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HYDROLOGY OF HEBER AND ROUND VALLEYS, WASATCH COUNTY, UTAH, WITH EMPHASIS ON SIMULATION OF GROUND-WATER FLOW IN HEBER VALLEY

By

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Prepared by the
United States Geological Survey
in cooperation with the
Utah Division of Water Resources,
Utah Division of Water Rights,
Wasatch County,
Wasatch County Water Users Association, and
Central Utah Water Conservancy District

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Conversion Factors and Related Information

For readers who prefer to use metric units, conversion factors for terms used in this report are listed below:

Multiply	By	To obtain
acre	0.4047	hectare
	4,047	square meter
acre-foot	0.001233	cubic hectometer
	1,233	cubic meter
acre-foot per year	0.00003907	cubic meter per second
cubic foot per second	0.02832	cubic meter per second
foot	0.3048	meter
foot per day	0.3048	meter per day
foot squared per day	0.0929	meter squared per day
foot per year	12.71	meter per year
foot per mile	0.1894	meter per kilometer
gallon per minute	0.00006308	cubic meter per second
	0.06308	liter per second
inch	25.4	millimeter
	0.0254	meter
mile	1.609	kilometer
square mile	2.59	square kilometer

Chemical concentration and water temperature are given only in metric units. Chemical concentration is given in milligrams per liter (mg/L) or micrograms per liter (μg/L). Milligrams per liter is a unit expressing the solute 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. Specific conductance is given in microsiemens per centimeter (μS/cm) at 25 degrees Celsius.

Flows are given in both acre-foot per year and cubic foot per second. To convert from acre-foot per year to cubic foot per second, multiply by 0.00138.

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

$$°F = 1.8\ (°C) + 32.$$

Sea level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)--a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called "Sea Level Datum of 1929."

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ABSTRACT

An investigation of the hydrologic system in Heber and Round Valleys was conducted to improve understanding of the surface-water and ground-water hydrology and the effects caused by changes in recharge. Ground water is present in consolidated rocks and in unconsolidated valley-fill deposits, but the principal ground-water reservoir is in the unconsolidated valley-fill deposits.

Recharge to the unconsolidated valley-fill deposits in Heber Valley from unconsumed irrigation water, stream infiltration, subsurface inflow from consolidated rocks, and precipitation is estimated to be 154 cubic feet per second. Discharge is by leakage to Deer Creek Reservoir, by springs and seeps, by seepage to the Provo River and other streams, by evapotranspiration, and by pumping from wells.

Recharge to the unconsolidated valley-fill deposits in Round Valley from stream infiltration, precipitation, unconsumed irrigation water and subsurface inflow from consolidated rocks is estimated to be 11 cubic feet per second. Discharge is by springs and seeps, by evapotranspiration, and by pumping from wells.

Seasonal water-level fluctuations of up to 30 feet occur primarily because of changes in recharge from unconsumed irrigation water. Water levels generally are highest during June or July when recharge from irrigation is at a maximum and lowest during the winter when irrigation is absent and recharge is at a minimum. Water levels in wells near Deer Creek Reservoir respond to changes in the reservoir level.

A modular, three-dimensional, finite-difference ground-water flow model developed by McDonald and Harbaugh (1988) was used to simulate the hydrologic system in the unconsolidated valley-fill deposits of Heber Valley. Model simulations indicate that decreased recharge to the unconsolidated valley-fill deposits causes a decrease in discharge to springs and seeps, streams, and leakage to Deer Creek Reservoir. Future decreases in ground-water recharge caused by changing from flood- to sprinkler-irrigation methods will cause future decreases in ground-water discharge that will be offset to some extent by increased surface-water flows.

INTRODUCTION

Heber and Round Valleys are about 50 miles southeast of Salt Lake City on the eastern side of the Wasatch Range, north-central Utah (fig. 1). Heber Valley, the largest of the two valleys, has an area of about 40 square miles and Round Valley has an area of about 25 square miles. The largest community

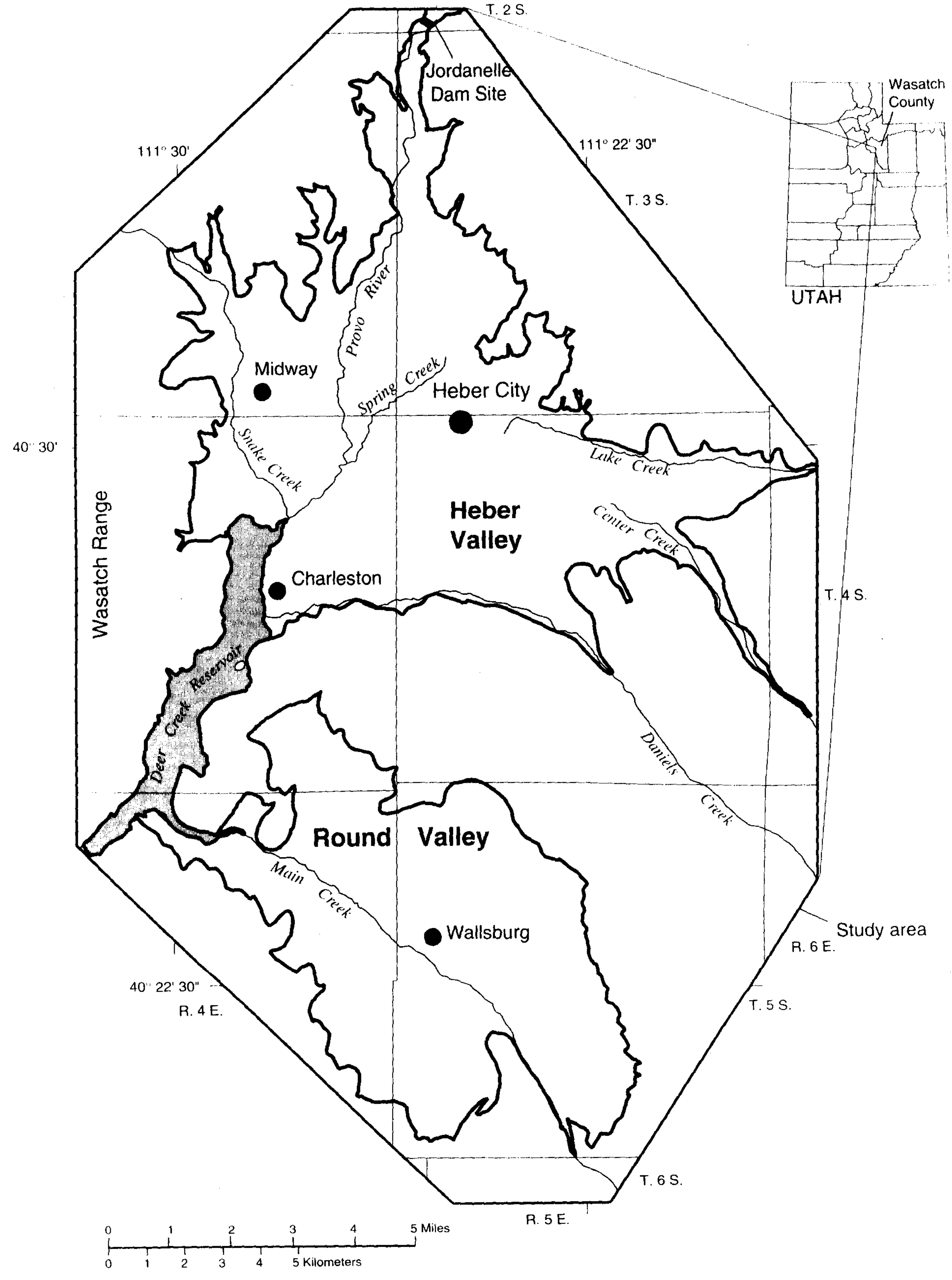

Figure 1.--Location of the study area.

in Heber Valley is Heber City and the largest community in Round Valley is Wallsburg.

The economic base of Heber and Round Valleys gradually has been changing from agriculture to recreation. The dairy industry, the livestock industry, and farming have been the primary economic activities in the past. Tourism, skiing, boating, and other outdoor activities are becoming increasingly important to the local economy.

The construction of the Jordanelle Dam (fig. 1) and filling of the reservoir will create additional storage for irrigation water. Water users in Heber Valley could use the increased storage and increased water pressure for sprinkler irrigation. These potential changes in irrigation practices and changes in surface-water flows associated with these irrigation practices could affect the ground-water resources of the area and are of concern to water users. In order to address these concerns, the U.S. Geological Survey, in cooperation with the Utah Division of Water Resources, Utah Division of Water Rights, Wasatch County, Wasatch County Water Users Association, and Central Utah Water Conservancy District, studied the surface- and ground-water resources of Heber and Round Valleys during 1988-90 with the emphasis on the ground-water system in the unconsolidated valley-fill deposits of both valleys. The surface-water studies were limited to streams, canals, and reservoirs that are in close connection with the unconsolidated valley-fill deposits. No attempt was made to provide a complete analysis of the surface water in Heber and Round Valleys.

Purpose and Scope

This report describes the results of the hydrologic study of Heber and Round Valleys. Hydrologic data collected in 1988-89 and selected data from previous studies were used to interpret the surface-water and ground-water hydrology in Heber and Round Valleys. These data also were used to develop a digital-computer model to simulate ground-water flow in the unconsolidated valley-fill deposits of Heber Valley.

Previous Studies

Previous hydrologic studies dealt primarily with the surface-water resources of the area and were conducted in connection with reclamation projects. General information about the ground-water resources of the area is provided in a water-resources study by Baker (1970). Information about the quality of ground and surface water in the study area is given in a water-quality reconnaissance report by Mundorff (1974). Irrigation practices and alternatives, in relation to the proposed construction and operation of the Jordanelle Dam and Reservoir, are described in a report by the Utah Division of Water Resources (1986).

Either 7.5- or 15-minute geologic maps are available for most of the study area (Bromfield and others, 1970, and Baker, 1976). Information on the thermal springs near Midway (fig. 1) is available in reports by Baker (1968), Mundorff (1970), and Kohler (1979). Data for soils are available from the U.S. Soil Conservation Service in Heber City. Reports describing foundation tests, percolation tests, and feasibility studies are available from private consulting companies.

Stream-discharge records are available from the U.S. Bureau of Reclamation, U.S. Geological Survey, Provo River Commissioner, and local irrigation companies. Water levels have been measured in selected wells from 1936 to 1989 by the U.S. Geological Survey and the Provo River Commissioner. Other information for wells and springs is available in the files of the U.S. Bureau of Reclamation and the Utah Division of Water Rights.

Numbering System for Hydrologic-Data Sites

The system of numbering wells, springs, and other hydrologic-data sites in this report (fig. 2) is based on the cadastral land-survey system of the U.S. Government. The number, in addition to designating the site, describes its position in the land net. By the land-survey system, the state of Utah is divided into four quadrants by the Salt Lake Base Line and Meridian. These quadrants are designated by the uppercase letters A, B, C, and D, which indicate 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 lower case letters indicating the quarter section, the quarter-quarter section, and the quarter-quarter-quarter section—generally 10 acres[1]; the 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; the letter S preceding the serial number denotes a spring. The letter W following the serial number denotes a stream and a letter B denotes a canal or ditch. Thus, (D-5-5)20cad-1 designates the first well constructed or visited in the SE$\frac{1}{4}$, NE$\frac{1}{4}$, SW$\frac{1}{4}$, sec. 20, T. 5 S., R. 5 E.

Acknowledgments

This study could not have been completed without the cooperation of local residents, who permitted access to their wells to measure water levels and to collect water samples for chemical analysis, and officials of irrigation companies, local utilities, municipalities, and Wasatch County. Special thanks are extended to the Provo River Water Commissioners and U.S. Soil Conservation Service. Their data and information were invaluable for the completion of this study.

Description of the Study Area

Physiography

Heber and Round Valleys are part of the Middle Rocky Mountains physiographic province described by Fenneman (1931). Altitudes in Heber and Round Valleys range from about 5,400 feet at Deer Creek Reservoir on the Provo River to about 6,200 feet near the valley margins. Altitudes in the mountains adjacent to Heber and Round Valleys are as much as 8,400 feet.

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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 divided 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.

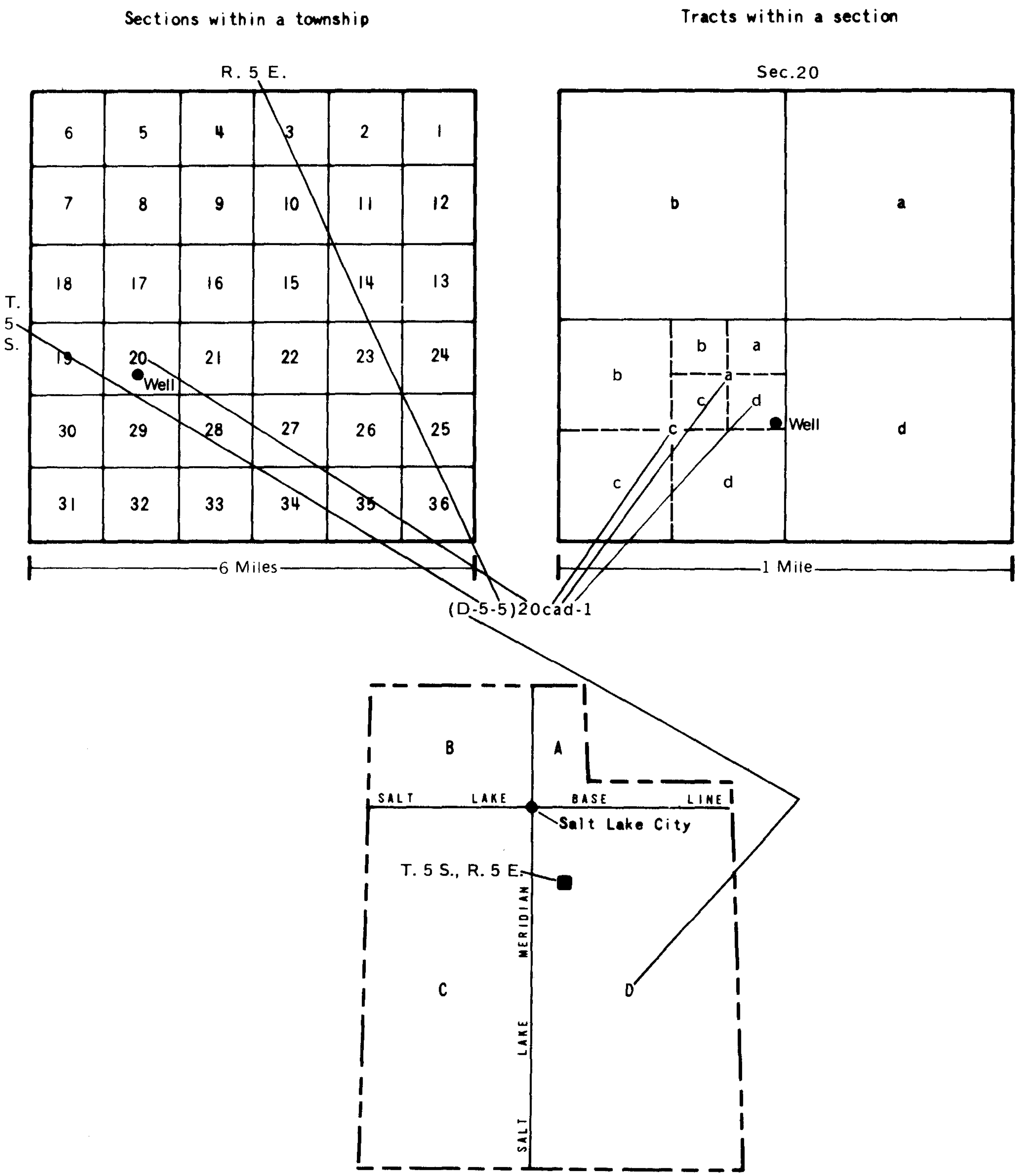


Figure 2.--Numbering system for hydrologic-data sites.

Heber Valley, the larger of the two valleys, is in the northern part of the study area and Round Valley is in the southern part. The valleys are separated by a ridge that forms a topographic divide between Daniels Creek in Heber Valley, and Main Creek in Round Valley. Heber Valley is drained by the Provo River, which enters the valley on the north and flows into Deer Creek Reservoir. Round Valley is drained by Main Creek, which enters the southeastern part of the valley and flows northwest into the southern end of Deer Creek Reservoir.

Geology

The rocks in the study area range in age from Precambrian to Quaternary (Bromfield and others, 1970; Baker, 1976). In Heber Valley, rocks ranging in age from Precambrian to Tertiary underlie and surround unconsolidated valley-fill deposits and tufa of Quaternary age. On the northern and western edges of the valley, sedimentary rocks of Precambrian through Triassic age have been faulted and folded by the emplacement of several intrusive igneous stocks of Tertiary age. On the east side of the valley, most of the older rocks have been covered by volcanic rocks of Tertiary age and only sandstone of Jurassic and Triassic age and limestone of Jurassic age are exposed east of Heber City. Limestone and sandstone of Pennsylvanian and Permian age crop out along the southern border of Heber Valley and underlie and surround the unconsolidated valley-fill deposits of Round Valley. The generalized geology of the study area is shown in figure 3.

Unconsolidated Quaternary valley-fill deposits underlying most of Heber and Round Valleys are the primary focus of this investigation. In Heber Valley, alluvial-fan deposits from Lake Creek, Center Creek, and Daniels Creek on the eastern side of the valley coalesce in the lower altitude areas of the valley with fluvial deposits from the Provo River and alluvial-fan deposits from the western side of the valley. Drillers' logs indicate the unconsolidated valley-fill deposits primarily consist of lenticular and discontinuous beds of poorly sorted material ranging in size from clay to boulders. Data for selected wells are listed in table 6 (at back of report). Drillers' lithologic logs of several deep wells, selected to show the greatest thickness of unconsolidated valley-fill deposits or the depth to consolidated rock, are given in table 7 (at back of report). The location of selected well sites are shown on plate 1 (in pocket).

Data documenting the thickness of the unconsolidated valley-fill deposits are not available for much of Heber Valley; however, thicknesses of unconsolidated valley-fill deposits determined during this study ranged from less than 100 feet to as much as 375 feet. Wells in the higher altitude areas of the alluvial fans of Lake and Center Creeks generally penetrate consolidated rock at depths of less than 100 feet (well (D-4-5)11abd-1, table 7), but some wells in the central and southern parts of the valley penetrate consolidated rock at depths of as much as 375 feet (well (D-4-5)5abb-1, table 7). Near the town of Midway, tufa deposits from numerous thermal springs crop out or interfinger with unconsolidated valley-fill deposits. The tufa deposits have an areal extent of about 5 square miles and are as much as 100 feet thick. Underlying the tufa deposits, unconsolidated valley-fill deposits have been penetrated to depths of about 200 feet (Kohler, 1979).

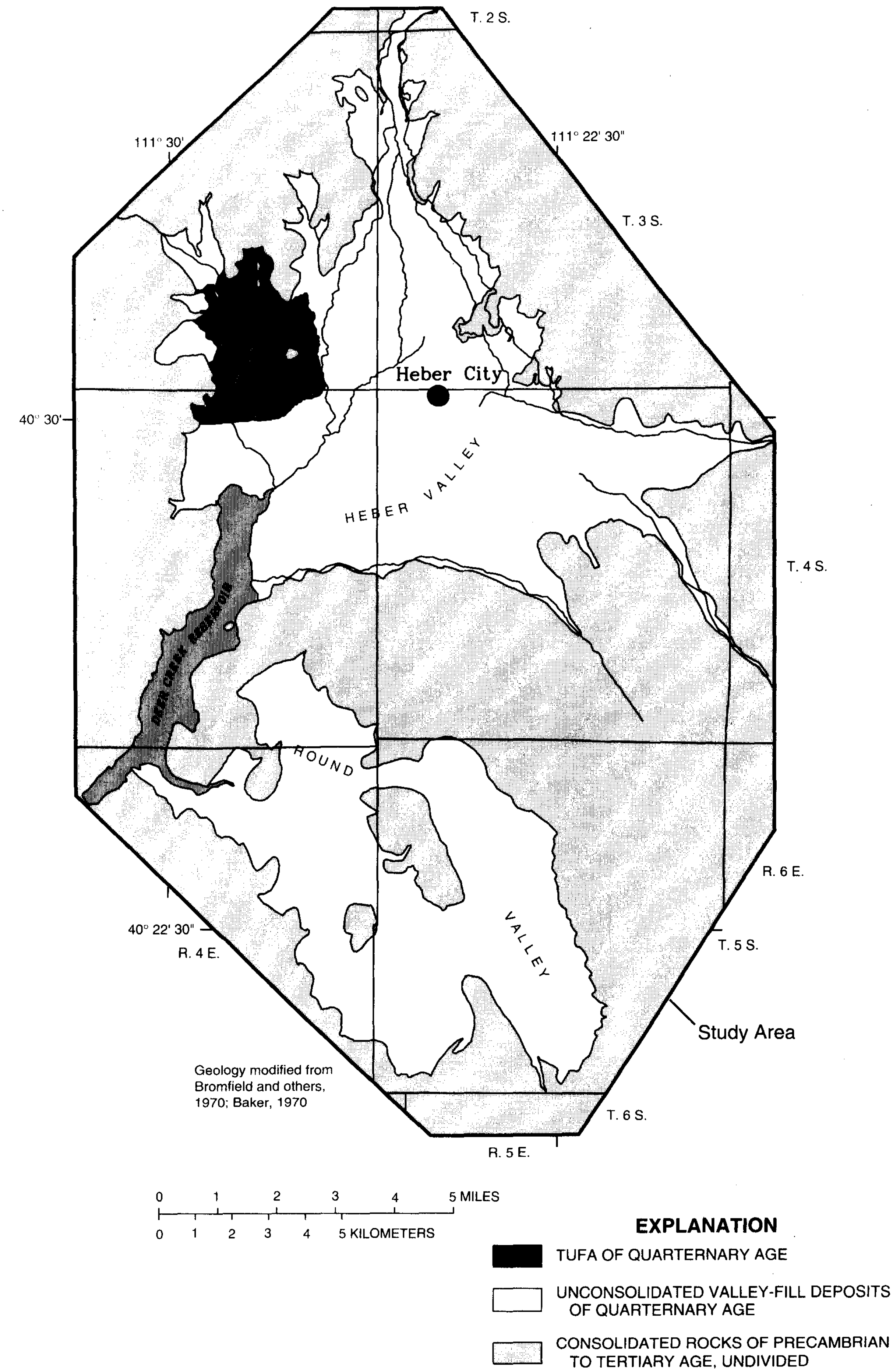


Figure 3.--Generalized geology, Heber and Round Valleys and vicinity.

In Round Valley, large coalescing alluvial fans on the sides of the valley slope steeply down to a narrow strip of reworked stream deposits in the center of the valley. The greatest thickness of unconsolidated valley-fill deposits is on the upper slopes of the alluvial fans where wells have been drilled to depths of as much as 315 feet before penetrating consolidated rock (well (D-5-4)24baa-1, table 7). The reworked stream deposits in the center of the valley are thin, and the depth to consolidated rock varies from a few feet near consolidated rock outcrops in the center of the valley to about 140 feet near Wallsburg (well (D-5-5)19aac-1, table 7).

Climate

The 1936-88 average annual precipitation at Heber City is 15.95 inches. The cumulative departure from average annual precipitation at Heber City (Burden and others, 1989) is shown in figure 4. Average annual precipitation in Round Valley is estimated to be 18 inches, based on an isohyetal map produced by the U.S. Weather Bureau (1963). Annual precipitation in the Wasatch Range adjacent to the western border of the study area is about 40 inches (U.S. Weather Bureau, 1963). Most of the precipitation in and adjacent to the study area falls during October-April.

Annual evaporation data for lakes in the study area are not available. However, the annual evaporation at Strawberry Reservoir, about 25 miles southeast of the study area at an altitude of 7,606 feet, is about 35 inches, and the annual evaporation at Utah Lake, about 20 miles southwest of the area at an altitude of 4,497 feet above sea level, is about 44 inches (Waddell and Fields, 1977, table 12). The annual evaporation from lakes in the study area is estimated to be 40 inches.

Heber and Round Valleys have cold winters and mild summers. Winter temperatures in the valleys commonly are less than 0 °F; summer temperatures rarely exceed 90 °F. The mean annual air temperature (1951-80) at Heber City was 44.1 °F (National Oceanic and Atmospheric Administration, 1984). The growing season in Heber Valley averages 84 days and extends from June 11 to September 2 (Eubank and Brough, 1979).

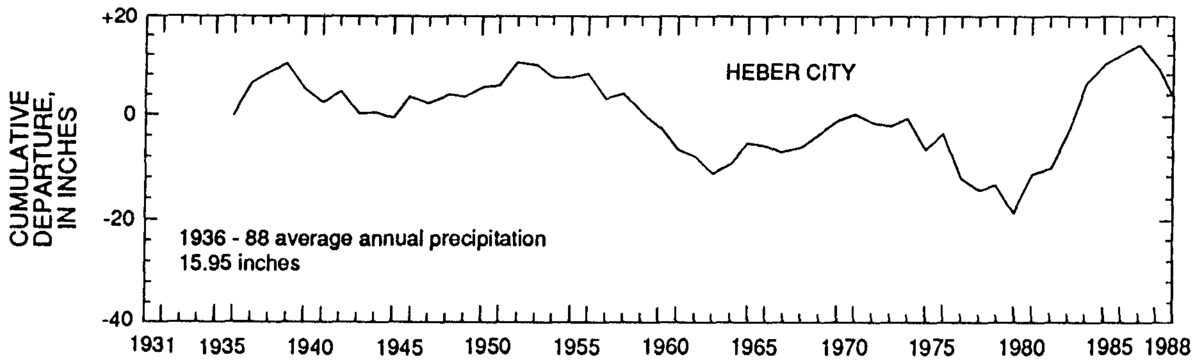


Figure 4.--Cumulative departure from average annual precipitation at Heber City.

Land Use

The primary use of land in Heber and Round Valleys is for agriculture, mostly by irrigated farming. Historically, water used for irrigated farming in the study area has been applied by flooding methods. Beginning in about 1978, a number of irrigation companies in Heber and Round Valleys changed from flood to sprinkler irrigation. Most of the changes have been in the Lake, Center, and Daniels Creek areas (fig. 1) of Heber Valley and in the upper part of the Round Valley. Changes from flood to sprinkler irrigation are expected to continue in the future.

SURFACE-WATER HYDROLOGY

Surface water in Heber and Round Valleys primarily originates from streamflow entering the valleys from the surrounding mountains. Some streams originate in the lower altitude areas of the valleys from springs, seeps, and drains, or on the margins of the valleys from springs that discharge primarily from consolidated rocks. The locations of continuous-recording streamflow gaging stations and miscellaneous streamflow-measuring sites where data were collected are shown on plate 1, and field measurements of discharge, temperature, and specific conductance at selected surface-water sites are listed in table 8 (at back of report).

Heber Valley

Major streams flowing into Heber Valley include the Provo River and Snake, Daniels, Lake, and Center Creeks (pl. 1). Within the valley, the Provo River and Snake Creek are perennial. In late spring, summer, and early fall, water from Daniels, Lake, and Center Creeks is diverted for irrigation at the margins of the valley and within the valley the creeks flow only during winter and spring. Spring Creek and a number of irrigation ditches receive water from springs and seeps in the lower altitude areas of Heber Valley and are perennial.

Provo River

The Provo River is the largest perennial stream in Heber Valley. U.S. Geological Survey gaging station 10155000, Provo River near Hailstone, Utah, about 4 miles upstream from the northern boundary of the study area, has been in operation since 1949. Average discharge at this station during water years 1954-88 (35 years of record) was 282 cubic feet per second (ReMillard and others, 1989, p. 255). The U.S. Bureau of Reclamation has operated several continuous-record streamflow-gaging stations on the Provo River and its tributaries since about 1978 (Nick Panas, U.S. Bureau of Reclamation, written commun., 1988). U.S. Bureau of Reclamation gaging station 1004, Provo River below Jordanelle Dam site (pl. 1), about 6 miles north of Heber City, has been in operation since 1978. Average discharge at this station during water years 1978-87 (10 years of record) was 302 cubic feet per second.

U.S. Geological Survey gaging station 10155500, Provo River near Charleston, Utah, upstream from the confluence of Snake Creek and the Provo River, was operated during water years 1939-50. Average discharge at this station during water years 1939-50 (12 years of record) was 192 cubic feet per second (Baker, 1970, p. 9). In 1978, the U.S. Bureau of Reclamation reactivated this station (1008, Provo River above Deer Creek Reservoir, pl. 1). Average discharge at this station during water years 1978-87 (10 years of record) was 307 cubic feet per second. Average discharge for 22 years (water years 1939-50, 1978-87) of combined record was 244 cubic feet per second.

U.S. Geological Survey gaging station 10159500, Provo River below Deer Creek Dam, Utah, just outside the study area, has been in operation since 1953. Average discharge at this station during water years 1954-88 (35 years of record) was 376 cubic feet per second. The average discharge was 412 cubic feet per second during water years 1978-87.

Snake Creek

Snake Creek discharges into the Provo River. U.S. Geological Survey gaging station 10156000, Snake Creek near Charleston, Utah, near the confluence of Snake Creek and the Provo River, less than 1 mile upstream from Deer Creek Reservoir, was operated during water years 1939-50. Average discharge at this station during water years 1939-50 (12 years of record) was 46 cubic feet per second (Baker, 1970, p. 9). U.S. Bureau of Reclamation gaging station 1010, Snake Creek near mouth (pl. 1), which is at the same site as the discontinued U.S. Geological Survey gaging station 10156000, has been in operation since 1978. Average discharge at this station during water years 1978-87 (10 years of record) was 57 cubic feet per second. Average discharge for 22 years (water years 1939-50, 1978-87) of combined record was 51 cubic feet per second.

