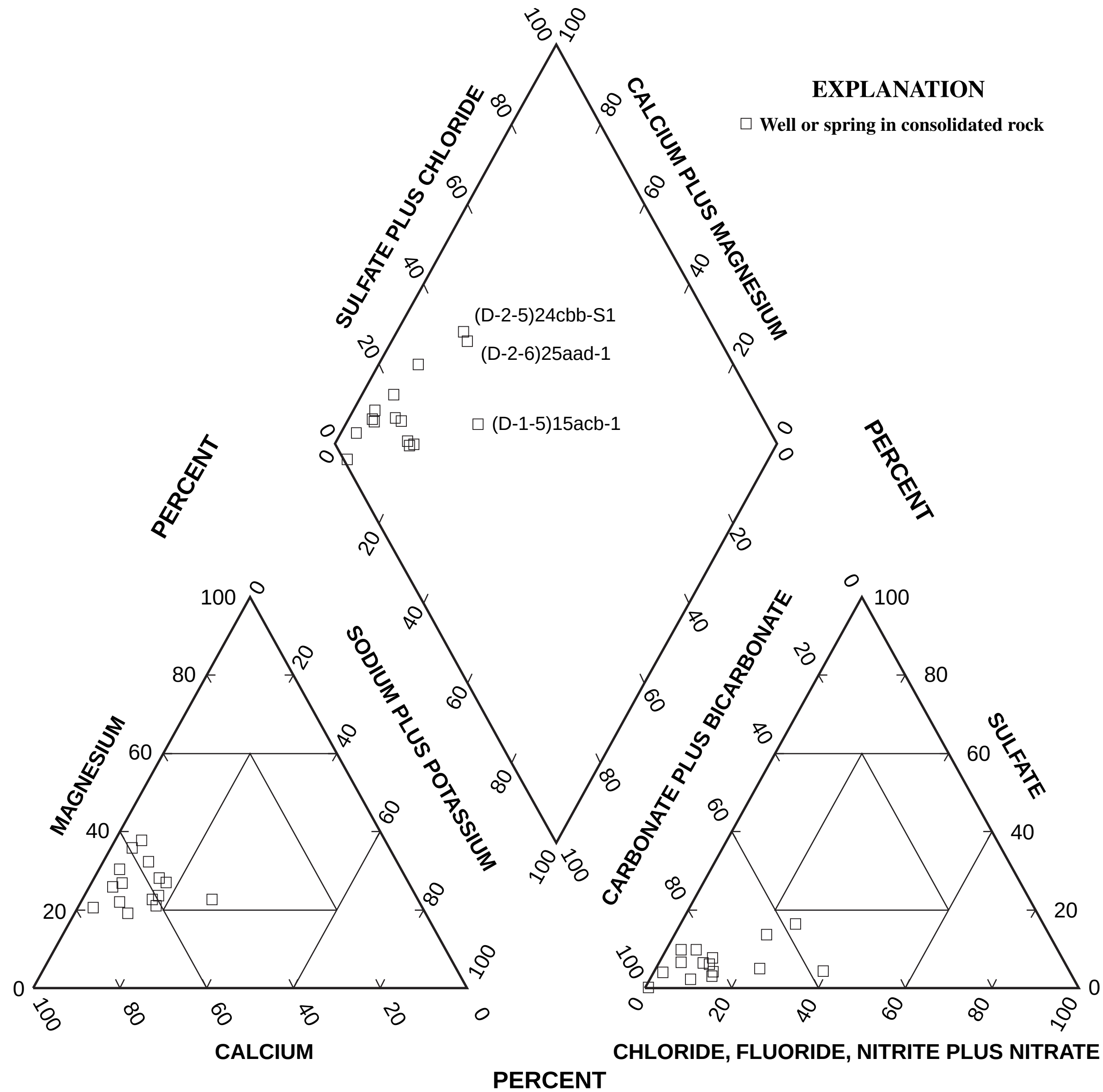

Figure 10. Chemical composition of water from consolidated rock, Kamas Valley and vicinity, Utah.

the elevated level of gross beta, indicate a possible source from the overlying Keetley Volcanics. Water from well (D-2-6)34dcd-1, completed in unconsolidated deposits and Keetley Volcanics, also contained measurable concentrations of gross alpha (4.4 pCi/L) and gross beta (6.9 pCi/L).

Pesticides were analyzed for in water from six wells. Analyses for 83 compounds indicate that all but 4 compounds were not detected in concentrations greater than laboratory reporting levels. Atrazine was detected in water from three of the six wells sampled in concentrations up to 0.006 μg/L. These concentrations, however, are substantially less than the State of Utah primary drinking-water standard of 3.0 μg/L (Utah Department of Environmental Quality, Division of Drinking Water, 2001). Acetochlor was detected in water from one well at an estimated concentration of 0.0031 μg/L; metolachlor was detected in water from one well at 0.005 μg/L; and simazine also was detected in water from one well at an estimated concentration of 0.0025 μg/L. On the basis of the samples analyzed, these constituents also may be present in water from other wells in the area. Although pesticides generally are not used on crops in Kamas Valley, trace amounts of these compounds may be derived from localized agricultural, roadside, or household use.

Potential for Water-Quality Degradation

Initially, elevated concentrations of nitrogen compounds, particularly nitrate, were thought to be present in ground water in areas where the density of septic systems is greatest, such as areas east of Marion, along Beaver Creek near Samak, and along parts of the upper Weber River. On the basis of results of analysis from both field screening tests for nitrate (photometric analysis) in surface water and water samples from wells throughout the study area, no concentrations of nitrate nor any other anthropogenic constituent, such as MBAS, exceeded the State of Utah drinking-water standards. Only two samples exceeded a nitrate concentration of 3.0 mg/L. Nitrate samples from surface water were collected during low flow conditions when potentially higher concentrations of these constituents would be expected. In addition, other constituents sampled that are often associated with high concentrations of nitrate derived from septic systems, such as dissolved organic carbon, boron, and bromide, also occurred in very low concentrations, and near expected background levels.

Although these results indicate that no relation currently exists between septic systems and water wells, relatively few samples were collected in comparison with the actual number of septic systems and wells in existence. Further, shallow wells located adjacent to surface streams that typically contain coliform bacteria can be particularly vulnerable to contamination, especially along losing stream reaches. Additional monitoring or sampling in these areas should be done during different hydrologic regimes to determine if potential problems exist.

Anomalous concentrations of chloride were detected in water from several wells along Beaver Creek near Samak and from a spring near City Creek, west of Kamas Valley. The proximity of these sites to nearby highways makes them particularly susceptible to contaminants in highway runoff, such as chloride salts used for de-icing. These and other points of discharge adjacent to highways in the study area also could be potentially susceptible to contaminants such as herbicides and chemicals from spills, particularly where water levels are near land surface or where wells are not completed properly.

NUMERICAL SIMULATION OF GROUND-WATER FLOW IN THE UNCONSOLIDATED DEPOSITS

A numerical ground-water flow model was developed to simulate the ground-water system in the unconsolidated deposits in Kamas Valley. The model was used to test the conceptual understanding of the ground-water system. Development of the model included compilation and examination of water-level and streamflow data, determination of methods and amounts of recharge and discharge, determination of the spatial distribution of hydraulic conductivity and specific yield, and numerical assessment of whether ground water can move through the system as conceptually understood. The “Model development” section of this report discusses how the model was used to test and change the conceptual understanding of ground-water flow in Kamas Valley. The “Model construction” section discusses the details of discretization, boundary conditions, and model parameters. The “Calibration” section discusses how the model was changed to match observed data and how adequately the model simulates the ground-water system.

The ground-water flow model was constructed using MODFLOW-2000, the most recent version of the three-dimensional, finite-difference, ground-water flow model known as MODFLOW (Harbaugh and others, 2000; and Hill and others, 2000). MODFLOW-2000 retains the same programming structure for solving the ground-water flow equation but involves significant changes in input files and incorporates observation analysis, sensitivity analysis, and parameter estimation.

Model Development

Model development required frequent analysis of differences between simulated results and measured water levels and streamflow. This analysis and sensitivity of the model to certain model parameters were used to refine both the conceptual and numerical models. Changes involved recharge from irrigation, evapotranspiration, steep gradients near Peoa and Francis, vertical discretization, and time discretization.

Recharge from Irrigation

Recharge from irrigation was originally assumed to occur everywhere that water was diverted from streams and applied to crops or pasture. Simulating this recharge caused simulated water levels in the middle of the valley to be much higher than land surface. The concept that recharge from irrigation does not occur in areas of evapotranspiration in the middle of the valley and near the Weber and Provo Rivers (fig. 6) was tested. The concept that all crop demand for water in those areas is satisfied by evapotranspiration and all applied irrigation water becomes surface-water runoff also was tested. Both concepts were later validated by collection of field data indicating ground-water discharge to Beaver Creek and Crooked Creek in the middle of the valley (Haraden and others, 2001, table 6). Field data were not collected near the Weber and Provo Rivers to validate the concepts at those locations. Incorporating these changes in the conceptual budget improved the water balance between recharge and discharge. Incorporating the changes in the model improved the match between simulated and measured water levels. In addition, the concepts are reasonable because the water table is near land surface in those areas.

In the Francis area, the model is sensitive to the location of areal recharge. The area northwest of Francis was originally thought to have no recharge because it is in an area of evapotranspiration (fig. 6), but water levels in the area could not be simulated correctly. Simulated water levels were as much as 50 ft below measured water levels. The same volume of irrigation water applied to the east of this area was extended into this area, making less irrigation recharge in ft/yr, but applying it over a larger area. The water levels became closer to measured levels with no changes in model hydraulic conductivity or other parameters.

Evapotranspiration

Evapotranspiration was originally assumed not to occur south and east of Francis. Many simulated summer water levels in this area, however, were higher than measured water levels. Measured water levels in several wells (pl. 1) reach a peak and remain a few feet below land surface during the summer, indicating that water is being removed from the system by evapotranspiration at those high ground-water levels. Simulating evapotranspiration in those areas improved the simulated water levels. It is also possible that ground water in Francis discharges to canals and ditches during the summer, but this discharge was not simulated. The conceptual budget was not changed in this area because the evapotranspiration occurs over a small area for a short time and has little effect on the ground-water budget of the unconsolidated deposits.

Steep Gradients

Ground-water levels on the bench above the Weber River near Peoa are estimated to be at least 100 ft higher than the Weber River, and ground-water levels on the bench above the Provo River near Francis are about 80 ft higher than the Provo River. Even with a small model grid in those areas, the steep hydraulic gradient could not be simulated, indicating that ground water on the benches might be separated from ground water near the rivers. Subsequent field work by the U.S. Geological Survey and Utah Geological Survey discovered Keetley Volcanics exposed on the scarp of both benches and evidence of spring discharge above the Keetley Volcanics. The Keetley Volcanics may limit downward movement of ground water, hydraulically separating water on the benches from water near the rivers. The model was changed to incorporate the scarps as no-flow boundaries and the springs as drains in active cells near the no-flow boundaries.

Vertical Discretization

The model was initially constructed to simulate three layers in the unconsolidated deposits. Model results were insensitive to vertical conductance, indicating that most simulated flow was horizontal. Further analysis of drillers' logs (Haraden and others, 2001, table 2) indicated little evidence of clay in the valley that could contribute to vertical gradients and provide some geological reason for multiple layers. Lenses of gravel, sand, silt, and clay are documented but do not appear continuous across even small areas. The layering probably does cause vertical conductivity to be less than horizontal conductivity, but no data were available to estimate the anisotropy or to measure its effect on the ground-water system. Therefore, a multi-layer simulation was considered unwarranted, and the model was changed to simulate one layer in the unconsolidated deposits.

Time Discretization

The model was initially constructed to simulate steady-state conditions with average annual recharge and discharge. This was considered adequate for several reasons. First, long-term water-level trends are not evident (pl. 1). Second, because most recharge is from irrigation water and most discharge is to streams, water levels are relatively unaffected by annual climate change. Irrigation methods and the average amount of water diverted and applied has not changed significantly in decades, and the system was assumed to have reached a steady-state equilibrium with the long-term irrigation practices. Third, water levels in much of the valley are controlled by numerous streams and ditches.

As model development continued, however, the inability to accurately simulate the system with a steady-state model became apparent. First, it was not reasonable to determine which seasonal levels should be used to calibrate a steady-state model. Second, the large seasonal fluctuations (pl. 1) are an important part of the ground-water system and could not be simulated with a steady-state model. For these reasons, the model was changed to simulate seasonally transient conditions.

Model Construction

Construction of the ground-water flow model is described in the following sections. Given the amount and complexity of the input data, it is impractical to present or reference all required information, so the model cannot be reconstructed from the information presented herein. A copy of the model and associated data sets can be obtained from the U.S. Geological Survey, Water Resources Division, Salt Lake City, Utah.

The model described in this report uses parameters (Harbaugh and others, 2000, p. 4) to define much of the input data. A parameter is a single value that is given a name and determines the value of a variable in the finite-difference ground-water flow equation at one or more model cells. When parameters are used, the data value for a cell is calculated as the product of the parameter value, which might apply to many cells, and a cell multiplier, which applies only to that cell (Harbaugh and others, 2000, p. 13). Sensitivity analysis (Hill and others, 2000, p. 98) was used to guide model construction and calibration.

Construction of the ground-water flow model was accomplished by horizontally discretizing the hydrologic properties of the ground-water system, establishing model boundaries that depict conceptual hydrologic boundaries, and assigning model parameters to recharge, evapotranspiration, hydraulic conductivity, specific yield, streambed conductance, and drain conductance. Because most recharge is areally distributed irrigation water and most discharge is to streams, model construction focused on being able to adequately simulate discharge to streams.

Discretization

Areally, the model is discretized into a grid of rectangular cells; each cell has homogeneous properties. Active cells, which delineate the lateral boundaries of the simulated ground-water system, generally correspond with the lateral extent of the unconsolidated deposits in Kamas Valley (fig. 11). The rectangular model grid contains 61 rows and 28 columns; cell size is variable and active cells range in size from about 15 to 55 acres. Areas of small cell size do not represent areas where more data are available. The model grid is oriented so that cell faces are generally parallel or perpendicular to major streams and is rotated counterclockwise about 15 degrees from true north. The ground-water flow equations are formulated at the center point of the cell. Flow area and gradient used to determine flow through the cell are determined at the center point of the cell and represent the average area and gradient through the cell.

Vertically, the model is a single layer representing the entire thickness of the unconfined, unconsolidated deposits. Altitude of the bottom of the layer was determined by subtracting the thickness of the unconsolidated deposits (Hurlow, 2002, pl. 4) from land-surface altitude. The ground-water model represents a probable maximum thickness of unconsolidated deposits of 1,100 ft (fig. 11). Around the edges of the model, the thickness of the unconsolidated deposits was increased slightly more than in Hurlow (2002, pl. 4) to aid numerical stability in areas where the water level is close to the bottom of the unconsolidated deposits.

Limitations in MODFLOW-2000 require the layer to be assigned as a convertible layer, and the model automatically changes to confined conditions if the layer becomes fully saturated. In Kamas Valley, full saturation results in standing water at land surface, not in confined conditions. To prevent the model from simulating unrealistic conditions, the top of the model layer was assigned an artificially high altitude of 7,000 ft at all locations instead of land-surface altitude.

The model uses two stress periods per year for 10 years. The first stress period simulates most recharge and all evapotranspiration, is 122 days long from April 1 to July 31, and is referred to as the "summer" stress period. The second stress period has little recharge, no evapotranspiration, is 243 days long from August 1 to March 31, and is referred to as the "winter" stress period. Streams were assumed to be constant stresses and do not change for each stress period. Simulated recharge and discharge are long-term averages. The two stress periods are repeated for 10 years to minimize the effects of initial heads. In a sense, the first 9 years of transient simulations create the initial heads for the actual simulation presented in the report. In theory, if enough identical transient stresses were simulated, the computed heads would only be a function of stress and not initial heads. East of Marion, however, simulated water levels were still changing after 10 years. Ending water levels were substituted for initial heads for several 10-year periods to minimize water-level changes in this area. The transient model was constructed to simulate seasonal water-level fluctuations, not water-level fluctuations occurring over periods greater than 1 year.

Boundary Conditions

The boundaries chosen for the model describe mathematically how the simulated ground-water system interacts with the surrounding hydrologic system. Mathematical boundaries used to represent hydrologic boundaries include no-flow boundaries, specified-flux boundaries, and head-dependent flux boundaries. These boundaries define the physical limits of the model and simulate recharge to and discharge from the ground-water system. No-flow boundaries are considered impermeable and no flow is simulated across them. Specified-flux boundaries allow a specified rate of water through the cell and are used to simulate some sources of recharge. Head-dependent flux boundaries simulate flow across the boundary proportional to the difference in heads across the boundary and are used to simulate some sources of recharge and all discharge in this model.

No-Flow Boundaries

Contacts between unconsolidated deposits and consolidated rock around and below the deposits are considered no-flow boundaries. These boundaries simulate the concept that flow between consolidated rock and unconsolidated deposits is insignificant in the ground-water budget of the unconsolidated deposits (see the "Interaction between consolidated rock and unconsolidated deposits" section of this report). As an inevitable result of discretization, it is possible that some consolidated rock north of Oakley is simulated as unconsolidated deposits.

In several areas, no-flow boundaries do not correspond with the extent of the unconsolidated deposits (fig. 11). Near Peoa and southwest of Francis, outcrops of Keetley Volcanics and springs along the benches indicate that ground water in unconsolidated deposits on the benches is not directly connected to ground water near the rivers below the benches. To force separation, inactive cells (no-flow boundaries) were placed along the benches. Little is known about the ground-water system near the Provo River, so the

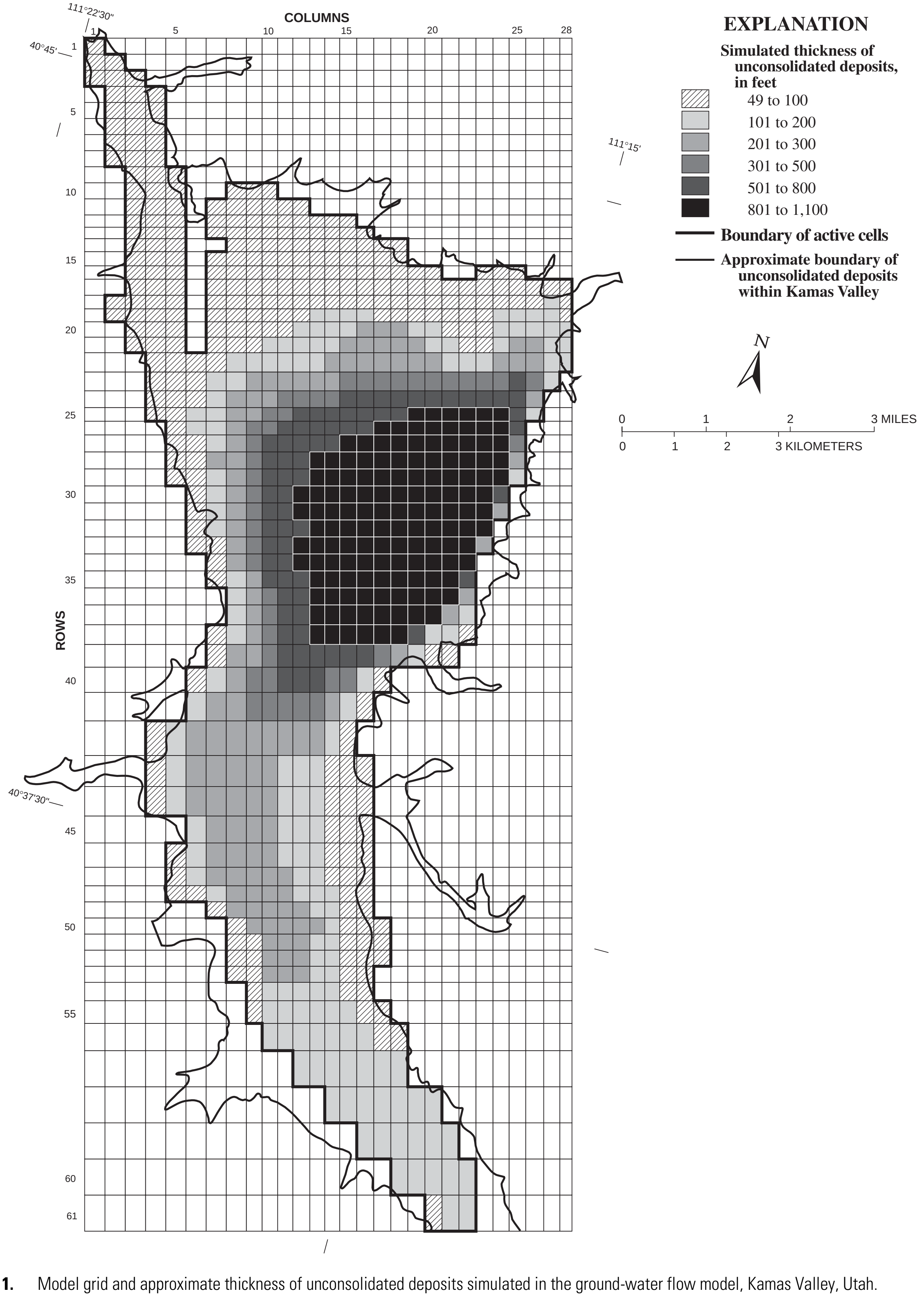

Figure 11. Model grid and approximate thickness of unconsolidated deposits simulated in the ground-water flow model, Kamas Valley, Utah.

area of active cells ends at the bench above the river south and west of Francis. East of Francis, the hydraulic gradient from the bench to the river is smaller, and the two systems may be connected. Instead of simulating the entire Provo River and floodplain in this area, ground-water discharge is simulated to a stream at the bottom of the bench. Along the Provo River, discharge is not limited exclusively to the stream channel; discharge occurs throughout the entire floodplain to seeps, small ditches, and feeder streams. Along the margins of the valley north of Oakley, the saturated thickness of the unconsolidated deposits is estimated to be less than 50 ft. The cells overlying those areas are assigned as inactive to prevent numerical instability.

In some areas, cells outside of the unconsolidated deposits were simulated as active cells, but the bottom was assigned an altitude similar to that of nearby unconsolidated deposits. This allowed for model interpolation needed for sensitivity analysis and parameter regression. Those components of MODFLOW-2000 do not function if observation wells are adjacent to inactive cells. Though these areas appear to be consolidated rock, the model is simulating a hypothetical extension of the unconsolidated deposits.

Recharge Boundaries

The top of the model layer represents a recharge boundary. Simulated recharge is from irrigation, precipitation, perennial streams, and ephemeral streams. Subsurface recharge from consolidated rock is neither conceptualized nor simulated. Specified-flux boundaries and head-dependent flux boundaries are used to simulate recharge. Recharge simulated by specified-flux boundaries does not change as simulated water levels change. Recharge simulated by head-dependent flux boundaries can change as a function of simulated water levels.

Areal recharge from precipitation, irrigation, canals and ditches, and ephemeral streams is simulated as a specified-flux boundary with the Recharge Package (Harbaugh and others, 2000, p. 67). Annual recharge, in acre-ft, in each irrigation area (fig. 5) and in nonirrigated areas from precipitation, irrigation, and canals and ditches was determined as explained in the "Surface-water hydrology" and "Ground-water hydrology" sections of this report. The recharge rate, in ft/yr, was assigned to each cell that corresponds with the irrigated or nonirrigated area with a multiplier array (fig. 12). Annual recharge from ungaged streams is described in the "Surface-water hydrology" section of this report. The recharge rate, in ft/yr, from ungaged streams was assigned to the cells corresponding to the location where the ephemeral stream crosses the unconsolidated deposits with a multiplier array (fig. 13). A separate multiplier array was used to divide these numbers by 122 to determine the rate of recharge in ft/d for each day of the summer stress period. No recharge from precipitation, irrigation, canals, or ungaged streams is simulated in the winter stress period.

The Weber River and Beaver Creek both contribute recharge to the unconsolidated deposits upstream of active model cells as listed in table B-1 in appendix B. Annual recharge, in acre-ft, was divided by the area of the model cells near where the streams enter the active model area to determine the recharge rate in ft/yr. This recharge is simulated as a specified-flux boundary. The rate is assigned to each cell with a multiplier array (fig. 13). This recharge is assumed to be constant throughout the year; a multiplier array was used to divide these numbers by 365 to determine the recharge rate in ft/d for each day of both stress periods.

The MODFLOW-2000 Recharge Package allows the value of recharge flux to be defined as one or more parameters (Harbaugh and others, 2000, p. 68). In this model, the multiplier arrays define the conceptual recharge at each cell and the recharge parameters multiply the conceptual recharge by a constant value. Recharge parameters were defined for recharge from irrigation and precipitation (parameters rechim1 and rechim2), ungaged streams (parameter rechem), and Weber River and Beaver Creek (parameter rechsm). Separate parameters were used so that sensitivity to each type of recharge could be evaluated. Each recharge parameter was set equal to 1 to simulate conceptual recharge.

Recharge to the ground-water system from the Weber River, Beaver Creek, Fort Creek, Rasmussen Creek, Thorn Creek, Crooked Creek, Weber-Provo Diversion Canal, and selected unnamed streams and ditches is simulated as a head-dependent boundary with the Streamflow-Routing Package (Prudic, 1989) (fig. 14). The Provo River was not modeled because no ground-water data were collected near the river or south of the river and because the Provo River does not appear to contribute recharge to the unconsolidated

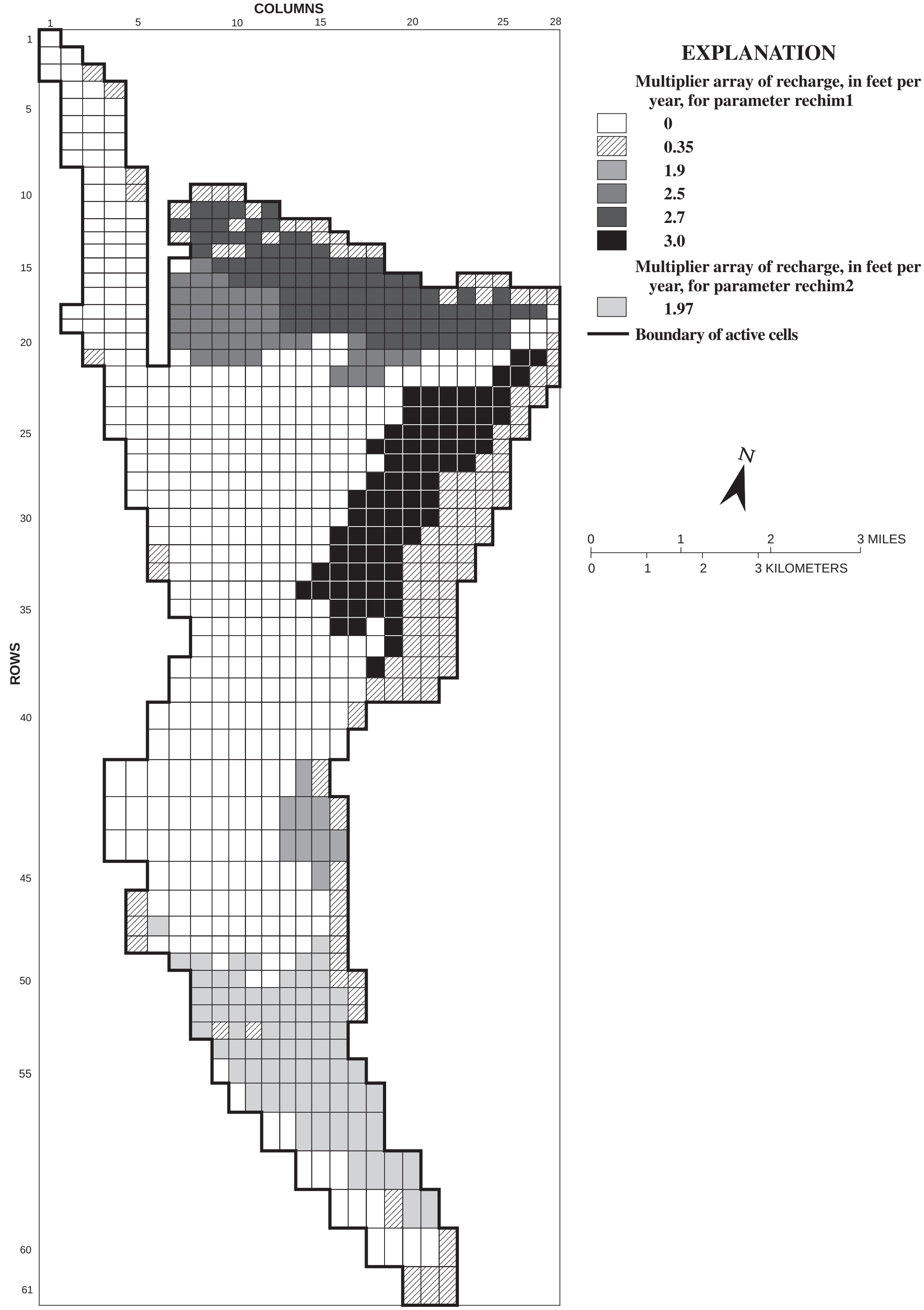

Figure 12. Distribution of recharge from irrigation, precipitation, and canals simulated in the ground-water flow model, Kamas Valley, Utah.

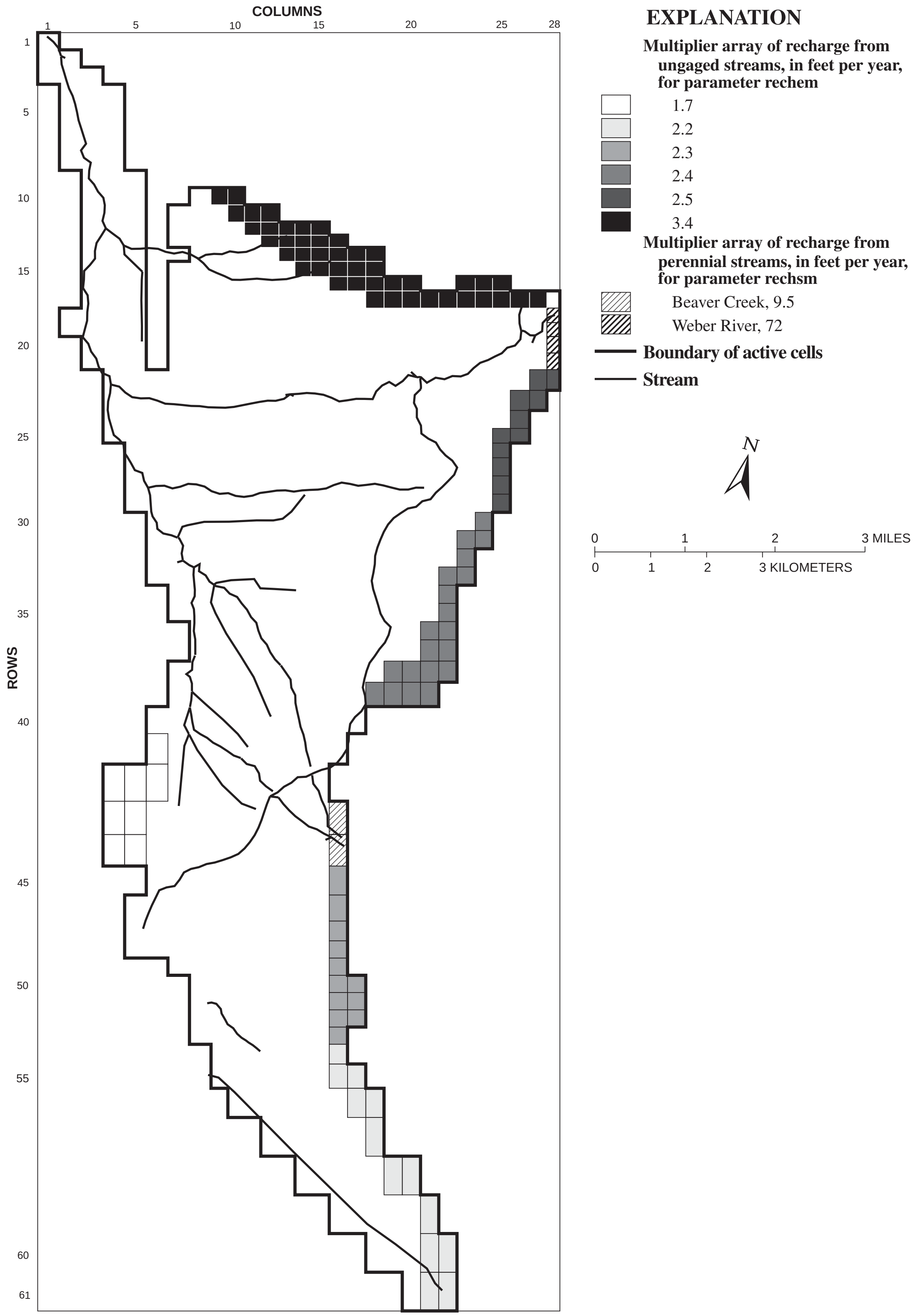

Figure 13. Distribution of recharge from streams simulated as areal recharge in the ground-water flow model, Kamas Valley, Utah.

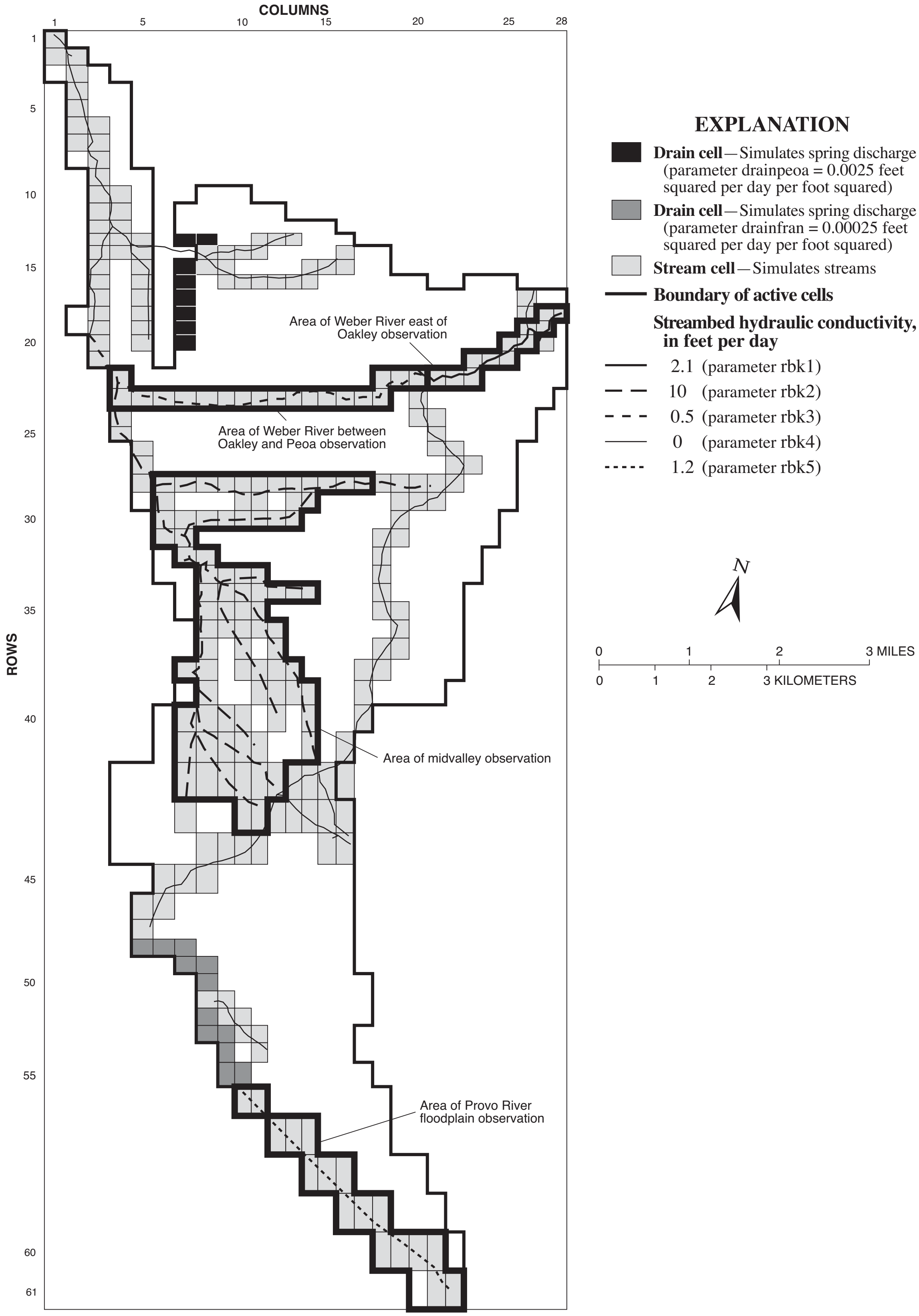

Figure 14. Distribution and hydraulic conductivity of streams and springs simulated in the ground-water flow model, Kamas Valley, Utah.

deposits. The Streamflow-Routing Package computes flow from the stream to the ground-water system as a function of simulated ground-water level at the center of the model cell, the water-surface altitude (stage) of the stream, and the streambed conductance (Prudic, 1989, fig. 3). Streams were discretized into segments and reaches as shown in Prudic (1989, fig. 1A).

Data required for the Streamflow-Routing Package include stream stage, altitude of the top and bottom of the streambed, flow at the beginning of each segment, and a term called "streambed conductance." Streambed conductance is the product of streambed width, streambed length in each cell, and hydraulic conductivity of the streambed, divided by the thickness of the streambed. Stage was estimated to equal land-surface altitude as determined from U.S. Geological Survey 1:24,000-scale topographic maps and is accurate to within 10 to 20 ft. Depth below stage to the top of the streambed and streambed width were determined from field observations as listed in table B-2 in appendix B. The bottom of the streambed was assumed to be 10 ft below the top of the streambed for all streams. This model was constructed such that the MODFLOW-2000 stream parameters (parameters rbk1 through rbk5) equal the streambed hydraulic conductivity in ft/d.