Daniels Creek

The discharge of Daniels Creek as it enters Heber Valley has been estimated to be about 15.6 cubic feet per second; 11.0 from Daniels Creek and 4.6 from transbasin diversion (Hyatt and others, 1969, p. 109). U.S. Bureau of Reclamation gaging station 1011, Daniels Creek below State Highway 113 (pl. 1), about 0.1 mile upstream from Deer Creek Reservoir, has been in operation since 1985. The average discharge at the station during water years 1985-88 (4 years of record) was 15.9 cubic feet per second. Discharge at this station represents flow from Daniels, Lake, and Center Creeks after diversion for irrigation; surplus water from the Wasatch Canal; and ground-water seepage (J. Olds, Utah State Division of Water Rights, written commun., 1990).

Lake and Center Creeks, and Other Ungaged Tributaries

Lake and Center Creeks enter Heber Valley on the eastern side of the valley. Estimated discharge entering Heber Valley from Lake Creek is 10.9 cubic feet per second, and that from Center Creek is 6.5 cubic feet per second (Hyatt and others, 1969, table 30). Discharge from other small ungaged tributaries, primarily west and northwest of Deer Creek Reservoir, was estimated using discharge records from U.S. Geological Survey gaging station 10160000, Deer Creek near Wildwood, Utah, operated from 1938-50. The area and average altitude of the adjacent Deer Creek drainage is similar to that of the ungaged tributaries. The average discharge (water years 1938-50) of 13.3 cubic feet per second from a drainage area of 26 square miles (a yield of about 0.5 cubic foot per second per square mile), was used to estimate an ungaged tributary discharge of 6 cubic feet per second to the west side of Deer Creek Reservoir from a 13-square mile area.

Diversions and Seepage to Canals and Ditches

Several canals and ditches divert water from the Provo River and deliver the water to irrigated croplands both east and west of the river. The largest of the canals is the Wasatch Canal, with an average annual (1952-82) discharge of about 26 cubic feet per second; the second largest is the North Fields Ditch with an average annual (1952-82) discharge of about 18.5 cubic feet per second; and the third largest is the Timpanogos Canal with an average annual (1952-82) discharge of about 13.2 cubic feet per second. The River Ditch has an average annual (1952-82) discharge of about 10.1 cubic feet per second (Utah Division of Water Resources, 1986).

Estimates of the volume of water diverted for irrigation from Lake Creek and Center Creek were made on the basis of diversion records provided by Heber Power and Light Company (unpublished records, 1989) for their power-generating plant on Lake Creek. Average annual discharge to diversions from Lake Creek is 7.3 cubic feet per second, and that from Center Creek is 4.3 cubic feet per second, which represents about 70 percent of the average discharge. About 11 cubic feet per second of water in Daniels Creek is estimated to be diverted for irrigation based on the same percentage.

Water from Snake Creek and Pine Creek drainages is diverted for irrigation at an average annual discharge rate of about 11.7 cubic feet per second--an average (1962-82) of 2.2 from the Snake Creek Power Plant, an average (1952-82) of 1.1 from the Probst Ditch, an average (1952-82) of about 2.6 from the West Bench Ditch, an average (1973-82) of 1.4 from Pine Creek, an average (1962-82) of 3.3 from Mahogany Springs (D-3-4)22bcc-S1, and an average (1967-82) of 1.1 from Snake Creek (Utah Division of Water Resources, 1986). Water from several unmeasured springs in the Snake Creek and Pine Creek drainages is diverted for irrigation. The estimated discharge from these springs is about 5 cubic feet per second. Total average annual discharge diverted for irrigation from the Snake Creek and Pine Creek drainages is estimated to be about 16.7 cubic feet per second.

A number of canals and ditches in the lower altitude areas of Heber Valley receive flow from springs, seeps, and drains. The Sagebrush/Spring Creek Canal has an estimated average annual discharge of 22.1 cubic feet per second based on streamflow records collected during the irrigation season (Utah Division of Water Resources, 1986) and estimates during the remainder of the year; the Upper Charleston Canal has an estimated discharge of 17.9 cubic feet per second; and the Lower Charleston Canal has an estimated discharge of about 8.3 cubic feet per second.

The Island Ditch receives about 3.7 cubic feet per second of water from the Provo River for irrigation of about 300 acres. During the late summer, the Provo River is completely diverted into canals several miles upstream from the Island Ditch, and water diverted to the ditch from the river is from seepage to the river channel upstream from the ditch or flow from Berkenshaw Creek.

In summary, about 107 cubic feet per second of water is diverted from the Provo River and major tributaries in the higher altitude areas of Heber Valley and used to irrigate about 15,000 acres. About 52 cubic feet per second of water from springs, seeps, and drains in the lower altitude areas of Heber Valley is used to irrigate about 2,400 additional acres. The diversions for irrigation in the higher and lower altitude areas of Heber Valley are listed in table 1.

Deer Creek Reservoir

Deer Creek Reservoir, which has a storage capacity of about 153,000 acre-feet, is in the southwestern part of the study area. Storage of water in the reservoir began in 1940. The reservoir is used for storage of irrigation and municipal water, hydroelectric-power generation, flood and debris control, and recreation. The average annual surface-water inflow and ground-water leakage to and surface-water outflow from Deer Creek Reservoir for water years 1978-87 is shown in table 2. The average annual surface-water inflow to the reservoir was about 408 cubic feet per second, and the average annual ground-water leakage was estimated to be 70 cubic feet per second. The average annual outflow from the reservoir was 478 cubic feet per second.

Round Valley

The estimated discharge entering Round Valley from Main, Little Hobble, and Maple Creeks is 13,800 acre-feet per year or 19 cubic feet per second (Hyatt and others, 1969, table 31). Main Creek (Round Valley Creek) is the largest stream in Round Valley. U.S. Geological Survey gaging station 10158500, Round Valley Creek near Wallsburg, Utah, at the mouth of Round Valley, near the confluence of Main Creek and Deer Creek Reservoir, was operated during water years 1939-50. Average discharge at this station during water years 1939-50 (12 years of record) was 13 cubic feet per second (Baker, 1970, p. 9). Since 1985, the U.S. Bureau of Reclamation has operated gaging station 1013 (pl. 1) at the same location as the discontinued U.S. Geological Survey gaging station 10158500. The average discharge for water years 1985-87 (3 years of record) was 36 cubic feet per second. The average discharge for 15 years (water years 1939-50, 1985-87) of combined record was 18 cubic feet per second.

Water from Main Creek is diverted for irrigation several miles upstream from Wallsburg, and the creek is perennial only downstream from Wallsburg where springs and seeps contribute flow to the creek.

Quality of Surface Water

The chemical quality of surface water in the area generally meets both national and local regulations for drinking water. Dissolved-solids concentrations generally are less than 500 milligrams per liter, with the exception of Snake Creek downstream from Midway where concentrations of some samples have exceeded 500 milligrams per liter. Increases in dissolved-solids concentrations in the Provo River near Charleston primarily are due to the inflow of water from Snake Creek, which receives some of its flow from a series of mineralized thermal springs in the area of Midway.

Table 1.--*Diversions for irrigation in Heber Valley*

Stream, canal, or ditch	Average annual diversion (cubic feet per second)
Higher altitude areas of Heber Valley	
Wasatch Canal	26.0
North Field Ditch	18.5
Timpanogos Canal	13.2
River Ditch	10.1
Lake Creek	7.3
Center Creek	4.3
Daniels Creek	11.0
Snake and Pine Creek	16.7
Total (rounded)	107
Lower altitude areas of Heber Valley	
Sagebrush/Spring Creek Canal	22.1
Upper Charleston	17.9
Lower Charleston	8.3
Island Ditch	3.7
Total	52.0

Table 2.--*Average annual water budget for Deer Creek Reservoir, water years 1978-87*

Budget element	Flow, in cubic feet per second
Inflow	
Provo River upstream from Deer Creek Reservoir (U.S. Bureau of Reclamation 1008)	307
Snake Creek near mouth (U.S. Bureau of Reclamation 1010)	57
Main Creek (Round Valley Creek) upstream from State Highway 189	[1]18
Daniels Creek downstream from State Highway 113	[2]16
Precipitation on Deer Creek Reservoir (estimated)[3]	4
Ungaged tributary inflow (estimated)	6
Total surface-water inflow	408
Ground-water leakage (residual)	[4]70
Total inflow	478
Outflow	
Provo River downstream from Deer Creek Dam	412
Salt Lake City Aqueduct[5]	52
Evaporation[5]	11
Change in storage, water years 1978-87	3
Total outflow	478

[1] Based on 1939-50 and 1985-87 water-year records from U.S. Geological Survey and U.S. Bureau of Reclamation gaging stations.

[2] Based on 1985-88 water-year records from the U.S. Bureau of Reclamation.

[3] Estimated from U.S. Weather Bureau (1963).

[4] Ground-water inflow was calculated by subtracting the total surface water inflow from the total outflow.

[5] Data on file with Utah State Division of Water Rights, Salt Lake City, Utah.

Mundorff (1974, table 20, sites 46-59) collected water samples from 16 surface-water sites in Heber and Round Valleys. In Heber Valley, the dissolved-solids concentration for the Provo River at U.S. Highway 40 near Hailstone (Mundorff, 1974, site 46, pl. 1; at or near present site of U.S. Bureau of Reclamation gage 1004) was 279 milligrams per liter on September 14, 1972 (Mundorff, 1974, p. 28). The dissolved-solids concentration for the Provo River downstream from Snake Creek (Mundorff, 1974, site 50), about 10 miles downstream from site 46, was 373 milligrams per liter on September 14, 1972. The dissolved-solids concentration for Snake Creek near Charleston (Mundorff, 1974, site 56, pl. 1; near present site of U.S. Bureau of Reclamation gage 1010) was 694 milligrams per liter on September 14, 1972. The dissolved-solids concentration for Main Creek near Wallsburg (Mundorff, 1974, site 59 and pl. 1; near present site of U.S. Bureau of Reclamation gage 1013) was 329 milligrams per liter on September 14, 1972.

As indicated by the preceding data, dissolved-solids concentrations in samples collected from the Provo River increase as the river passes through Heber Valley. The effect is most noticeable during periods of low flow when dissolved-solids concentrations in the river might increase by as much as three times as it passes through the valley (Mundorff, 1974, p. 29). Most of the increase in dissolved solids can be attributed to tributary inflow to the Provo River from Snake Creek; on September 14, 1972, more than one-half of the dissolved-solids load in the Provo River downstream from Snake Creek was contributed by Snake Creek.

In 1984, a group of more than 20 Federal, State, local, and private organizations formed the Deer Creek and Jordanelle Reservoir Water Quality Technical Committee, and formulated the Deer Creek Reservoir and Proposed Jordanelle Reservoir Water Quality Management Plan. The primary objective of the committee was to decrease phosphorus loads to Deer Creek Reservoir in order to reverse eutrophic trends. In 1987, the water-quality objectives were phosphorus and nutrient control, but also included an evaluation of the ground-water system and how land-use practices were affecting ground-water quality. A summary of the water-quality conditions in Heber Valley in 1987 (Sowby and Berg, 1988) lists phosphorus contamination from dairies and high bacteria counts in the Lower Charleston Canal as major problems.

GROUND-WATER HYDROLOGY OF HEBER AND ROUND VALLEYS

Ground water in the study area occurs in both consolidated rocks and unconsolidated valley-fill deposits. The consolidated rocks crop out in mountain areas surrounding the valleys and underlie the unconsolidated valley-fill deposits within the valleys. Some consolidated rocks crop out within the valleys (fig. 3) or underlie the unconsolidated valley-fill deposits at shallow depths. The unconsolidated valley-fill deposits are exposed at the land surface throughout most of Heber and Round Valleys, and along the major drainages in the mountainous areas. Tufa deposits crop out or interfinger with unconsolidated valley-fill deposits at shallow depths in the vicinity of Midway. These tufa deposits are considered to be part of the unconsolidated valley-fill deposits for the purposes of this report.

Consolidated Rocks

The consolidated rocks range in age from Mississippian to Tertiary and are extensively jointed, faulted, and folded in the Midway area. Fractures and solution openings in the limestone are common in this area, and most ground water in the consolidated rocks probably moves along these openings. Baker (1970, table 1) listed the water-yielding properties of the consolidated rocks in the study area.

Recharge to the consolidated rocks is by infiltration of precipitation, stream infiltration, and leakage from unconsolidated valley-fill deposits. Most recharge takes place in the mountains surrounding the study area. Estimates of the quantity of recharge to consolidated rocks are not available.

Movement of water in consolidated rocks generally is from recharge areas in the mountains surrounding the valleys toward streams or large springs near the margins of the valleys. Faults or joints might control the direction of ground-water flow in localized areas. Construction of the Jordanelle Dam and future filling of the Jordanelle Reservoir might affect ground-water movement in consolidated rocks underlying and adjacent to the reservoir (Holmes and others, 1986, p. 40).

Discharge of ground water from consolidated rocks is by flow from springs, by leakage to unconsolidated valley-fill deposits, and by pumping from wells. The total quantity of ground water discharging from consolidated rocks has not been estimated. Large springs, those with a discharge of greater than about 1.1 cubic feet per second, generally discharge from limestone.

The public water supplies for residents of Center Creek, Charleston, Daniels, Heber City, Midway, and Wallsburg primarily originate from springs discharging from consolidated rocks. During 1985, about 5.5 cubic feet per second was diverted from springs by the public water suppliers of the area (Johnson, 1988, p. 109). Discharge from thermal springs in the Midway area was estimated by Mundorff (1970, p. 46) to be about 10 cubic feet per second. Baker (1968, p. D69) suggested that the water discharging from the thermal springs in the Midway area originated in carbonate rocks of Mississippian and Pennsylvanian age that underlie the tufa. Data from selected springs in the study area (table 3) indicate that the estimated discharge from consolidated rocks to springs is at least 38.5 cubic feet per second or 17,300 gallons per minute.

Discharge from consolidated rocks to the unconsolidated valley-fill deposits in Heber Valley was estimated by Baker (1970, p. 27) to be about 41 cubic feet per second (30,000 acre-feet per year). Some of the discharge from the consolidated rocks to the unconsolidated valley-fill deposits occurs in the area of Midway, where tufa deposits are interfingered with unconsolidated valley-fill deposits. Test wells drilled through the tufa and unconsolidated valley-fill deposits contained isothermal temperature profiles that indicate the free circulation of water between the unconsolidated valley-fill deposits and tufa deposits (Kohler, 1979, p. 7-12). Artesian pressure in consolidated rocks underlying the tufa and unconsolidated valley-fill deposits in one of the test wells (Kohler, 1979) caused the well to flow an estimated 1.6 cubic feet per second.

Table 3.—*Records of selected springs*

Location: See explanation of the numbering system for hydrologic-data sites.
Altitude of land surface: In feet above sea level; interpolated from U.S. Geological Survey topographic maps.
Probable source of water: Geologic unit from which spring discharges; Q alvm., unconsolidated alluvium of Quaternary age; T volc., volcanic breccia of Tertiary age; J ls., limestone of Jurassic age; J ss., sandstone of Early Jurassic age; Tr ls., limestone of Early Triassic age; P ss., limey sandstone of Early Permian age; ₽ qtz., quartzite of Late Pennsylvanian age; P₽ ss.,ls., interbedded sandstone and limestone of Permian and Pennsylvanian age; M ls., limestone of Late Mississippian age; M ls.,ss., interbedded limestone and sandstone of Late Mississippian age.
Field measurements: Letters appearing after measurements: R, reported. C, see table 9 for additional water-quality data.
Discharge: gal/min, gallons per minute.
Specific conductance: μS/cm, microsiemens per centimeter.
Water temperature: °C, degrees Celsius.
--: Indicates no data available.

Location	Name	Altitude of land surface (feet)	Probable source of water	Field measurements: Discharge (gal/min)	Field measurements: Specific conductance (μS/cm)	Field measurements: Water temperature (°C)	pH	Date
(D-3-4)21bbb-S1	Epperson Spring	6,120	M ls.	1,290	360C	9.0	7.7	11-23-88
21dcd-S1	Gerber Spring	5,870	M ls.	1,144R	440C	11.5	7.4	11-23-88
22bcc-S1	Mahogany Spring	5,890	M ls.,ss.	3,120	510C	10.5	7.6	11-23-88
24cdb-S1	--	5,630	TR ls.	150	420	11.0	7.5	12-01-88
26bcc-S1	Cunningham Lake Spring	5,630	₽ qtz.	1,270	1,360	24.0	6.9	11-30-88
26dba-S1	Mitchell Spring	5,555	TR ls.	250	835	12.5	7.0	07-31-89
26dbb-S1	Kohler Spring	5,570	TR ls.	365	990	15.5	7.0	07-31-89
27aba-S1	Warm Ditch Spring	5,740	₽ qtz.	565	875	26.5	6.8	07-27-89
27abb-S1	Joe Dean Huber	5,750	₽ qtz.	125R	--	1.0R	--	08-01-67
27baa-S1	--	5,750	₽ qtz	90	6,490C	46.0	6.5	11-23-88
27bad-S1	--	5,735	₽ qtz.	94	2,590C	41.0	6.5	11-30-88
27bdd-S1	Homestead Inc.	5,755	₽ qtz.	25	2,810	40.0	6.8	11-30-88
27cbd-S1	--	5,751	₽ qtz.	5	2,730C	28.5	6.7	11-30-88
27ccb-S1	Slough Ditch	5,760	₽ qtz	651	1,860	26.0	--	07-28-89
(D-3-5)20ccd-S1	London Spring	5,655	T volc.	1,570	300	12.0	7.5	06-15-89
29bab-S1	London Spring (on Fitzgerald property)	5,650	T volc.	388	305	11.5	6.9	08-01-88
32bad-S1	Hatch Spring	5,590	T volc.	1,500	365C	12.5	7.8	12-01-88
34ddc-S1	Smedley-Bond	5,995	J ss.	1.5	605	12.5	7.2	07-31-89
35ccc-S1	Coyote Hollow	6,000	J ss.	92	210	15.5	7.9	07-31-89
(D-4-4) 2cbd-S1	Utah Division of Wildlife Resources	5,460	TR ls.	[1]1,436R	1,160	14.5	7.1	12-01-88
4add-S1	Indian Spring	5,720	TR ls.	45	585	15.0	6.4	07-28-89
15dbc-S1	--	5,390	Q alvm.	5	455C	11.0	7.9	10-21-88
15dbc-S2	--	5,390	Q alvm.	5	450C	14.0	7.9	10-21-88
16bcb-S1	Soldier Hollow	5,800	J ss.	40R	772R	--	8.0R	04-01-88

Table 3.--*Records of selected springs*—Continued

Location	Name	Altitude of land surface (feet)	Probable source of water	Field measurements Discharge (gal/min)	Specific conductance (µS/cm)	Water temperature (°C)	pH	Date
(D-4-5) 4abd-S1	Upper Broadhead Spring	5,760	J ls.	1,346	386R	--	7.8R	11-01-88
21aab-S1	Billy Bethers Spring	5,900	PP ss.,ls.	8R	--	--	--	03-01-82
24bdc-S1	Nichol's Spring	6,240	PP ss.,ls.	[2]56R	507R	--	7.8R	03-28-88
(D-5-5)18aca-S1	Wallsburg Spring	5,675	PP ss.,ls.	1,190	595C	11.5	--	07-07-89
33acb-S1	Warm Spring	6,190	P ss.	449R	--	--	--	01-01-81

[1]Discharge measurement was made on 1-16-90.
[2]Discharge measurement was made in 1914.

Unconsolidated Valley-Fill Deposits

Water in the unconsolidated valley-fill deposits is the primary focus of this study. Unconsolidated valley-fill deposits extend throughout most of Heber and Round Valleys (fig. 3). These deposits consist of poorly sorted material ranging in size from clay to boulders. Drillers' logs (table 7) indicate that discontinuous layers of clay occur in most of the unconsolidated valley-fill deposits.

On the basis of geophysical data, Baker (1970, fig. 22) interpreted the maximum thickness of low-density rock (assumed to be unconsolidated valley fill) in Heber Valley to be greater than 800 feet. Test drilling by the Utah Geological and Mineral Survey (Kohler, 1979) indicated that the thickness of unconsolidated valley-fill deposits is less than one-fourth of the thickness of low-density rock as interpreted by Baker. Data reported in drillers' logs were used to estimate the thickness of the unconsolidated valley-fill deposits rather than using the contours of thickness interpreted by Baker. Wells in Heber Valley have penetrated unconsolidated valley-fill deposits to depths of as much as 375 feet.

Tufa deposits in the Midway area are interfingered and in hydraulic connection with the unconsolidated valley-fill deposits (Kohler, 1979, p. 11); therefore, for the purposes of this study, the tufa and unconsolidated valley-fill deposits are considered as single hydrologic unit.

The thickness of the unconsolidated valley-fill deposits in Round Valley was reported by Baker (1970, p. 45), on the basis of data from two wells, to be only a few tens of feet. More recent data from drillers' logs (table 7) indicate the thickness is greater than previously reported, but generally is less than 100 feet.

An estimated ground-water budget for the unconsolidated valley-fill deposits in Heber and Round Valleys is presented in table 4. The methods and calculations used to derive the individual budget elements are discussed in the following sections.

Table 4.--*Estimated ground-water budget for the unconsolidated valley-fill deposits, Heber and Round Valleys*

[NA, not applicable]

Budget element	Flow, in cubic feet per second		
	Heber Valley		Round Valley
Recharge	Baker, 1970	This study	
Precipitation	0	5	3
Infiltration from Provo River	0	20	NA
Stream infiltration	0	7	5
Unconsumed irrigation water	77.4	98	2
Subsurface inflow from consolidated rocks	[1]41.4	[2]24	[2]1
Total recharge (rounded)	119	154	11
Discharge			
Evapotranspiration	15.2	17	1.8
Leakage to Deer Creek Reservoir	64.9	70	NA
Seepage to Provo River	15.2	18	NA
Springs and seeps	[3]0	[4]48	9
Wells	0	1.2	0.2
Subsurface outflow to consolidated rocks	[5]23.5	[6]0	0
Total discharge (rounded)	119	154	11

[1] Difference between total recharge and recharge from unconsumed irrigation water.

[2] Difference between total discharge and all other forms of recharge.

[3] Included in seepage to Provo River in Baker (1970, p. 12).

[4] From Utah Division of Water Resources (1986).

[5] Difference between total recharge and all other forms of discharge.

[6] Assumed to be zero.

Recharge

Recharge to the unconsolidated valley-fill deposits is from precipitation, stream infiltration, unconsumed irrigation water, and subsurface inflow from consolidated rocks. Total recharge in Heber Valley was estimated by Baker (1970, p. 28), using the average annual change in saturated thickness, to be 86,000 acre-feet per year, or 119 cubic feet per second. In this study, recharge to Heber Valley is estimated to be 154 cubic feet per second. Recharge to Round Valley is estimated to be 11 cubic feet per second (table 4).

Precipitation

Baker (1970, p. 27) assumed that precipitation on the valley floor was entirely consumed by evapotranspiration. More recent studies in Utah (Hood and Fields, 1978, table 3; Razem and Steiger, 1981, table 2) indicate that, where annual precipitation is 14 to 18 inches, recharge ranges from 2 to 20 percent of the total precipitation. Recharge from precipitation in Heber Valley is estimated to be about 3,500 acre-feet per year or about 5 cubic feet per second based on about 26,000 acres of unconsolidated valley-fill deposits, an average of 16 inches of precipitation per year (U.S. Weather Bureau, 1963), and assuming 10 percent of the precipitation recharges the valley fill.

Recharge from precipitation in Round Valley is estimated to be 2,400 acre-feet per year, or about 3 cubic feet per second. The estimate is based on an area of about 16,000 acres of unconsolidated valley-fill deposits, an average of 18 inches of precipitation per year (U.S. Weather Bureau, 1963), and assuming 10 percent of the precipitation recharges the valley fill.

Stream infiltration

Recharge from stream infiltration occurs from the Provo River and from Lake, Center, and Daniels Creeks in Heber Valley, and from Main, Little Hobble, and Maple Creeks in Round Valley. Seepage studies conducted on the Provo River from August 30 to September 1, 1988 indicate average losses of about 20 cubic feet per second in the reach from U.S. Bureau of Reclamation gage 1004 (pl. 1) at the north end of Heber Valley to a streamflow-measurement site on the river at (D-3-4)24cdd-2W (table 8, and pl. 1).

Baker (1970, p. 29) stated that Lake, Center, and Daniels Creeks are losing streams, but an estimate of recharge from stream infiltration during high flow or prior to their diversion for irrigation is not included in his discussion. Data on recharge from stream infiltration were not available for most of the streams in the area. Mower (1965, tables 5 and 9) determined that 17 percent of the tributary inflow to Pahvant Valley recharged the unconsolidated valley-fill deposits. Because infiltration rates are large in Heber and Round Valleys (Utah Division of Water Resources, 1986, p. 35), a value of 25 percent of the tributary inflow was used to estimate recharge from stream infiltration.

Recharge to the unconsolidated valley-fill deposits from infiltration from Lake, Center, and Daniels Creek is estimated to be about 7 cubic feet per second, assuming that 25 percent of the average flow of 28.4 cubic feet per second (see section on surface-water hydrology) recharges the unconsolidated valley-fill deposits before being diverted for irrigation.

Recharge to the unconsolidated valley-fill deposits from stream infiltration from Little Hobble, Main, and Maple Creeks in Round Valley is estimated to be about 5 cubic feet per second assuming that 25 percent of the average flow of 19 cubic feet per second (Hyatt and others, 1969, table 31) recharges the unconsolidated valley-fill deposits.

Unconsumed irrigation water

Recharge from unconsumed irrigation water in Heber Valley was estimated by Baker (1970, p. 29) to be about 56,000 acre-feet per year, or 77.4 cubic feet per second. The 56,000 acre-feet of estimated recharge from unconsumed irrigation water was based on 87,000 acre-feet of water diverted for irrigation, plus 12,000 acre-feet of precipitation available to crops during the irrigation season, minus a crop requirement of 43,000 acre-feet.

Data primarily from the Utah Division of Water Resources (1986) and Hyatt and others (1969) indicate an average yearly diversion of about 77,500 acre-feet or 107 cubic feet per second of water from the Provo River and major tributaries in the higher altitude areas of Heber Valley (table 1) to irrigate about 15,000 acres. An average of about 52 cubic feet per second of water is collected from springs, seeps, and drains in the lower altitude areas of Heber Valley, most of which is used to irrigate about 2,400 additional acres. Another 12,000 acre-feet of water, or 17 cubic feet per second, is available to crops from precipitation during the irrigation season (Baker, 1970, p. 29).

The Utah Division of Water Resources (1986) estimated average potential crop requirements in Heber Valley at about 29,900 acre-feet per year, or 41 cubic feet per second (about 17,400 acres times an average consumptive use value of 1.72 feet per year). Facilities for storing high flows in the spring and early summer months are not available, with the exception of some small reservoirs in the high-altitude areas of Center and Lake Creeks. During an average year, a shortage of 11,600 acre-feet of irrigation water exists in Heber Valley (Utah Division of Water Resources, 1986, p. 42). The actual consumptive use value is about 18,300 acre-feet (29,900-11,600) or about 1.05 acre-feet per acre (18,300/17,400); therefore, the estimated recharge from unconsumed irrigation water in Heber Valley is the quantity diverted for irrigation plus precipitation during the irrigation season, minus the consumptive use value (77,500 + 12,000 - 18,300), which is 71,200 acre-feet per year, or about 98 cubic feet per second.

Recharge from unconsumed irrigation water can be divided into losses from large canals and losses from small canals, ditches, and irrigated fields. Herbert and others (U.S. Geological Survey, written commun., 1990) conducted seepage studies on several large canals in Heber Valley. The results indicate losses of about 22 percent of the water diverted into Timpanogos Canal and losses of about 9 percent of the water diverted into the Wasatch Canal. Similar seepage studies were conducted on River Ditch as part of this study. The estimated losses from River Ditch amounted to about 28 percent of the water diverted at the head of the ditch. Measurements of discharge, water temperature, and specific conductance from River Ditch are given in table 8.

The average recharge from leakage from canals can be estimated based on the seepage studies and the average diversions reported by the Utah Division of Water Resources (1986), as summarized in the "Surface-Water Hydrology" section of this report. The estimated recharge is 2.9 cubic feet per second from the Timpanogos Canal, 2.3 cubic feet per second from the Wasatch Canal, and 2.8 cubic feet per second from River Ditch. The remainder of the 98 cubic feet per second of recharge from unconsumed irrigation water, about 90 cubic feet per second, is from leakage from small canals, ditches, and irrigated fields.

Recharge from unconsumed irrigation water in Round Valley was reported by Hyatt and others (1969, table 31) to be 1,500 acre-feet per year or about 2 cubic feet per second. Although data are not available, the change from flood to sprinkler irrigation in parts of Round Valley since about 1978 might have changed the quantity of recharge from unconsumed irrigation water, although data are not available to substantiate this.

Subsurface inflow from consolidated rocks

Recharge from subsurface inflow from consolidated rocks was estimated by Baker (1970, p. 29) to be about 41.4 cubic feet per second (30,000 acre-feet per year). The 41.4 cubic feet per second was a residual in the recharge part of his budget and was based on an estimated total recharge of 86,000 acre-feet per year minus recharge from irrigation of 56,000 acre-feet per year. The ground-water budget determined during this study indicated that recharge from subsurface water inflow from consolidated rocks was about 24 cubic feet per second. This recharge was calculated as the difference between total discharge and all other forms of recharge (table 4). Most recharge from consolidated rocks probably occurs in the Midway area.

Recharge from subsurface inflow from consolidated rocks in Round Valley was estimated to be 1 cubic foot per second. This recharge was calculated as the difference between total discharge and all other forms of recharge.

Ground-Water Movement

The potentiometric surface in the unconsolidated valley-fill deposits in Heber and Round Valleys in April and May 1989 is shown on plate 1. Movement of ground water in the unconsolidated valley-fill deposits in Heber Valley generally is toward the Provo River and Deer Creek Reservoir at an average hydraulic gradient of about 50 feet per mile. Movement of ground water in the unconsolidated valley-fill deposits in Round Valley generally is down the valley toward Deer Creek Reservoir at an average hydraulic gradient of about 100 feet per mile. A change in the hydraulic gradient to about 200 feet per mile in the area of Center and Lake Creeks, southeast of Heber City, and about 300 feet per mile near Daniels, south of Heber City, has been attributed to a relatively shallow bedrock surface (U.S. Bureau of Reclamation, 1963, p. 349). Southeast of Wallsburg, similar changes in hydraulic gradient probably occur.

Local variations in direction of flow occur near springs, drains, or gaining canals and streams where the flow is toward these discharge areas. The local variations in direction of flow occur in the center of Heber Valley, where a number of gaining canals and streams (Sagebrush/Spring Creek Canal, Upper Charleston Canal and Lower Charleston Canal, and the Provo River) receive flow from the unconsolidated valley-fill deposits.

The occurrence of discontinuous clay layers in most of the unconsolidated valley-fill deposits (table 7) probably impedes the vertical movement of water. In order to gain an understanding of the vertical movement, three sets of nested wells (wells (D-4-4)10daa-1 and -2, 15ddd-1 and -2, and (D-5-4)12cad-1 and -2, table 6) were monitored. The deeper of the nested wells were 65 to 100 feet deep and the shallow wells were 10 to 30 feet deep. Surveying equipment was used to establish the relative difference in altitude of the land surface at the deep and shallow wells.

Water-level measurements during April 1989 showed less than 0.3 foot of difference in water levels between the deep and shallow wells at (D-4-4)10daa-1 and -2 and (D-5-4)12cad-1 and -2. The water level in well (D-4-4)15ddd-1, the deeper of the two nested wells near Deer Creek Reservoir, was about 3 feet higher than 15ddd-2, the shallower of the two nested wells. The higher water levels in the deeper well indicate a potential for upward movement of water at this location.

Discharge

Discharge from the unconsolidated valley-fill deposits in Heber Valley is from evapotranspiration, leakage to Deer Creek Reservoir, seepage to the Provo River, springs and seeps, and wells. Discharge from the unconsolidated valley-fill deposits was estimated by Baker (1970, p. 27) to be about 119 cubic feet per second; 15.2 from evapotranspiration, 64.9 from leakage to Deer Creek Reservoir, 15.2 from seepage to the Provo River, and 23.5 from subsurface outflow. In this study, discharge from the unconsolidated valley-fill deposits is estimated to be 154 cubic feet per second (table 4). Discharge from the unconsolidated valley-fill deposits in Round Valley is from evapotranspiration, springs and seeps, and wells. Discharge from the unconsolidated valley fill in Round Valley is estimated to be 11 cubic feet per second (table 4).

Evapotranspiration

The Utah Division of Water Resources conducted a land-use study and identified vegetative cover in Heber and Round Valleys (Lloyd Austin, Utah Division of Water Resources, written commun., 1989). The estimated area covered by phreatophytes (classified as wetland riparian, nonirrigated alfalfa, wetland pasture, and wetland hayland) in Heber Valley was 4,610 acres. The consumptive use value of similar phreatophytes in the Drain Tunnel Creek drainage, about 1 mile north of the study area, was reported by Holmes and others (1986, p. 16) to be 2.6 feet per year. Using the 2.6 feet per year consumptive-use value, the annual discharge from evapotranspiration by phreatophytes in Heber Valley was calculated to be about 12,000 acre-feet, or about 17 cubic feet per second, which compares favorably to the 15.2 cubic feet per second estimated by Baker (1970, p. 27).

The Utah Division of Water Resources identified about 510 acres of phreatophytes in Round Valley. Using the consumptive-use value of 2.6 feet per year, the discharge by evapotranspiration from phreatophytes in Round

Valley was estimated to be about 1,300 acre-feet, or 1.8 cubic feet per second.

Leakage to Deer Creek Reservoir

Baker (1970, p. 8) estimated 64.9 cubic feet per second of ground-water leakage to Deer Creek Reservoir from the unconsolidated valley-fill deposits, based on streamflow records for water years 1940-49. Hyatt and others (1969, p. 113) estimated about 61 cubic feet per second of ground-water leakage to Deer Creek Reservoir. Additional gaging station records, primarily records from U.S. Bureau of Reclamation gages 1008 and 1010 (table 2), were available for water years 1978-87 and were used to estimate ground-water leakage to Deer Creek Reservoir. The estimated ground-water leakage to Deer Creek Reservoir was 70 cubic feet per second (table 4). This estimate is comparable to the earlier estimates of Hyatt and others (1969) and Baker (1970).

Seepage to Provo River

Baker (1970, p. 12) reported discharge by seepage to the Provo River of 15.2 cubic feet per second. More detailed seepage studies conducted in the summer of 1988 indicated gains of 18 cubic feet per second in the river between streamflow measurement site (D-3-4)24cdd-2W (pl. 1) and U.S. Bureau of Reclamation gage 1008, near the confluence with Deer Creek Reservoir. Discharge, water temperature, and specific conductance collected during the seepage study are given in table 8.

Springs and Seeps

Data compiled by the Utah Division of Water Resources (1986) indicate that an average of 48 cubic feet per second is discharged by springs and seeps. This discharge is collected in several canals in the lower altitude areas of Heber Valley. Seepage studies were conducted on Sagebrush/Spring Creek, Upper Charleston, and Lower Charleston Canals in the summer of 1989 (Herbert and others, U.S. Geological Survey, written commun., 1990). The seepage studies indicated that most of the water from the springs and seeps enter the Sagebrush/Spring Creek Canal in two areas, about 1 mile north of Heber City and south of State Highway 113 between Heber City and Midway. No substantial gains or losses occurred in the other parts of the canal. The Upper Charleston Canal receives most of its water from springs and seeps upstream from State Highway 113 and an additional 5 cubic feet per second enters the canal in a 1-mile reach downstream from State Highway 113. The Lower Charleston Canal receives most of its water from springs and seeps in sec. 11, T. 4 S., R. 4 E. Springs and seeps in the area north and east of Midway discharge into Snake Creek. Data are not available to estimate this discharge.

Springs and seeps in the lower altitude areas of Round Valley, downstream from Wallsburg, account for most of the discharge from the unconsolidated valley-fill deposits as well as for the flow of Main Creek (Round Valley Creek), except during spring runoff, which is from about March to June. Water is pumped from Main Creek during the summer months (June to September) to irrigate some pastures and alfalfa. During October-February, streamflow from the higher altitude areas of the valley, evapotranspiration, and pumpage from Main Creek would be small. Thus, the average October-February discharge of about 9 cubic feet per second at U.S. Bureau of Reclamation gaging station 1013 is used as the best estimate of the discharge from springs and seeps in the lower altitude areas of the valley.

Wells

Discharge from wells in Heber Valley is estimated to be about 1.2 cubic feet per second; about 0.3 cubic foot per second of water is pumped from large public-supply wells in Charleston and Heber City (Johnson, 1988, p. 108-109), and about 0.9 cubic foot per second of water is pumped from about 640 small-diameter domestic and stock wells that pump about 1 acre-foot per year per well (Boyd Clayton, Utah Division of Water Rights, oral commun., 1989). In Round Valley, an estimated 0.2 cubic foot per second is pumped from about 115 small-diameter domestic and stock wells.

Subsurface outflow

Baker (1970, p. 34) estimated discharge from subsurface outflow to consolidated rocks, to be 23.5 cubic feet per second. The 23.5 cubic feet per second of discharge from subsurface outflow represents the imbalance in his ground-water budget, although no evidence of subsurface outflow was available. No evidence of subsurface outflow to consolidated rocks was found during this study; thus, subsurface outflow to consolidated rocks was assumed to be zero.

Storage and Water-Level Fluctuations

Baker (1970, p. 33) estimated about 280,000 acre-feet of water was theoretically recoverable from the upper 100 feet of unconsolidated valley-fill deposits in Heber Valley, but he qualified his estimate of recoverable water by stating that it was not possible to remove ground water from the unconsolidated valley-fill deposits for consumptive use value without affecting streamflow. Data are not available to provide a better estimate of ground-water storage in Heber Valley. The quantity of ground water stored in the unconsolidated valley-fill deposits of Round Valley was not estimated because of a lack of data on the thickness of the saturated deposits.

Water-level fluctuations result from long-term changes in recharge and discharge or from seasonal changes in recharge and discharge. The degree of fluctuation generally is related to the distance from sources of recharge and discharge, and to the rates of recharge and discharge. Hydrographs of selected wells completed in unconsolidated valley-fill deposits are shown in figure 5 and water-level measurements are given in table 9 (at back of report).

Long-term water-level data are available for only two observation wells in Heber Valley (wells (D-3-5)29cac-1 and (D-4-5)4ddd-1, fig. 5). On the basis of data from these two wells, no long-term water-level changes are apparent and no changes in water levels due to changes in irrigation practices since about 1978 are apparent. Changes might have occurred, but the only two long-term observation wells might not be located in areas where changes might be detected, therefore, for most of the study area, long-term water-level change cannot be determined.

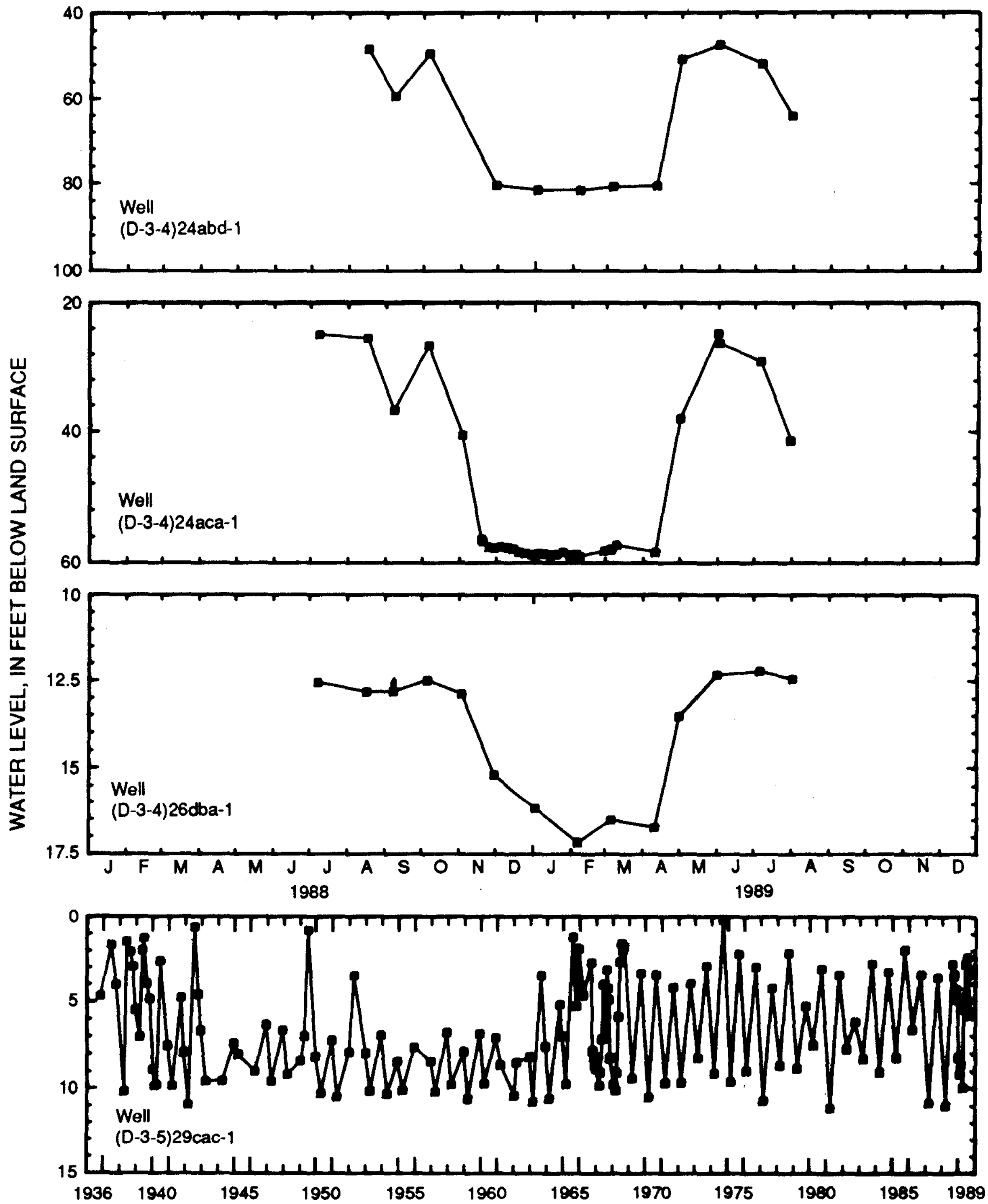


Figure 5.--Water levels in selected wells completed in unconsolidated valley-fill deposits.

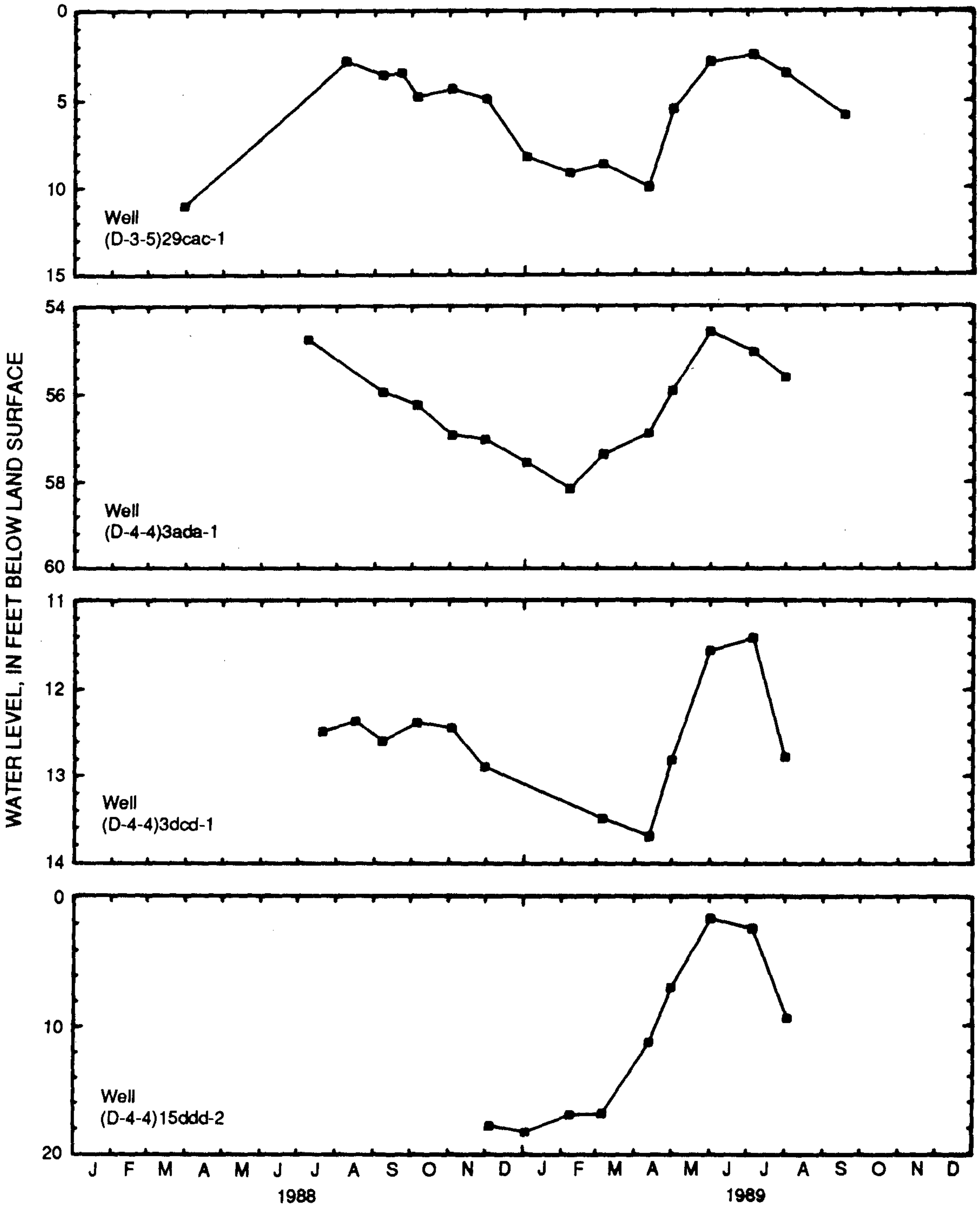


Figure 5.--Water levels in selected wells completed in unconsolidated valley-fill deposits--Continued.

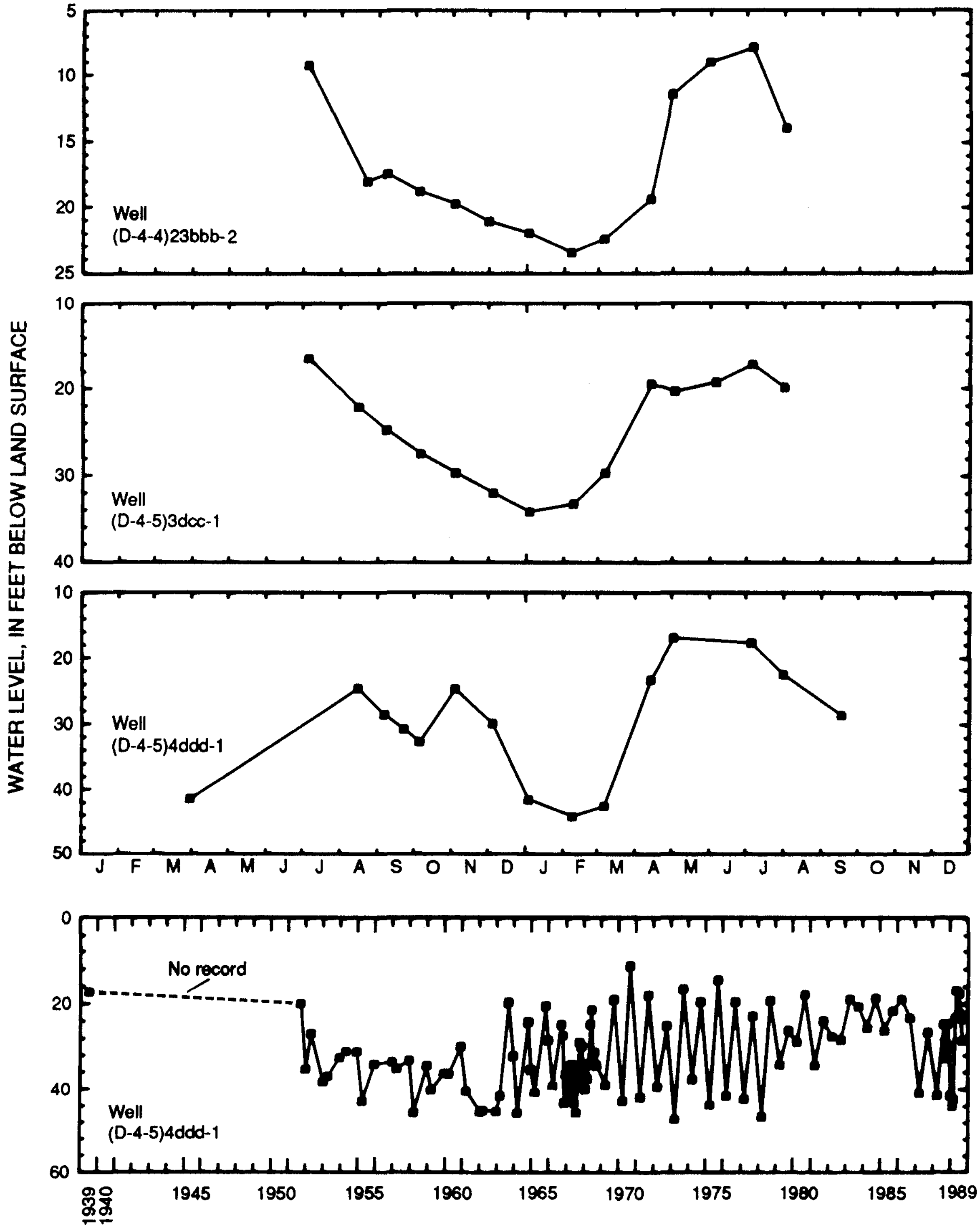


Figure 5.--Water levels in selected wells completed in unconsolidated valley-fill deposits--Continued.

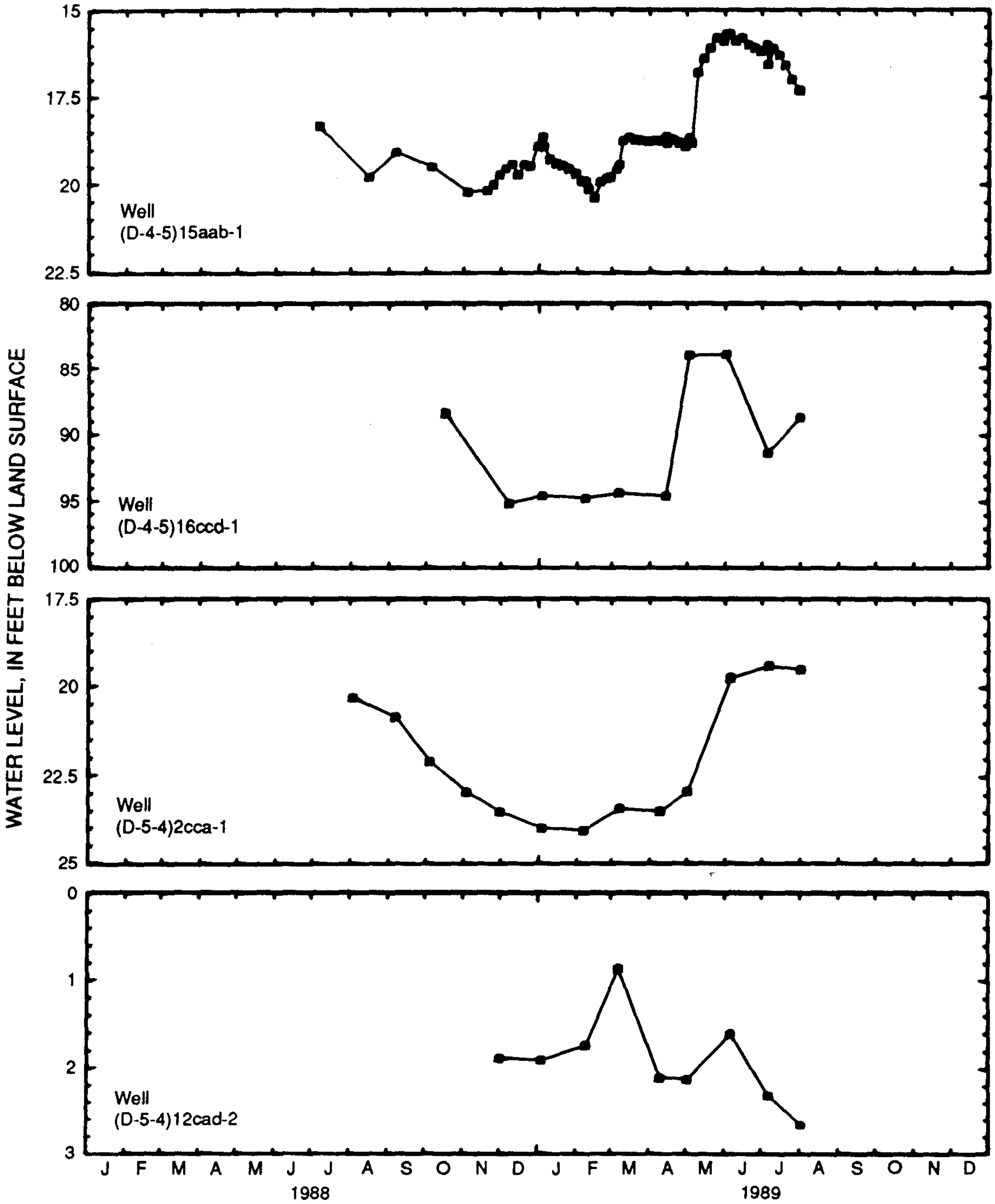


Figure 5.--Water levels in selected wells completed in unconsolidated valley-fill deposits--Continued.

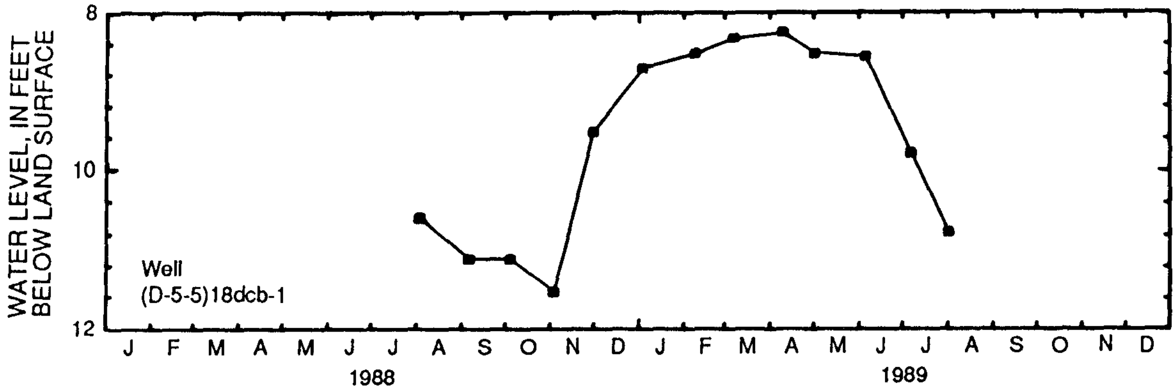


Figure 5--Water levels in selected wells completed in unconsolidated valley-fill deposits--Continued.

Seasonal water-level fluctuations in wells near Lake, Center, and Daniels Creeks in eastern and southeastern Heber Valley (wells (D-4-5)3dcc-1, (D-4-5)4ddd-1, (D-4-5)15aab-1, and (D-4-5)16ccd-1, fig. 5 and table 9) are about 5 to 30 feet. Water levels generally are highest in May, June, or July, when recharge from unconsumed irrigation water and stream infiltration is near maximum, and lowest in the winter, when recharge is at a minimum.

Seasonal water-level fluctuations in wells in the northern part of Heber Valley (wells (D-3-4)26dba-1, and (D-3-5)29cac-1, fig. 5 and table 9) generally are about 4 to 8 feet. These wells are near streams and in spring areas that are in direct hydraulic connection with the unconsolidated valley-fill deposits; therefore, the degree of water-level fluctuation is small. Water levels are highest in July or August and lowest in February and April. Wells (D-3-4)24abd-1 and (D-3-4)24aca-1 are near the River Ditch. According to the owner, well (D-3-4)24abd-1 is completed in consolidated rocks. Well (D-3-4)24aca-1 is completed in unconsolidated valley-fill deposits. Rapid water-level rises and declines in the wells (fig. 5) correspond to the periods when water is diverted into and out of canals in Heber Valley (Utah Division of Water Resources, 1986). The consolidated rocks and the unconsolidated valley-fill deposits receive recharge from seepage from River Ditch in this area.

Seasonal water-level fluctuations in wells in the western and southwestern part of Heber Valley (wells (D-4-4)3ada-1, (D-4-4)3dcd-1, (D-4-4)15ddd-2, and (D-4-4)23bbb-2, fig. 5 and table 9) are about 2 to 17 feet. The largest fluctuations occur in wells near Deer Creek Reservoir. Baker (1970, fig. 13 and p. 29) indicated that water levels in wells near the reservoir fluctuated in response to changes in the water level in the reservoir.

Seasonal water-level fluctuations in wells in Round Valley (wells (D-5-4)2cca-1, (D-5-4)12cad-2, and (D-5-5)18dcb-1, fig. 5 and table 9) are about 2 to 5 feet. Seasonal water-level fluctuations in wells (D-5-4)12cad-2 and (D-5-5)18dcb-1 (fig. 5), in the central part of Round Valley, are about 2 to 4 feet, with the highest water levels occurring in the winter or spring months. The higher water levels in the winter or spring are the result of recharge from stream infiltration from nearby Main Creek, which does not flow during the summer and fall because the creek is diverted for irrigation (Bryant Riddle, Main Creek Water Users Assoc., oral commun., 1989). Well (D-5-4)2cca-1 is near where Main Creek flows into Deer Creek Reservoir. Water levels in this well fluctuate about 5 feet and are highest in July when recharge from unconsumed irrigation water probably is at a maximum.