Flow information required for the simulated streams and their associated tributaries and diversions is listed in tables B-3 and B-4. Annual flows for Weber River near Oakley, Beaver Creek at Grist Mill, and Weber-Provo Diversion Canal (table 2) were used as the starting flow for those streams. Beaver Creek at Grist Mill is outside the modeled area and the annual flow could not be entered directly as streamflow. Instead, the flow in Thorn Creek and Beaver Creek below Thorn Creek were used as starting flows. Annual diversions from the Weber River and Beaver Creek (table 3) were simulated as short stream segments to allow proper accounting in the stream package, but the entire length of individual canals and ditches was not simulated because data are not available concerning gains and losses. Surface-water flow from small streams entering the valley, from runoff from precipitation on the valley, and from irrigation return flow, was used either as the starting flow for streams simulated in the valley, or was simulated as only a short segment to allow proper accounting in the Streamflow-Routing Package.

Discharge Boundaries

The top of the model layer represents a discharge boundary. Simulated discharge from the ground-water system is discharge to streams, to springs, and by evapotranspiration. Discharge to wells in the study area is negligible and was not simulated. All forms of simulated discharge are head dependent. Total simulated discharge, therefore, is directly correlated to simulated recharge, most of which is specified. Subsurface discharge to consolidated rock or through thin unconsolidated deposits underlying the Weber and Provo Rivers is neither conceptualized nor simulated.

Discharge to streams is simulated for the same streams as described for recharge from streams with the Streamflow-Routing Package (Prudic, 1989). An additional unnamed stream is simulated at the bottom of the bench near the Francis area (fig. 14) to simulate discharge from the bench to the Provo River floodplain. Part of this stream is real, the other part was placed in the model to simulate the Provo River without modeling the intervening floodplain. Discharge from the bench appears to collect in small streams and then flow into the Provo River. Constructing the model this way eliminated the necessity of modeling ground-water flow in the Provo River floodplain where data are not available.

Discharge to springs is simulated near Peoa and Francis (fig. 14) with the Drain Package (Harbaugh and others, 2000, p. 71). Simulated springs are at the contact of unconsolidated deposits and Keetley Volcanics where ground-water discharge is evident along benches. The Drain Package simulates a head-dependent flux boundary for each cell to which it is assigned and discharge is a function of simulated water level and drain conductance (McDonald and Harbaugh, 1988, fig. 41). Data required for the Drain Package are altitude and conductance of the drain. This model was constructed such that the conductance factor listed in the Drain Package input file is the area of the drain in each cell. The MODFLOW-2000 drain parameters (parameters drainpeoa and drainfran) are multiplied by the conductance factor to obtain drain conductance for each cell.

Discharge by evapotranspiration is simulated as a head-dependent flux boundary with the Evapotranspiration Package (Harbaugh and others, 2000, p. 73). The amount of evapotranspiration simulated depends on the consumptive use of the vegetation, the depth below land surface at which transpiration stops (extinction depth), and the ground-water level (McDonald and Harbaugh, 1988, fig. 42). Data required for the Evapotranspiration Package are the altitude of the evapotranspiration surface, extinction depth, and the maximum evapotranspiration rate. The altitude of the evapotranspiration surface was estimated as land surface from U.S. Geological Survey 1:24,000-scale topographic maps. In most areas of evapotranspiration, the error associated with the altitude estimate is 10 ft. An extinction depth of 5 ft was used for both pasture grass and riparian bushes and trees. The rate of evapotranspiration from ground water in each irrigation area and in nonirrigated areas (table 8) in ft/yr was assigned to each cell that corresponds with the irrigation area or nonirrigated area with a multiplier array (fig. 15). A separate multiplier array was used to divide the numbers by 122 to determine the rate of evapotranspiration, in ft/d, for each day of the summer stress period. No evapotranspiration is simulated in the winter stress period. The MODFLOW-2000 Evapotranspiration Package allows the value of maximum evapotranspiration flux to be defined as a parameter (Harbaugh and others, 2000, p. 74). The multiplier array equals the conceptual evapotranspiration rate at each cell, and the evapotranspiration parameter (parameter etm) used in this model multiplies the conceptual evapotranspiration rate by a constant value.

Distribution of Aquifer Characteristics

The single model layer represents unconfined, saturated, unconsolidated deposits. The hydraulic characteristics that control simulated water levels under these conditions are hydraulic conductivity and specific yield. The model was constructed to allow hydraulic conductivity and specific yield to be different for each surficial geologic unit (fig. 3) by using zone arrays (Harbaugh and others, 2000, p. 15) to delineate the geologic units. The MODFLOW-2000 parameters for hydraulic conductivity (parameters hk1 through hk7) and specific yield (parameters sy1 through sy7) are the actual values; no multiplier array is used.

Hydraulic conductivity is transmissivity divided by the saturated thickness of the unconsolidated deposits. As explained in the “Aquifer characteristics” section of this report, estimates of transmissivity vary by four orders of magnitude throughout the valley. The depth of the unconsolidated deposits varies by one order of magnitude; therefore, hydraulic conductivity is expected to vary by three orders of magnitude throughout the valley. Data indicate little correspondence between transmissivity and surficial geology (fig. 3 and fig. 7), but the geologic units provide the model variability needed for calibration and will allow greater ease in adapting the model if more data become available about transmissivity in each geologic unit. Very little data exist to determine specific yield, and for ease in modeling, it also is allowed to vary by geologic unit. Varying amounts of seasonal water-level fluctuations throughout the valley (pl. 1) indicate that specific yield is highly variable.

Calibration

The purpose of calibration is to obtain a model that reasonably represents ground-water recharge, movement, and discharge, and reasonably matches measured water levels. The differences between simulated heads and flows and measured heads and flows should be acceptable for the intended use of the model. This model has been developed to simulate general ground-water flow throughout Kamas Valley and seasonal water-level fluctuations. It should adequately represent valley-wide changes caused by changes in irrigation but has not been developed to simulate drawdown from pumping wells or other local effects. The model is a simplified representation of the ground-water system and does not represent local heterogeneity in aquifer properties, recharge, or discharge.

Ground-water levels typically measured in July 1999 and March 2000, one-time measurements of stream loss and gain, flow measurements of Marchant ditch (Haraden and others, 2001, table 5), and the conceptual surface- and ground-water budgets were compared to simulated values to determine if the model adequately simulates the ground-water system. MODFLOW-2000 calculates simulated values of water levels and flow at the location of input observations, then calculates and prints the difference between observation values and simulated values, weighted residuals, and other statistical measures of model fit. Water levels and variance used for observations are listed in table B-5. Flow measurements and coefficient of variation used for observations are listed in tables B-6 and B-7.

Figure 15. Distribution of evapotranspiration simulated in the ground-water flow model, Kamas Valley, Utah.

Parameter Adjustment

During model calibration, parameters were adjusted to achieve a model that reasonably represents the ground-water system by minimizing the sum of squared errors between simulated and measured values, while still simulating approximate known or estimated water-budget components. Values of specific yield, hydraulic conductivity, and streambed conductance were changed both by modifying the distribution of the parameters and by changing the parameter values. Drain conductance and maximum evapotranspiration rate were changed by modifying the parameter values. The evapotranspiration parameter (etm) was adjusted to achieve conceptually estimated evapotranspiration. Parameters defining areal recharge from irrigation and precipitation, canals, ephemeral streams, and Weber River and Beaver Creek upstream of the active model area were not considered calibration parameters and were not adjusted during the calibration process. This is consistent with attempting to simulate the conceptual understanding of the ground-water system. Although areal recharge was not adjusted, the sensitivity of individual observations to areal recharge was examined. Modifying the recharge parameters would increase some residuals and decrease others, implying a variation in recharge distribution that was not included in this study.

The sensitivity of observations to parameters was used to aid model calibration. Composite scaled sensitivities can be used to evaluate whether available observations provide adequate information to estimate each parameter, and can provide an overall view of the parameters to which the observations are most sensitive (Hill and others, 2000, p. 96). Simulated values at observation locations were more sensitive to initial specific-yield and hydraulic-conductivity parameters than to initial stream or drain parameters (fig. 16a); therefore, more effort was spent refining specific yield and hydraulic conductivity than other calibration parameters. The observations are relatively insensitive to some model parameters (fig. 16b); as a consequence, those parameters may not be estimated correctly in the simulation.

Specific Yield

Initially, one specific-yield parameter was assigned a value of 0.1 and was used for all zones in the zone array representing surficial geologic units. The composite scaled sensitivities (fig. 16a) indicate that enough observations are available to assign different values of specific yield to different areas. Specific-yield parameters were added and assigned to different zones. Both the distribution and the value of the parameters were adjusted during model calibration to cause simulated water levels to more closely match observed water levels. In some areas, the zone array changes within a geologic unit, which changes the value of the specific yield. This was done purely to aid model calibration and is not based on aquifer tests or more detailed geology. It is reasonable, however, that specific yield changes within surficial geologic units and that deeper units also influence ground-water movement. Composite scaled sensitivities indicate that more observations are available near Francis to estimate specific yield than in other parts of the valley (fig. 16b). The final distribution of specific yield is shown in figure 17. These values are uncertain because of the lack of aquifer-test data to determine these parameters independently of the model.

Hydraulic Conductivity

Initially, one hydraulic-conductivity parameter was assigned a value of 2 ft/d and was used for all zones in the zone array representing the surficial geologic units. The composite scaled sensitivities (fig. 16a) indicate that enough observations are available to assign different values to different areas. Hydraulic-conductivity parameters were added and assigned to different zones. Both the distribution and the value of the parameters were adjusted during model calibration to cause simulated water levels to more closely match observed water levels. In some areas, the zone array changes within a geologic unit, which changes the value of hydraulic conductivity. This was done purely to aid model calibration and is not based on aquifer tests or more detailed geology. It is reasonable, however, that hydraulic conductivity changes within surficial geologic units and that deeper units also influence ground-water movement. Composite scaled sensitivities indicate that more observations are available near Francis to estimate hydraulic conductivity than in other parts of the valley (fig. 16b). The final distribution of hydraulic conductivity is shown in figure 18. These values are uncertain because of the lack of aquifer-test data to determine these parameters independently of the model.

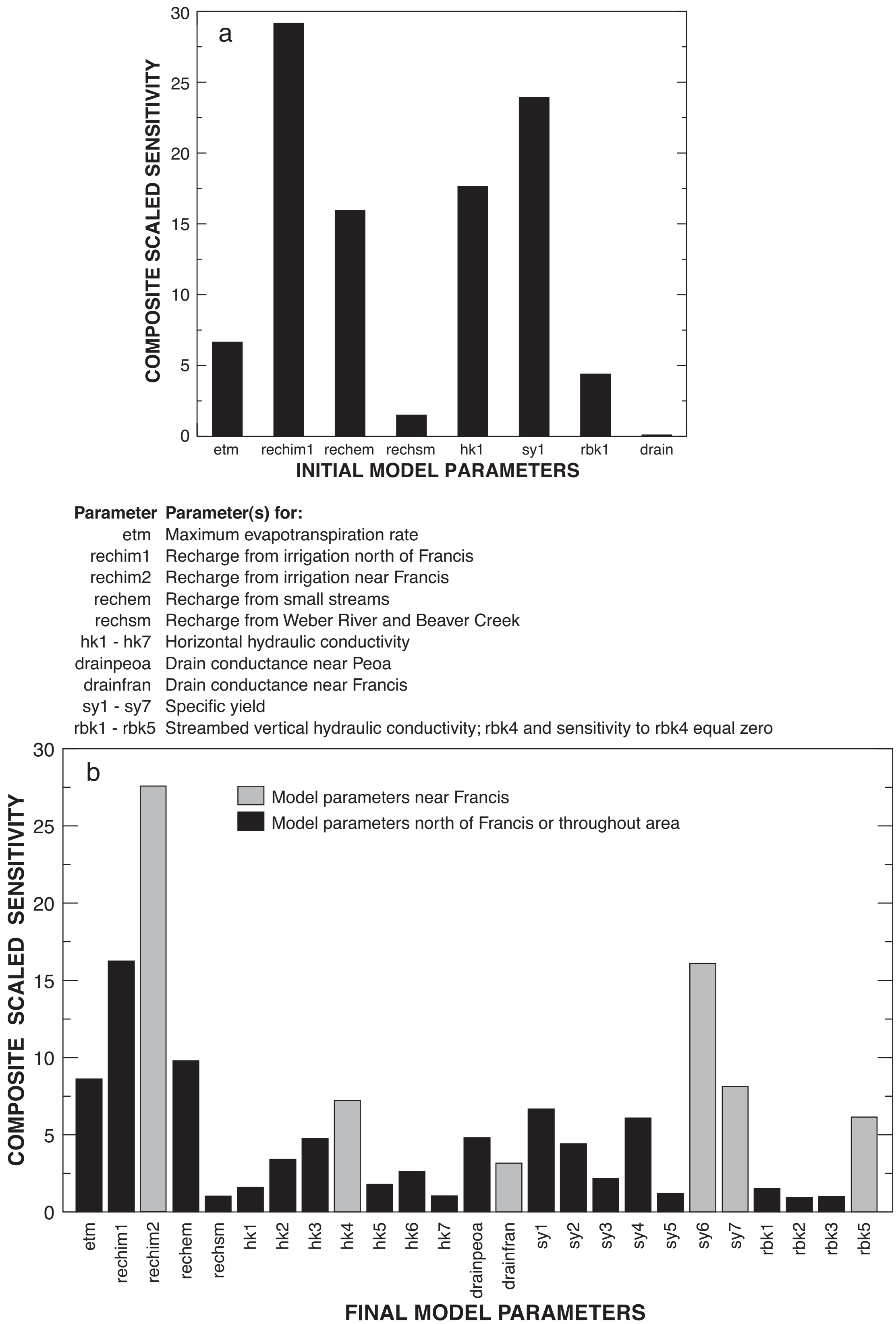

Figure 16. Composite scaled sensitivity of observations to (a) initial and (b) final model parameters simulated in the ground-water flow model, Kamas Valley, Utah.

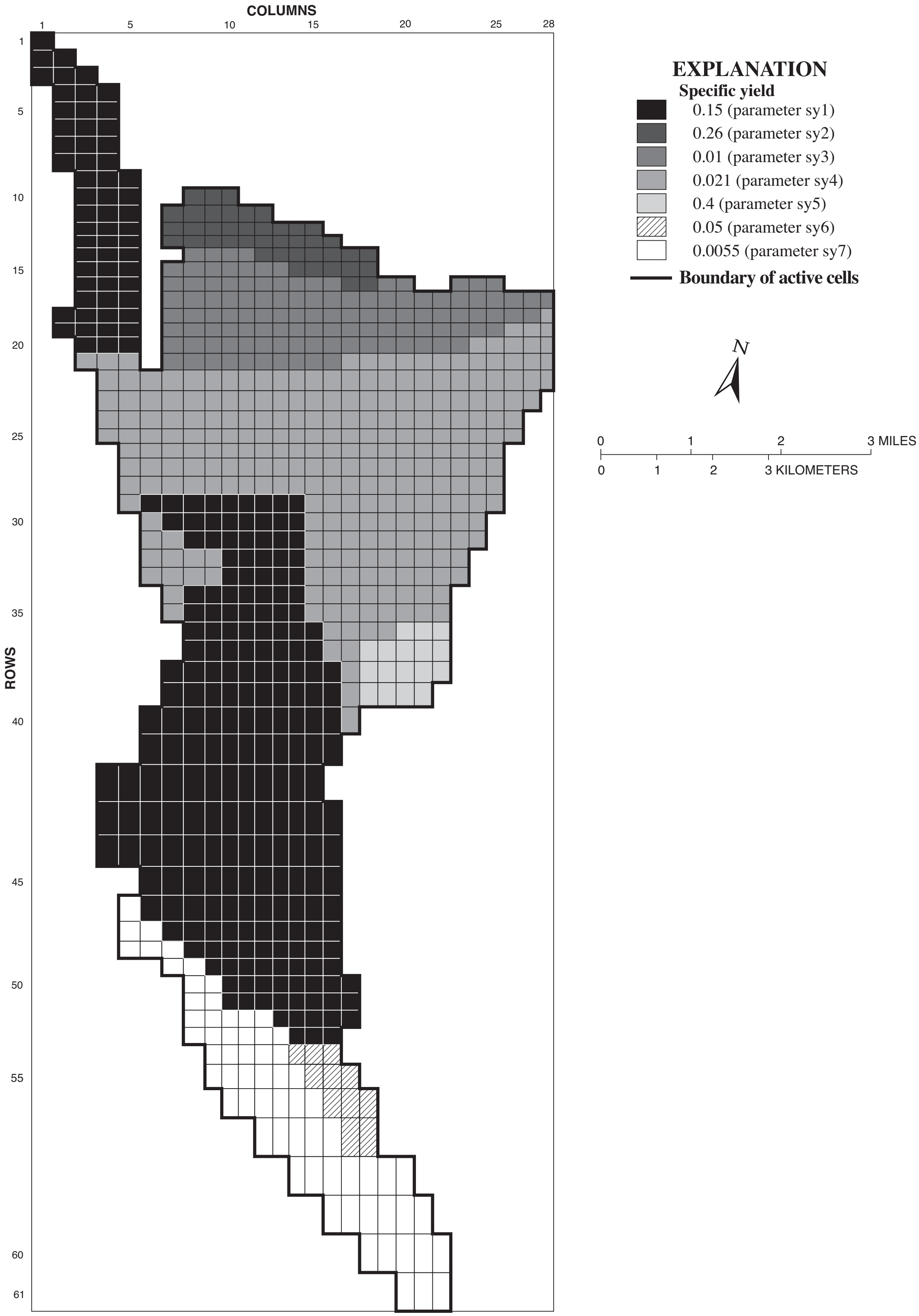

Figure 17. Specific yield simulated in the ground-water flow model, Kamas Valley, Utah.