Aquifer Characteristics

Hydraulic-conductivity and transmissivity values for the unconsolidated valley-fill deposits in Heber Valley were estimated from specific-capacity values determined from drillers' reports. The method used is described by Theis and others (1963). An estimated hydraulic-conductivity value of 50 feet per day and estimated transmissivity values of 6,700 to 20,000 feet squared per day were reported by Baker (1970, p. 26). Baker's estimated hydraulic-conductivity value of 50 feet per day represented the largest values calculated from specific-capacity values. Baker (1970, p. 26) stated, "Because the specific capacity of a well is greatly influenced by the well construction--thickness of aquifer penetrated and open to the well, method of finish, method and amount of development, and a host of other factors--as well as the duration of the test, the largest specific capacities are probably most indicative of the potential of the aquifer." Other studies in Utah (Mower, 1965, p. 39, and Bjorklund and McGreevy, 1971, p. 25) also indicated that hydraulic-conductivity values, based on specific-capacity data commonly are small when compared with those based on aquifer-test data from the same wells.

As part of this study, 55 specific-capacity values determined from drillers' reports were used to estimate hydraulic conductivity in Heber Valley. Hydraulic-conductivity values ranged from 1 to about 200 feet per day. The largest values generally were in the Daniels and Charleston areas. Hydraulic-conductivity values for most of the valley generally were much smaller than values in the Daniels and Charleston areas. The number of values within ranges of transmissivity computed as part of this study are shown in figure 6. With the exception of the Daniels and Charleston areas, transmissivity values for most of the valley are less than 500 feet squared per day.

Baker (1970, p. 26) assumed that the unconsolidated valley-fill deposits could be treated as a single, virtually homogeneous, water-table aquifer. More recent data indicate that in lower altitude areas of the valley near Deer Creek Reservoir and in the area near Midway, artesian conditions exist at depths greater than 50 feet. Data from drillers' logs (wells (D-4-4)1ddc-1 and (D-4-4)23aab-1, table 7) for wells in the lower altitude areas of Heber Valley indicated that numerous layers of clay and silt are confining layers. In these lower altitude areas, an upward hydraulic gradient of 3 feet was measured using nested wells (wells (D-4-4)15ddd-1 and -2, table 6). (See section on ground-water movement.) Also, in the area near Midway, tufa overlies saturated unconsolidated valley-fill deposits and is a confining unit in the area.

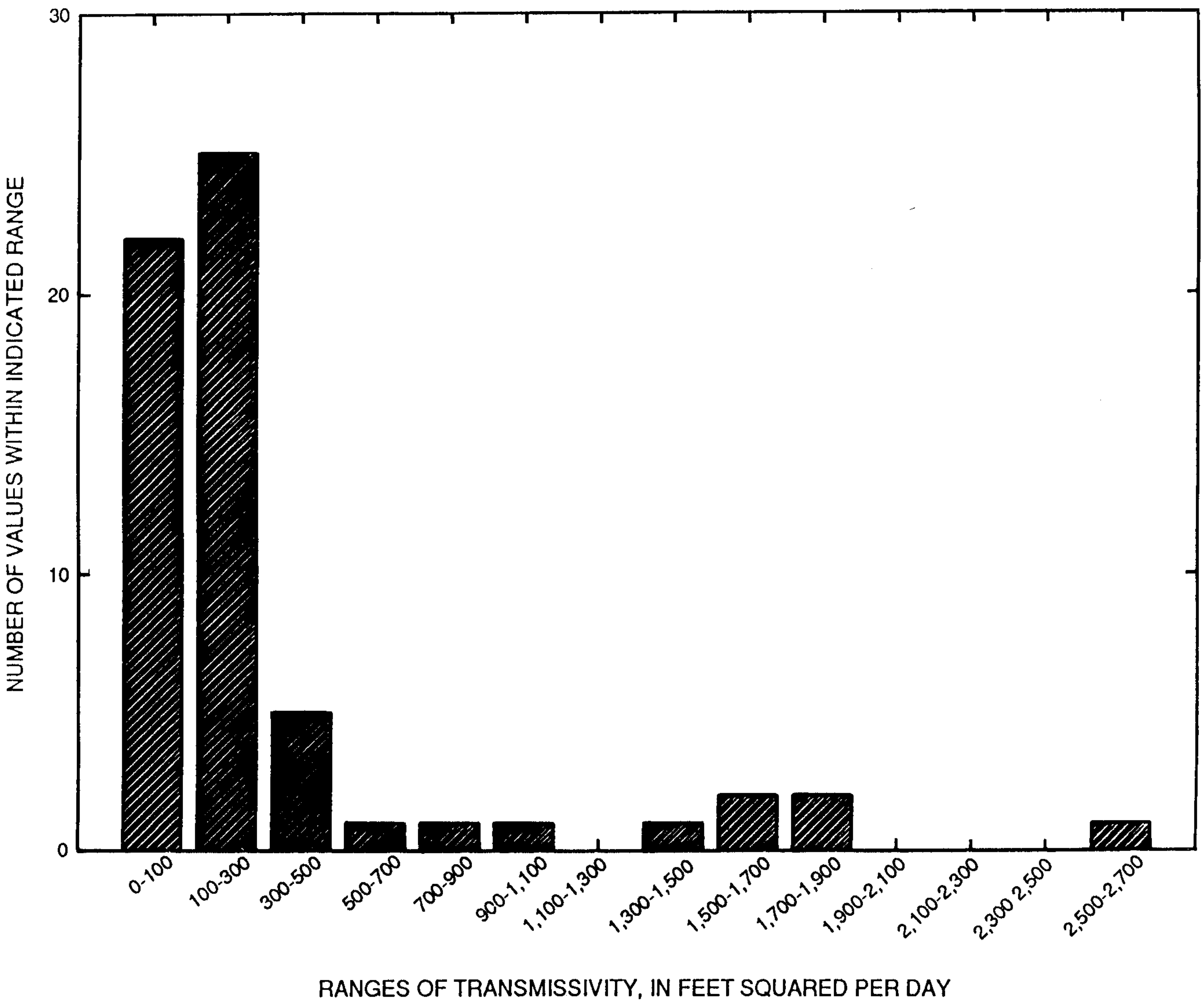


Figure 6.--Number of values within ranges of transmissivity computed for Heber Valley.

Baker (1970, p. 26) estimated that the specific yield of the unconsolidated valley-fill deposits in Heber Valley ranged from 0.07 to 0.21. Data are not available to improve this estimate of the specific yield of the unconsolidated valley-fill deposits.

The hydraulic-conductivity, transmissivity, and specific-yield values for the unconsolidated valley-fill deposits in Round Valley are similar to values estimated for Heber Valley. Confined conditions are evident in Round Valley at well (D-5-4)12abd-1 (table 6) where the water level in August 1989 was 10.40 feet above land surface. The extent of the confined conditions is unknown, but probably is localized in a small area.

Quality of Ground Water

Protection of drinking-water supplies and eutrophication of Deer Creek Reservoir are primary concerns of area water managers. Chemical analyses of water from selected wells and springs are listed in table 10. Ground-water in the study area generally has dissolved-solids concentrations of less than 500 milligrams per liter. Near Midway, however, some ground-water samples had a dissolved-solids concentration of greater than 500 milligrams per liter, and sulfate concentrations greater than 250 milligrams per liter, both of which exceed State of Utah Secondary Drinking Water Standards (Utah Department of Health, 1986, p. 3-1 to 3-6). The water in wells in the Midway area is similar in chemical quality to water discharging from a number of springs in the area.

The movement of nutrients, primarily nitrogen and phosphorus, through the ground-water system in Heber Valley into Deer Creek Reservoir and potential eutrophication of the reservoir is of concern to area water managers. A water-quality assessment of Deer Creek Reservoir (Merritt and others, 1977) indicated that the degree of eutrophication varied from strongly eutrophic conditions at the north end of the reservoir to mesotrophic conditions at the south end. Some contamination of shallow ground water by septic tanks, feed lots, and sewage effluent has occurred in the Heber Valley (Merritt and others, 1977). Concentrations of copper, iron, and manganese as well as coliform bacteria have exceeded State of Utah Secondary Drinking Water Standards in some ground-water samples (Sowby and Berg, 1988, p. 64).

Several ground-water samples collected and analyzed during this study (table 10) had concentrations of manganese that exceeded the State of Utah Secondary Drinking Water Standards of 50 micrograms per liter. Ground-water samples collected during this study did not indicate large concentrations of nitrogen or phosphorus in the ground-water system. Water samples collected from two springs that discharge directly into Deer Creek Reservoir (springs (D-4-4)15dbc-S1 and -S2, pl. 1 and table 10) had concentrations of dissolved nitrate plus nitrite of 1.40 milligrams per liter and concentrations of dissolved orthophosphorus of 0.04 and 0.05 milligram per liter (table 10). Data are insufficient to determine if ground-water quality has changed substantially since the previous study by Baker (1970).

Digital-Computer Simulation of the Hydrologic System in the Unconsolidated Valley-Fill Deposits in Heber Valley

Model Construction

The modular, three-dimensional, finite-difference ground-water flow model developed by McDonald and Harbaugh (1988) was used to simulate the hydrologic system in the unconsolidated valley-fill deposits of Heber Valley. The model is referred to as modular because it has a main program and a series of independent subroutines called modules. The model can simulate confined and unconfined conditions, well discharge, areal recharge, evapotranspiration, drains, and streams. The model was used to simulate assumed steady-state conditions in 1950, monthly transient conditions from October 1949 to

September 1950, assumed steady-state conditions from 1952-82, and monthly transient conditions from July 1988 to August 1989.

The unconsolidated valley-fill deposits in Heber Valley were represented by two layers. A two-dimensional, single-layer model could have been used to simulate the hydrologic system in the unconsolidated valley-fill deposits in Heber Valley, but future simulations of ground-water withdrawals from the unconsolidated valley-fill deposits probably would not yield satisfactory results using a single-layer model. In addition, drillers' logs in the study area (table 7) indicate that layers of clay and tufa deposits occur at different depths and in different locations throughout the valley; thus, the vertical movement of water is impeded in much of the valley.

Simulating two layers in the unconsolidated valley fill made it possible to simulate vertical gradients in part of the valley. Layer 1 was simulated as an unconfined layer with a saturated thickness of about 50 feet except in the areas of Lake, Center, and Daniels Creeks where a steep hydraulic gradient of as much as 300 feet per mile or about 75 feet per 0.25-mile cell required that the saturated thickness be as much as about 100 feet.

Layer 2 was simulated using a confined/unconfined layer option described by McDonald and Harbaugh (1988). The option allows the storage term to be converted from confined to unconfined when the water level in a cell declines below the top of the cell. In all simulations discussed in this report, layer 2 remained under confined conditions.

Model Grid

The area covered by unconsolidated valley-fill deposits was discretized into a uniform rectangular horizontal grid (fig. 7). The grid consists of 45 rows and 45 columns of cells, and each cell is 0.25 mile on each side. A point in the center of each cell in the grid, called a node, is the point where the model bases its calculations for that cell. Active nodes, those for which flow equations are solved in the model, number 638 in layer 1 and 520 in layer 2. The locations of the active nodes used for each layer are shown in figure 8. The figures in this report do not show all of the inactive nodes in the model grid.

Boundary Conditions

The physical and hydrologic limits of a simulated ground-water-flow system are defined as the boundaries of that system. The mathematical representation of these boundaries can be accomplished in several ways in the modular model. No-flow, free-surface, and head-dependent flux boundaries (Franke and others, 1984) are used in the simulations of Heber Valley.

No-flow boundaries were used to approximate the contact between the surrounding, virtually impermeable, consolidated rock and the permeable unconsolidated valley-fill deposits, except in the Midway area. In the simulations, these no-flow boundaries were along the border between the active and inactive cells (fig. 8).

The upper boundary of the model is considered a free-surface recharge or discharge boundary that is represented by the altitude of the water table.

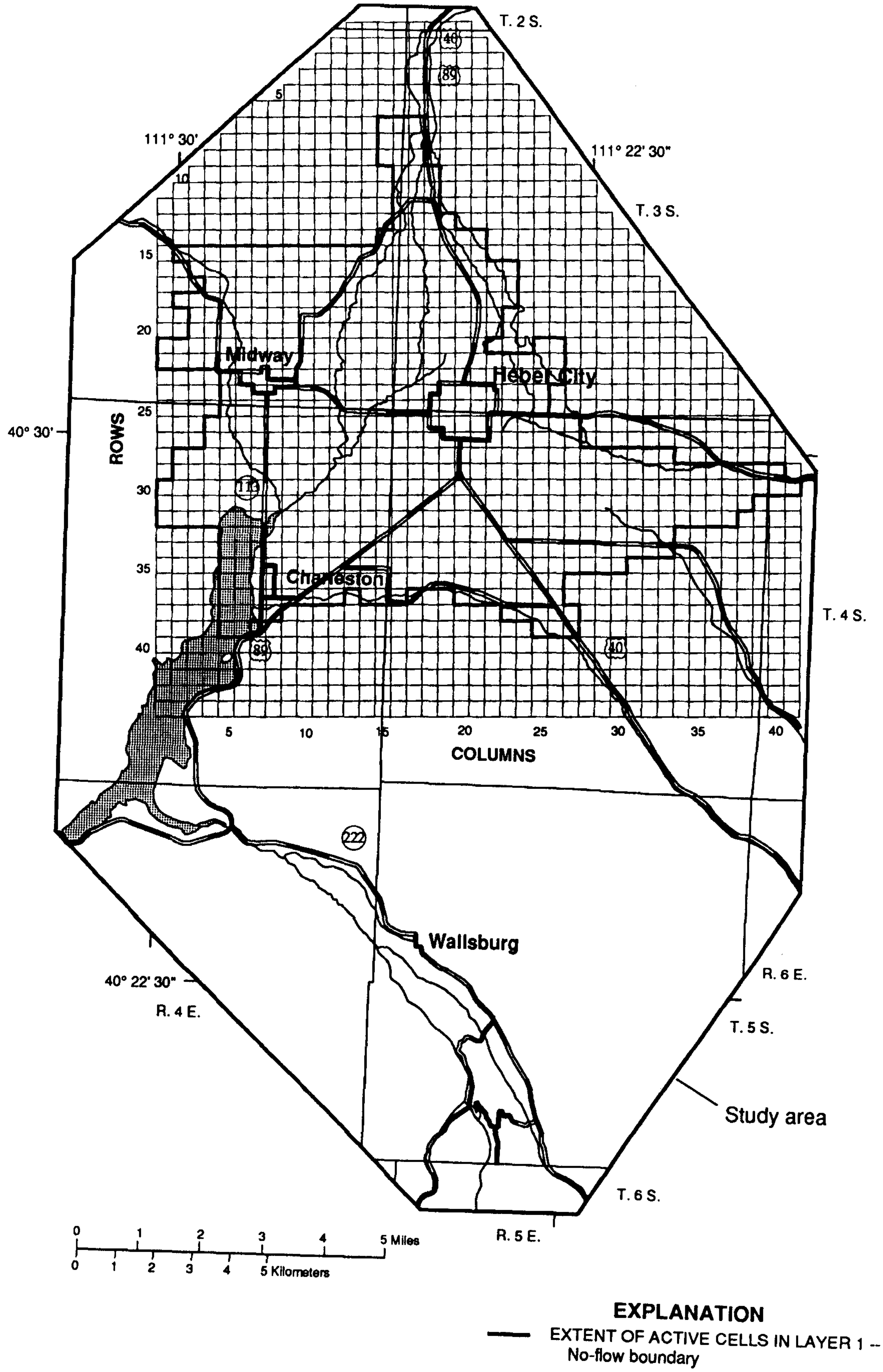


Figure 7.--Area of the simulation in relation to the study area.

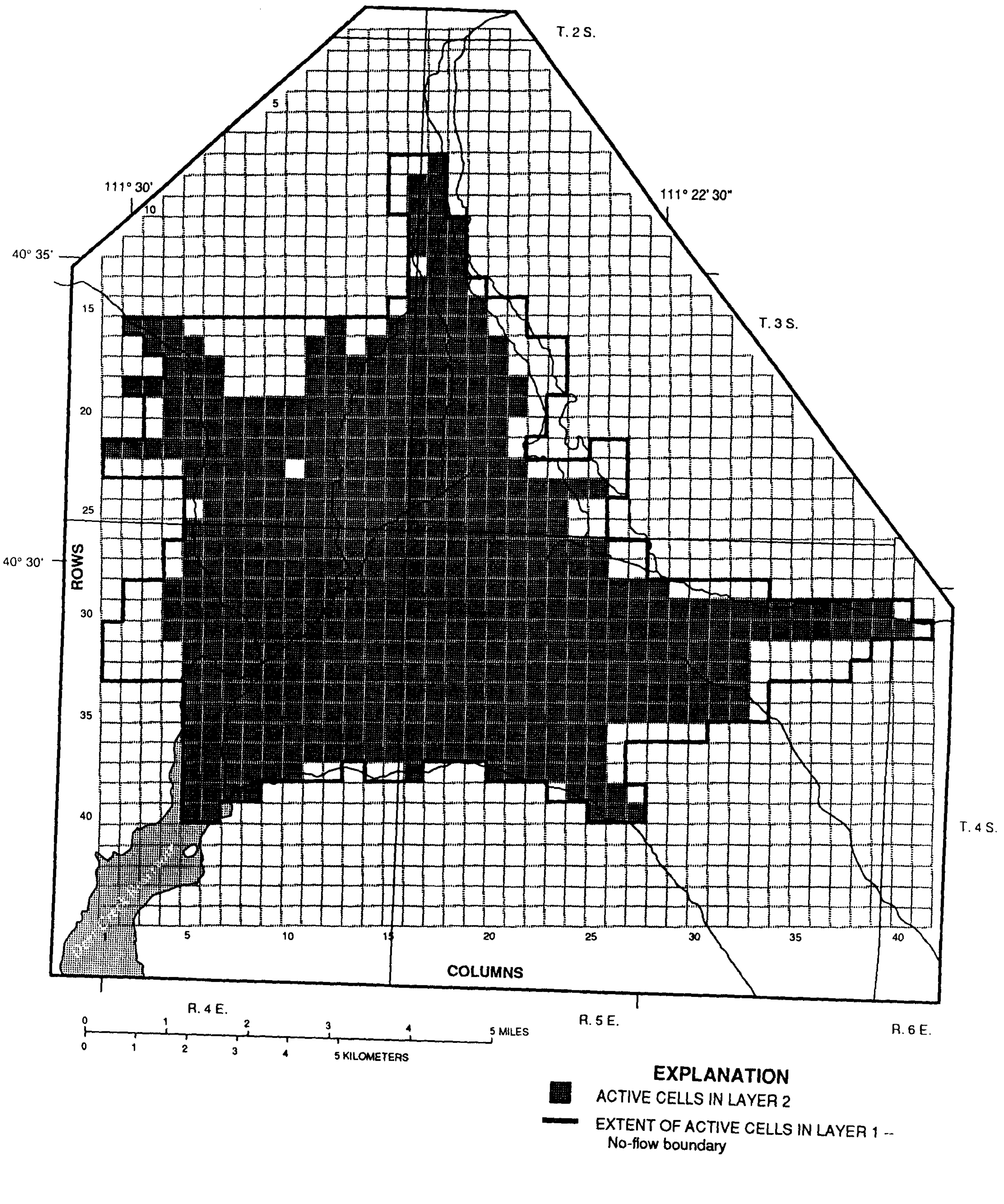


Figure 8.--Location of active nodes used in the digital-computer model.

The altitude can change in response to changes of recharge or discharge quantities.

A head-dependent flux boundary, in the form of general-head boundary cells, was used to simulate leakage between Deer Creek Reservoir and the aquifer. General-head boundary cells were used to simulate the leakage because they allowed the altitude of the water level of the reservoir to change in each stress period during the transient-state calibration.

Water levels from a well completed in bedrock near Midway (Kohler, 1979), indicate an upward hydraulic gradient between consolidated rock and the overlying unconsolidated valley-fill deposits. General-head boundary cells (fig. 9) also were used to simulate flow from consolidated rock to unconsolidated valley-fill deposits in layer 2. (See section on subsurface inflow from consolidated rocks.) The hydraulic-head values for the general-head boundary cells were set at the average land-surface altitude for each cell because the water levels in the tufa mounds reached equilibrium at or near land surface.

A general-head boundary cell (fig. 9) also was used to simulate underflow entering Heber Valley from unconsolidated valley-fill deposits along Center Creek. The hydraulic head for this boundary cell also was set at the average land-surface altitude. When the hydraulic head in the unconsolidated valley-fill deposits declined below land surface during simulations, the general-head boundary cell allowed flow into layer 1.

Several other types of head-dependent flux boundary cells were used in the simulations, including river cells, drain cells, and streamflow cells. The location of these head-dependent flux boundary cells used in the simulations are shown in figure 9. Average stream-channel altitude for each cell was used for river, drain, and streamflow cells. The River Package (McDonald and Harbaugh, 1988) was used to simulate Snake Creek. A creek stage of about 3 feet was used. Spring Creek and Sagebrush/Spring Creek and Upper Charleston Canals all gain water from the ground-water system in the upper reaches and do not lose water in the lower reaches. Therefore, all of the flow in these streams was simulated using the Drain Package (McDonald and Harbaugh, 1988).

Streamflow data for the Provo River and numerous diversion records were used to develop appropriate data input for a computer program to simulate stream-aquifer relations (Streamflow Package) described by Prudic (1989). The Streamflow Package was used to simulate changes in stage in the Provo River and corresponding gains or losses of water from or to the ground-water system. The Streamflow Package also was used to simulate the routing of surface-water flow along a stream and to account for additions or subtractions of flow from tributaries or diversions. Using a modified Manning's equation, stream stage is computed and gains to or losses from the ground-water system are calculated.

Data Input

A complete set of ground-water and surface-water data was needed to calibrate the Heber Valley model. These data were available only for 1949-50 and 1988-89. The same hydrologic conditions did not exist during 1949-50 and

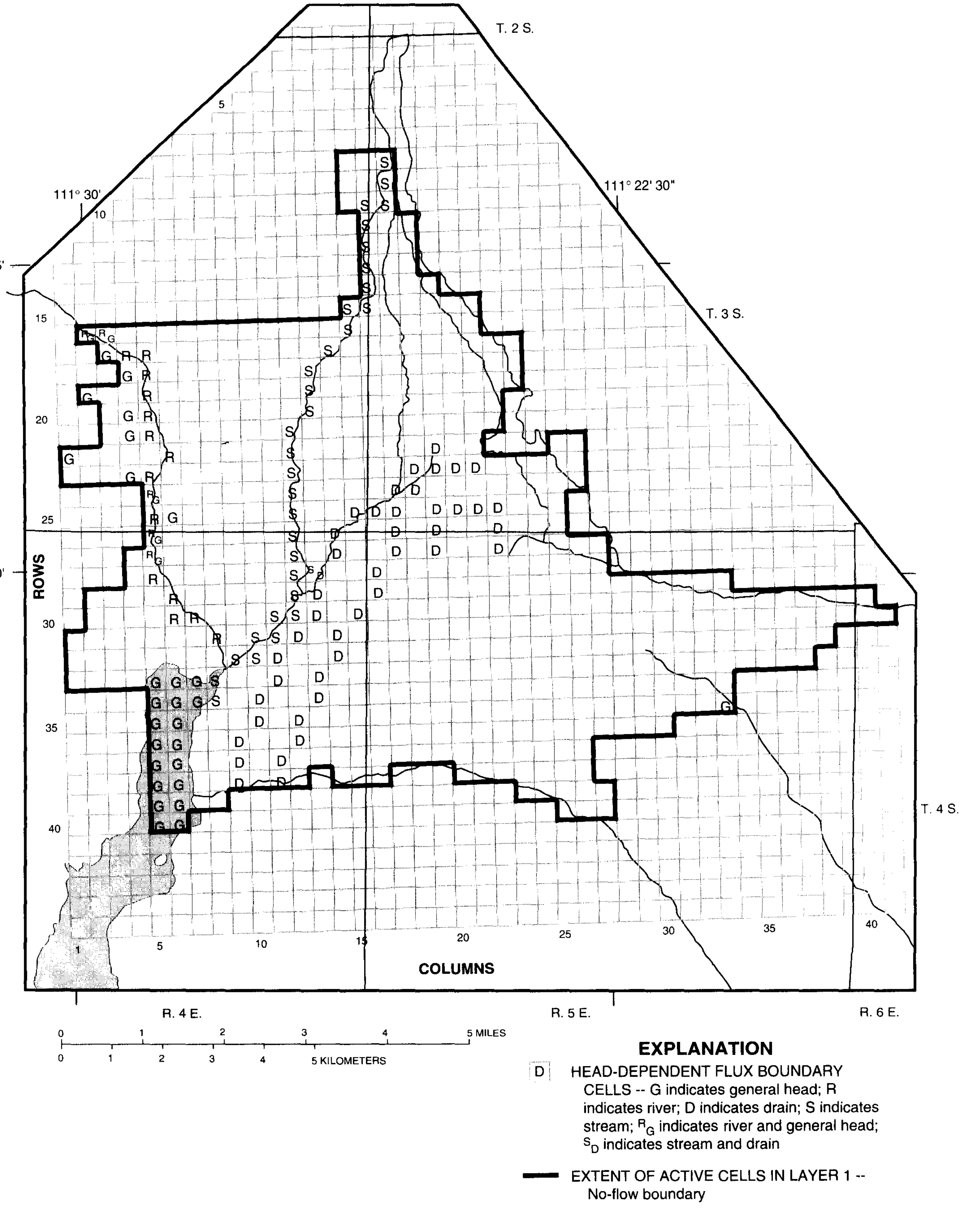


Figure 9.--Location of head-dependent flux boundary cells.

1988-89. Precipitation for 1949-50 was about the same as the historical average precipitation, but the precipitation for 1988-89 was less than average; irrigation during 1949-50 was by flood methods, and irrigation during 1988-89 was by flood and sprinkler methods.

Initial water levels

Water levels in wells in most parts of Heber Valley were measured monthly during 1949-50 by the Deputy Provo River Water Commissioner. These measurements were published in Provo River Water Commissioner's reports. Water levels in September 1950 approximated the average yearly water levels and were used as initial water levels in the model.

Recharge

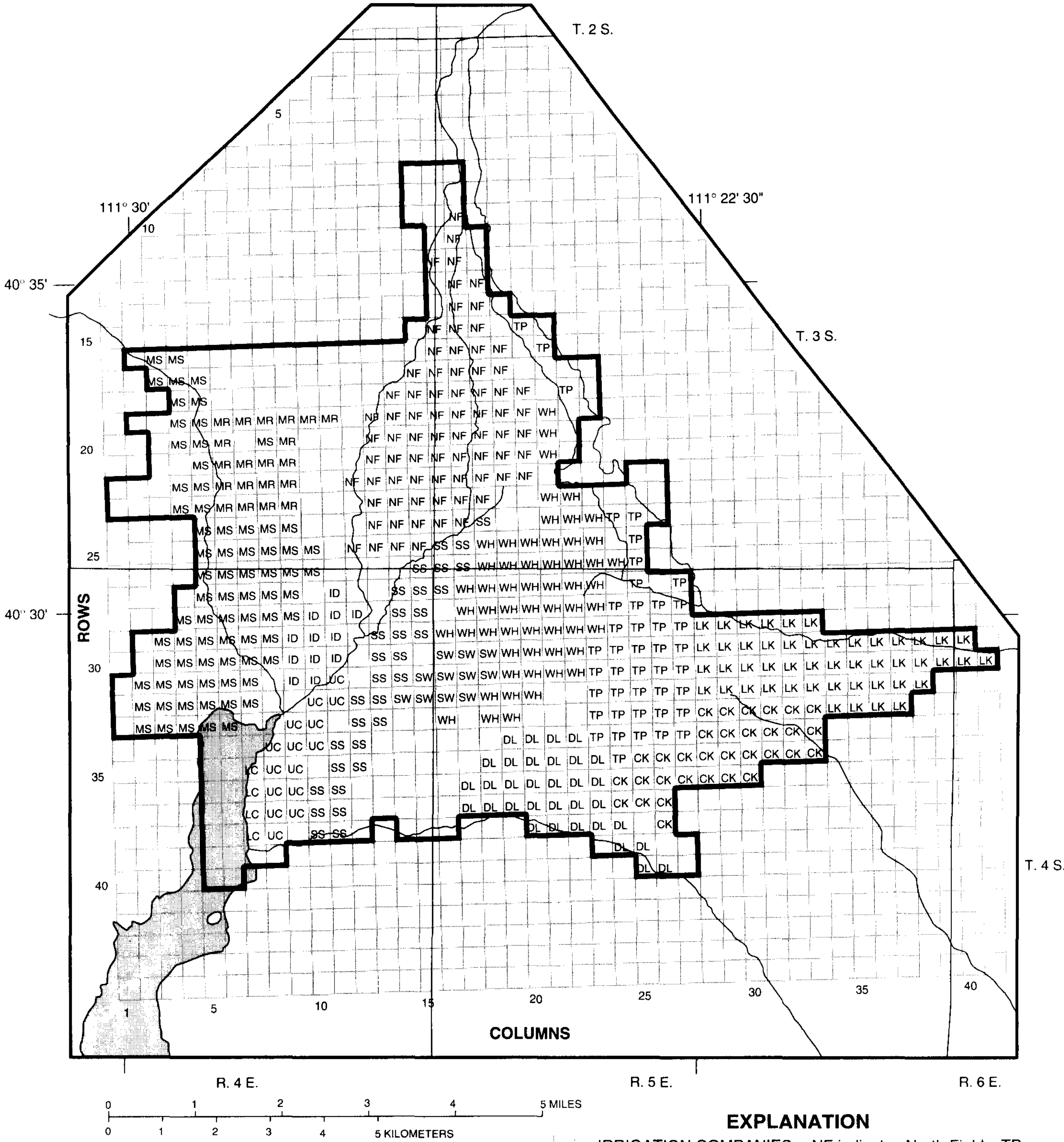
The estimated average recharge to the unconsolidated valley-fill deposits in Heber Valley is 154 cubic feet per second (table 4). The largest source of this recharge is unconsumed irrigation water; secondary sources are subsurface inflow from consolidated rocks, stream infiltration including infiltration from the Provo River, and precipitation. Recharge from unconsumed irrigation water, part of the stream infiltration, and precipitation was simulated in layer 1 using the Recharge Package described by McDonald and Harbaugh (1988).