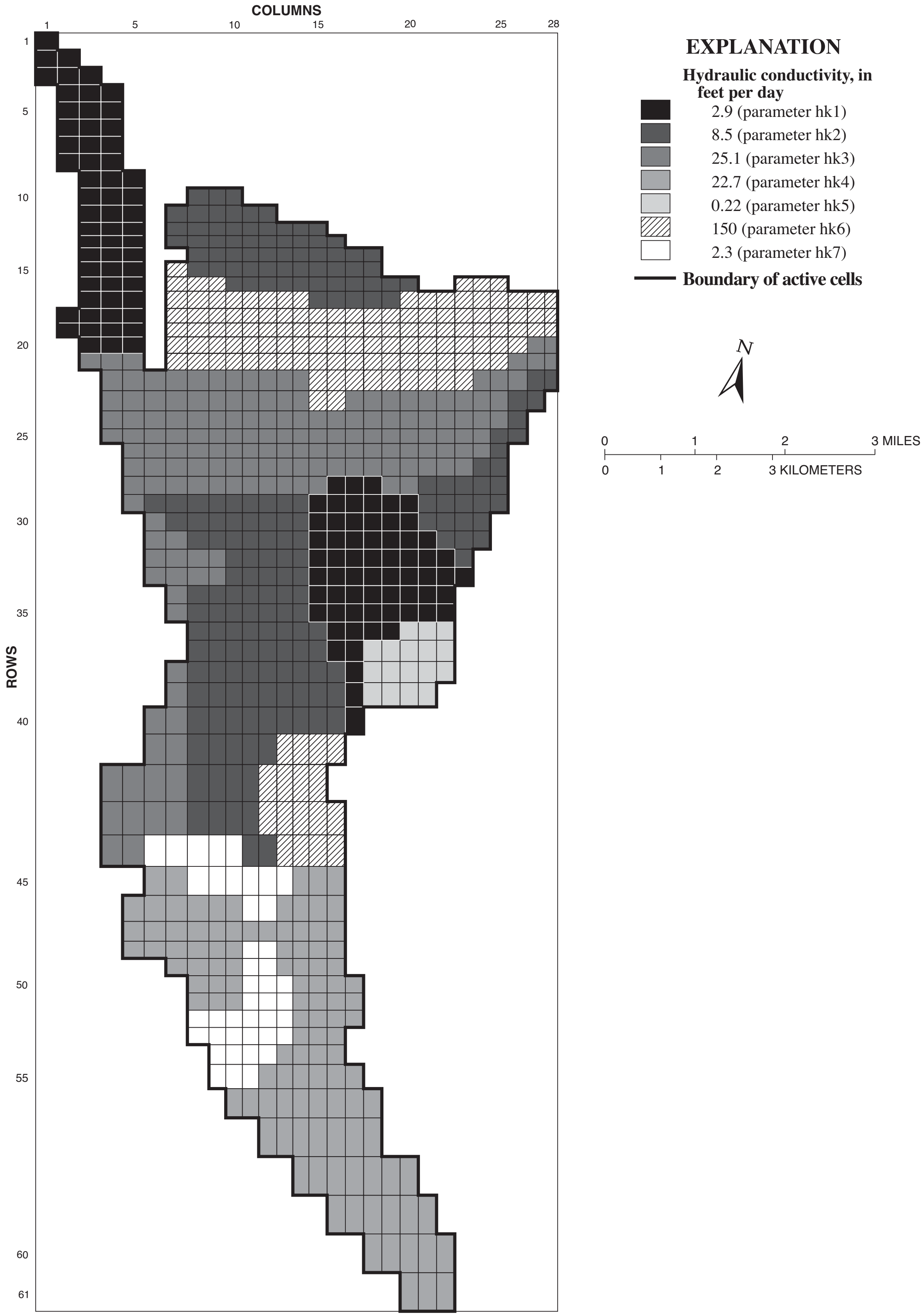

Figure 18. Hydraulic conductivity simulated in the ground-water flow model, Kamas Valley, Utah.

Other Parameters

Initially, one parameter representing streambed hydraulic conductivity (parameter rbk) was assigned a value of 1 ft/d for all streams. Generally, simulated water levels at observations are not very sensitive to the stream parameter (fig. 16). South and east of Francis, however, simulated water levels at several observations are sensitive to the stream parameter controlling discharge to the stream at the bottom of the bench. Therefore, that stream was assigned a new parameter (rbk5), which was adjusted to cause simulated water levels to more closely match observed water levels. Other stream parameters were added and adjusted (fig. 14) to cause simulated recharge from and discharge to streams to more closely match observed gains and losses or to minimize simulating water levels above land surface.

Initially, one drain parameter (drain) was set equal to 0.1 $(ft^2/d)/ft^2$ for all drains. Generally, simulated water levels at observations are not very sensitive to the drain parameter (fig. 16). Several observations south, west, and north of Francis, however, are sensitive to the parameter for drains simulating discharge along the bench; a new parameter (drainfran) was added and adjusted to cause simulated water levels to more closely match observed water levels in that area. The final parameter value for those drains was 0.00025 $(ft^2/d)/ft^2$. Near Peoa, simulated water levels at one observation are sensitive to the drain parameter, but because of limited water-level data, the parameter (drainpeoa) was adjusted to cause discharge to the drains to more closely match observed discharge rather than to try to match the one water level. The final parameter value for the drains near Peoa was 0.0025 $(ft^2/d)/ft^2$.

Simulated values at observations are sensitive to the evapotranspiration parameter (etm) but are not sensitive enough (fig. 16) to warrant splitting the parameter into additional parameters for different areas. The parameter was adjusted during calibration to cause the amount of simulated evapotranspiration to more closely match the conceptual amount of evapotranspiration. The final parameter value was 1.65.

Although the amount of recharge from irrigation was not adjusted during this calibration, the model was changed to include two parameters that define the amount of irrigation recharge, instead of one. Initial simulations indicated that simulated values at observations were more sensitive to the irrigation-recharge parameter (rechim) than to any other parameter (fig. 16a). This indicates that enough observations are available to justify splitting the parameter into more than one parameter. The final model includes one parameter (rechim2) for irrigation recharge near Francis in the Washington/South Kamas Canal irrigation area (table 8) and one parameter (rechim1) for all other irrigation recharge. The value of both parameters remained equal to 1 to simulate conceptual recharge from irrigation. Even with this refinement, simulated values at observations are more sensitive to the parameter defining irrigation recharge near Francis (rechim2) than to any other model parameter (fig. 16b). This indicates that enough observations are available to further refine irrigation-recharge parameters in this area, which was beyond the scope of the model described in this report.

Simulated Water Levels

Overall, the model described in this report adequately simulates water levels. Simulated levels of many observations are within 10 ft of the measured water level and most are within 20 ft (figs. 19 and 20). Higher residuals generally occur in areas where fewer data are available or that have uncertain geology, such as north of Oakley and east of Marion. Simulated water movement as indicated by contours of simulated water levels (figs. 19 and 20) is similar to water movement indicated by contours of measured water levels (pl. 1). The similarities between simulated water levels and measured water levels indicate that most recharge and discharge is adequately understood and simulated and that the amount of water in the conceptual budget can flow through the system.

Simulated seasonal water levels adequately match measured seasonal water levels at several locations throughout the valley (fig. 21, hydrographs A-L). Many of these locations are near Francis, reflecting that more water-level data were available in that area to refine the model. Simulation of water-level fluctuations that match measured fluctuations indicates that amount, timing, and location of ground-water recharge and discharge are adequately understood and simulated. At other locations in the valley, the simulated seasonal water-level fluctuation adequately matches the measured fluctuation, but simulated water levels are above or below measured water levels (fig. 21, hydrographs M-V). Simulated water-level fluctuation at most of these locations is sensitive to

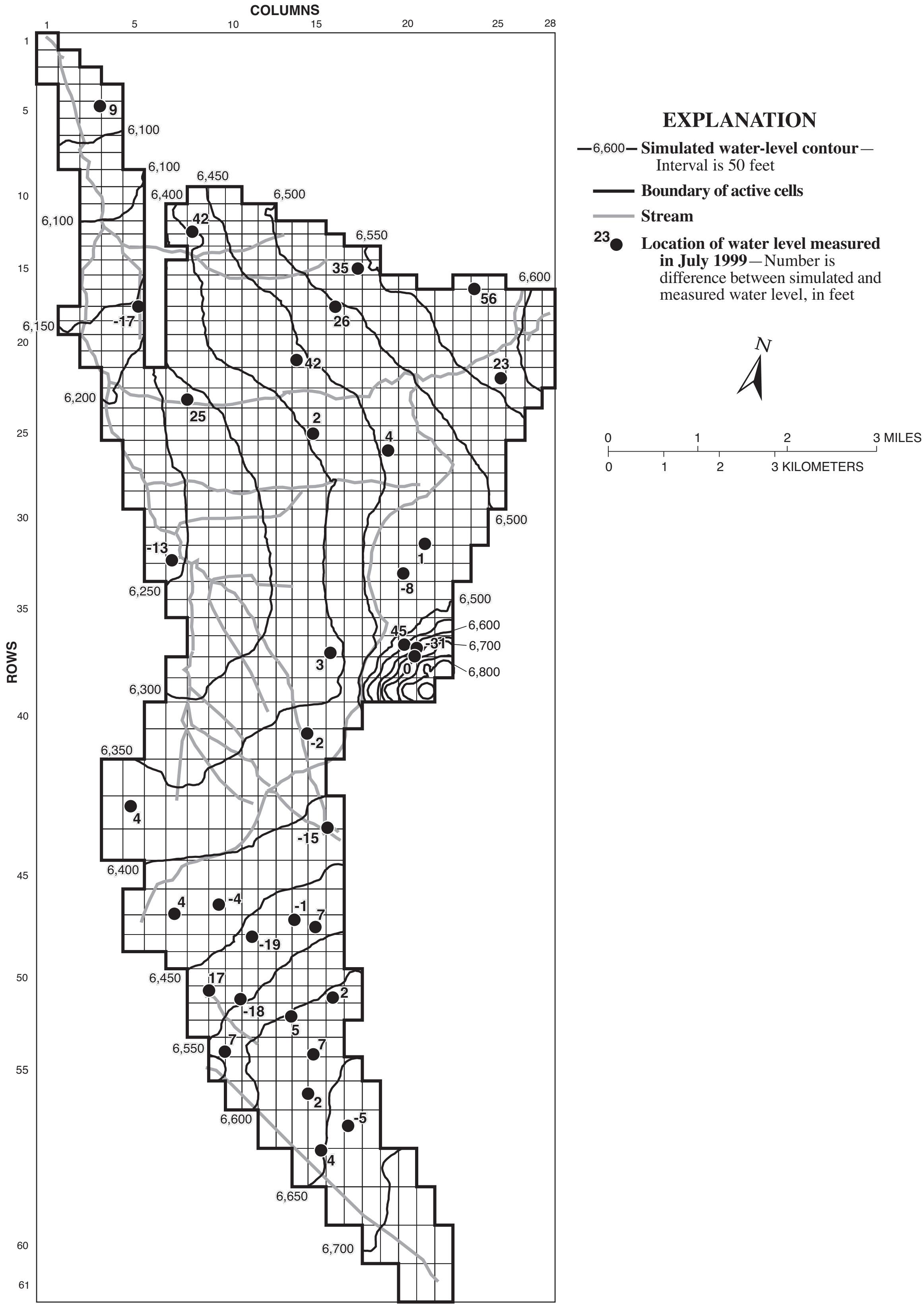

Figure 19. Simulated ground-water levels at the end of stress period 19 in the ground-water flow model and difference between simulated ground-water levels at the end of stress period 19 and ground-water levels measured in July 1999, Kamas Valley, Utah.

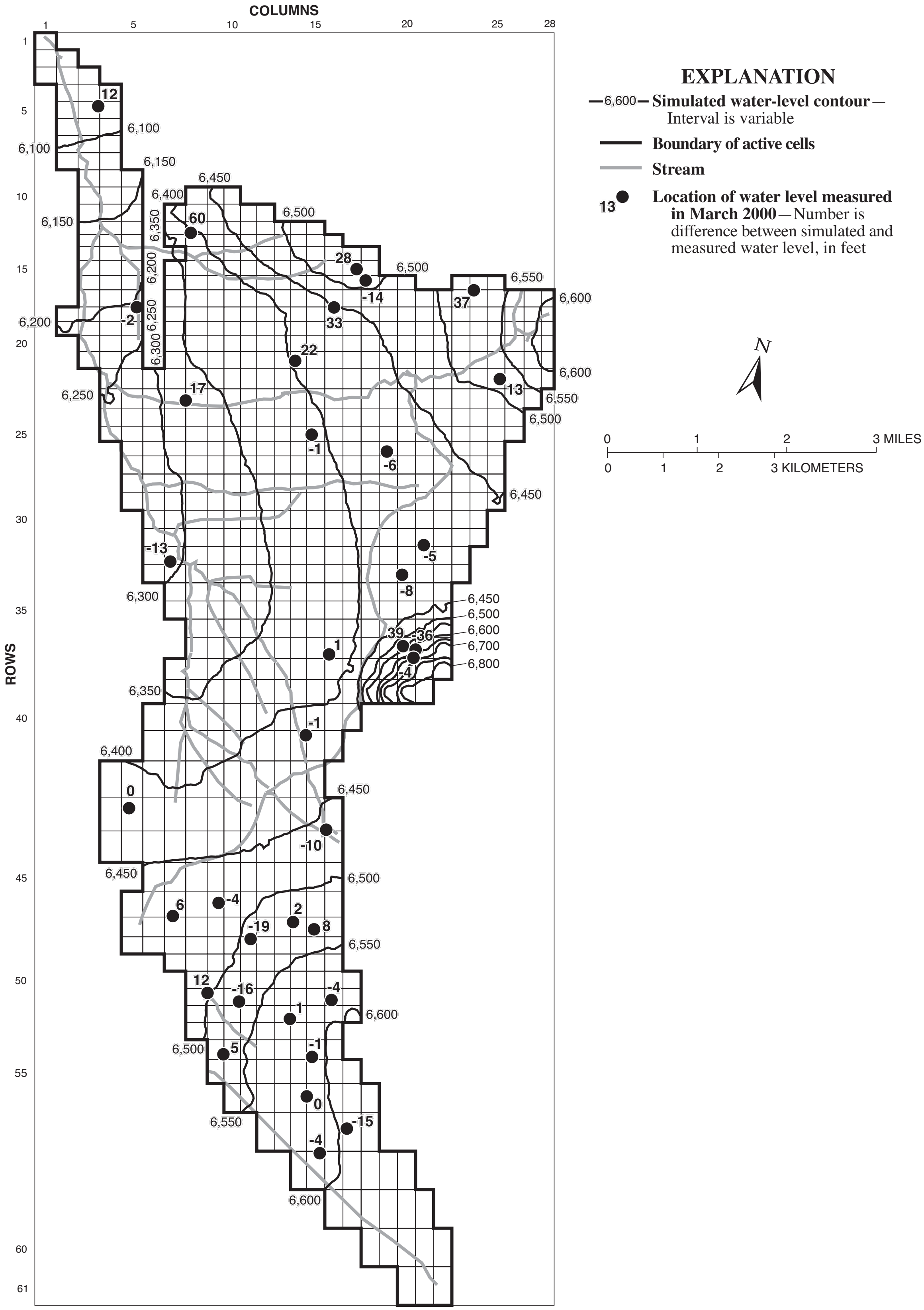

Figure 20. Simulated ground-water levels at the end of stress period 20 in the ground-water flow model and difference between simulated ground-water levels at the end of stress period 20 and ground-water levels measured in March 2000, Kamas Valley, Utah.

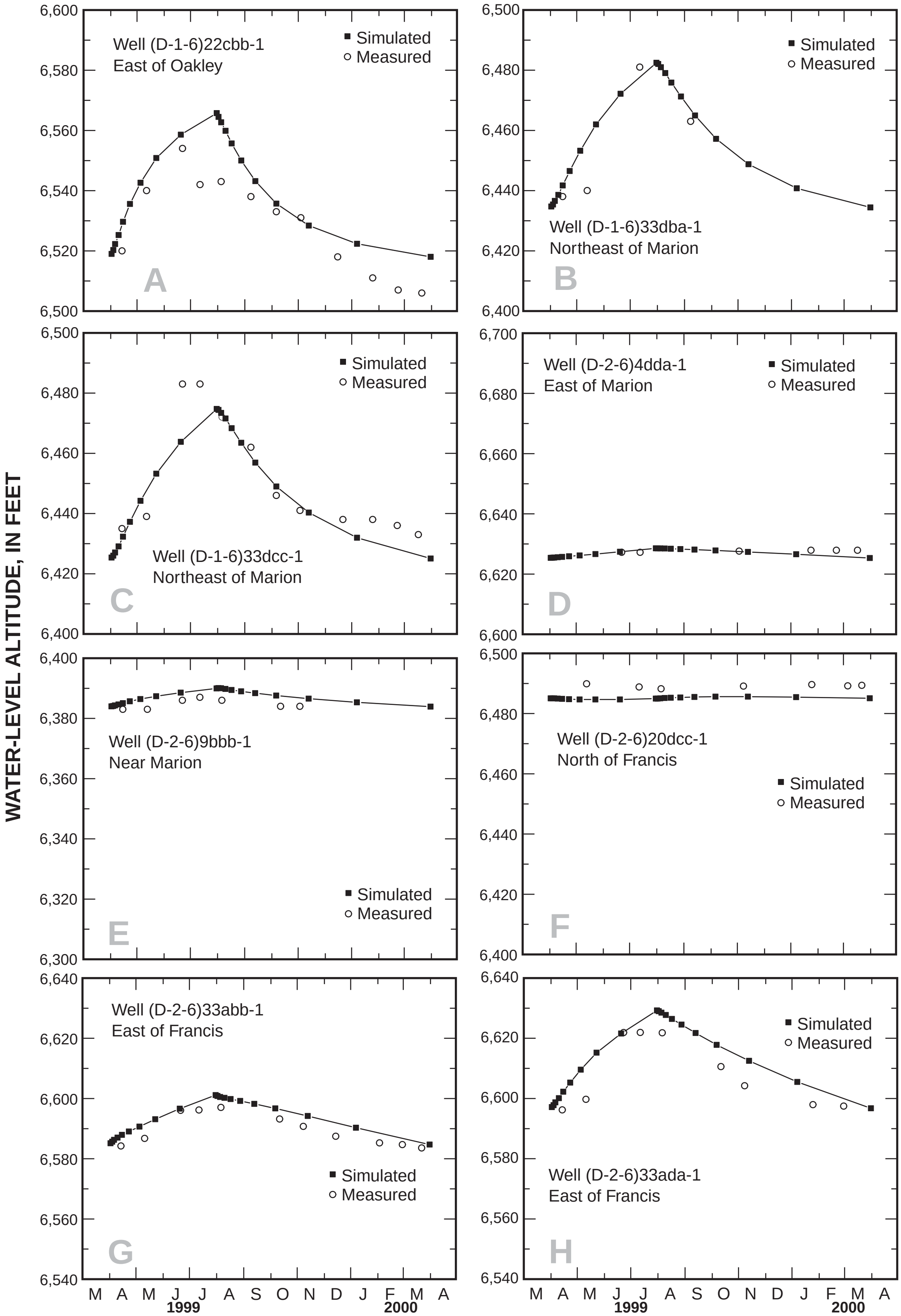

Figure 21. Simulated ground-water levels at the end of each time step in stress periods 19 and 20 in the ground-water flow model and measured ground-water levels, April 1999 to March 2000, Kamas Valley, Utah.

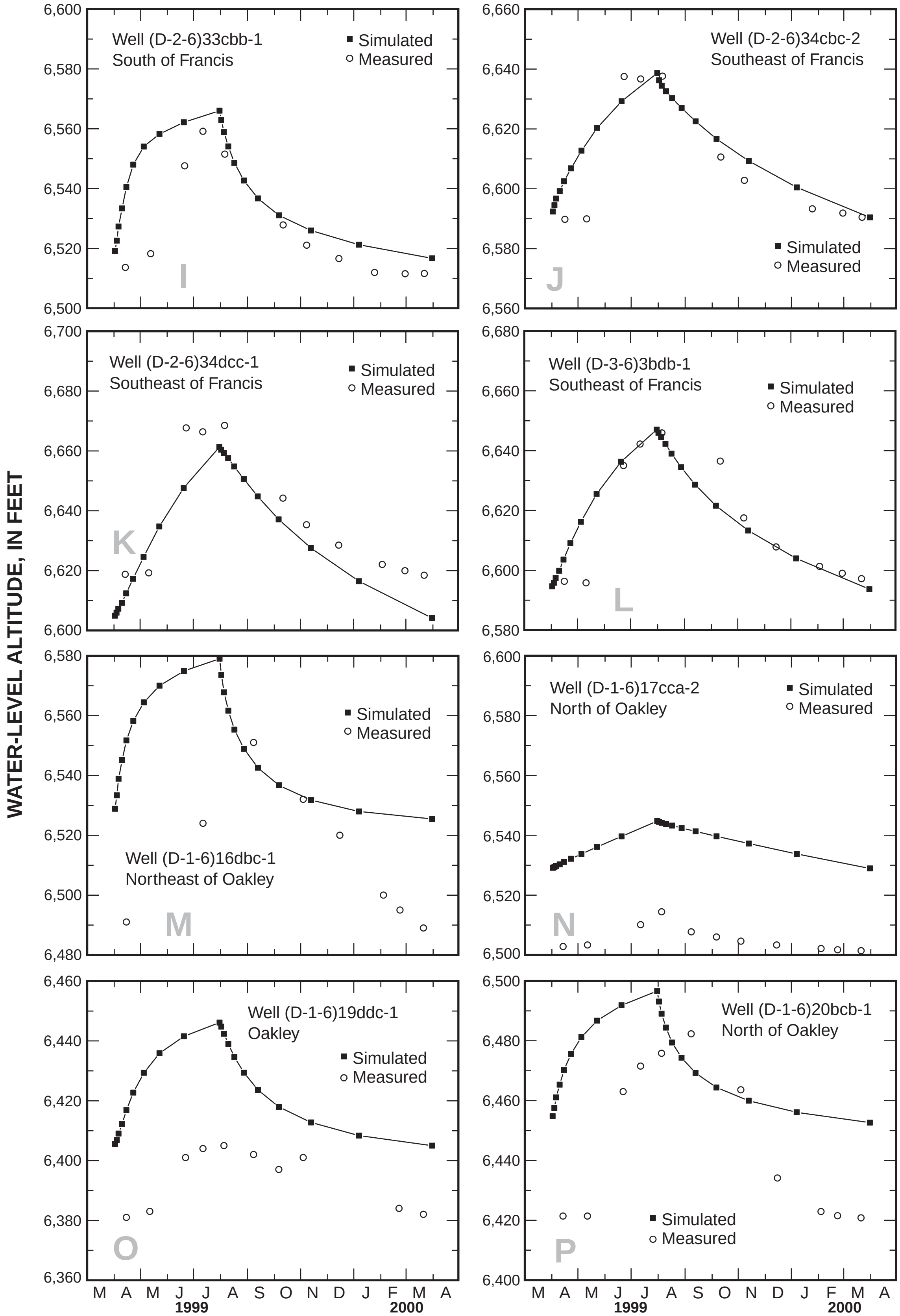

Figure 21. Simulated ground-water levels at the end of each time step in stress periods 19 and 20 in the ground-water flow model and measured ground-water levels, April 1999 to March 2000, Kamas Valley, Utah—Continued.

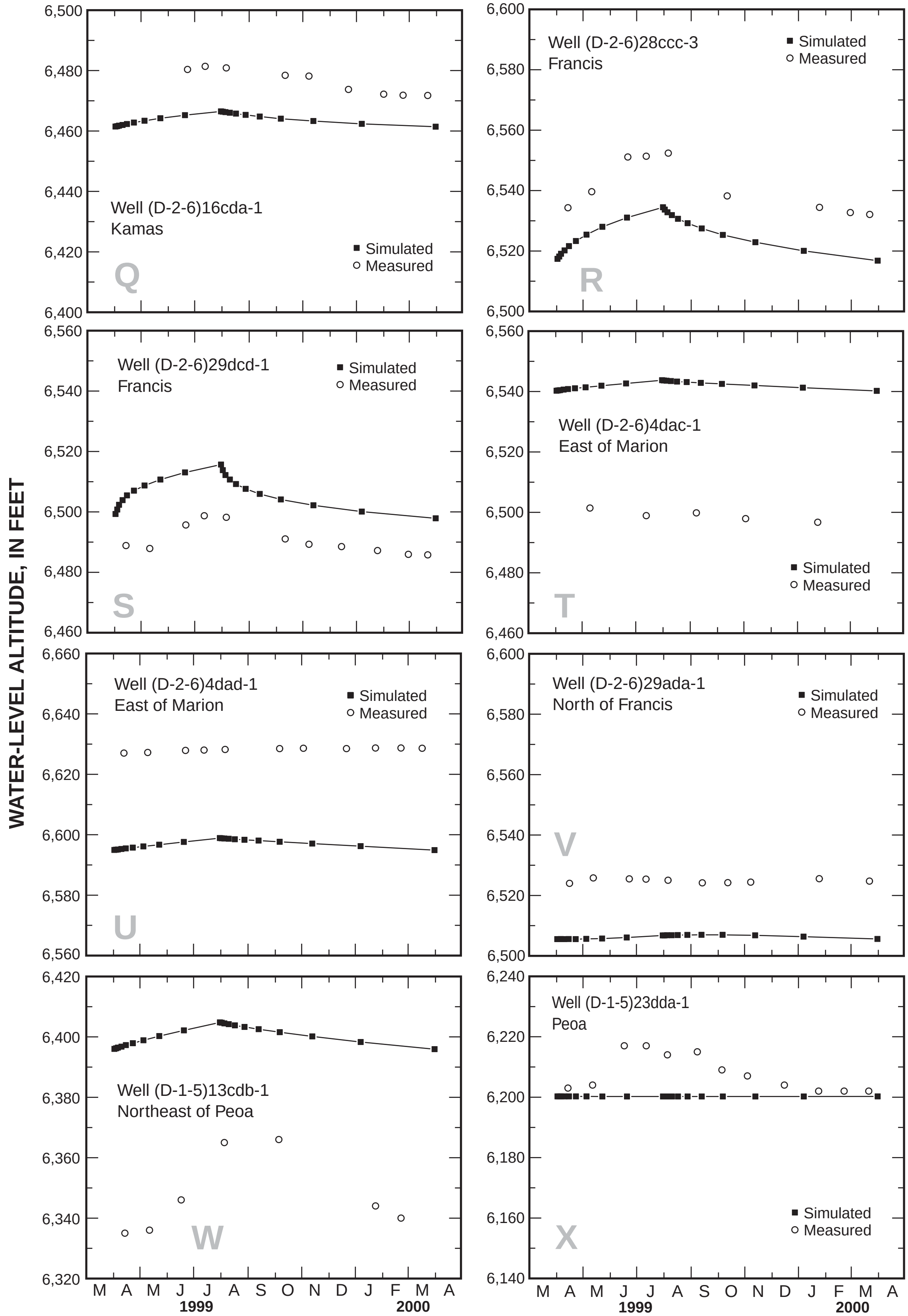

Figure 21. Simulated ground-water levels at the end of each time step in stress periods 19 and 20 in the ground-water flow model and measured ground-water levels, April 1999 to March 2000, Kamas Valley, Utah—Continued.

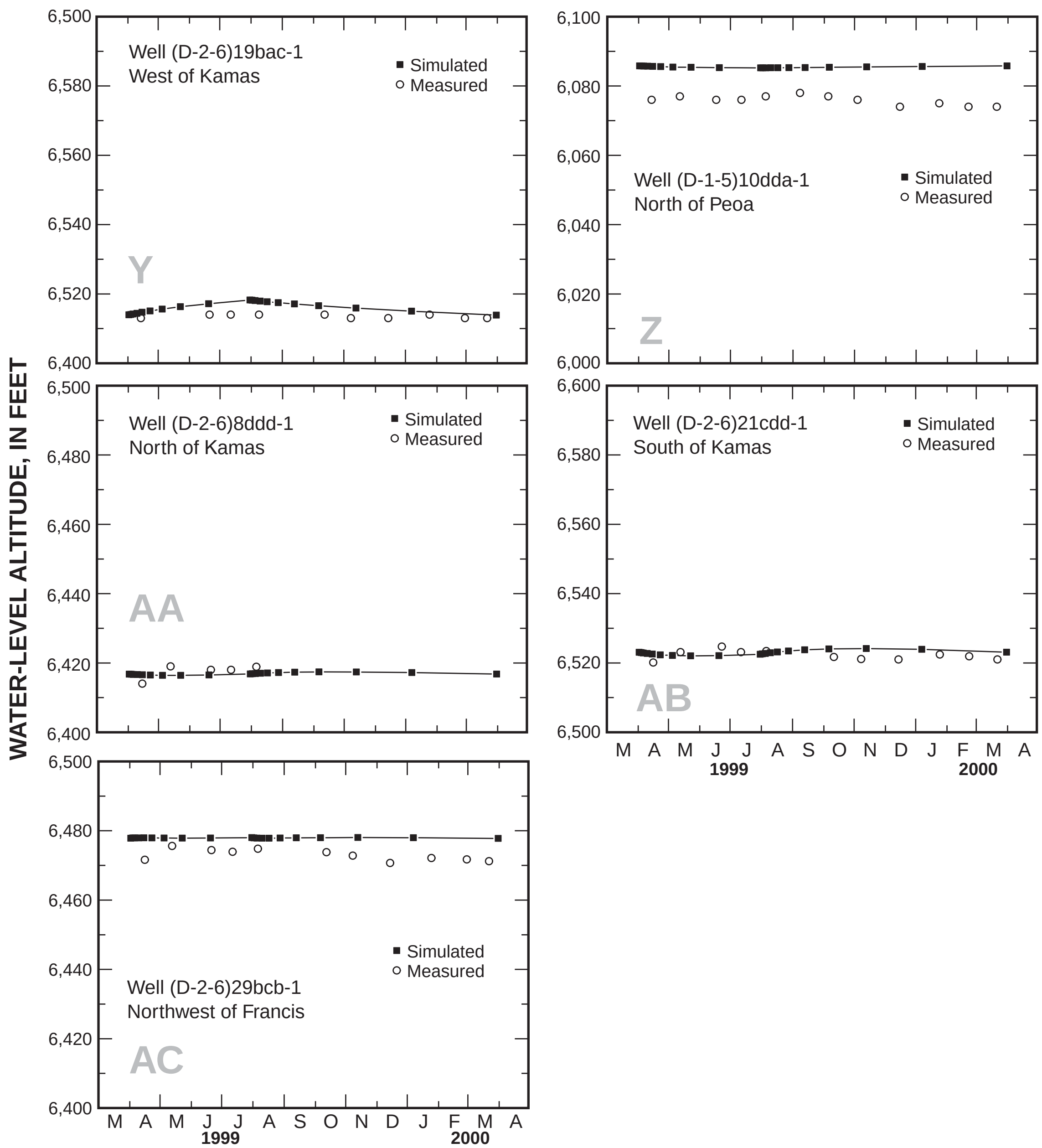

Figure 21. Simulated ground-water levels at the end of each time step in stress periods 19 and 20 in the ground-water flow model and measured ground-water levels, April 1999 to March 2000, Kamas Valley, Utah—Continued

recharge and hydraulic conductivity. Simulated water levels may differ from observed levels because of areal differences in simulated recharge and actual recharge in 1999. These hydrographs indicate that although local variations in recharge or hydraulic conductivity are not simulated exactly, the conceptual budget is reasonable.

At two locations in the valley, simulated seasonal water-level fluctuations are different than measured fluctuations (fig. 21, hydrographs W and X). At these locations, simulated water-level fluctuation is insensitive to all model parameters, indicating that some components of the system may have not been adequately simulated. These two wells are near no-flow boundaries, and the inability to match measured fluctuations may be caused by incorrect boundary conditions in this area.

Several locations scattered throughout the valley have small simulated water-level fluctuations that do not match the small measured water-level fluctuations. This inability to accurately simulate small fluctuations may be caused by local conditions, not major conceptual misunderstandings of the ground-water system.

Recharge, Discharge, and Streamflow

Conceptual and simulated ground-water recharge, discharge, and flow in selected streams are listed in table 11. The model simulates about 15 percent more recharge and discharge than estimated in the conceptual budget. This is an adequate approximation of the conceptual ground-water flow system. Areal recharge (irrigation, precipitation, and ephemeral streams) and discharge by evapotranspiration and to springs match the conceptually estimated amounts. Recharge from and discharge to streams exceed the conceptually estimated amounts.

Because discharge to streams is the largest component of ground-water discharge in Kamas Valley, the model was adjusted to match the conceptual discharge to streams as closely as possible, while still minimizing the weighted residuals of water-level and stream observations. Discharge to streams cannot be measured as accurately as ground-water levels; as a result, stream observations were given a much lower weight and differences between observed flow and simulated flow add little to the sum of the squares of the weighted residuals. Considering all observations, the most accurate simulation resulted in simulated discharge to streams that exceeded conceptual discharge to streams by 5,000 acre-ft/yr, about 20 percent. Simulated recharge from streams exceeded conceptual recharge from streams by 5,000 acre-ft/yr, about 125 percent. It is possible that more surface-water/ground-water interaction actually occurs than is estimated in the conceptual budget; the conceptual budget represents the net difference between recharge and discharge both within areas of the valley and the entire valley. For example, discharge to Beaver Creek (table 3) indicates that Beaver Creek gains 15,000 acre-ft/yr between the Weber-Provo Diversion Canal and the Rocky Point gage near Peoa. This could occur as no recharge and 15,000 acre-ft/yr discharge, as 15,000 acre-ft/yr recharge and 30,000 acre-ft/yr discharge, or any other combination. The delineation between recharge and discharge is limited in the conceptual budget by location and accuracy of measurements. The model grid is finer than the area of field measurements (fig. 4), and the model simulates recharge and discharge on a finer scale than was measured.

The distribution of recharge from and discharge to streams reasonably matches the conceptual flow in Kamas Valley (table B-1) for 10 zones (appendix B, fig. B-1). Most differences in discharge to streams occur over small areas, and most of the difference occurs in the midvalley area. Conceptual recharge from streams in this area is negligible, but simulated recharge from streams in this area is about 3,000 acre-ft/yr (table B-1, zone 6). The net simulated discharge in the midvalley area is about 13,000 acre-ft/yr, which is 9,000 acre-ft/yr less than the conceptual discharge. The simulated discharge to Crooked Creek east of U.S. Highway Alt. 189 is about 2,000 acre-ft/yr more than conceptually estimated (table B-1, zone 8), and discharge to the lower part of Beaver Creek upstream from where it flows into the Weber River is about 3,000 acre-ft/yr more than conceptually estimated (zone 10 in table B-1). Simulated discharge to the Weber River between Oakley and Peoa is about 2,000 acre-ft/yr more than conceptually estimated (table B-1, zone 5). In a trial simulation, discharge to the Weber River in this area was reduced by reducing streambed conductance but this caused simulated heads to be above land surface. The model simulates a net of about 21,000 acre-ft/yr ground-water discharge near the midvalley area, but not exactly in the same area as the 23,000 acre-ft/yr estimated on the basis of measurements of Beaver Creek (Haraden and others,

Table 11. Conceptual ground-water budget and ground-water budget simulated in the ground-water flow model, Kamas Valley, Utah

Budget component	Conceptual flow (rounded) (acre-feet per year)	Conceptual flow (rounded) (cubic feet per year)	Method of simulation	Simulated flow (rounded) (acre-feet per year)	Simulated flow (rounded) (cubic feet per year)
Recharge					
Areal recharge[1]	[2]33,000	1,400,000,000	Specified flux in Recharge Package	33,000	1,430,000,000
Recharge from streams	4,000	170,000,000	Head-dependent flux in Streamflow-Routing Package	[3]9,000	410,000,000
Total (rounded)	**37,000**	**1,600,000,000**		**42,000**	**1,800,000,000**
Discharge					
Discharge to streams	24,000	1,000,000,000	Head-dependent flux in Streamflow-Routing Package	[3]29,000	1,270,000,000
Discharge to springs	5,000	220,000,000	Head-dependent flux in Drain Package	6,000	270,000,000
Evapotranspiration	[4]7,000	300,000,000	Head-dependent flux in Evapotranspiration Package	7,000	300,000,000
Discharge to wells	1,000	44,000,000	Not simulated	not simulted	not simulated
Total (rounded)	**37,000**	**1,500,000,000**		**42,000**	**1,800,000,000**
Streamflow					
Beaver Creek at Rocky Point	40,000	1,700,000,000	Streamflow-Routing Package, segment 35, reach 1	36,000	1,590,000,000
Weber River near Peoa, Utah	138,000	6,010,000,000	Streamflow-Routing Package, segment 49, reach 3	149,000	6,480,000,000

[1]Includes 4,000 acre-feet per year recharge from Weber River and 1,000 acre-feet per year recharge from Beaver Creek upstream of model boundary.
[2]About 1,000 acre-feet per year of irrigation recharge is not included in the modeled area.
[3]About 1,000 acre-feet per year greater than table B-1 because of rounding and time discretization. Budgets in table B-1 calculated as average flow in stress period 19 as estimated by flow in time step 8 plus average flow in stress period 20 as estimated by flow in time step 8.
[4]About 1,000 acre-feet per year of evapotranspiration is not included in the modeled area.

2001, table 6) and estimates of discharge to Weber River. Part of the difference may be caused by the input altitude of the streams in the model. From topographic maps, these altitudes are accurate to within 10 ft. In the midvalley area, the hydraulic gradient is small enough that an altitude difference of 10 ft could change a stream from simulating discharge to simulating recharge. Incorporating more accurate stream altitudes in the model may change the location of simulated discharge to streams. One-percent scaled sensitivities indicate the amount a simulated observation would change in response to a one-percent change in each parameter. One-percent scaled sensitivities indicate that simulated discharge to streams in midvalley increases most with increasing areal recharge parameters rechim1 and rechem, increasing stream parameter rbk2, increasing hydraulic-conductivity parameter hk3, and decreasing evapotranspiration parameter (fig. 22). Simulated discharge to the Weber River between Oakley and Peoa decreases most (fig. 22) with decreasing areal recharge parameter rechim1 and decreasing stream parameter rbk3. Longer-term flow data in the midvalley area and more detailed flow data on the Weber River would increase the number of flow observations for different seasons and increase the accuracy of the observations, which may allow future recalibration of the model to more accurately simulate this area.

Simulated recharge from the Weber River east of Oakley is similar to conceptually estimated recharge (table B-1, zone 4). Simulated discharge to springs near Peoa is similar to conceptually estimated discharge (table B-1, zone 1). Because few observation wells are near these locations, streambed and drain conductance could be adjusted to match the conceptual budget without significantly affecting the sum of the squares of the weighted residuals.