Diversion records of irrigation companies for 1949-50 were obtained from the Provo River Water Commissioner's Report (Wentz, 1949; and 1950) and were used to estimate recharge from unconsumed irrigation water for most of the valley for the 1949-50 simulation. The quantity of water diverted in 1949-50 by the Lake Creek, Center Creek, and Daniels Irrigation Companies was not reported by the Provo River Water Commissioner; therefore, the quantity of water diverted by these companies was assumed to be the same as the quantity estimated by Hyatt and others (1969).

Diversion records for 1952-82 and 1988-89 (Utah Division of Water Resources, 1986) were used to establish initial conditions for the 1988-89 transient simulation. The Provo River Water Commissioner's records (Stanley Roberts, oral commun., 1989) were used in the 1988-89 simulations. Heber Power and Light Company has records of water diverted by the Lake Creek Irrigation Company since the company converted from flood to sprinkler irrigation. For the 1988-89 simulations, the recharge for the Lake Creek and the similar Center Creek irrigation areas was based on these diversion records.

The irrigation boundaries reported by the Utah Division of Water Resources (1986) were used to approximate the areas serviced by each irrigation company. The service area for each irrigation company is shown in figure 10. To simplify the simulations, it was assumed that the service areas of the irrigation companies did not overlap and that water diverted by a company was distributed evenly over the company area. It also was assumed that boundaries reported by the Utah Division of Water Resources (1986) were the same boundaries that existed in 1949-50 and 1988-89.

Recharge to the areas with flood irrigation was based on the quantity of water diverted by each irrigation company. Transmission losses were determined from seepage studies reported earlier in this report (see section



EXPLANATION

ID IRRIGATION COMPANIES -- NF indicates North Fields; TP indicates Timpanogos; MS indicates Midway from Snake Creek; MR indicates Midway from River Ditch; WH indicates Wasatch; SS indicates Sagebrush/Spring Creek; LK indicates Lake Creek; ID indicates Island Ditch; CK indicates Center Creek; UC indicates Upper Charleston; LC indicates Lower Charleston; DL indicates Daniels; SW indicates Wasatch with sprinkler irrigation

EXTENT OF ACTIVE CELLS IN LAYER 1 -- No-flow boundary

Figure 10.--Service areas of irrigation companies in Heber Valley.

on recharge from unconsumed irrigation water) and were applied as areal recharge. Recharge from the flood-irrigated fields was calculated by subtracting a consumptive use value of 1.72 feet per year (Utah Division of Water Resources, 1986) from the available irrigation water (total diversion minus transmission losses). This calculation yielded the average recharge rate in all areas except the North Fields area. In the North Fields area, the quantity diverted was the quantity of recharge applied. The North Fields area is covered by phreatophytes, such as alfalfa, salt grass, cottonwoods, and willows. The consumptive use value for the North Fields area was computed by the Evapotranspiration Package of the model (McDonald and Harbaugh, 1988) and is discussed later in this report.

Recharge to the Lake Creek, Center Creek, and Daniels Creek irrigation-company areas, where sprinkler irrigation was simulated in the 1989 steady-state and the 1988-89 transient-state simulations, was estimated to be 35 percent of the quantity applied after subtraction of the transmission losses. The 35 percent was derived using a 65-percent sprinkler efficiency as described by the Utah Division of Water Resources (1986). A 65-percent sprinkler efficiency means that 35 percent of the water applied goes back into the system as either surface-water runoff or ground-water recharge. Losses to evaporation and consumptive use are included in the 65 percent. Because infiltration rates in Heber Valley are fast, it is assumed that all of the water going back into the system enters as recharge.

In the Sagebrush/Spring Creek, Midway, Wasatch, and Upper Charleston irrigation-company areas, both flood- and sprinkler-irrigation methods are used. In these areas, an average of the two recharge rates was used in the model for the 1989 steady-state simulation and the 1988-89 transient-state simulation.

Seepage from irrigation canals and infiltration from streams are important components of recharge to the ground-water system. The percentage of loss from the irrigation canals, based on seepage studies during this study and seepage studies by Herbert and others (written commun., 1990), was used to calculate recharge rates from the canals. The quantity of water diverted to canals, based on Provo River Water Commissioner's reports, was multiplied by the percentage loss, as determined from seepage studies, and distributed evenly among the nodes that simulated recharge from canals in the model. Recharge from stream infiltration was either estimated from streamflow records reported in previous sections of this report or calculated by the model in the River (McDonald and Harbaugh, 1988) or Streamflow (Prudic, 1989) Packages. The location of recharge nodes used to simulate seepage from canals and infiltration from streams is shown in figure 11.

In the Midway area, the subsurface inflow from the consolidated rocks to the unconsolidated valley-fill deposits was simulated by the General-Head Boundary Package of the model (McDonald and Harbaugh, 1988). Recharge from subsurface inflow was calculated by the model during each simulation of the model.

The rate of recharge from precipitation was estimated to be 10 percent of the normal annual 1931-60 precipitation (U.S. Weather Bureau, 1963). In monthly simulations, recharge from precipitation during the winter months

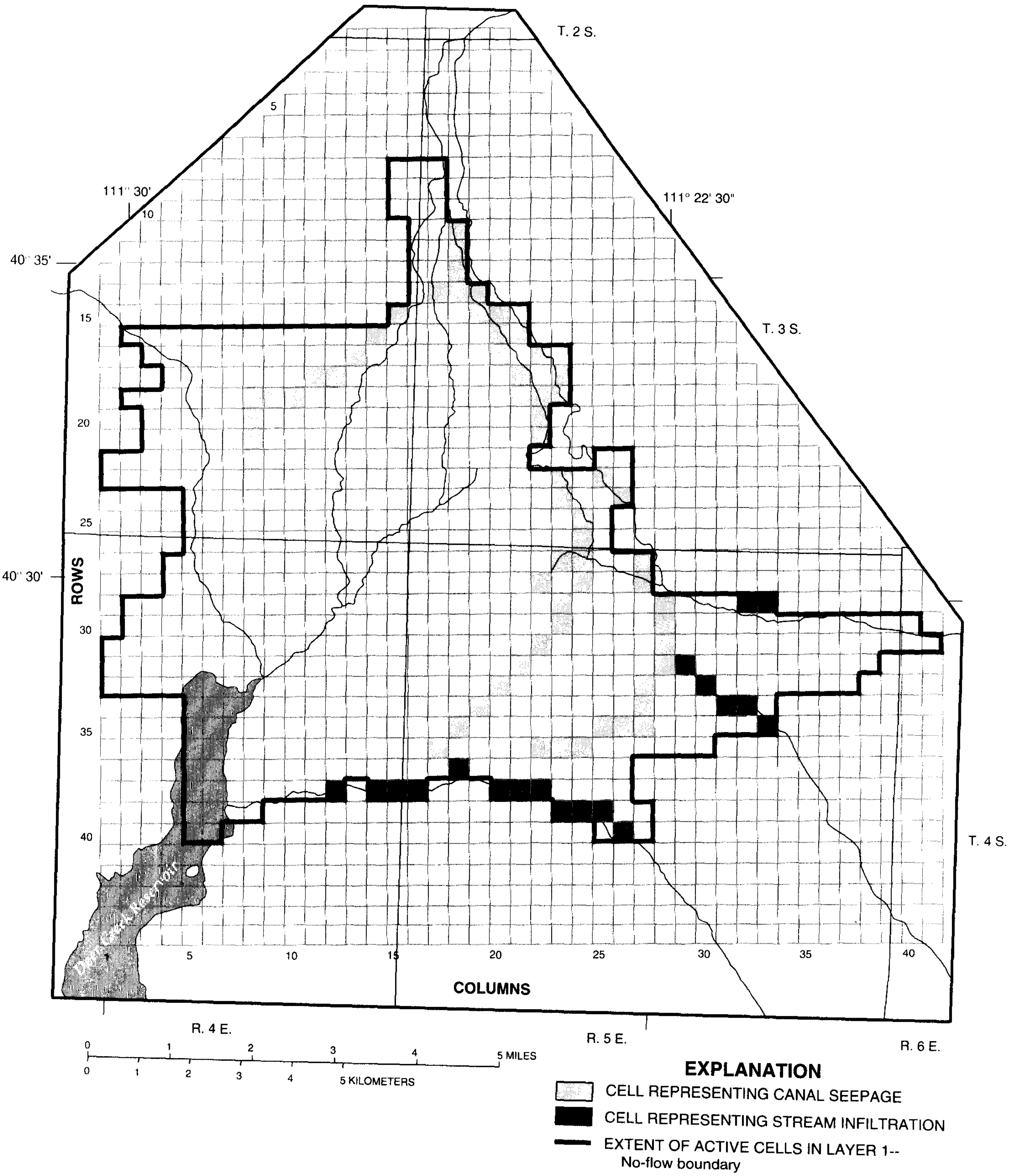


Figure 11.--Location of cells used to simulate recharge from canal seepage and stream infiltration.

(December-February) was applied during March to simulate recharge during the spring thaw. The rates and distribution of recharge used in the 1950 steady-state simulation are shown in figure 12.

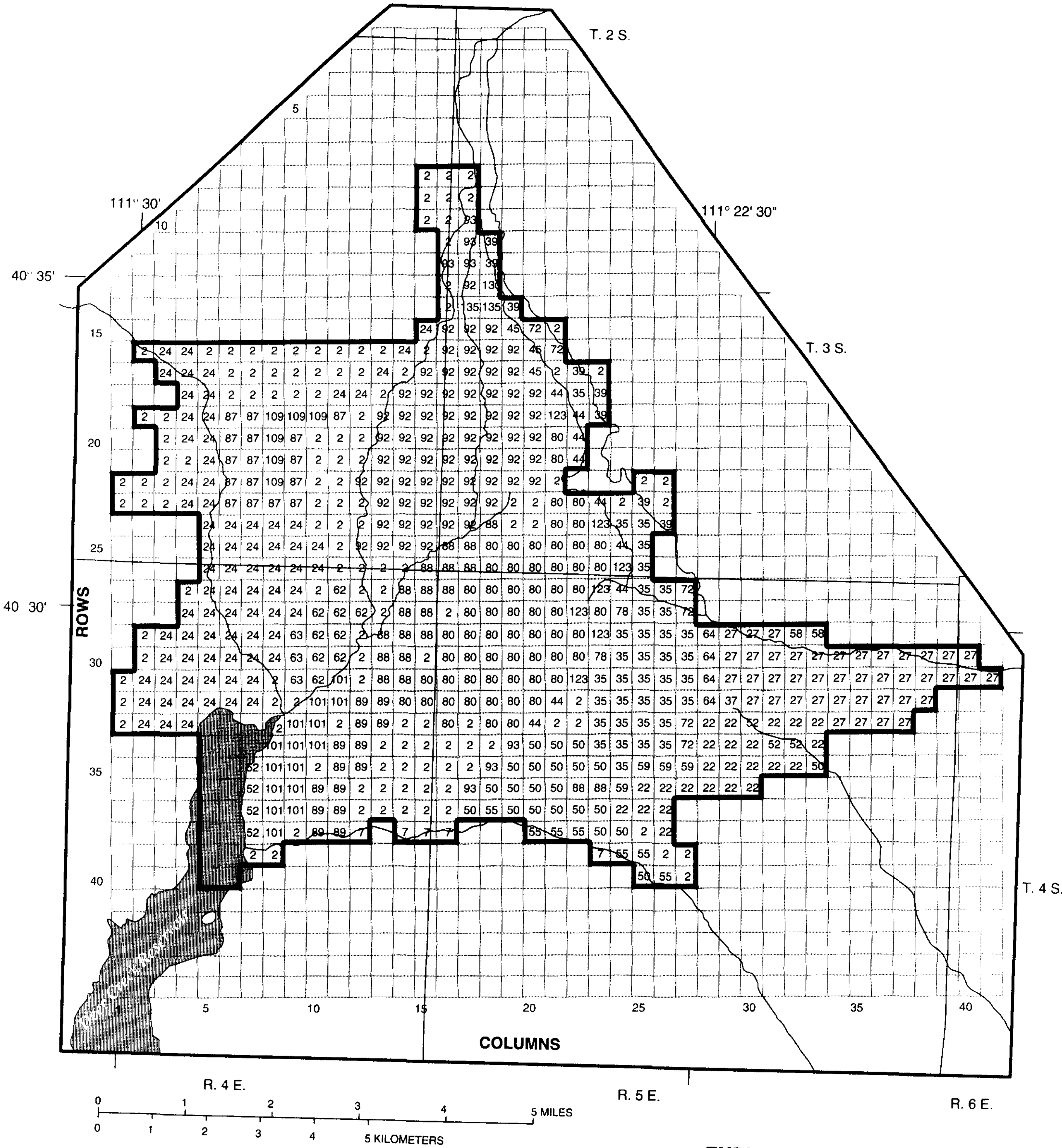
Aquifer characteristics

Initially, hydraulic conductivity in layer 1 was set at a uniform value of 20 feet per day. The value of 20 feet per day rather than the value of 50 feet per day reported by Baker (1970, p. 26) was chosen because Baker based his estimate of 50 feet per day only on the largest values of specific capacity, whereas 20 feet per day represents the average of the specific-capacity values determined during this study. The transmissivity in layer 2 initially was set at a uniform 100 feet squared per day. The value of 100 feet squared per day is representative of a large percentage of the values shown in figure 6. As the calibration progressed, the values of hydraulic conductivity and transmissivity were varied, within limits of available data, until a final distribution was reached.

The final values of hydraulic conductivity and transmissivity derived by the model are shown in figures 13 and 14. The average of the values of hydraulic conductivity and transmissivity generally are larger than the values estimated from specific capacities from drillers' logs, although the areas of large and small values are approximately the same. The transmissivity values derived by the model ranged from 500 to 40,000 feet squared per day, which generally are about 10 times greater than the values estimated from specific-capacity values. The values used in the model are similar to the values of 6,700 to 20,000 feet squared per day reported by Baker (1970, p. 26). Baker disregarded the small values of transmissivity and attributed the small values to poor well efficiency. Another possible explanation for the small values is that the wells do not penetrate the total thickness of the unconsolidated valley-fill deposits and, at least for short duration tests, the values calculated from specific-capacity values probably are too small.

Less is known about the vertical hydraulic conductivity than any other hydrologic property in Heber Valley. An initial value of 1.25×10^{-4} per day for vertical leakance was used in the model. Vertical leakance is described in McDonald and Harbaugh (1988). Vertical leakance values were varied during the calibration process. The final distribution of vertical leakance is shown in figure 15. Smaller values of vertical leakance were used in the Midway area to represent the cap-rock effect of the tufa on the underlying unconsolidated sediments. Smaller values were used in the Lake and Center Creek area to indicate the presence of more clay layers to impede vertical flow.

Conductance values are used in the Streamflow, General-Head Boundary, River, and Drain Packages. Streambed-conductance values for the Provo River initially were calculated using a method described by Prudic (1989, p. 7). The conductance values were varied during the calibration process. The final streambed conductance values ranged from 0.12 to 0.38 foot squared per day. Uniform values of conductance initially were assigned to Deer Creek Reservoir, the Midway area, Center Creek, Snake Creek, and drains. The values were varied during the calibration process. Final values used in the model were



EXPLANATION

24 AREAL RECHARGE, IN INCHES PER YEAR (ROUNDED TO THE NEAREST INCH)

EXTENT OF ACTIVE CELLS IN LAYER 1 -- No-flow boundary

Figure 12.--Distribution of areal recharge used in the 1950 steady-state simulation.

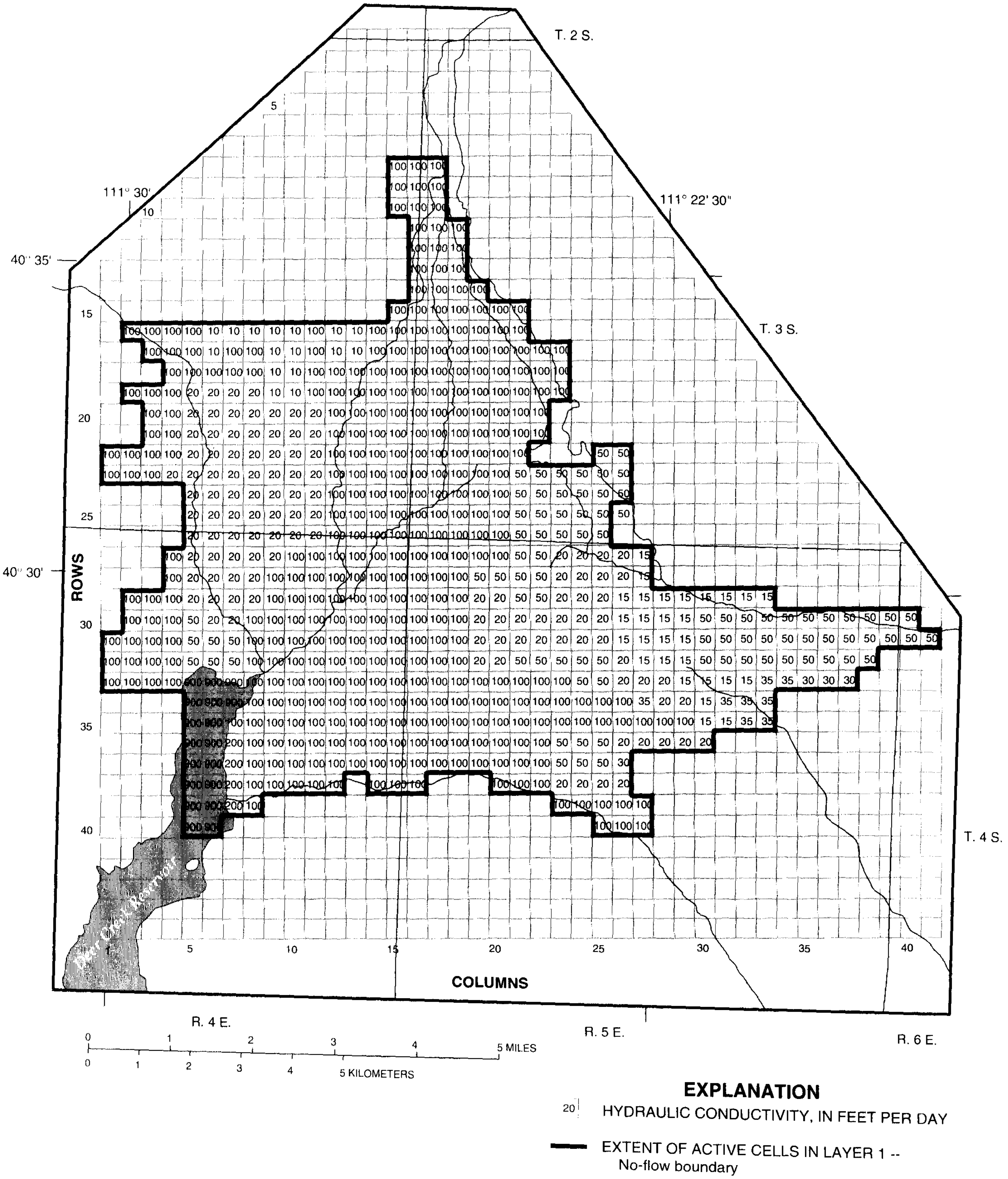
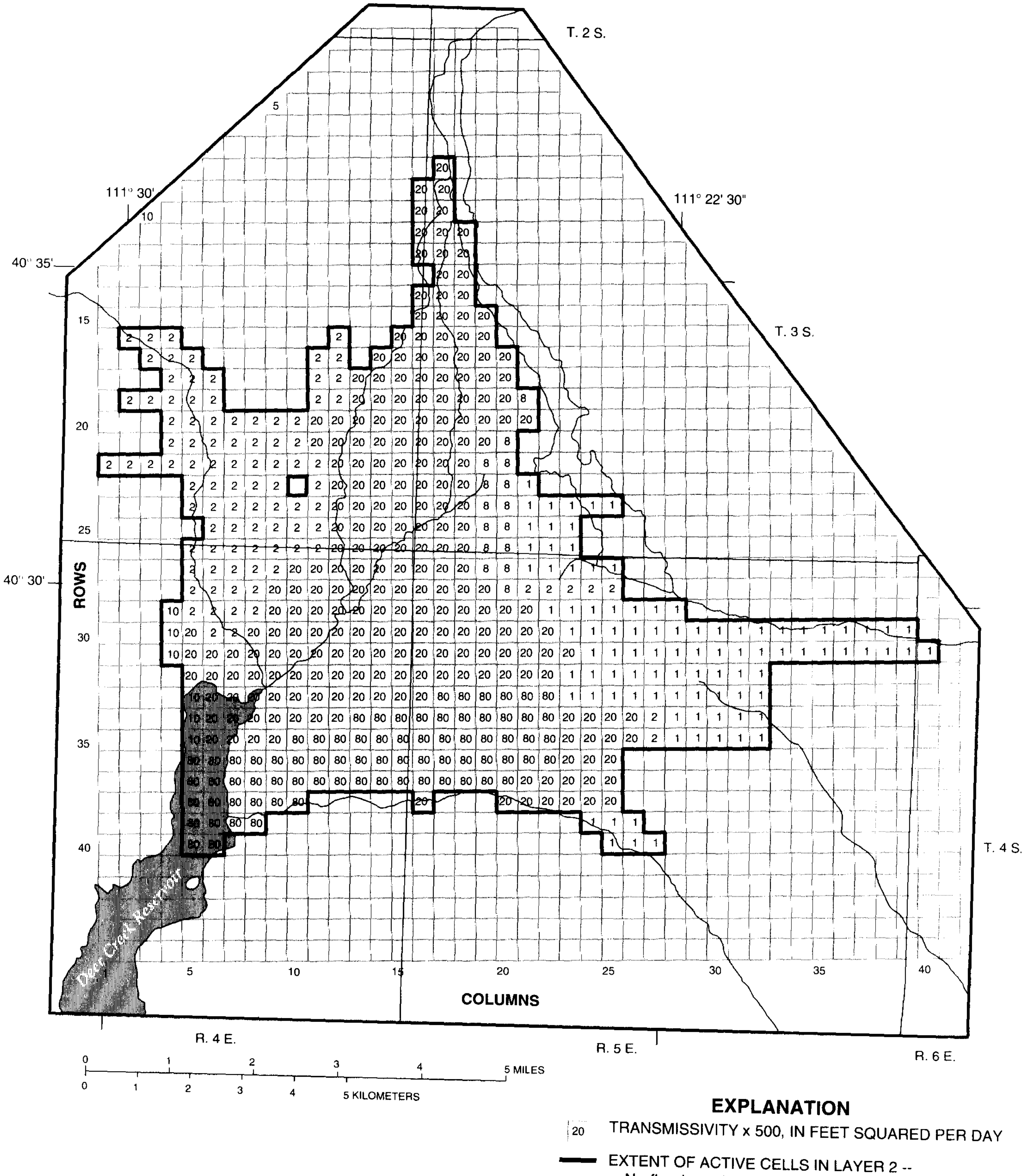


Figure 13.--Distribution of hydraulic conductivity in layer 1.



EXPLANATION

20 TRANSMISSIVITY x 500, IN FEET SQUARED PER DAY

EXTENT OF ACTIVE CELLS IN LAYER 2 -- No-flow boundary

Figure 14.--Distribution of transmissivity in layer 2.

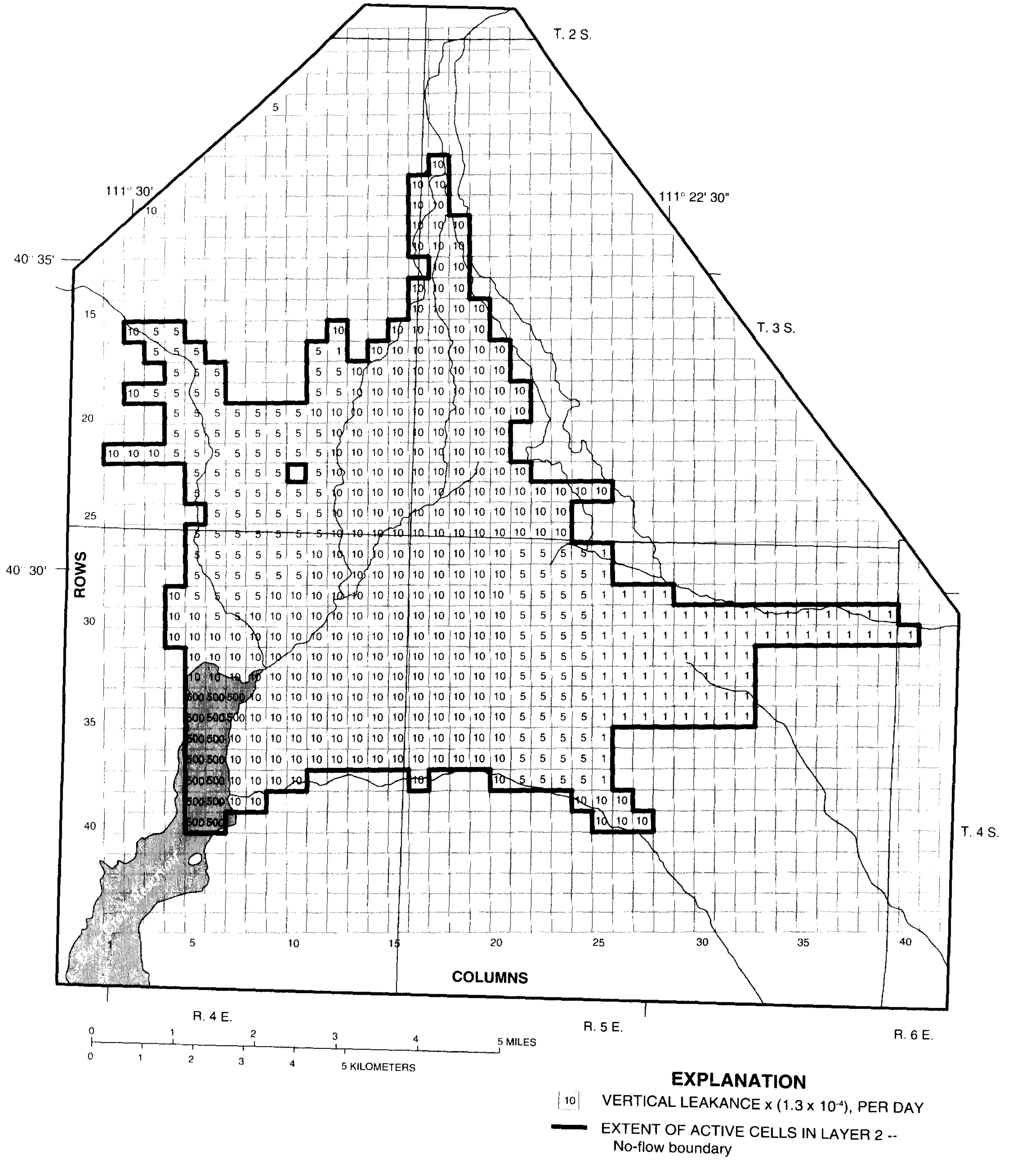


Figure 15.--Distribution of vertical leakance between layers 1 and 2.

1.0 foot squared per second for Deer Creek Reservoir and Center Creek, 0.7 foot squared per second in the Midway area, 0.05 foot squared per second for Snake Creek, and 0.9 foot squared per second for drains.

The initial value of specific yield in layer 1 was set at 0.20. The specific-yield values were varied until the final distribution was reached. Values of specific yield in the Midway area and the Lake Creek area are smaller than values for the surrounding area in order to simulate smaller storage caused by the tufa in the Midway area and clays in the Lake Creek area. The specific-yield values are within the expected range of values as reported earlier in this report. The final distribution of specific yield in layer 1 is shown in figure 16.

Layer 2 was assigned an artesian storage coefficient of 1 X 10^{-4} . A specific-yield value in layer 2 would be used by the model if the water level were to drop below the top of the cell. If this condition were to occur, the same distribution of specific-yield values as in layer 1 would be used by the model in layer 2. This condition did not occur in any of the simulations documented in this report.

Discharge

Discharge from the unconsolidated valley-fill deposits in Heber Valley primarily is from evapotranspiration, leakage to Deer Creek Reservoir, seepage to the Provo River, and discharge from springs and seeps (table 4). The sum of all discharge components was estimated to be 154 cubic feet per second.

Evapotranspiration from the unconsolidated valley-fill deposits occurs mainly where the water table is within a few feet of the land surface and phreatophytes such as alfalfa, salt grass, willows, and cottonwoods are present. Evapotranspiration occurs in the North Fields and Midway areas and near the Provo River. Areas where evapotranspiration was simulated are shown in figure 17. These areas were simulated using the Evapotranspiration (ET) Package from McDonald and Harbaugh (1988). The depth of extinction used in the simulation was 5 feet, and the maximum evapotranspiration rate was set at 30 inches per year.

Discharge by leakage to Deer Creek Reservoir (fig. 9) was simulated using the General-Head Boundary Package described by McDonald and Harbaugh (1988). This package allows the user to vary the altitude of the general-head boundary cells (fig. 9) before each stress period in transient simulations. Data on the altitude of the water surface in Deer Creek Reservoir were obtained from the Provo River Commissioner's reports (Wentz, 1949; 1950), Utah Division of Water Resources (1986), and Harold Ford (U.S. Bureau of Reclamation, oral commun., 1989).