Simulated discharge to the stream at the bottom of the Francis bench is about 2,000 acre-ft/yr more than conceptually estimated (table B-1, zone 3). Measured water levels show ground-water movement to this area

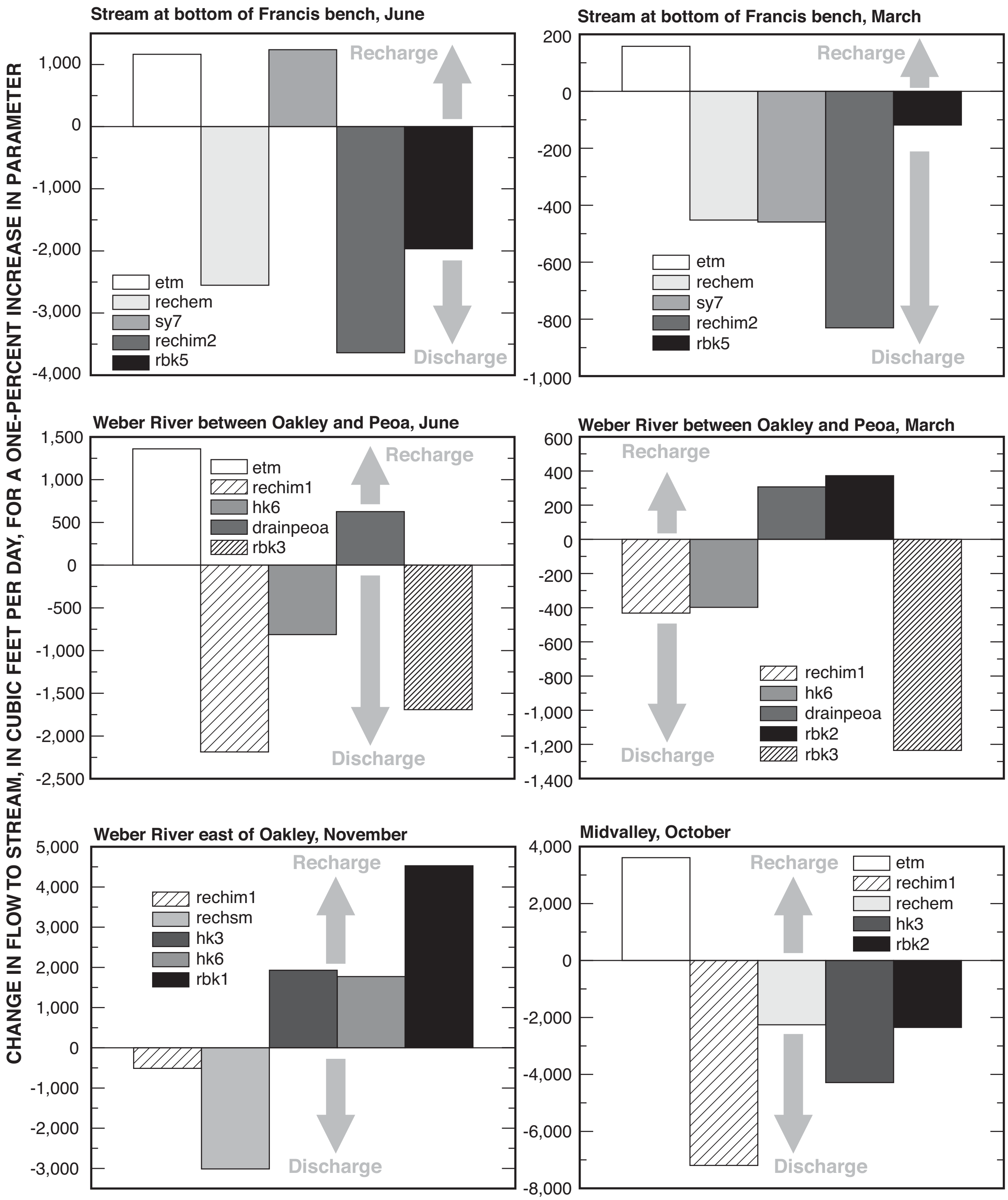

Figure 22. One-percent scaled sensitivity of discharge to streams or recharge from streams for selected model parameters for stress period 20 in the ground-water flow model, Kamas Valley, Utah.

(pl. 1). Trying to reduce this discharge by reducing drain and stream conductance created larger residuals in water-level observations near Francis. Simulated water levels are above land surface in a few cells near the Provo River. Part of the reason for this may be that discharge actually occurs along the bench at altitudes higher than the river. Simulated discharge to the stream at the bottom of the bench decreases most with decreasing areal recharge parameter rechim2 and decreasing stream parameter rbk5 (fig. 22). Simulated discharge to springs near Francis decreases most with decreasing areal recharge parameter rechim2 (fig. 23). Measurements of discharge to the Provo River and springs would increase the number of flow observations for different seasons and increase the accuracy of the observations, which may allow future recalibration of the model to more accurately simulate this area.

Parameter Correlation, Sensitivity Analysis, and Need for Additional Data

The hydraulic properties simulated in this model are reasonable approximations of the actual hydraulic properties if the conceptual ground-water budget is correct. This ground-water model, however, should not be considered unique. Other combinations of recharge, discharge, and aquifer properties may yield a similar or improved match to measured water levels and flows. Flow measurements are typically more useful than water-level measurements in trying to obtain a unique simulation.

Some parameters defining specific yield, hydraulic conductivity, areal recharge, and streambed conductance near Francis are highly correlated and cannot be determined independently. Parameters with correlation coefficients greater than about 0.95 are listed in table B-8. Correlation coefficients close to 1 indicate parameter values that cannot be uniquely estimated with the observations used (Hill, 1998, p. 28). If the parameter values are not unique, the model is likely to produce inaccurate predictions of quantities that depend on the individual parameter values (M.C. Hill and C. Tiedeman, U.S. Geological Survey, written commun., 2001). In this case, inaccurate predictions of drawdown around wells, seasonal fluctuations resulting from different recharge than simulated in this model, flow near the Provo River, or other quantities dependent on specific yield, hydraulic conductivity, recharge, or streambed conductance near Francis could occur. The correlation coefficients determined by MODFLOW-2000 (table B-8) are dependent upon the accuracy of the observed discharge to streams and springs. Values of discharge or accuracy different from those used in this simulation (tables B-6 and B-7) would result in different correlations.

More information on ground-water discharge from the Francis bench to the Provo River would reduce parameter correlation. Assuming that discharge to the river is 1,000 acre-ft/yr and accurate to within 20 percent instead of 50 percent, the model has no highly correlated parameters. Better definition of ground-water discharge to the Provo River also slightly reduces the uncertainty in the parameters as determined by the model. An accuracy of 20 percent should be possible with seepage runs conducted at several times of year. If irrigation practices near Francis change significantly, additional seepage runs may be required. Better definition of ground-water recharge from the Weber River, ground-water discharge to the Weber River between Oakley and Peoa, ground-water discharge to Beaver Creek, or ground-water discharge to springs near Francis does not reduce correlation or uncertainty significantly.

The composite scaled sensitivities (fig. 16) indicate that water levels, water-level fluctuations, and discharge to streams and springs in most of the modeled area provide more data about irrigation-recharge parameters than about any other model parameters. Future efforts to refine the estimate of location and amount of irrigation recharge may improve model fit and refine the conceptual understanding of the ground-water system. If recharge is determined to be significantly different than used in the construction of this model, then simulated aquifer characteristics and other model parameters may not be realistic estimates of actual hydrologic properties.

One-percent scaled sensitivities indicate the amount a simulated observation would change in response to a one-percent change in each parameter. One-percent scaled sensitivities for discharge to streams and drains was discussed in the “Calibration” section of this report (figs. 22 and 23). In general, stream and drain observations in June are more sensitive to model parameters than observations in March. This indicates that measurements during the irrigation season may be the most useful in understanding the ground-water system and refining the model.

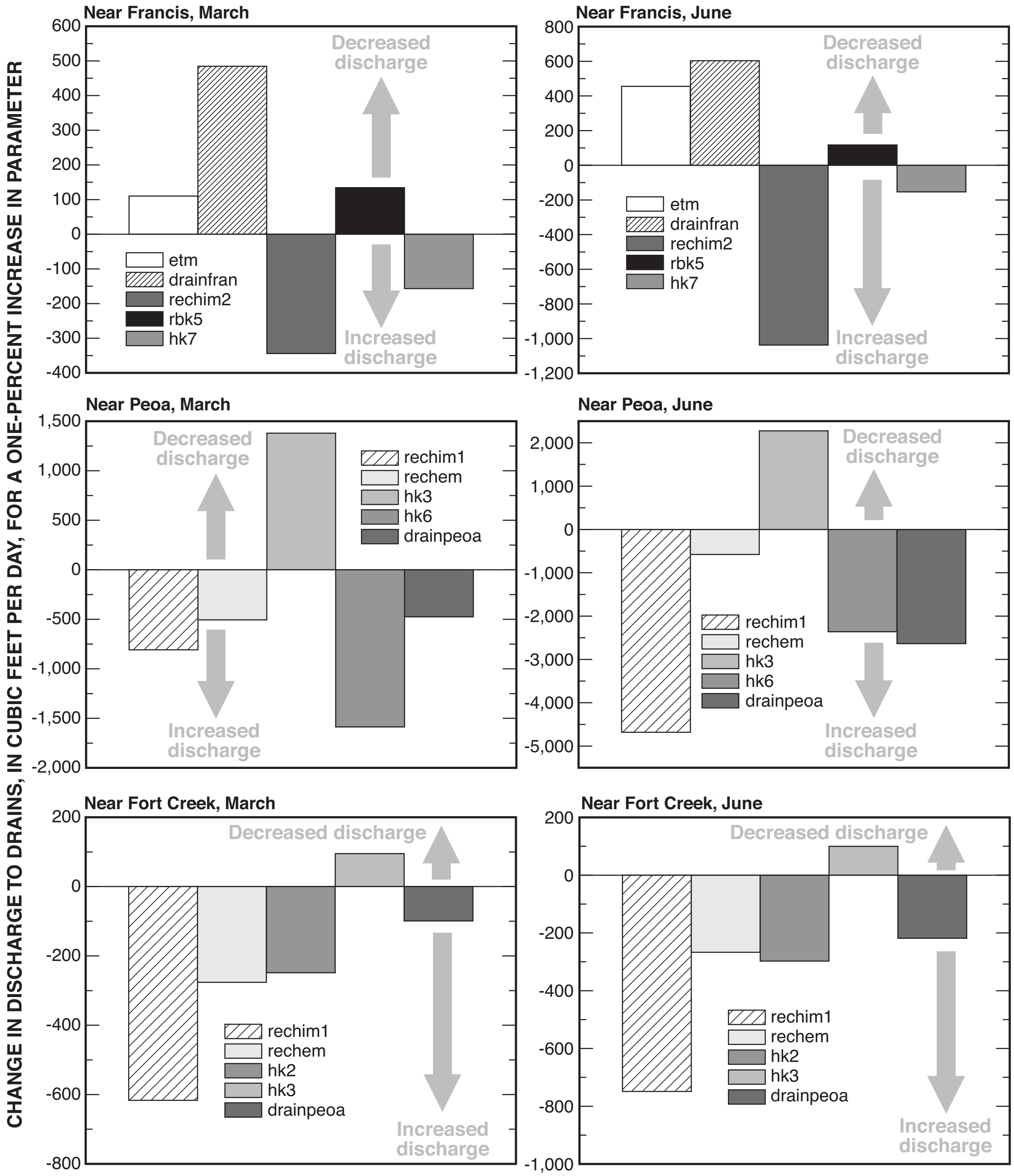

Figure 23. One-percent scaled sensitivity of discharge to drains for selected model parameters for stress period 20 in the ground-water flow model, Kamas Valley, Utah.

One-percent scaled sensitivities also are available for simulated water levels, providing a value for each cell in the model grid. These sensitivity maps can be used to delineate areas of the valley where water-level observations may be the most sensitive to certain parameters, and therefore, help define those parameters. An analysis of these maps indicated that several observation wells used in this model are located in areas most sensitive to certain parameters (table B-9). For several parameters, however, water-level observations are not available at the areas most sensitive to the parameter. The locations of available water-level observations and other locations with the highest one-percent scaled sensitivity to model parameters are shown in figure 24. Water-level data collected at sites where data were not available during this study may help refine the model and the conceptual understanding of the ground-water system. Seasonal water-level fluctuations would be needed to refine estimates of specific yield. Additional water-level data collected at the sites used during this study could detect any changes occurring to the ground-water system.

SUMMARY

Residential development is increasing in Kamas Valley, Utah, and water needed to support the development will come mostly from ground water. Increased development has expanded the number of wells and septic systems in the valley. The U.S. Geological Survey, in cooperation with state and local agencies, completed a hydrologic study of the area from 1997 to 2001.

The major sources of water in Kamas Valley are the Weber River, Beaver Creek, and Provo River. These streams carry about 350,000 acre-ft/yr of water through the valley. Most streamflow in the study area originates in the Uinta Mountains on the eastern border and exits through canyons in the northwest and southwest. Inflow to streams includes perennial streamflow entering the valley; irrigation return flow; ground-water discharge to streams; ungaged perennial, intermittent, and ephemeral streamflow; and runoff from precipitation in the valley. Much of the flow from ungaged drainage basins does not contribute flow directly to the Weber or Provo Rivers because it infiltrates the ground and becomes ground-water recharge. In addition to ground-water discharge directly to streams, ground water also contributes streamflow through diffuse discharge to springs and natural drains in the lower altitude parts of the valley, and along benches near Peoa and Francis. Outflow from streams includes streamflow leaving the valley, irrigation diversions, and ground-water recharge from streams. Irrigation diversions and irrigation return flow are major components of the surface-water budget in Kamas Valley.

The ground-water system in the study area consists of water in unconsolidated deposits and consolidated rock. Withdrawal from wells in unconsolidated deposits and consolidated rock is not a significant source of discharge from the ground-water system. Interaction between ground water in unconsolidated deposits and consolidated rock is not known, but is considered to be small. This does not mean, however, that unconsolidated deposits and consolidated rock are hydrologically separate. Recharge to consolidated rock occurs mostly as precipitation at higher altitudes where rock is exposed or covered only by a thin veneer of unconsolidated deposits. Discharge from consolidated rock occurs mostly to springs and streams upgradient from Kamas Valley. Most municipal water systems in Kamas Valley use water from springs and wells in consolidated rock. The ground-water system in consolidated rock is estimated to be in a long-term steady-state condition.

The ground-water budget of 38,000 acre-ft/yr presented in this report is for ground water in the unconsolidated deposits. One reason for this emphasis is that increased residential development will affect ground water in the unconsolidated deposits in more complex ways than in consolidated rock. Recharge to unconsolidated deposits is from infiltration of irrigation water, precipitation, streams, and canals. Discharge from unconsolidated deposits occurs as seepage to streams, springs, and canals; evapotranspiration; and withdrawal from wells.

Water-level fluctuations are caused by changes in recharge to and discharge from the ground-water system. Water levels in Kamas Valley rise in spring and early summer, and decline during the winter. This pattern indicates the dominance of surface water on the hydrologic system of the valley. In areas where irrigation from surface water occurs, seasonal water levels can fluctuate by 50 ft or more. With the exception of the bench areas between Francis and Woodland, seasonal water-level fluctuations near perennial streams are moderated.

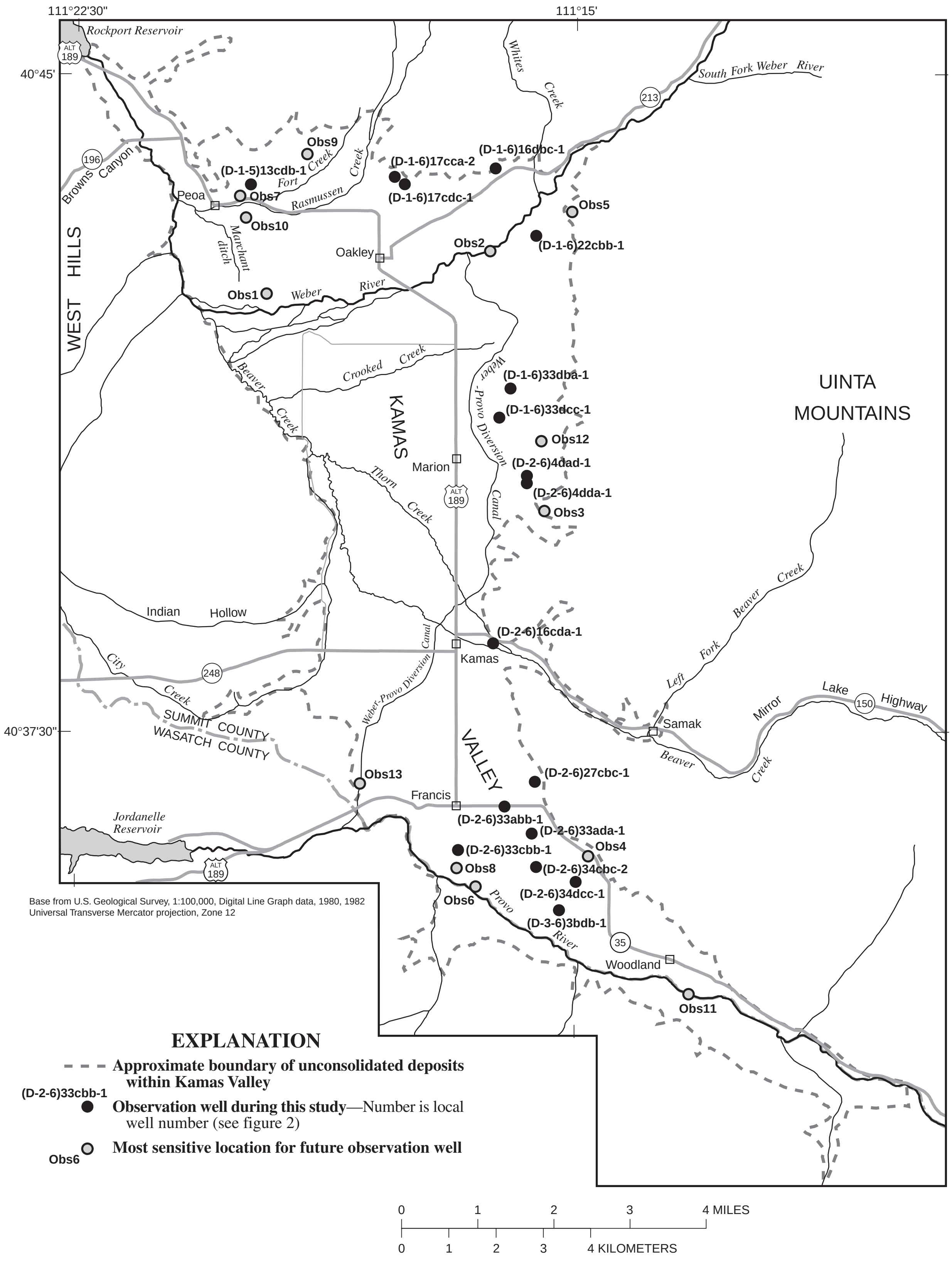

Figure 24. Location of simulated water levels with greatest one-percent scaled sensitivity to selected model parameters simulated in the ground-water flow model, Kamas Valley, Utah.