Springs and seeps discharge ground water to many of the canals in the center of the valley, to Snake Creek in the Midway area, and to the Provo River in the lower parts of the valley. Discharge from seeps and springs to canals in the center of the valley was simulated using the Drain Package described by McDonald and Harbaugh (1988). Discharge to Snake Creek was simulated using the River Package (McDonald and Harbaugh, 1988), and discharge to the Provo River was simulated using the Streamflow Package (Prudic, 1989).

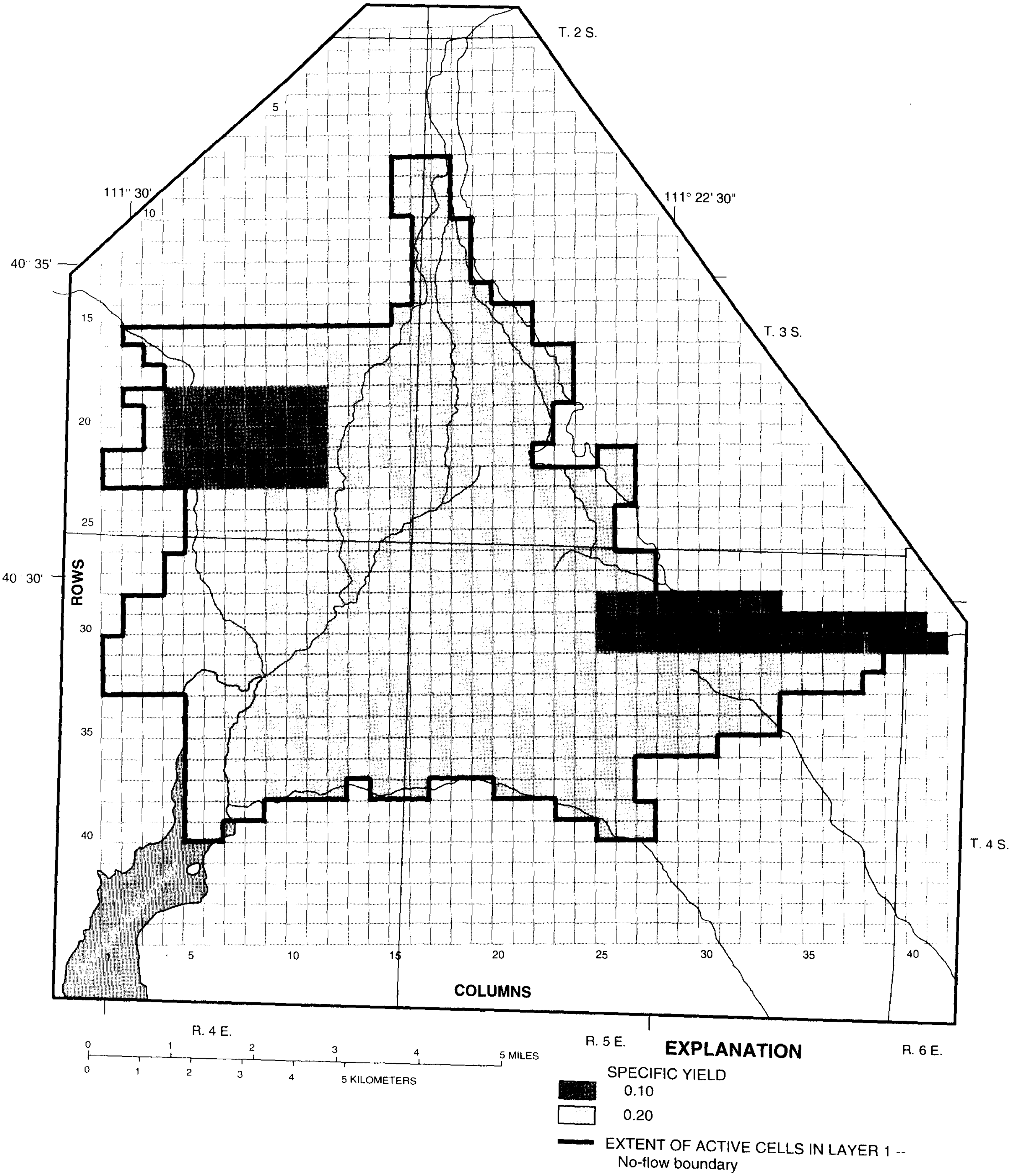


Figure 16.--Distribution of specific yield in layer 1.

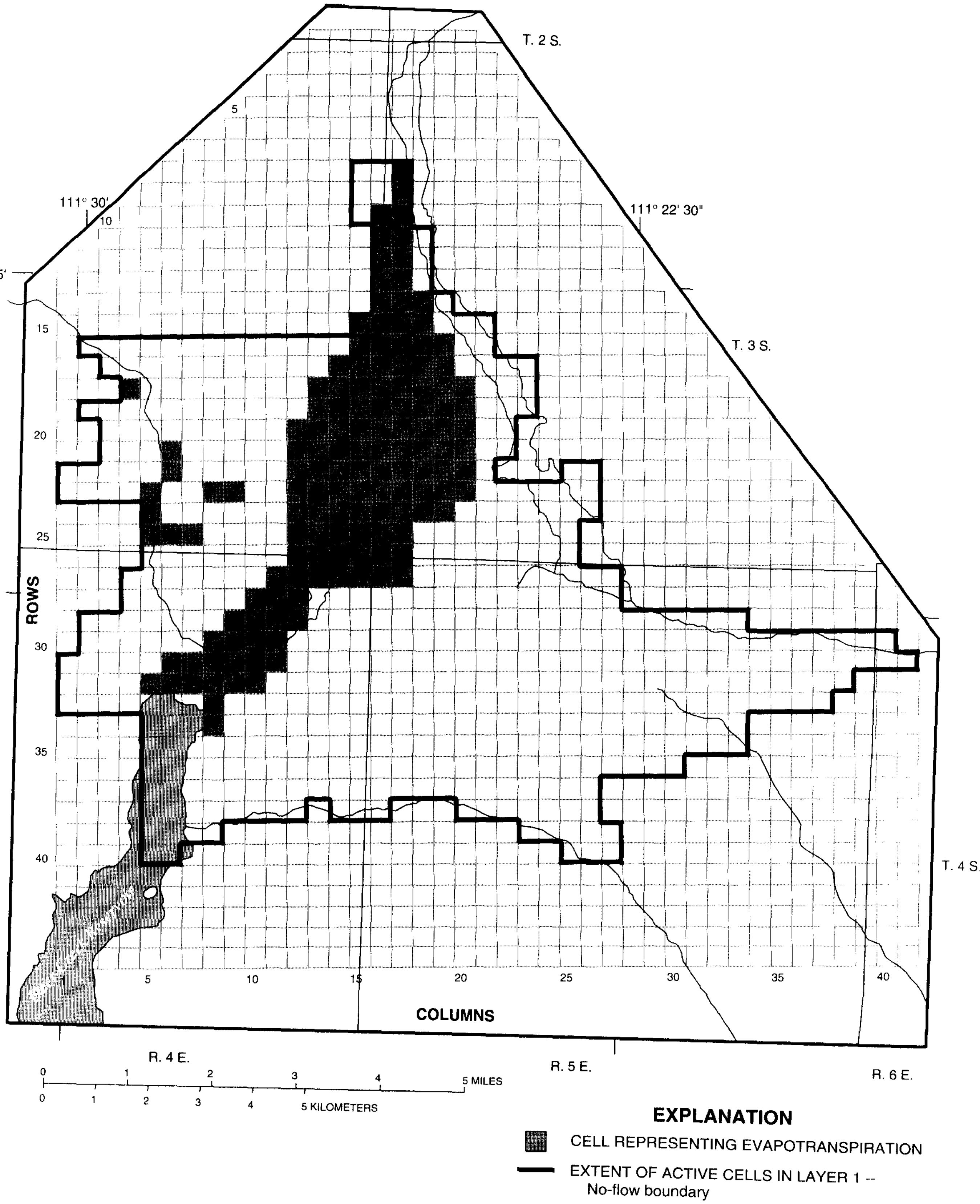


Figure 17.--Location of cells used to simulate evapotranspiration.

Calibration

Simulations for 1950 steady-state, 1949-50 monthly transient-state, 1989 steady-state, and 1988-89 monthly transient-state conditions were used in the calibration process. The 1950 steady-state simulation was used to establish initial conditions for the 1949-50 monthly transient-state simulation, and the 1989 steady-state simulation was used to establish initial conditions for the 1988-89 monthly transient-state simulation. The major difference between the conditions in the 1949-50 and 1988-89 monthly simulations was that flood-irrigation methods were simulated for 1949-50 and flood- and sprinkler-irrigation methods were simulated for 1988-89.

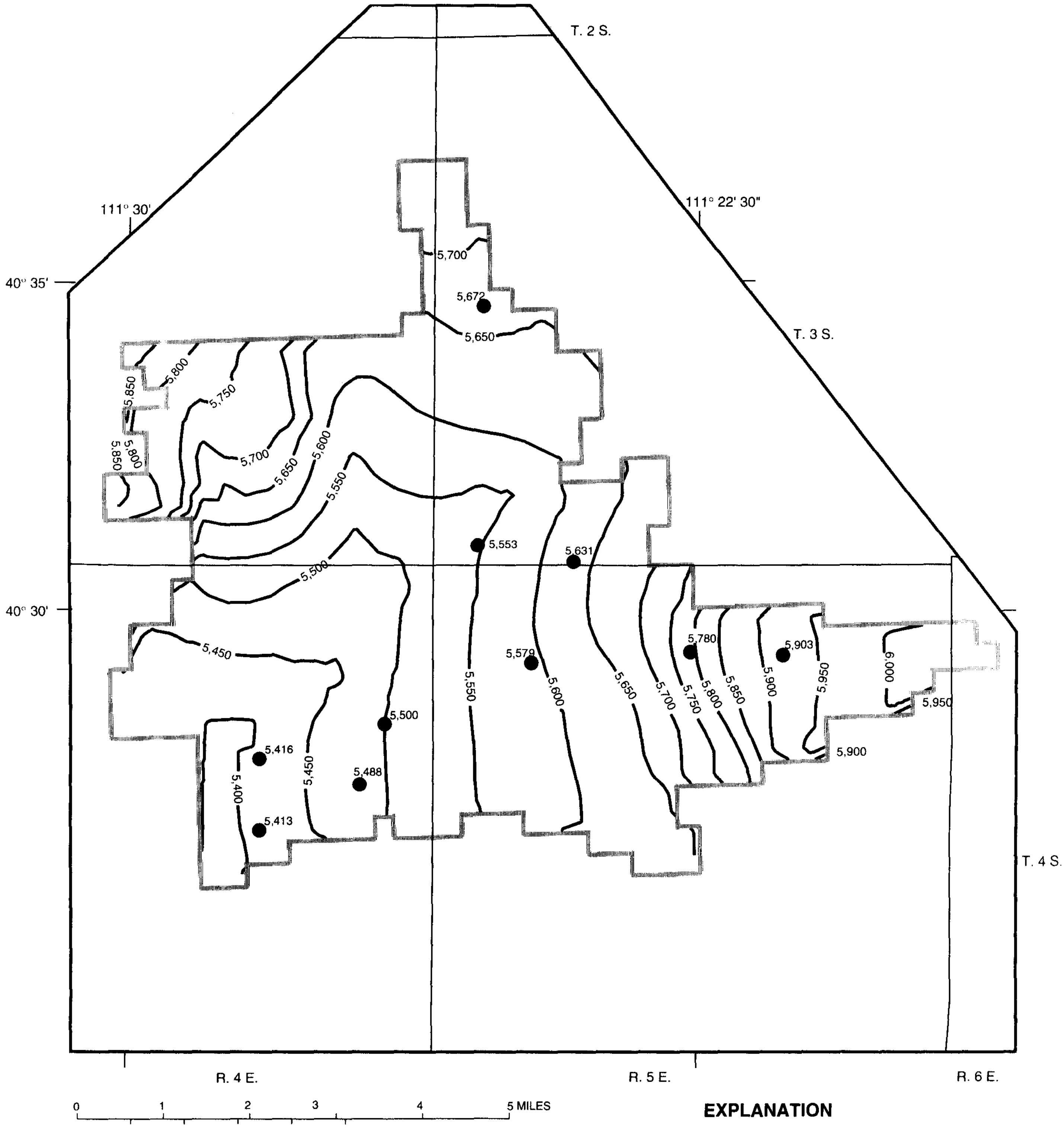
1950 steady-state calibration

No apparent long-term water-level changes occurred in Heber Valley from the late 1940's to the middle 1950's (wells (D-3-5)29cac-1 and (D-4-5)4ddd-1, fig. 5). The only changes that occurred in the hydrologic system were seasonal changes in the quantity of recharge and changes in the altitude of the water surface in Deer Creek Reservoir; therefore, the ground-water system in Heber Valley in 1950 was considered to be in steady state. Discharge records for the Provo River, diversion records, and water-level records for 10 observation wells were available for 1950.

Model-calculated water levels for the 1950 steady-state simulation were compared to the water levels measured in September 1950, which approximate the yearly average water level. In addition, the model-calculated ground-water budget values were compared with the estimated ground-water budget values (table 4). Hydrologic properties were varied within reasonable limits during the calibration process to obtain an acceptable match. The properties varied were the hydraulic conductivity of layer 1, transmissivity of layer 2, vertical leakance between the layers, conductance of the general-head boundary, and conductance in the Stream Package. The distribution and quantity of recharge was not varied during the steady-state calibration process because estimates of the recharge were considered more reliable than estimates of other hydrologic components.

The altitude of the water levels in 10 observation wells in September 1950 and the potentiometric surface simulated by the steady-state model are shown in figure 18. The largest differences between measured and simulated water levels occurred in the Lake, Center, and Daniels Creek areas, where a steep hydraulic gradient of 200 to 300 feet per mile exists (pl. 1). The average absolute difference of 1.5 feet between the measured and simulated 1950 water levels indicated a fairly even distribution of differences. The largest difference between measured and simulated water levels was for a well in the upper Lake Creek drainage where the simulated water level was 22 feet higher.

The model-calculated 1950 steady-state ground-water budget and the estimated ground-water budget listed in table 4 are presented in table 5. Recharge from infiltration from the Provo River is smaller in the model-calculated budget than in the estimated ground-water budget. The estimated recharge from infiltration from the Provo River was based on seepage studies



EXPLANATION

5,500 POTENTIOMETRIC CONTOUR -- Shows altitude of potentiometric surface simulated by the steady-state model. Contour interval 50 feet. National Geodetic Vertical Datum of 1929

EXTENT OF ACTIVE CELLS IN LAYER 1 -- No-flow boundary

5,672 ● OBSERVATION WELL -- Number indicates altitude of water level, September 1950, in feet above National Geodetic Vertical Datum of 1929

Figure 18.--Altitude of water levels in observation wells, September 1950, and simulated 1950 steady-state potentiometric surface.

Table 5.--*Model-calculated ground-water budgets and estimated ground-water budget from table 4*

Budget element	Flow, in cubic feet per second				
	Model-calculated budgets				Estimated ground-water budget (table 4)
Recharge	1950 steady state	1949-50 transient state[1]	1989 steady state	1988-89 transient state[1]	
Precipitation, unconsumed irrigation water, and stream infiltration	135	140	114	108	110
Infiltration from Provo River	4	4	4	5	20
Subsurface inflow from consolidated rocks	10	10	10	10	24
Subsurface inflow from Center Creek	2	1	2	2	[2]0
Total Recharge (rounded)	151	155	130	125	154
Discharge					
Evapotranspiration	11	12	9	9	17
Leakage to Deer Creek Reservoir	45	38	38	39	70
Seepage to Provo River	[3]43	[3]42	[3]37	[3]34	18
Springs and Seeps	[3]52	[3]50	[3]46	[3]37	48
Wells	[4]0	[4]0	[4]0	[4]0	1.2
Total Discharge (rounded)	151	142	130	119	154
Water going into (+) or out of (-) storage	0	[5]+15	0	[5]+7	

[1] Transient-state simulation for 12-month period.
[2] Not determined.
[3] Includes flow from river and drain cells (fig. 9).
[4] Not simulated.
[5] Difference between recharge and discharge may not be equal to the change in storage due to simulation constraints and rounding.

conducted on the Provo River from August 30 to September 1, 1988. This one-time study might not be representative of the long-term average recharge from the Provo River.

The model-calculated recharge of 10 cubic feet per second from subsurface inflow from consolidated rocks was 14 cubic feet per second less than the estimated recharge of 24 cubic feet per second (table 5). The model-calculated value was determined by adjusting the conductance in the general-head boundary near Midway until the hydraulic heads generated by the model were in close agreement with potentiometric contours based on actual water-level measurements in April and May 1989 (pl. 1). The 1989 data were used because data for the Midway area were not available for the 1950 steady-state calibration period. The difference in the values was not considered substantial because the estimated discharge of 24 cubic feet per second was a residual in the budget calculations and might represent uncertainties in the other budget elements.

Leakage to Deer Creek Reservoir in the model-calculated budget is smaller than the value in the estimated ground-water budget. Attempts to increase the quantity of leakage to Deer Creek Reservoir by increasing the conductance in the general-head boundary failed. The estimated leakage to Deer Creek Reservoir was calculated for 1978-87. Precipitation during this period was greater than average (fig. 4) and may not be representative of average conditions.

Seepage to the Provo River calculated by the model is greater than estimated. The larger calculated value for seepage might be related to the fact that flow to the river, as calculated by the model, is for the area of the river cell including inflow from springs and drains near the river; whereas, flow measured during seepage studies is for the main river channel only.

The sensitivity of each model component was tested during the steady-state calibration. Changes in the hydraulic conductivity in the Lake and Center Creek areas led to the largest changes in water levels. The center of Heber Valley was less sensitive to changes in hydraulic conductivity because changes in conductivity resulted in changes in flow to springs and seeps rather than water-level changes. Changes in the transmissivity of layer 2 resulted in minor water-level changes. Differences in head in the two layers were very sensitive to changes in the vertical leakance, especially near Deer Creek Reservoir.

1949-50 transient-state calibration

Monthly stress periods from October 1949 to September 1950 were used in a transient-state simulation. Initial conditions for the 1949-50 transient simulation were obtained from the results of the 1950 steady-state simulation. The largest monthly stresses on the ground-water system in Heber Valley are changes in the quantity of recharge and changes in the level of Deer Creek Reservoir. The monthly recharge rates used in the transient-state simulation were calculated from monthly data, and the average monthly altitude of the water surface in Deer Creek Reservoir was varied. The monthly recharge for the 1949-50 transient-state simulation and the 1950 steady-state recharge used in the digital-computer model are shown in figure 19.

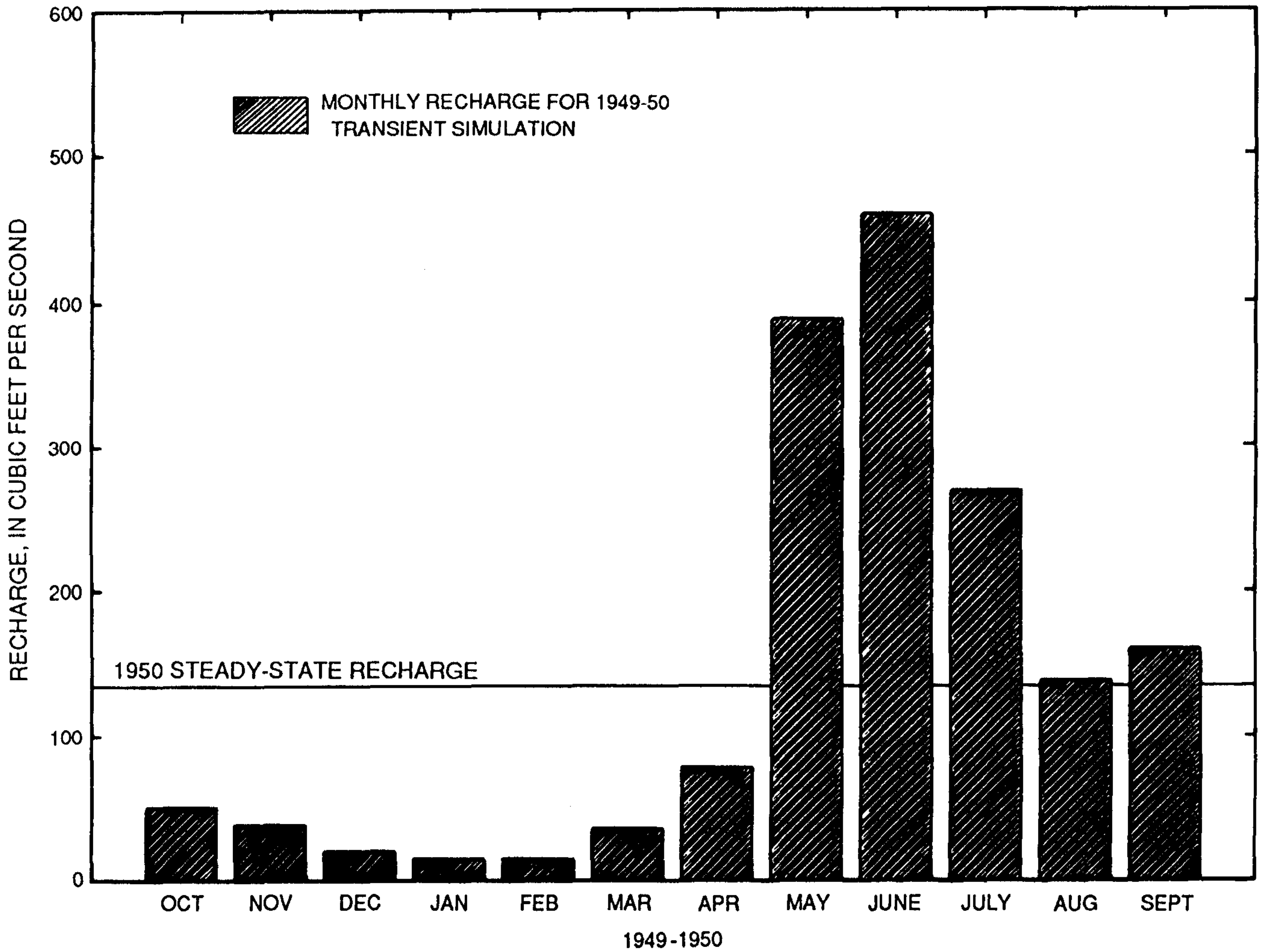


Figure 19.--Monthly recharge for the 1949-50 transient simulation and 1950 steady-state recharge.

The transient-state simulation was calibrated by visually comparing the simulated monthly water levels to monthly water levels measured by the Assistant Provo River Water Commissioner. Also, the flow of the Provo River at the U.S. Geological Survey gaging station 10155500 (U.S. Bureau of Reclamation gage 1008) was compared to the flow calculated by the model. No changes were made in the hydraulic parameters, with the exception of storage in the 1949-50 transient-state calibration.

Hydrographs of the measured and model-calculated water-level changes for the 1949-50 monthly transient-state simulation are shown in figure 20. Model-calculated flow of the Provo River from October 1949 to September 1950 and measured flow at U.S. Geological Survey gaging station 10155500 (U.S. Bureau of Reclamation gage 1008) for the same period are shown in figure 21. The hydrographs of monthly water levels indicate that the model is capable of simulating the measured monthly water levels with a reasonable degree of accuracy in most parts of the Heber Valley.

The model-calculated budget for the 1949-50 transient simulation is similar to the 1950 steady-state budget (table 5). The larger volume of recharge compared to discharge indicates an increase in ground-water storage that is reflected in the hydrographs shown in figure 20.

The sensitivity of the model to changes in storage was analyzed during the transient-state simulation. The model was sensitive to small changes in specific yield in layer 1. Small changes in specific yield led to large water-level fluctuations. Changes in the storage coefficient in layer 2 had little or no effect on the model results.

Simulations of present-day conditions

A 1988-89 monthly transient simulation for July 1988 to August 1989 was used to test the reliability of the model using an additional simulation of monthly stress conditions. Initial conditions for the monthly transient simulation were obtained by running a 1989 steady-state simulation corrected to include recharge quantities that would result from both flood and sprinkler irrigation. The simulation used average 1952-82 diversions (Utah Division of Water Resources, 1986) to compute recharge from unconsumed irrigation water. Data on diversions for 1982-87 were not available for use in the steady-state simulation.

The 1989 steady-state simulation more closely approximates recent long-term hydrologic conditions in the valley. Model-calculated water levels for the 1989 steady-state simulation were compared with water levels measured in April and May 1989 (pl. 1). The 1989 steady-state budget is shown in table 5. Some minor changes in hydraulic conductivity of layer 1, transmissivity of layer 2, and leakage between layers were required because additional water-level data were available to use in the calibration process. These new values of hydraulic conductivity, transmissivity, and leakage were then used in the 1950 steady-state simulation and the 1949-50 transient simulation, and the results were still within the limits of calibration criteria.

Precipitation, streamflow, and diversion records for 1988-89 were used to compute recharge for the 1988-89 monthly transient simulation. Discharge data for the Provo River were not available for the 1988-89 simulation period for comparison with model-calculated flows, but data from seepage studies of the Provo River in August of 1988 were compared to model-computed seepage. Recharge for 1988-89 was divided into monthly recharge. The monthly distribution of the 1988-89 recharge and the 1989 steady-state average recharge is shown in figure 22. As in the previous transient simulations, measured monthly water levels were compared to model-calculated monthly water levels. Hydrographs of measured monthly water-level changes and model-

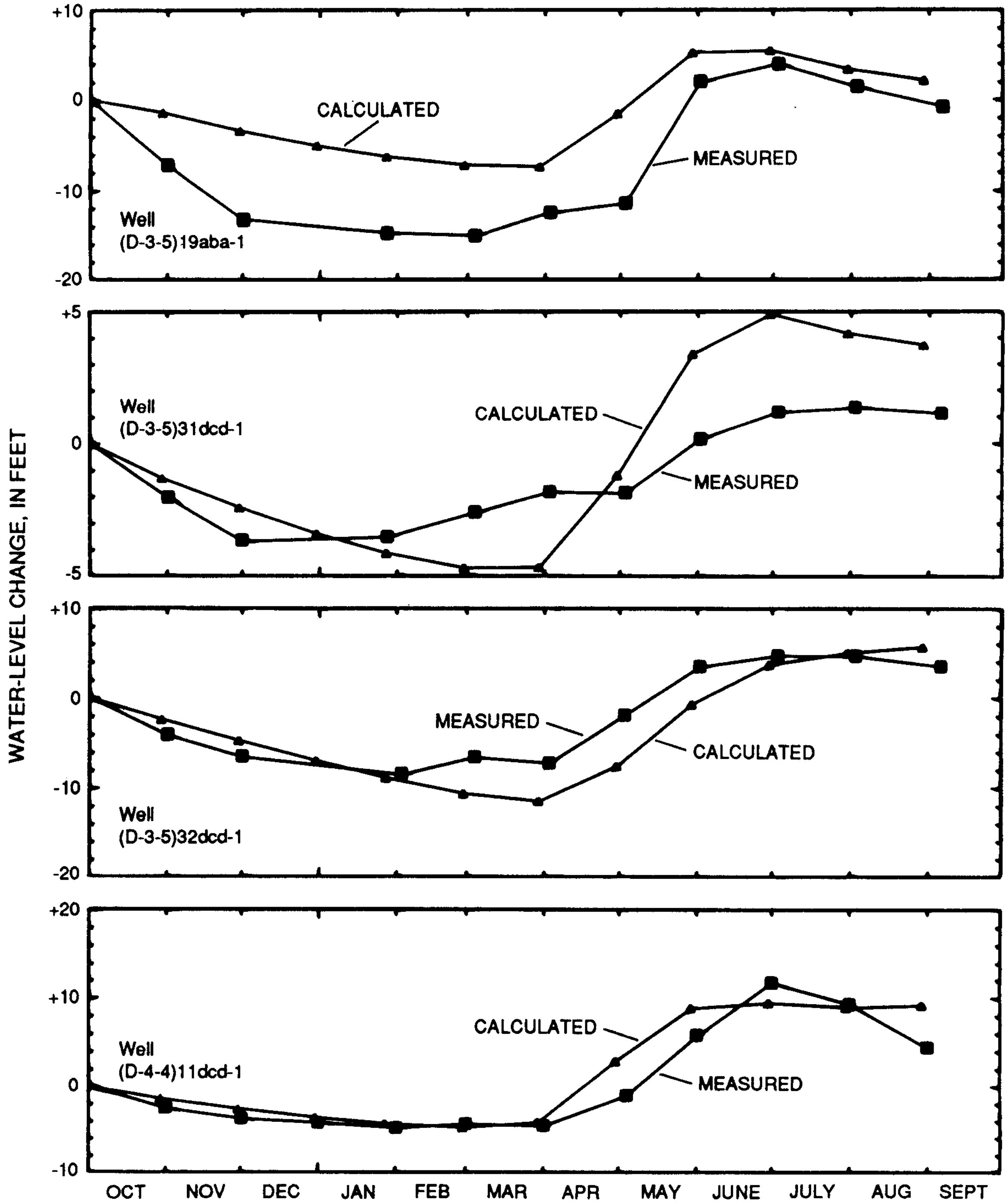


Figure 20.--Measured and model-calculated water-level changes for the 1949-50 monthly transient-state simulation.

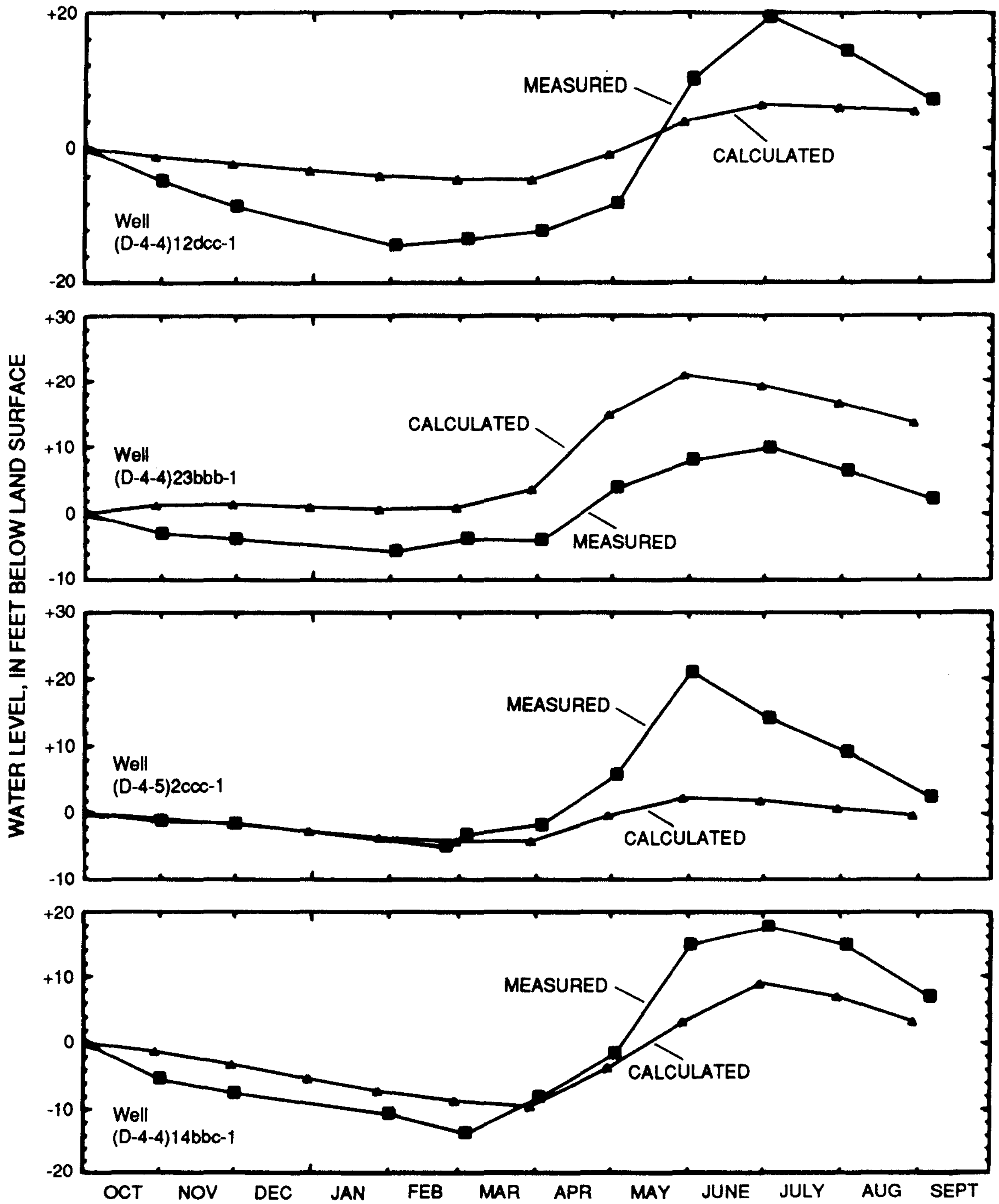


Figure 20--Measured and model-calculated water-level changes for the 1949-50 monthly transient-state simulation--Continued.

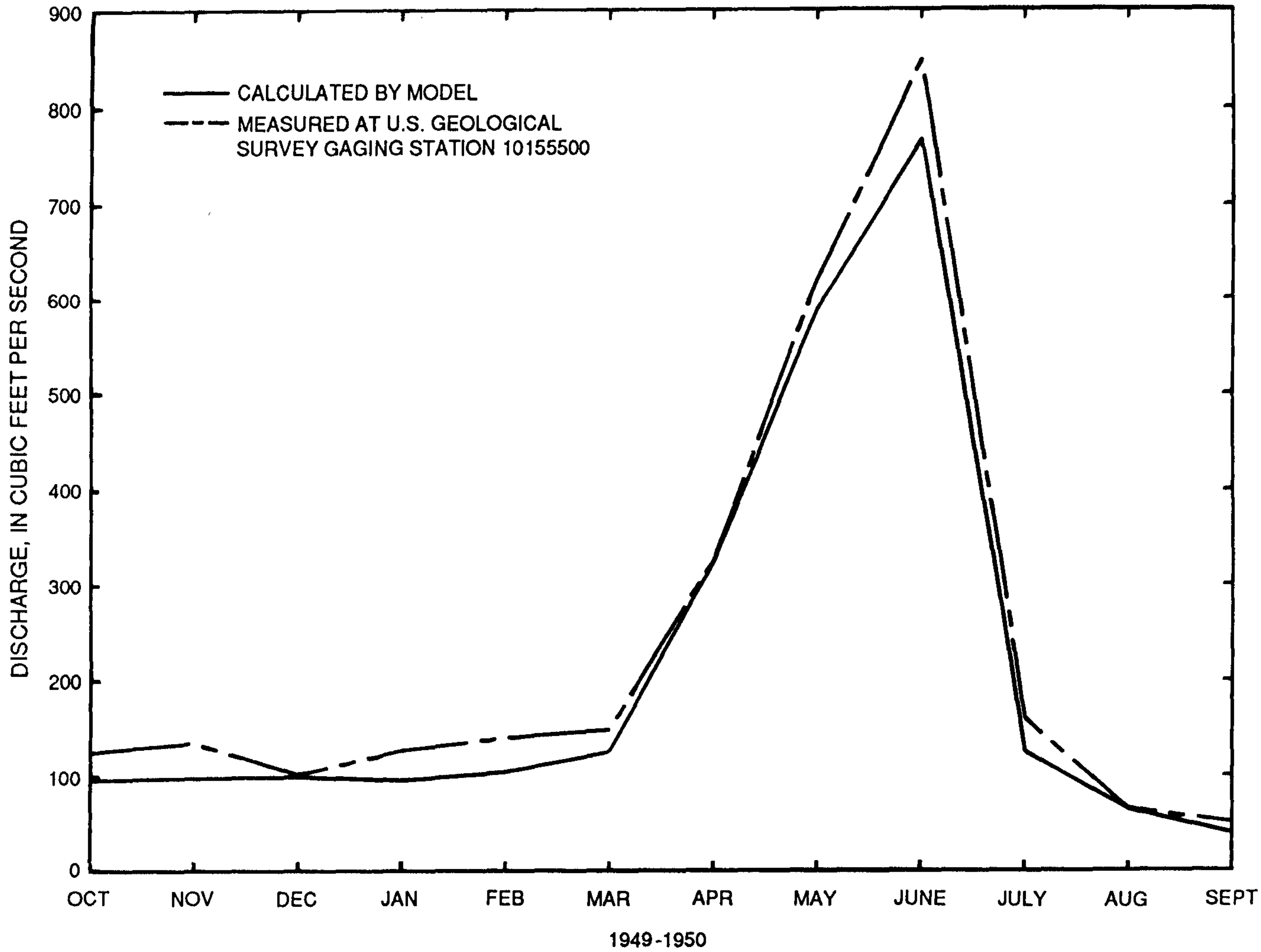


Figure 21.--Measured discharge at U.S. Geological Survey gaging station 10155500 from October 1949 to September 1950 and model-calculated discharge of the Provo River.

calculated monthly water-level changes are shown in figure 23. The potentiometric surface for April and May of 1989 and the model-calculated 1989 steady-state potentiometric surface are shown in figure 24. The model-calculated ground-water budget for September 1988 to August 1988 (12 months) is given in table 5.

The monthly model-calculated water levels are in reasonable agreement with the measured water levels (fig. 23), and the model-calculated potentiometric surface for May 1989 is in reasonable agreement with the potentiometric surface based on actual measurements made in April and May 1989 (fig. 24). For April 1989, a comparison of the upward vertical head difference of 2.82 feet measured at wells (D-4-4)15ddd-1 and -2 (table 6) and the model-computed head difference of 2.6 feet at the same location in the model (row 37, column 7) indicated that the values were in close agreement.

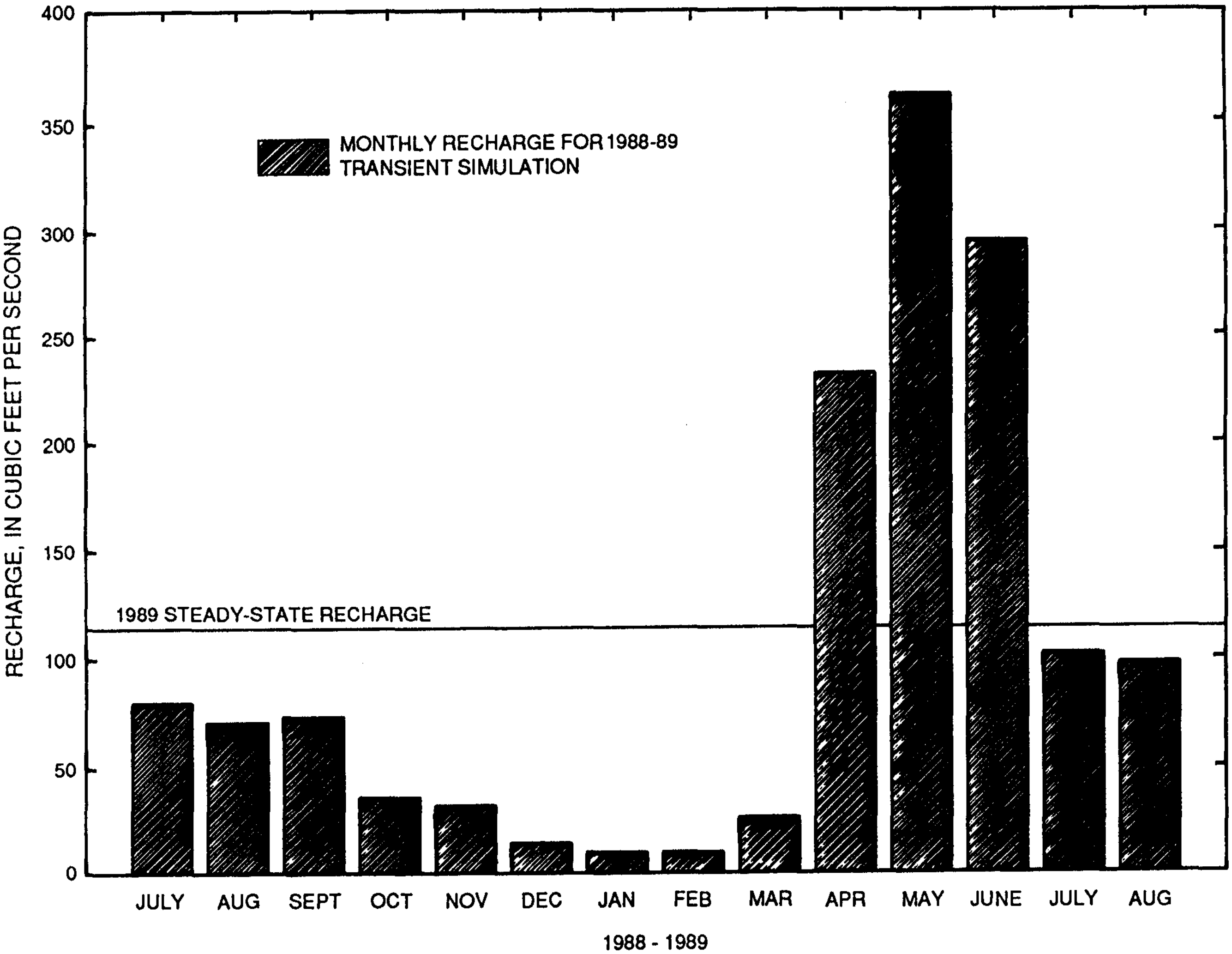


Figure 22.--Monthly recharge for the 1988-89 transient simulation and 1989 steady-state recharge.

The model-calculated discharge by seepage to the Provo River was almost twice as much as determined by the seepage studies in August 1988. Some of the difference between the model-calculated discharge and that determined by the seepage studies is the result of tributary inflow from seeps and springs near the river, primarily in the Lower Charleston Canal, that were not counted as direct gains to the river during the seepage studies but were calculated as river gains by the model.

The model-calculated ground-water budgets presented in table 5 can be used to gain some insight into how the ground-water system reacts to changes in recharge. A comparison of the 1950 and 1989 steady-state model-calculated budgets (table 5) shows a decrease in recharge of 21 cubic feet per second. The decrease in recharge primarily is due to a decrease in diversions for irrigation, which provide recharge in the Lake, Center, and Daniels Creek areas where conversion from flood- to sprinkler-irrigation methods has taken

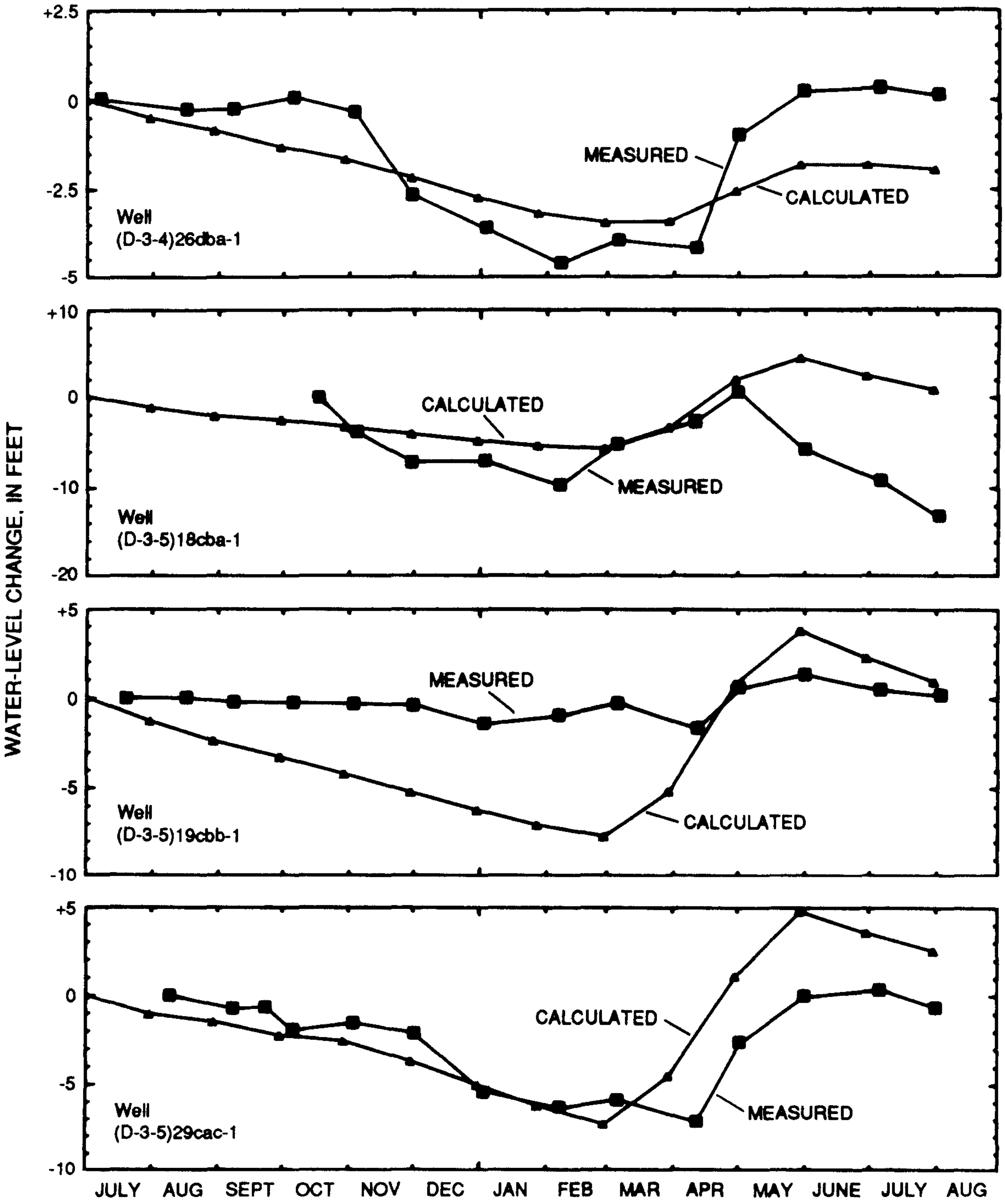


Figure 23.--Measured and model-calculated water-level changes for the 1988-89 monthly transient-state simulation.

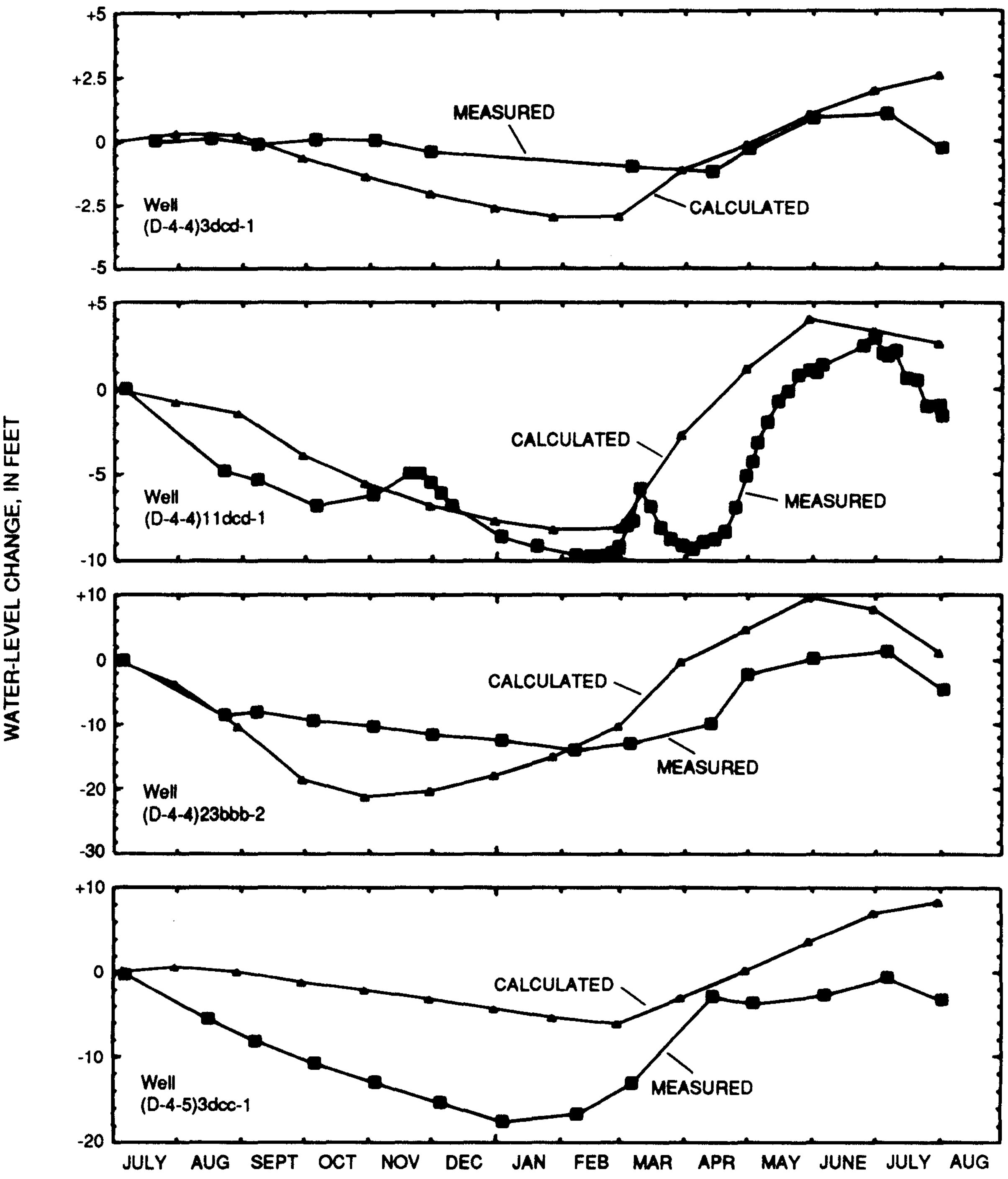


Figure 23.--Measured and model-calculated water-level changes for the 1988-89 monthly transient-state simulation--Continued.

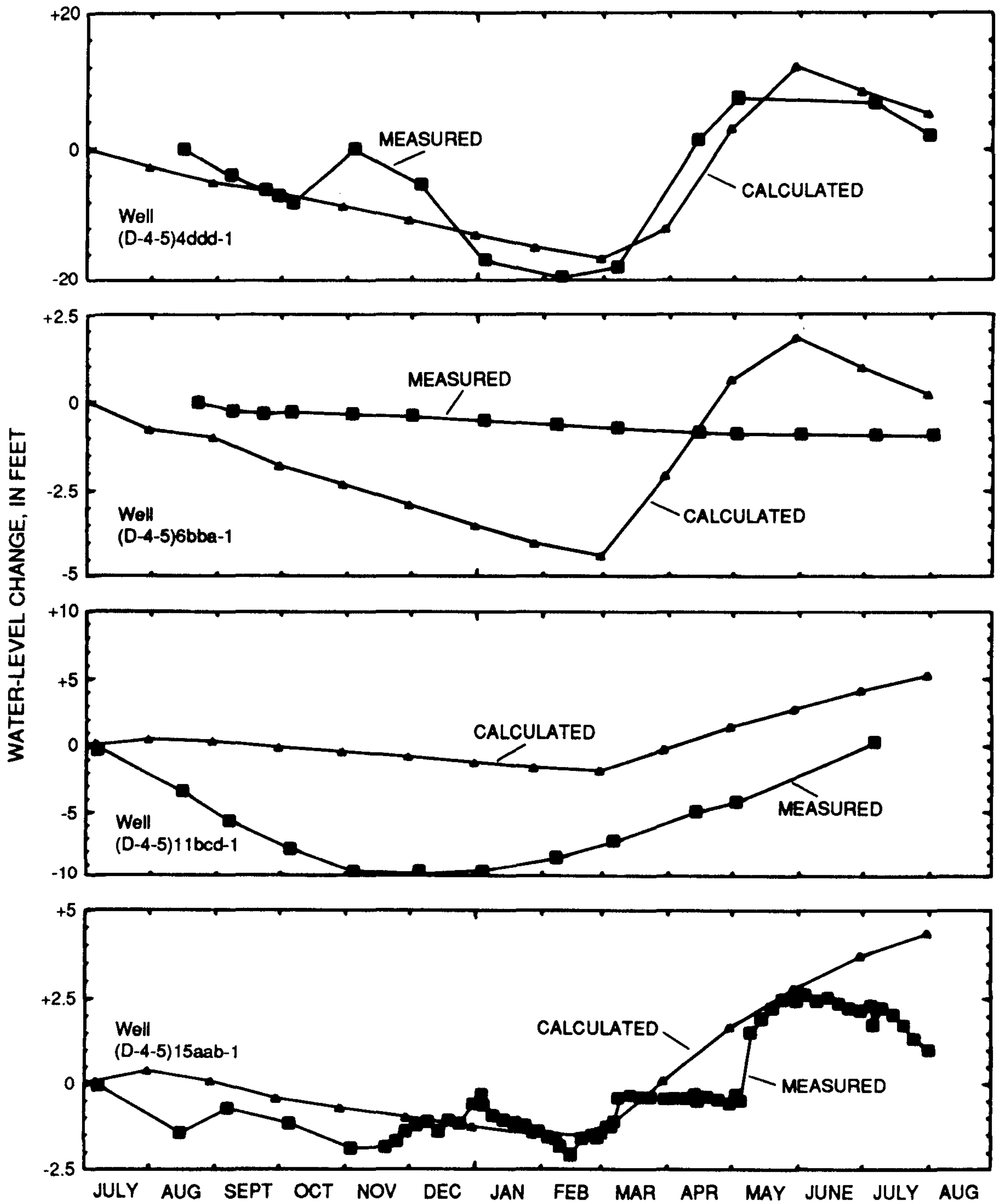


Figure 23.--Measured and model-calculated water-level changes for the 1988-89 monthly transient-state simulation--Continued.

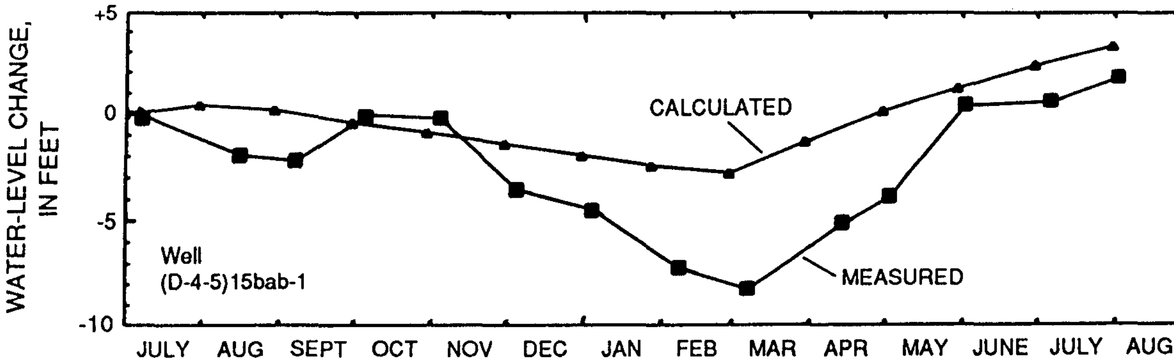


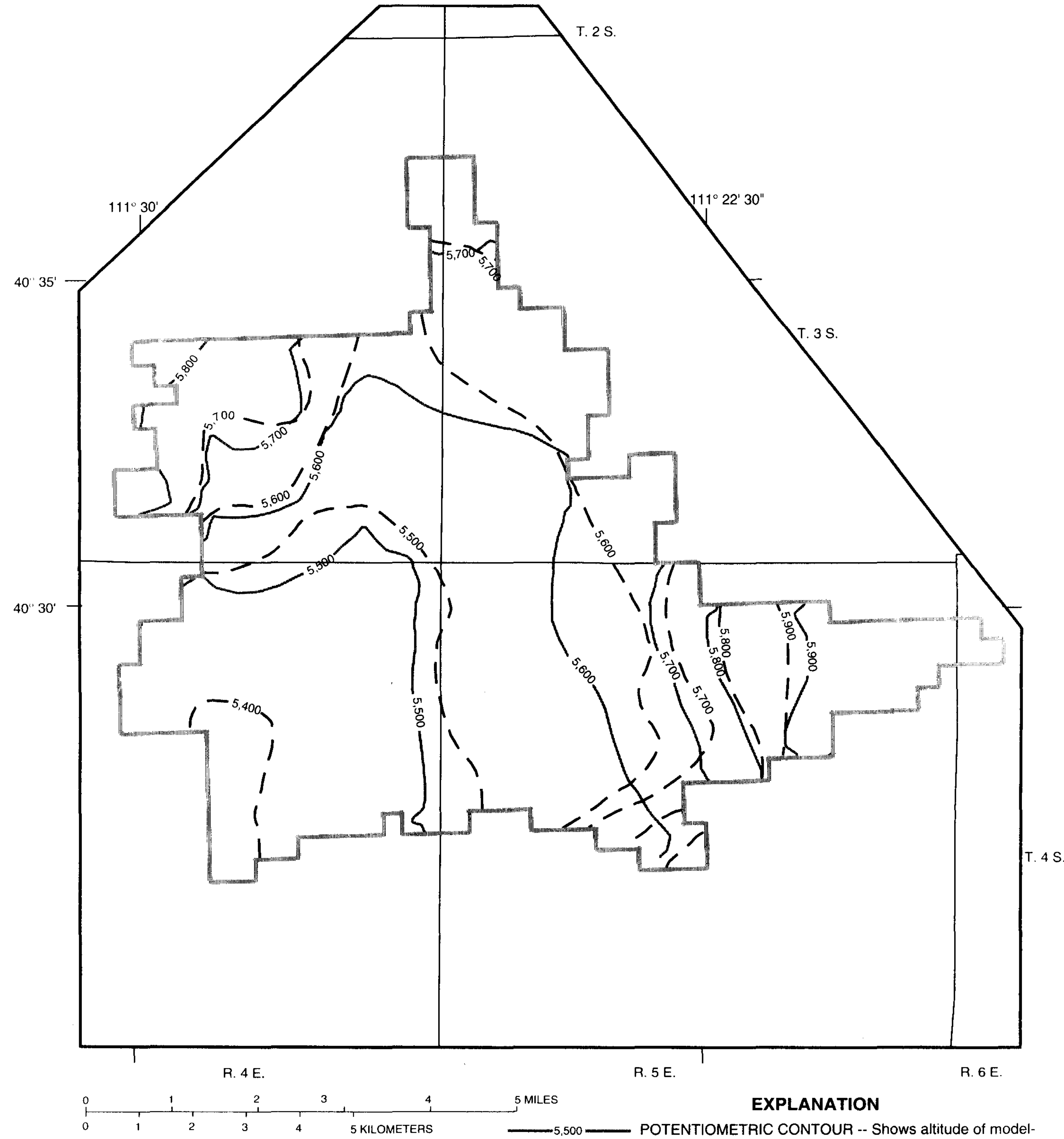
Figure 23.--Measured and model-calculated water-level changes for the 1988-89 monthly transient-state simulation--Continued.

place. This decrease in recharge also is accompanied by a decrease in discharge of 21 cubic feet per second (table 5). Discharge by evapotranspration is decreased by 2, leakage to Deer Creek Reservoir by 7, seepage to the Provo River by 6, and discharge to springs and seeps by 6 cubic feet per second. Thus, 10 percent of the decrease in discharge was evapotranspiration, 33 percent in leakage to Deer Creek Reservoir, 29 percent in seepage to the Provo River, and 29 percent in discharge to springs and seeps.