Ground water generally moves from recharge areas on the benches to discharge areas near Beaver Creek and Weber River; most discharge occurs to Beaver Creek. A ground-water divide near Francis causes some water to flow to Provo River. Flow in the Keetley Volcanics near Indian Hollow is from higher altitude toward Kamas Valley; the amount of flow from the Keetley Volcanics to the unconsolidated deposits is estimated to be small. Water-level data indicate discharge from the Keetley Volcanics to the creek in Indian Hollow.

Estimates of transmissivity from specific-capacity data indicate that transmissivity varies by four orders of magnitude in both unconsolidated deposits and consolidated rock. The typical value of transmissivity in unconsolidated deposits is 1,000 to 10,000 ft^2/d. The typical value in consolidated rock is 100 ft^2/d. The average value of hydraulic conductivity in unconsolidated deposits is about 50 ft/d. Average aquifer characteristics of Kamas Valley are such that closely spaced domestic wells turning on and off in response to daily water needs will not interfere with one another.

Water samples were collected from selected wells, springs, and surface-water sites and analyzed for physical properties, major ions, dissolved-solids concentration, nutrients, dissolved organic carbon, MBAS, coliform bacteria, trace elements, radionuclides, and pesticides. These constituents were selected to characterize general water quality and to target potential contaminants. Nitrate plus nitrite (as N) concentrations in surface water and well water throughout the Kamas Valley area are substantially below the Utah Department of Environmental Quality drinking-water standard of 10 mg/L. Total and fecal coliform bacteria were detected in samples from selected surface-water sites along Weber River, Beaver Creek, and Marchant ditch but were very low or absent in ground water. Coliform bacteria probably originate from livestock and domestic animals rather than septic systems. Low concentrations of nutrients and related anthropogenic constituents in well water do not indicate a degradation of ground-water quality from septic systems.

Concentrations of trace elements in surface streams and well water were very low and no constituent was present in concentrations that exceed Utah Department of Environmental Quality drinking-water standards. Pesticides were detected in very low concentrations in water from the Weber River, Marchant ditch, and three of six wells sampled. Concentrations of these constituents did not exceed 0.005 µg/L. On the basis of dissolved-solids concentrations, most ground water in the Kamas Valley area could be classified as Class 1A — Pristine Ground Water. Results of analysis for major-ion chemistry of water from wells in unconsolidated deposits and consolidated rock indicate that water in the Kamas Valley area is generally a calcium-bicarbonate type. Anomalous concentrations of chloride detected in water from several sites may be derived from road salt.

A numerical ground-water flow model was developed to simulate the ground-water system in the unconsolidated deposits in Kamas Valley to test the conceptual understanding of the ground-water system. Analyses of model fit and sensitivity of the model to certain parameters were used to refine both the conceptual and numerical models. This model has been developed to simulate general ground-water flow through Kamas Valley and seasonal water-level fluctuations; it has not been developed to simulate drawdown from wells or other local effects. Overall, the model described in this report adequately simulates water levels, indicating that most recharge and discharge is adequately understood and simulated and that the amount of water in the conceptual budget can flow through the system. The model simulates about 15 percent more recharge and discharge than estimated in the conceptual budget; recharge from streams and discharge to streams exceed conceptually estimated amounts, but other sources of recharge and discharge match conceptually estimated amounts.

More information on ground-water discharge, especially from the Francis bench to the Provo River, would be helpful in trying to obtain a unique numerical simulation. Future efforts to refine the estimate of location and amount of irrigation recharge may improve model fit and refine the conceptual understanding of the ground-water system. Ground-water levels near the valley margins and southeast of Francis are sensitive to most model parameters and could help refine those parameters.

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APPENDIX A

Error analysis of water-budget components

Table A-1. Error analysis of annual runoff and recharge from ungaged drainage basins surrounding Kamas Valley, Utah

[Amounts in acre-feet, rounded]

Error range of runoff over unconsolidated deposits: Low end of range equals minimum precipitation minus maximum consumptive use, with a minimum of 10 percent of minimum precipitation. High end of range equals maximum precipitation minus minimum consumptive use with a maximum of 35 percent of maximum precipitation.

Error range of recharge to unconsolidated deposits: Low end of range equals 50 percent of minimum runoff over unconsolidated deposits. High end of range equals 90 percent of maximum runoff over unconsolidated deposits.

Error range of runoff to surface water: Low end of range equals 10 percent of minimum runoff over unconsolidated deposits. High end of range equals 50 percent of maximum runoff over unconsolidated deposits.

Location of drainage	Precipitation (10 percent error)	Consumptive use (20 percent error)	Error range of runoff over unconsolidated deposits	Error range of recharge to unconsolidated deposits	Error range of recharge to surface water
Flow to Weber River					
West of valley	12,300 to 15,100	9,400 to 14,000	1,200 to 5,300	[1]0	1,200 to 5,300
North of valley	15,800 to 19,400	11,200 to 16,800	1,600 to 6,800	800 to 6,100	200 to 3,400
East of valley	4,300 to 5,300	3,000 to 4,600	400 to 1,900	200 to 1,700	0 to 1,000
Total for Weber River	**32,400 to 39,800**	**23,600 to 35,400**	**3,200 to 14,000**	**1,000 to 7,800**	**1,400 to 9,700**
Flow to Beaver Creek					
West of valley	3,500 to 4,300	2,200 to 3,200	400 to 1,500	[1]0	400 to 1,500
East of valley	11,000 to 13,400	7,400 to 11,200	1,100 to 4,700	600 to 4,200	100 to 2,400
Total for Beaver Creek	**14,500 to 17,700**	**9,600 to 14,400**	**1,500 to 6,200**	**600 to 4,200**	**500 to 3,900**
Flow to Provo River					
Southeast of valley	7,400 to 9,000	4,700 to 5,700	1,700 to 3,200	800 to 2,900	200 to 1,600
South of valley	42,900 to 52,500	28.700 to 43,100	4,300 to 18,400	[1]0	4,300 to 18,400
Total for Provo River	**50,300 to 61,500**	**33,400 to 48,800**	**6,000 to 21,600**	**800 to 2,900**	**4,500 to 20,000**
Total (rounded)	**97,000 to 119,000**	**67,000 to 99,000**	**11,000 to 42,000**	**2,000 to 15,000**	**6,000 to 34,000**

[1]Runoff occurs near major streams and flow is assumed to contribute to surface water with little ground-water interaction.

Table A-2. Error analysis of annual irrigation budget components, Kamas Valley, Utah

[Amounts in acre-feet, rounded; ET, evapotranspiration]

Range in amount applied: Low end of range is minimum amount diverted minus maximum direct return flow minus maximum ground-water recharge from canals. High end of range is maximum amount diverted minus minimum direct return flow minus minimum ground-water recharge from canals.
Range in runoff from fields: Low end of range is 15 percent of minimum amount applied for non-ET areas and 50 percent of minimum amount applied for ET areas. High end of range is 50 percent of maximum amount applied for non-ET areas and 100 percent of maximum amount applied for ET areas.
Range in amount effectively applied: Low end of range is 50 percent of minimum amount applied for non-ET areas and 0 for ET areas. High end of range is 85 percent of maximum amount applied for non-ET areas and 50 percent of maximum applied for ET areas.

Unofficial name of irrigation area (fig. 5)	Amount diverted (10 percent error)	Direct return flow (5 to 20 percent of amount diverted)	Ground-water recharge from canals (0 to 15 percent of amount diverted)	Range in amount applied	Range in runoff from fields	Range in amount effectively applied
Diverted from Weber River, return flow to Weber River						
New Field and North Bench Canals	7,200 to 8,900	400 to 1,800	0 to 1,100	4,400 to 8,400	700 to 4,200	2,200 to 7,200
Non-ET parts of Marion area[1]	4,500 to 5,500	200 to 1,100	0 to 700	2,700 to 5,300	400 to 2,700	1,400 to 4,500
Non-ET parts of Peoa South Bench Canal	3,600 to 4,500	200 to 900	0 to 500	2,200 to 4,200	300 to 2,100	1,100 to 3,600
ET parts of Peoa South Bench Canal	900 to 1,100	45 to 200	0 to 100	500 to 1,100	300 to 1,100	0 to 500
Richards, Young, and Marchant and Miles Ditches	4,500 to 5,500	200 to 1,100	0 to 700	2,700 to 5,300	1,400 to 5,300	0 to 2,700
Sage Bottom Ditch	1,800 to 2,200	90 to 400	0 to 300	1,100 to 2,100	500 to 2,100	0 to 1,100
Total return flow to Weber River		**1,100 to 5,500**			**3,600 to 17,400**	
Diverted from Weber River, return flow to Beaver Creek at Rocky Point						
Non-ET parts of Marion area[1]	3,600 to 4,400	200 to 900	0 to 500	2,200 to 4,200	300 to 2,100	1,100 to 3,600
ET parts of Marion area[1]	5,400 to 6,600	300 to 1,300	0 to 800	3,300 to 6,300	1,600 to 6,300	0 to 3,200
Diverted from Beaver Creek, return flow to Beaver Creek at Rocky Point						
Non-ET parts of Beaver Creek	900 to 1,100	45 to 200	0 to 100	500 to 1,100	100 to 500	300 to 900
ET parts of Beaver Creek	15,300 to 18,700	800 to 3,700	0 to 2,300	9,300 to 17,900	4,600 to 17,900	0 to 9,000
Diverted from Provo River, return flow to Beaver Creek at Rocky Point						
Non-ET parts of Washington/South Kamas Canal	2,700 to 3,300	100 to 700	0 to 400	1,600 to 3,200	200 to 1,600	800 to 2,700
Total return flow to Beaver Creek		**1,400 to 6,900**			**6,900 to 28,500**	
Diverted from Provo River, return flow to Provo River						
Non-ET parts of Washington/South Kamas Canal	5,400 to 6,600	300 to 1,300	0 to 800	3,300 to 6,300	500 to 3,200	1,600 to 5,400
ET parts of Washington/South Kamas Canal	2,700 to 3,300	100 to 700	0 to 400	1,600 to 3,200	800 to 3,200	0 to 1,600
Total return flow to Provo River		**40 to 2,000**			**1,300 to 6,300**	
Total (rounded)	**58,000 to 72,000**	**3,000 to 14,000**	**0 to 9,000**	**35,000 to 69,000**	**12,000 to 52,000**	**8,000 to 46,000**

[1]Marion area includes all areas estimated to be irrigated by Upper Marion Ditch, Lower Marion Ditch, Gibbons Ditch, and Boulderville Ditches.

Table A-3. Error analysis of annual runoff from precipitation, Kamas Valley, Utah

[Amounts in acre-feet, rounded]

Name of drainage	Normal annual precipitation	10 percent error range of precipitation	Error range of 10 percent to 30 percent runoff
Weber River	14,800	13,300 to 16,300	1,300 to 4,900
Beaver Creek	14,200	12,800 to 15,600	1,300 to 4,700
Provo River	6,900	6,200 to 7,600	600 to 2,300
Total (rounded)	**36,000**	**32,000 to 40,000**	**3,000 to 12,000**

Table A-4. Possible range of annual surface-water budget components, Kamas Valley, Utah

[Amounts in acre-feet]

Inflow		Outflow	
Weber River			
Weber River near Oakley, Utah	151,000 to 167,000	Weber River near Peoa, Utah	124,000 to 152,000
Beaver Creek at Rocky Point	32,000 to 48,000	Diversion from Weber River to Weber-Provo Diversion Canal	34,000 to 38,000
Irrigation return flow	5,000 to 23,000	Irrigation diversions from the Weber River	31,000 to 39,000
Ground-water discharge to Beaver Creek downstream from Rocky Point gage	3,500 to 10,500	Ground-water recharge from the Weber River	4,000 to 12,000
Runoff from precipitation in valley	1,300 to 4,900		
Ungaged streamflow	1,400 to 9,700		
Ground-water discharge on bench near Peoa	2,000 to 3,000		
Ground-water discharge near Fort Creek	500 to 1,500		
Ground-water discharge to Weber River near Oakley and Peoa	500 to 1,500		
Total inflow (rounded)	**197,000 to 269,000**	**Total outflow**	**193,000 to 241,000**
Beaver Creek			
Inflow		**Outflow**	
Beaver Creek at Lind Bridge near Kamas, Utah	20,000 to 30,000	Beaver Creek at Rocky Point	32,000 to 48,000
Irrigation return flow	8,000 to 35,000	Irrigation diversions from Beaver Creek	14,000 to 22,000
Ground-water discharge to Beaver Creek	7,500 to 22,500	Diversion from Beaver Creek to Weber-Provo Diversion Canal	4,000 to 6,000
Runoff from precipitation in valley	1,300 to 4,700	Ground-water recharge from Beaver Creek	500 to 1,500
Ungaged streamflow	500 to 3,900		
Indian Hollow and City Creek	700 to 1,100		
Total inflow (rounded)	**38,000 to 97,000**	**Total outflow (rounded)**	**50,000 to 78,000**
Provo River			
Inflow		**Outflow**	
Provo River near Woodland, Utah	153,000 to 169,000	Provo River near Hailstone, Utah	196,000 to 216,000
Weber-Provo Diversion Canal	36,000 to 44,000	Irrigation diversions from the Provo River	11,000 to 13,000
Ungaged streamflow	4,500 to 20,000		
Irrigation return flow	1,000 to 8,000		
Runoff from precipitation in valley	600 to 2,300		
Ground-water discharge to Provo River	500 to 1,500		
Ground-water discharge on bench near Francis	500 to 1,500		
Total inflow (rounded)	**196,000 to 246,000**	**Total outflow**	**207,000 to 229,000**

Table A-5. Error analysis for annual ground-water recharge from irrigation and precipitation and evapotranspiration from ground water, Kamas Valley, Utah

[Amounts in acre-feet; —, no data available; ET, evapotranspiration; na, evapotranspiration not applicable to these areas]

Recharge: Low end of range equals minimum Surface water effectively applied plus 70 percent of minimum Annual precipitation minus maximum Consumptive use, with a minimum of 0. High end of range equals maximum Surface water effectively applied plus 90 percent of maximum Annual precipitation minus minimum Consumptive use, with a minimum of 0.

Evapotranspiration: Low end of range equals minimum Consumptive use minus maximum Surface water effectively applied minus 90 percent of maximum Annual precipitation, with a minimum of 0. High end of range equals maximum Consumptive use minus minimum Surface water effectively applied minus 70 percent of minimum Annual precipitation.

Unofficial name of irrigation area (fig. 5)	Surface water effectively applied (see table A-2)	Annual precipitation (10 percent error)	Consumptive use (10 percent error)	Recharge	Evapotrans-piration
New Field and North Bench Canals	2,200 to 7,200	2,400 to 3,000	3,000 to 3,600	0 to 6,900	na
Non-ET parts of Marion area[1]	2,500 to 8,100	2,900 to 3,500	3,100 to 3,700	800 to 8,200	na
ET parts of Marion area[1]	0 to 3,200	2,200 to 2,600	2,500 to 3,100	0 to 3,100	0 to 1,600
Non-ET parts of Peoa South Bench Canal	1,100 to 3,600	1,300 to 1,500	1,600 to 2,000	0 to 3,400	na
ET parts of Peoa South Bench Canal	0 to 500	200	300	0 to 400	0 to 200
Richards, Young, and Marchant and Miles Ditches	0 to 2,700	2,100 to 2,500	2,500 to 3,100	0 to 2,500	0 to 1,600
Sage Bottom Ditch	0 to 1,100	1,300 to 1,500	1,500 to 1,900	0 to 1,000	0 to 1,000
Non-ET parts of Beaver Creek	300 to 900	300	300	200 to 900	na
ET parts of Beaver Creek	0 to 9,000	6,400 to 7,800	7,600 to 9,200	0 to 8,500	0 to 4,700
Non-ET parts of Washington/South Kamas Canal	2,400 to 8,100	4,300 to 5,300	4,600 to 5,600	0 to 8,300	na
ET parts of Washington/South Kamas Canal	0 to 1,600	1,700 to 2,100	1,700 to 2,100	0 to 1,800	0 to 900
Small streams[2]	—	500 to 700	700 to 900	0	na
Nonirrigated sage and other dry areas	0	3,800 to 4,600	2,400 to 3,000	0 to 1,700	na
Nonirrigated crop and riparian areas	0	2,900 to 3,500	4,400 to 5,400	0	1,200 to 3,400
Total (rounded)	**8,000 to 46,000**	**32,000 to 39,000**	**36,000 to 44,000**	**1,000 to 47,000**	**1,000 to 13,000**

[1] Includes all areas estimated to be irrigated by Upper Marion Ditch, Lower Marion Ditch, Gibbons Ditch, and Boulderville Ditches.

[2] Recharge from streams included in stream loss. Recharge from precipitation is negligible.

Table A-6. Possible range of annual ground-water budget components, Kamas Valley, Utah

[Amounts in acre-feet]

Budget component	Flow
Recharge	
Precipitation and irrigation	1,000 to 47,000
Weber River	4,000 to 12,000
Ungaged streamflow	2,000 to 15,000
Canals	0 to 9,000
Beaver Creek	500 to 1,500
Total recharge (rounded)	**8,000 to 84,000**
Discharge	
Beaver Creek	12,000 to 32,000
Evapotranspiration from crop areas	0 to 10,000
Springs on bench near Peoa, Utah	2,000 to 3,000
Evapotranspiration from riparian areas along Weber and Provo Rivers	1,200 to 3,400
Springs near Fort Creek	500 to 1,500
Weber River near Oakley and Peoa	500 to 1,500
Provo River	500 to 1,500
Springs on bench near Francis	500 to 1,500
Wells	1,000
Total discharge (rounded)	**18,000 to 55,000**

APPENDIX B

Ground-water budget zones and selected model data

Table B-1. Conceptual and simulated ground-water budgets for zones in the ground-water flow model, Kamas Valley, Utah

Zone number (fig. B-1)	Description of zone	Description and areal recharge (acre-feet per year)		Recharge from streams and discharge (-) to streams (acre-feet per year)		Description and discharge to springs (acre-feet per year)	
		Conceptual	Simulated	Conceptual	Simulated	Conceptual	Simulated
1	Oakley North Bench and Peoa South Bench	New Field and North Bench irrigated areas = 3,700 Peoa South Bench irrigated areas = 1,700 Ungaged streams = 2,800 Canals = 1,800 **Total = 10,000**	10,000	0	0	Springs near Peoa into Marchant ditch = 3,000 Springs near Fort Creek = 1,000 **Total = 4,000**	5,100
2	Lower Weber	0	100	0	-200	0	0
3	Francis area	South Kamas irrigated area = 3,100 Ungaged streams = 2,100 Canals = 1,300 Nonirrigated areas = 200 **Total = 6,700**	6,700	-1,000	-2,700	1,000	1,100
4	Upper Weber	Weber River upstream of model, applied at closest model cells = 4,600	4,700	3,800	5,100 -900	0	0
5	Mid-Weber	0	100	-1,000	100 -3,100	0	0
6	Midvalley	1/5 of Marion irrigated area = 900 1/5 of Marion canals = 300 1/3 City Creek recharge = 200 **Total = 1,400**	1,200	-22,000	2,800 -15,400	0	0
7	Kamas area	Beaver Creek irrigated area = 500 Canals = 200 Ungaged streams = 300 Beaver Creek upstream of modeled area = 1,000 Nonirrigated areas = 100 **Total = 2,100**	1,900	0	100	0	0
8	Marion area	4/5 of Marion irrigated area = 3,700 4/5 of Marion Canals = 1,100 Ungaged streams = 2,300 Nonirrigated dry areas = 400 **Total = 7,500**	7,500	0	-2,100	0	0
9	City Creek area	2/3 City Creek recharge = 500	500	0	0	0	0
10	Lower Beaver Creek	0	0	0	-3,300	0	0
Total (rounded)		**33,000**	**33,000**	**4,000** **-24,000**	[1]**8,000** [1]**-28,000**	**5,000**	**6,000**

[1]About 1,000 acre-feet per year less than in table 11 because of rounding and time discretization. Budgets in this table calculated as average flow in stress period 19 as estimated by flow in time step 8 plus average flow in stress period 20 as estimated by flow in time step 8.

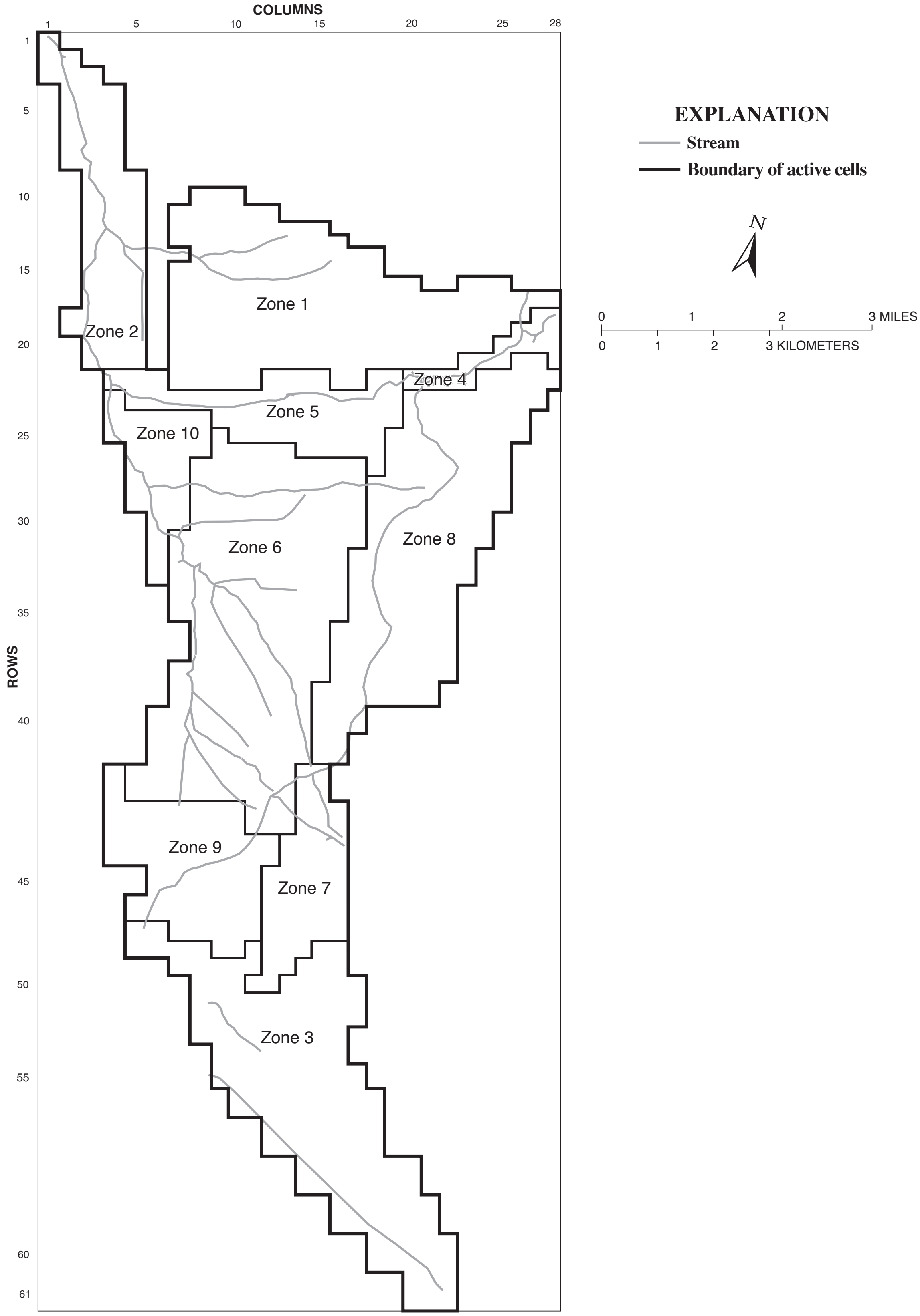

Figure B-1. Area assigned to each zone for zone budgets simulated in the ground-water flow model, Kamas Valley, Utah.

Table B-2. Depth below stage to top of streambed and streambed width simulated in the ground-water flow model, Kamas Valley, Utah

Stream	Top of streambed, in feet below stream stage	Width of streambed, in feet
Weber River	2	30
Beaver Creek downstream from confluence with Thorn Creek	2	30
Weber-Provo Diversion Canal	2	20
Beaver Creek upstream from Weber-Provo Diversion Canal	1	20
Thorn Creek upstream from Weber-Provo Diversion Canal	1	20
Crooked Creek	1	10
Fort Creek downstream from confluence with Rasmussen Creek	1	10
Other streams	1	5

Table B-3. Inflow to streams simulated with the Streamflow-Routing Package in the ground-water flow model, Kamas Valley, Utah

[na, inflow modeled only as short stream reach]

Simulated starting flow: Ungaged runoff plus Runoff from precipitation plus Irrigation return flow, converted to model units.

Modflow segment number	Stream name	Description and ungaged runoff (acre-feet per year) (table 4)	Description and runoff from precipitation in valley (acre-feet per year) (table 9)	Description and irrigation return flow (acre-feet per year) (table 5)	Simulated starting flow (cubic feet per day, rounded)
1	Weber River near Oakley, Utah[1]				19,000,000
4	Whites Creek	1/3 of north of valley = 230			27,000
9	na		Richards, Young, Marchant and Miles area = 460 1/2 of nonirrigated crop and riparian areas = 320	Richards, Young, Marchant, and Miles = 5,000	690,000
36	Crooked Creek	East of valley to Weber River = 200	Marion area to Weber River = 360 1/2 of nonirrigated sage and other dry areas = 420	Marion area to Weber River = 1,200	260,000
40	Fort Creek	1/3 of north of valley = 230	1/2 of New Field and North Bench = 270 1/4 of nonirrigated sage and other dry areas = 210	1/2 of New Field and North Bench area = 1,000	200,000
41	Rasmussen Creek	1/3 of north of valley = 230	1/2 of New Field and North Bench = 270 1/4 of nonirrigated sage and other dry areas = 210	1/2 of New Field and North Bench area = 1,000	200,000
44	Marchant ditch		Peoa South Bench area = 320 1/2 of nonirrigated crop and riparian areas = 320	Peoa South Bench = 2,000	320,000
48	na	West of valley to Weber River = 2,000	Sage Bottom area = 280	Sage Bottom = 2,000	510,000
12	Beaver Creek below Grist Mill[2]				1,100,000
15	Beaver Creek downstream from Weber-Provo Diversion Canal		1/5 of Beaver Creek drainage area = 560	1/3 of Beaver Creek to Beaver Creek = 5,700	750,000
17	Unnamed		1/5 of Beaver Creek drainage area = 560	Provo River to Beaver Creek = 800	160,000
21	Unnamed		1/5 of Beaver Creek drainage area = 560	1/3 of Beaver Creek to Beaver Creek = 5,700	750,000
25	Thorn Creek[3]				950,000
26	Thorn Creek downstream from Weber-Provo Diversion Canal	East of valley to Beaver Creek = 600	1/5 of Beaver Creek drainage area = 560	Weber River to Beaver Creek = 7,000	970,000
29	Unnamed		1/5 of Beaver Creek drainage area = 560	1/3 of Beaver Creek to Beaver Creek = 5,700	750,000
32	na	West of valley to Beaver Creek = [4]800			95,000

[1] Perennial flow into valley equals 159,000 acre-feet per year.

[2] Flow at Grist Mill equals 23,000 acre-feet per year, simulated as 9,000 acre-feet per year in Beaver Creek, 8,000 acre-feet per year in Thorn Creek, and unmodeled diversion of 6,000 acre-feet per year at Grist Mill.

[3] About 8,000 acre-feet per year of Beaver Creek at Grist Mill.

[4] Includes 200 acre-feet per year from City Creek and Indian Hollow.

Table B-4. Diversions from streams simulated with the Streamflow-Routing Package in the ground-water flow model, Kamas Valley, Utah

Modflow segment number	Diversion name and flow, in acre-feet per year	Flow (acre-feet per year)	Flow (cubic feet per day)
	Weber River		
3	New Field and North Bench Canal = 8,000 Upper Marion Ditch, Lower Marion Ditch, Boulderville Ditches, Gibbons Ditch = 15,000	23,000	2,700,000
7	Peoa South Bench = 5,000 Richards Ditch, Young Ditch, and Marchant and Miles Ditch = 5,000	10,000	1,200,000
10	Sage Bottom Ditch	2,000	240,000
43	Weber-Provo Diversion Canal	36,000	4,300,000
	Beaver Creek		
13	Diversions in Kamas City	4,000	480,000
20	Weber-Provo Diversion Canal	5,000	600,000

Table B-5. Water levels used for observations in the ground-water flow model, Kamas Valley, Utah

Local well number (fig. 2)	Date of water-level measurement	Water-level altitude, in feet	Variance, in feet	Water-level change, in feet	Variance, in feet	Stress period	Day
(D-1-5)10dda-1	07-12-1999	6,076	11			19	103
	03-21-2000			-2	1	20	233
(D-1-5)13cdb-1	08-05-1999	6,365	22			20	5
	02-22-2000			-26	1	20	205
(D-1-5)23dda-1	07-12-1999	6,217	10.5			19	103
	03-21-2000			-15	1	20	233
(D-1-5)25dbd-1	07-12-1999	6,309	10.5			19	103
	03-12-1999			0	1	20	224
(D-1-6)16dbc-1	07-12-1999	6,524	30			19	103
	03-21-2000			-35	1	20	233
(D-1-6)17cca-2	07-12-1999	6,510.1	10.1			19	103
	03-12-2000			-8.7	0.1	20	224
(D-1-6)17cdc-1	03-12-1999	6,530.5	10.1			20	224
(D-1-6)19ddc-1	07-12-1999	6,404	10.5			19	103
	03-21-2000			-22	1	20	233
(D-1-6)20bcb-1	07-12-1999	6,471.5	1.1			19	103
	03-21-2000			-50.7	.1	20	233
(D-1-6)22cbb-1	07-12-1999	6,542	11			19	103
	03-21-2000			-37	1	20	233
(D-1-6)28cbc-1	07-12-1999	6,455	11			19	103
	03-12-1999			-20	1	20	224
(D-1-6)29cbd-1	07-12-1999	6,406	11			19	103
	03-21-2000			-12	1	20	233
(D-1-6)33dba-1	07-12-1999	6,481	21			19	103
	03-15-1999			-42	1	20	227
(D-1-6)33dcc-1	07-12-1999	6,483	21			19	103
	03-17-2000			-50	1	20	229
(D-2-6)4dac-1	07-13-1999	6,498.9	15.1			19	104
	03-15-1999			+2.1	.1	20	227
(D-2-6)4dad-1	07-13-1999	6,628.0	15.1			19	104
	03-17-2000			+.6	.1	20	229
(D-2-6)4dda-1	07-03-1999	6,627.2	15.1			19	104
	03-17-2000			+.7	.1	20	229
(D-2-6)6bcc-1	07-12-1999	6,308	22			19	103
	03-06-2000			0	1	20	218
(D-2-6)8ddd-1	07-12-1999	6,418	10.5			19	103
	03-15-1999			-1	1	20	227
(D-2-6)9bbb-1	07-12-1999	6,387	10.5			19	103
	03-15-1999			-4	1	20	227
(D-2-6)16cda-1	07-13-1999	6,481	20			19	104
	03-22-2000			-10	1	20	234
(D-2-6)19bac-1	07-12-1999	6,414	11			19	103
	03-22-2000			0	1	20	234
(D-2-6)20dcc-1	07-12-1999	6,488.8	1.1			19	103
	03-06-2000			+0.4	.1	20	218
(D-2-6)21cdd-1	07-12-1999	6,523.1	1.1			19	103
	03-22-2000			-2.2	.1	20	234
(D-2-6)21dcc-2	07-03-2000	6,528.2	1.1			19	94
	03-07-2000			-4.3	.1	20	219
(D-2-6)27cbc-1	07-12-1999	6,605.2	1.1			19	103
	03-15-1999			-7.9	0.1	20	227

Table B-5. Water levels used for observations in the ground-water flow model, Kamas Valley, Utah—Continued

Local well number (fig. 2)	Date of water-level measurement	Water-level altitude, in feet	Variance, in feet	Water-level change, in feet	Variance, in feet	Stress period	Day
(D-2-6)28ccc-3	07-12-1999	6,551.4	1.1			19	103
	03-22-2000			-19.3	.1	20	234
(D-2-6)29ada-1	07-12-1999	6,525.4	1.1			19	103
	03-22-2000			-0.7	.1	20	234
(D-2-6)29bcb-1	07-12-1999	6,473.9	1.1			19	103
	03-22-2000			-2.7	.1	20	234
(D-2-6)29dcd-1	07-12-1999	6,498.7	1.1			19	103
	03-22-2000			-12.9	.1	20	234
(D-2-6)33abb-1	07-12-1999	6,596.2	1.1			19	103
	03-22-2000			-12.6	.1	20	234
(D-2-6)33ada-1	07-12-1999	6,621.9	1.1			19	103
	02-29-2000			-24.4	.1	20	212
(D-2-6)33cbb-1	07-12-1999	6,559.1	1.1			19	103
	03-22-2000			-47.5	.1	20	234
(D-2-6)34cbc-2	07-12-1999	6,636.7	1.1			19	103
	03-22-2000			-46.2	.1	20	234
(D-2-6)34dcc-1	07-12-1999	6,666.4	1.1			19	103
	03-22-2000			-47.9	.1	20	234
(D-3-6)3bdb-1	07-12-1999	6,642.2	1.1			19	103
	03-22-2000			-45.0	.1	20	234

Table B-6. Ground-water recharge from and discharge to streams used for observations in the ground-water flow model, Kamas Valley, Utah

Stream	Ground-water recharge or discharge (-), in cubic feet per day	Stream segments	Stream reaches	Coefficient of variation	Stress period	Day
Stream at bottom of Francis bench, June[1]	-163,000	54	All	0.5	19	75
Stream at bottom of Francis bench, March[1]	-98,000	54	All	.5	20	228
Midvalley, October	-2,600,000	15-23	All	.5	20	75
		26-34	All			
		36	4-16			
Weber River east of Oakley, November	46,000	1-2	All	.5	20	95
		5	All			
Weber River between Oakley and Peoa, June[1]	-163,000	11	All	.5	19	75
Weber River between Oakley and Peoa, March[1]	-98,000	11	All	.5	20	228

[1]Discharge not measured. Field observations indicate some discharge in these areas.

Table B-7. Ground-water discharge to drains used for observations in the ground-water flow model, Kamas Valley, Utah

Drain	Ground-water discharge (-), in cubic feet per day	Rows	Columns	Coefficient of variation	Stress period	Day
Near Peoa, June	-432,000	15-20	7	0.2	19	75
Near Peoa, March	-259,000		Same cells	.2	20	228
Near Fort Creek, June[1]	-163,000	13	7-8	.5	19	75
Near Fort Creek, March[1]	-98,000		Same cells	.5	20	228
Near Francis, June[1]	-163,000	48	5-7	.5	19	75
		49	7-8			
		50	8			
		52	8			
		53	8-9			
		54	9			
		55	9-10			
Near Francis, March[1]	-98,000		Same cells	.5	20	228

[1]Discharge not measured. Field observations indicate some discharge in these areas.

Table B-8. High parameter correlation in the ground-water flow model, Kamas Valley, Utah

Parameter	Parameter	Correlation Coefficient
sy1	sy6	0.97
sy1	rechim2	.97
sy6	rechim2	.97
hk4	rechim2	.97
sy6	rbk5	.96
rechem	rbk5	.95
hk4	sy1	.95
hk4	sy6	.95

Table B-9. Locations with greatest one-percent scaled sensitivity to selected model parameters at the end of stress period 20 in the ground-water flow model, Kamas Valley, Utah

[Observations starting with "Obs" were not available during this study; parameters with absolute one-percent scaled sensitivity less than 0.10 not listed]

Model Parameter	Observations most sensitive to parameter	Approximate change in simulated water level for a one percent increase in parameter
rechim1	Obs9	0.37
	(D-1-6)17cca-2	.28
	(D-1-5)13cdb-1	.26
rechim2	(D-2-6)33abb-1	.27
	(D-2-6)27cbc-1	.25
	(D-2-6)33ada-1	.25
rechem	Obs3	.54
	(D-2-6)4dda-1	.34
	(D-2-6)4dad-1	.31
rechsm	Obs5	.61
hk1	Obs12	-.36
	(D-2-6)4dad-1	-.16
hk2	Obs9	-.61
	(D-1-6)17cca-2	-.52
	(D-1-6)17cdc-1	-.42
hk3	Obs5	-.55
	(D-1-6)22cbb-1	-.37
hk4	Obs11	-.32
	Obs4	-.31
	(D-2-6)27cbc-1	-.29
	Obs6	.20
hk5	Obs3	-.62
	(D-2-6)4dda-1	-.36
hk6	(D-1-6)16dbc-1	-.16
	Obs1	.16
	(D-2-6)16cda-1	-.13
hk7	Obs8	.16
	(D-2-6)33abb-1	-.13
sy4	Obs12	.12
	(D-1-6)33dcc-1	.10
	(D-1-6)33dba-1	.10
sy6	Obs4	.20
	(D-2-6)34dcc-1	.16
sy7	Obs11	.28
drainpeoa	Obs7	-.32
	Obs10	-.21
	(D-1-5)13cdb-1	-.19
drainfran	Obs8	-.23
	Obs13	-.19
	(D-2-6)33cbb-1	-.15
rbk1	Obs2	.31
	(D-1-6)22cbb-1	.23
rbk5	Obs6	-.46
	(D-3-6)3bdb-1	-.24
	(D-2-6)34cbc-2	-.23
	(D-2-6)34dcc-1	-.22