Future decreases in ground-water recharge caused by changes in irrigation practices or less-than-normal precipitation can be expected to cause similar decreases in ground-water discharge. Decreases in recharge to the ground-water system resulting from conversion from flood- to sprinkler-irrigation methods will be offset to some extent by the potential for increased surface-water flows in the Provo River. Thus, the overall effect of converting to sprinkler irrigation is a decrease in ground-water recharge and an increase in surface-water flows.

Limitations of model

This model is based on a simplified set of assumptions about the hydrologic system in Heber Valley. Many of the hydrologic properties of the unconsolidated valley-fill deposits are not accurately known. These properties include horizontal and vertical hydraulic conductivity, transmissivity, evapotranspiration rates, specific yield, and storage coefficient of the unconsolidated valley-fill deposits. Because the model simulated a limited range of recharge and discharge values, any simulations outside these ranges must be performed with caution. Prolonged periods of drought, wet periods, or large ground-water withdrawals were not simulated; therefore, model simulation of such conditions may be in error. Also, the model is non-unique because many different combinations of data entered into the model may yield the same results. However, this model can be used as a tool to better understand interactions between the surface- and ground-water systems.



EXPLANATION

5,500 POTENTIOMETRIC CONTOUR -- Shows altitude of model-calculated 1989 steady-state potentiometric surface. Contour interval 100 feet. National Geodetic Vertical Datum of 1929

5,900 POTENTIOMETRIC CONTOUR -- Shows altitude at which water level would have stood in tightly cased wells, April and May 1989. Contour interval 100 feet. National Geodetic Vertical Datum of 1929. Reproduced from plate 1

EXTENT OF ACTIVE CELLS IN LAYER 1 -- No-flow boundary

Figure 24.--Potentiometric surface in April and May of 1989 and simulated 1989 steady-state potentiometric surface.

Monthly water-level data for 10 wells were used for calibration in the 1949-50 transient simulation, and monthly water-level data for 18 wells were used in the 1988-89 transient simulation. Water-level data are limited in the Midway area and calculated water levels might not accurately represent actual water levels in areas distant from the data points used in the calibration.

Several areas in Heber Valley have steep hydraulic gradients and caution needs to be used when simulating these areas. (See section on ground-water movement.) The largest areas are in the higher altitude areas of Lake, Center, and Daniels Creeks. The model-calculated water levels in these areas are not as reliable as those in areas where hydraulic gradients are less steep. Also, if large decreases in recharge are simulated for these areas, the simulated saturated thickness in layer 1 might decrease to zero and cause instability in the model.

One monthly stress period is required by the model to let the storage terms approach equilibrium. By adding one additional stress period to a simulation before the time of interest, the model will have the time to equilibrate.

To improve the reliability of the Heber Valley model, water levels in observation wells need to be monitored on at least an annual basis. If changes in recharge are anticipated, monthly measurements of water levels and discharge to springs and streams need to be made. Aquifer tests need to be conducted to improve the estimate of hydraulic properties. With this additional information, changes in water levels and discharge to springs and streams due to changes in recharge could be used to update the model.

Data are not available to develop a ground-water model in Round Valley. Information on diversions for irrigation, leakage from streams, hydraulic properties of the aquifers, and long-term water levels is needed to develop a model.

SUMMARY AND CONCLUSIONS

An investigation of the hydrologic system in Heber and Round Valleys was conducted to improve current understanding of the ground-system and the possible effects of changes in recharge. Unconsolidated valley-fill deposits underlie most of Heber and Round Valleys and were the primary focus of the study.

Surface water in Heber and Round Valleys primarily originates from streamflow entering the valleys from the surrounding mountains. Some streams originate in the lower altitude areas of the valleys from springs, seeps, and drains, or on the margins of the valleys from springs that discharge primarily from consolidated rocks. About 107 cubic feet per second of water is diverted from the Provo River and major tributaries in the higher altitude areas of Heber Valley and used to irrigate about 15,000 acres. About 52 cubic feet per second of water from springs, seeps, and drains in the lower altitude areas of Heber Valley is used to irrigate about 2,400 additional acres.

Concentrations of dissolved-solids in surface water generally are less than 500 milligrams per liter, with the exception of Snake Creek below Midway, where concentrations may exceed 500 milligrams per liter. Increases in dissolved-solids concentrations in the Provo River near Charleston primarily are due to the inflow of water from Snake Creek, which receives some of its flow from a series of mineralized thermal springs in the area of Midway.

Ground water in the study area occurs in both consolidated rocks and unconsolidated valley-fill deposits. Estimated recharge for the unconsolidated valley-fill deposits is 154 cubic feet per second in Heber Valley and 11 cubic feet per second in Round Valley. Recharge primarily is from unconsumed irrigation water. Previous studies estimated recharge from subsurface inflow from consolidated rocks in Heber Valley to be about 35 percent of the total recharge. A more detailed analysis of recharge made during this study, however, indicates that estimated recharge from consolidated rocks is only 16 percent of the total recharge.

Ground water in Heber Valley generally moves toward and discharges to Deer Creek Reservoir, the Provo River, or springs and seeps. Total discharge is estimated to be 154 cubic feet per second. Ground water in Round Valley generally moves toward Deer Creek Reservoir but primarily discharge is to springs and seeps in the lower altitude areas of the valley. Discharge to wells in both Heber and Round Valleys is small.

Water levels in Heber Valley fluctuate from changes in recharge and, near Deer Creek Reservoir, from changes in the altitude of the water surface in Deer Creek Reservoir. Water levels in wells generally are highest in the summer months, when recharge from irrigation is at a maximum, and are lowest in the winter months when irrigation is absent and recharge is at a minimum.

The ground water in the study area generally has dissolved-solids concentrations of less than 500 milligrams per liter, but dissolved-solids concentrations exceeded 500 milligrams per liter in some samples from a small area near Midway. Ground-water samples of water discharging from springs directly into Deer Creek Reservoir did not contain large concentrations of nitrogen and phosphorus.

A digital-computer model was developed to simulate the hydrologic system in Heber Valley. Data from numerous sources were compiled and used to estimate recharge in the model. Additional data were collected as part of the study to aid in the calibration of the model. Hydrologic properties were varied during the calibration to give the best fit to measured water levels and to the quantity of water moving in and out of the aquifer during simulations. The model is capable of simulating changes in recharge and the effects of the changes on water levels and discharge by evapotranspiration, leakage to Deer Creek Reservoir, seepage to the Provo River, and discharge to springs and seeps. Comparison of 1950 and 1989 steady-state model-calculated water budgets indicates that a decrease in recharge will have the greatest effect on discharge as leakage to Deer Creek Reservoir, with lesser effects on seepage to the Provo River and discharge to springs and seeps. Only a small decrease in discharge by evapotranspiration will occur.

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Table 6.--*Records of selected wells*

Location: See explanation of the numbering system for hydrologic-data sites on p. 4.
Owner or user: Refers to last known owner or user.
Casing: Diameter: reported from driller's log or measured in the field. Finish: P, perforated; O, open end; S, screened.
Upper and lower limits of perforations or screen given in feet below the land surface.
Altitude of land surface is given in feet above sea level.
Water levels are given in feet and decimal fractions. Letters appearing after measurements: R, reported.
Other data available: C, chemical analysis (table 10); W, water-level measurements (table 9); L, driller's log (table 7).
--: Indicates no data available.

Location	Owner or user	Year drilled	Casing Diameter (inches)	Casing Depth (feet)	Casing Finish (feet)	Altitude of land surface	Water level Above (+) or below land surface	Water level Date	Other data available
(D-3-4)13daa-1	Utah Department of Transportation	--	4	9	P 0- 9	5,700	4.01	04-11-89	
13ddc-1	Hult, D. Ray	1971	5	220	P100-(?)	5,720	104.15	04-11-89	
23daa-1	Proctor, Michael	1978	8	150	P100-150	5,755	145.96	04-11-89	C
24abd-1	Wilson, Mark	--	6	--	--	5,670	80.61	04-11-89	W
24aca-1	Wilson, Mark	1980	6	92	P 75- 92	5,660	58.35	04-11-89	W
24acc-1	Wilson, Emer	1963	8	90	P 60- 90	5,630	42.52	04-11-89	
26aaa-1	Remund, J.G. & G.	1988	6	155	P120-155	5,660	70.50	04-11-89	
26bac-1	Clegg, Steven R.	--	--	--	--	5,790	75.40	04-12-89	
26dba-1	Kohler, Leroy	1934	48	50	0 --	5,580	16.72	04-11-89	W,C
26ddb-1	--	--	6	--	--	5,565	17.99	04-11-89	
27acb-1	Huber, Joe Dean	1981	6	180	--	5,710	1.05	04-12-89	
33aad-1	Nelson, Jim	1980	6	140	--	5,800	47.10	04-13-89	C
34bdd-1	Morrison, Rick	1978	6	57	--	5,595	11.89	04-12-89	
35bba-1	Utah Geological and Mineral Survey	1978	1	279	[1]0 --	5,640	--	00-01-78	L
35dab-1	Neerings, Abraham	1960	6	94	--	5,530	58.00R	01-01-60	C
35ddd-1	Gobel	--	--	--	--	5,530	66.95	04-13-89	
36bab-1	Provost, Thomas	1979	6	80	P 20- 70	5,560	16.00	02-08-79	
36bab-2	Provost, Laren	1978	6	--	--	5,555	10.75	04-12-89	
(D-3-5) 6bab-2	Jordan RV Park	1958	4	160	P110-155	5,870	10.30	04-11-89	C
6bac-1	Bureau of Reclamation	1984	1	11	--	5,854	3.74	04-11-89	
6bac-2	Bureau of Reclamation	1984	1	9	--	5,856	3.49	04-11-89	
6bdb-1	Bureau of Reclamation	1984	2	12	--	5,846	8.91	04-11-89	
6bdc-1	Jordan, William Cliff	1959	6	35	--	5,860	--	--	
6cac-1	Bureau of Reclamation	1984	1	10	--	5,833	7.10	04-11-89	
6cdb-1	Bureau of Reclamation	1984	1	10	--	5,823	4.36	04-11-89	
7baa-1	Bureau of Reclamation	1984	1	15	--	5,803	3.14	04-11-89	
7bab-1	Bureau of Reclamation	1984	2	8	--	5,798	1.75	04-11-89	
7bdd-1	Best, Susan Anne	--	6	--	--	5,840	30.00	11-01-88	
7cdb-1	Heber City Corp.	1940	4	88	P 78- 88	5,759	4.74	04-10-89	W
7cdb-2	Givens, G. and S.	1972	8	120	P100-120	5,759	9.00	11-24-72	
18baa-1	Probst, Lee	--	--	--	--	5,755	14.26	04-11-89	
18cba-1	L.D.S. Church	1973	6	140	P120-140	5,700	17.70	04-11-89	W
18dbb-1	Baum, Isaac	1952	6	36	P 26- 36	5,717	14.28	04-13-89	
18dbb-2	Baum, Bill	--	--	--	--	5,840	97.10	04-13-89	
18dcc-1	Smith, Hugh	1979	8	243	P143-149 P222-235	5,695	98.62	04-12-89	W,L
18ddb-1	Anderson, Robert E.	1985	6	200	P160-200	5,690	97.10	04-13-89	
19aba-1	Pace, G.M.	--	--	--	--	5,690	28.50R	05-03-50	W
19aba-2	Moulton, John B.	1961	6	176	P 60-176	5,710	5.00	07-21-61	
19aba-3	Wyatt, Paul and Clea	1973	6	127	P 90-118	5,700	66.21	04-12-89	
19abb-1	--	1955	6	83	0 --	5,690	43.00	04-01-55	
19abb-2	Webb, Floyd	--	--	--	--	5,695	31.35	04-12-89	
19adc-1	--	--	--	--	--	5,660	25.67	04-13-89	
19add-1	MacEwan, A.D.	1961	6	80	--	5,680	30.00R	07-01-61	C
19bdd-1	Cummings, M.C.	1970	6	30	--	5,654	10.11	04-12-89	
19cbb-1	Sorensen, Don D.	--	6	--	--	5,650	11.63	04-12-89	W
20cbd-1	Winkler, James	1986	8 6	174 300	P280-295	5,700	35.77	04-13-89	

Table 6.—*Records of selected wells*—Continued

Location	Owner or user	Year drilled	Casing: Diameter (inches)	Casing: Depth (feet)	Finish (feet)	Altitude of land surface	Water level: Above (+) or below land surface	Water level: Date	Other data available
(D-3-5)20ccb-1	Winkler, J.W. & B.J.	1918	36	36					
			8	300	—	5,640	--	--	
29bdb-1	Fitzgerald C.	1957	6	52	—	5,630	10.00	05-01-57	
29bdb-2	Olsen, G. Jed	1985	8	112	—	5,630	16.35	04-13-89	
29bdc-1	Keeling, Thomas	1948	6	48	—	5,625	12.00	09-29-48	
29cac-1	North, Leslie A.	--	--	--	—	5,608	9.96	04-12-89	W
29cdb-1	Suburban Propane	1962	6	75	0 —		5,590		20.00
10-11-62									
29cdb-2	Heber Christian Fellowship	--	--	--	—	5,580	9.73	04-13-89	
29cdc-1	Snider, Jerry	--	--	--	—	5,595	53.43	04-13-89	
30bcc-1	U.S. Geological Survey	1988	2	6	S 3- 6	5,594	2.70	04-12-89	W,C
31dcd-1	Witt	--	--	12	—	5,557	6.62R	05-03-50	W
32bba-1	Price, Vernon	1950	6	80	P 60- 71	5,580	14.94	04-13-89	
32bbb-1	Buell, Wayne & Kathy	1982	6	120	—	5,570	8.68	04-14-89	
32dcd-1	Watson	--	--	--	—	5,636	10.25R	05-03-50	W
33cdd-1	--	--	6	--	—	5,720	96.97	04-21-89	
(D-4-4) 1bdd-1	Wascher, Vernon	1977	6	104	—	5,500	10.87	04-25-89	
1dcc-1	Harding, John	--	8	--	—	5,518	36.83	04-14-89	
1ddc-1	Shmittel	1974	6	101	—	5,535	36.60	04-14-89	L
3ada-1	Kohler, Alvin	1983	6	150	—	5,490	56.87	04-12-89	W,C
3bbc-1	Floor, Manny	1976	6	166	—	5,645	125.78	07-20-88	
3ccd-1	Toronto, Al	1987	6	140	—	5,540	62.39	04-15-89	
3dcd-1	Pride Lane Farm	--	6	--	—	5,475	13.69	04-13-89	W
10acc-1	Durtschi, Frederick	1934	--	--	—	5,450	5.84	07-21-88	
10daa-1	U.S. Geological Survey	1988	2	65	S 57- 62	²5,430.17	3.44	04-13-89	W,C
10daa-2	U.S. Geological Survey	1988	2	15	S 10- 12.5	5,430	3.23	04-13-89	W,C
11dcd-1	Winterton, Sharron J.	1914	30	--	—	5,470	22.38	04-13-89	W
12aaa-1	Greenwood, Perry	1905	30	65	—	5,555	15.05	07-20-88	
12bad-1	--	--	6	--	—	5,522	24.52	04-19-89	
12dcc-1	Heber Valley Special Services District	--	6	--	—	5,535	66.30	04-14-89	W
13ada-1	Carlile, Milton	1977	6	169	—	5,605	118.55	04-14-89	C
13cba-1	Anderson, Ivan	1961	8	100	—	5,540	--	--	C
13cba-2	Anderson, Jack B.	1964	6	110	P 70-110	5,530	61.39	04-14-89	
13cbb-1	Webb	1895	36	90	—	5,530	49.00R	05-03-50	W
14bab-1	Edwards, Norman	--	36	11	—	5,445	10.80	04-13-89	
14bbc-1	Edwards, Elmer	1899	48	18		5,426	10.66R	10-02-50	
14ccd-1	Probst, Calvin	--	30	--	—	5,445	29.90	04-13-89	
15daa-1	Kendrick, V. and E.	--	--	28	—	5,430	8.85	07-05-88	W
15ddd-1	U.S. Geological Survey	1988	1	79	S 67- 77	5,420	8.02	04-13-89	W
15ddd-2	U.S. Geological Survey	1988	1	30	S 18- 28	²5,420.46	11.30	04-13-89	W
23aab-1	Binggeli, Joe	1972	12	170	P100-130				
					P160-170	5,500	35.00R	06-02-72	L
23bbb-2	Lewis, Shirley	1905	36	25	—	5,426	19.29	04-13-89	W
23bbc-1	Wright, J.E.	1906	48	23	—	5,425	10.46R	05-03-50	
(D-4-5) 1cac-1	Crook, Curtis F.	--	--	--	—	6,100	8.20	04-20-89	
1cad-1	Lynch, Leo	1987	6	125	P 80-125	6,110	173.25	04-20-89	
1ddb-1	Allsop, Dale A.	1979	6	270	P240-270	6,165	214.16	04-14-89	
1ddd-1	Atkinson, Alvin	1964	6	600	—	6,210	264.42	04-24-89	
2acb-1	Titcomb, John	1966	6	180	P 85-180	6,080	43.89	04-24-89	C
2ccc-1	Allison	1890	--	--	—	5,930	23.53	04-20-89	W
2daa-1	Wall, Russel	--	--	--	—	6,090	158.40	04-24-89	
3cbc-1	Christensen, C.J.	1982	6	60	P 50- 60	5,800	15.39	04-20-87	
3dcc-1	Federal Land Bank	1975	6	75	P 60- 75	5,880	19.45	04-14-89	W
3ddd-1	Bauer, G. & S.	1981	6	80	P 60- 80	5,920	22.06	04-20-89	
4acc-1	Valley Bank	1900	--	--	—	5,750	11.75	07-07-88	

Table 6.—*Records of selected wells*—Continued

Location	Owner or user	Year drilled	Casing Diameter (inches)	Casing Depth (feet)	Casing Finish (feet)	Altitude of land surface	Water level Above (+) or below land surface	Water level Date	Other data available
(D-4-5) 4bcc-1	Giles, Calvin	--	6	135	--	5,690	117.14	04-21-89	
4ccb-1	Giles Dan & Rosemary	1978	6	217	P150-205	5,700	151.05	04-21-89	L
4ddd-1	Mair, Tressa McDonald	--	48	52	--	5,798	23.24	04-14-89	W
4ddd-3	Street, Michael	1988	--	--	--	5,785	80.95	04-21-89	
5abb-1	City of Heber	1979	12	494	P128-136 P142-343	5,640	90.00R	05-07-79	L
5ccc-1	Rozzelle, Joe	1952	6	135	0 --	5,630	60.00R	12-01-52	C
6bba-1	Bureau of Reclamation	1961	1	11	--	5,526	2.04	04-14-89	W
6bcc-1	Haytt, Robert	1986	6	121	--	5,535	36.63	04-14-89	
6ccc-1	Nelson, Jennie	1900	--	--	--	5,555	--	--	
7aac-1	Clegg, Ferris	1955	6	152	0 --	5,630	112.00R	01-01-55	C
7acb-1	Breeden, Robert	1971	6	116	--	5,615	96.73	04-19-89	
7ada-1	Simpson, Jay	1961	6	158	0 --	5,560	110.00R	09-01-61	C
7bbb-1	Godfrey, Randy	1974	8	122	P100-121	5,555	52.51	04-14-89	
7cad-1	Heber City Corp.	1949	6	--	--	5,640	85.00	07-28-49	
7daa-1	Sulser, Lynn	1985	6	160	P140-160	5,665	148.73	04-24-89	C
7dab-1	Wall, Joan L.	1983	--	--	--	5,650	132.47	04-14-89	
7dbd-1	--	1984	6	140	P120-140	5,635	112.30	04-25-89	
8bbb-1	Baird	1884	36	142	--	5,636	110.70R	05-03-50	W
8bbc-1	Holloway, Darlene	1972	10	220	P200-210	5,650	127.94	04-24-89	
8cbc-1	Foy, Enid	--	--	--	--	5,670	155.49	04-24-89	
8dda-1	Cummings, W.R.	1982	6	260	P220-260	5,740	204.93	04-24-87	
8ddc-1	Hainsworth, T.A.	1971	6	--	--	5,754	210.00	06-01-71	
9baa-1	Snow	--	--	--	--	5,740	142.30	04-21-89	
9bcc-1	George, Charlene	1977	8	275	P245-255	5,715	190.52	04-21-89	C
9bda-1	Hansen, Steven L.	1985	6	160	P120-160	5,740	83.60	04-21-89	
9ccc-1	Heber Utah East Stake	1976	8	483	P257-280 P376-475	5,768	192.00	06-19-76	
9daa-1	Burningham, Jay	--	--	--	--	5,810	110.50	04-21-89	
10baa-2	--	1961	6	74	--	5,855	19.77	04-20-89	C
10bbc-1	Hardman, Kay	--	6	80	--	5,810	24.65	04-20-89	
11aaa-1	Fosgate, Jim	--	--	--	--	6,040	37.89	04-20-89	C
11abd-1	Allen, Robert	1961	6	590	P301-590	6,015	220.00R	12-24-61	L
11bcd-1	West, John M.	1986	6	123	P 0-20	5,930	15.40	04-14-89	W
11cbc-1	Sweat, Otis	--	--	--	--	5,930	9.22	04-20-89	
14aac-1	Dansie, Charles	1964	6	104	P 40-100	6,020	11.19	04-14-89	W,C
14baa-1	Jeffs, Hal	1986	6	100	P 80-100	5,980	13.64	04-20-89	
14bbb-1	Applegate, Danny R.	--	--	--	--	5,935	10.90	04-20-89	C
14bda-1	Ryan, Lowell	1975	8	65	P 60-65	6,020	12.53	04-20-89	
15aab-1	Sweat, Doyle	1969	6	150	--	5,900	18.61	04-14-89	W
15abb-1	Sweat, Kevin	--	6	175	--	5,880	144.89	04-24-89	
15bab-1	Sweat, Theon	1961	6	164	--	5,850	132.37	04-14-89	W
15bbb-1	Thacker, Larry J.	1987	8	265	P223-229	5,820	140.72	04-24-89	C
16baa-1	Lowell, Hillyard	1980	--	--	--	5,790	208.70	04-24-89	
16bbb-2	Renz, Willis D.	1980	6	285	P265-285	5,768	242.66	04-24-89	
16bca-1	Knight, Tony	1978	6	400	P100-400	5,810	276.56	04-25-89	C
16bcc-1	Webb, William H.	1972	6	284	P268-284	5,805	201.00R	11-14-72	L
16ccd-1	Webster, Blaine	1974	8	150	P145-150	5,850	94.55	04-14-89	W
17bcb-2	Lemely, Lloyd	1989	--	--	--	5,710	--	--	C
17bcd-1	Taylor, Shirley	1977	6	273	--	5,740	220.00	04-15-77	
17bcd-2	Taylor, Bliss	1977	6	325	--	5,730	222.60	04-25-89	
17caa-1	Tack, Dennis	--	--	--	--	5,775	259.45	04-25-89	
17cda-1	Watson, O. & E.	1973	6	291	P285-290	5,780	240.27	04-25-89	
17daa-1	Cherry, Ed	--	--	--	--	5,810	217.30	04-24-89	
17dda-1	McLean, Michael	--	--	--	--	5,840	60.23	04-24-89	C
18bbc-1	Smith, Earl	1960	6	190	P150-162 P172-186	5,603	109.00	01-01-60	
18ccc-1	Sullivan, Michael	1976	8	200	P168-200	5,620	145.60	04-14-89	C
21adb-1	Calister, Larry	1981	6	160	--	5,930	28.27	04-25-89	C
21bbb-2	Willis, Kathy	1984	6	120	P 80-120	5,850	82.25	04-25-89	

Table 6.—*Records of selected wells*—Continued

Location	Owner or user	Year drilled	Casing: Diameter (inches)	Casing: Depth (feet)	Casing: Finish (feet)	Altitude of land surface	Water level: Above (+) or below land surface	Water level: Date	Other data available
(D-5-4) 1bcb-1	Ivory & Co.	--	--	--	--	5,560	25.34	04-10-89	W
2cca-1	Dudley, Nick	1972	8	90	--	5,470	23.47	04-10-89	W
2cda-1	Ripple, R.W.	1974	6	150	--	5,490	20.00R	06-01-74	L
2cdc-1	K and C Partnership	--	--	--	--	5,490	--	--	C
2dcb-1	Ripple, Paul	1971	6	100	P 87- 95	5,525	18.00	03-01-71	
3ddd-1	Ford, Neil A.	1971	6	92	--	5,440	3.11	05-01-89	
12abd-1	Mecham, Dazel	1980	6	100	P 80-100	5,560	+10.40	08-01-89	C
12baa-1	Mecham, Harvey	1974	6	102	P 98-102	5,540	4.53	04-10-89	W
12bab-1	Carlson, Paul	1977	8	113	--	5,550	24.00	05-05-77	
12cad-1	Finch, Doug	--	6	100	0 --	[2]5,540.29	2.68	04-10-89	W,C
12cad-2	U.S. Geological Survey	1988	2	10	S 5.75-8.25	5,540	2.10	04-10-89	W,C
13adc-1	Roundy, Bert	1966	6	126	P 70-123	5,620	22.15	05-01-89	C
24baa-1	Soutwich, Glen W.	1972	8	435	--	6,110	410.00R	02-05-72	L
(D-5-5)17aca-1	--	--	--	--	--	5,975	--	--	C
17adc-1	Kinsey, Elaine	1978	6	200	P140-142 190-200	5,950	+1.01	05-01-89	
17cda-3	Richins, C. Grant	--	--	--	--	5,790	66.00	05-01-89	
18aba-1	Larsen, Roy	1978	6	110	P100-110	5,725	81.08	04-10-89	W
18dcb-1	Mecham, Dee	1903	--	--	--	5,680	8.25	04-10-89	W
19aac-1	O'Driscoll, Rob	1986	6	190	--	5,740	14.15	05-01-89	C,L
19bca-1	Fulmer	1979	6	60	P 50-60	5,760	31.16	05-01-89	C
20aad-1	Brimhall, Leon H.	1976	6	110	P100-110	5,960	40.15	04-27-89	
20abb-1	Kountz	--	--	--	--	5,810	39.31	05-01-89	C
20adb-1	Petri, Michael	1969	6	141	--	5,890	30.00	07-02-69	
20add-3	Ellis, Sarah & Ron	1988	6	158	--	5,900	60.05	04-27-89	C
20add-4	Petri, Michael	1982	6 6.8	545 1040	P350-545 --	5,920	47.60	04-27-89	
20cab-1	Park, Robert C.	1973	6	150	P144-149	5,815	8.77	04-27-89	
20cad-1	Bigney	1975	6	81	--	5,850	10.77	04-10-89	W
20dca-1	--	--	--	--	--	5,890	33.97	04-27-89	
21aca-1	Harrison, Pedro	1986	6	200	P120-140 P180-200	6,260	101.60	05-01-89	C
21bdc-1	Thatcher, Peggy	1976	6	200	P180-200	6,065	7.82	05-01-89	
21ccd-1	Mecham, Rose	1975	6	142	P120-140	5,960	29.87	04-10-89	W,L
28dcd-1	Young, John	1958	36	24	--	6,160	17.95	04-27-89	
29acb-1	--	--	6	--	--	5,940	37.48	04-26-89	
33abd-1	--	--	--	--	--	6,190	--	--	C

[1] Open-end tubing was capped for temperature gradient study.

[2] Altitudes reported to the nearest 0.01 foot are not necessarily true altitudes. These altitudes represent the difference in land surface between two wells that are located next to each other.

Table 7.—*Drillers' logs of selected wells*

Location: See explanation of the numbering system for hydrologic-data sites on p. 4.
Altitude: Altitude (Alt.) of land surface in feet above sea level.
Thickness: In feet.
Depth: Depth to bottom of interval in feet below land surface.

Material	Thickness	Depth
(D-3-4)35bba-1. Log by James F. Kohler Alt. 5,640.		
(0 to 5 feet not reported)		
Tufa, white-light tan. . .	55	60
Clay with sand	10	70
Clay, light green-gray . .	10	80
Silt, very fine with clay, yellow-brown, light gray.	5	85
Sand with gravel	25	110
Sand with minor gravel . .	5	115
Clay, dark-gray.	10	125
Sand with minor gravel . .	10	135
Clay with some sand and gravel.	5	140
Sand and gravel, angular and poorly sorted	5	145
Silt with minor sand, gravel, and clay.	10	155
Gravel with minor silt . .	5	160
Sand (major) and gravel with minor silt and clay.	15	175
Sand with small gravel . .	20	195
Clay, light-tan.	5	200
Sand and gravel; may contain tufa fragments. .	15	215
Clay	3	218
Quartzite, light-tan; hot artesian water.	27	245
Limestone fragments. . . .	5	250
Quartzite, highly fractured	30	280
(D-3-5)18dcc-1. Log by W.R. Bacon and Son Drilling Co. Alt. 5,695.		
Topsoil with clay.	4	4
Clay	14	18
Clay and cobbles, gray . .	2	20
Sand and boulders; surface water at 40 feet	40	60
Silt and sand, gray. . . .	20	80
Clay, gray	10	90
Sand, brown.	20	110
(D-3-5)18dcc-1 --Continued		
Clay and light layers of sand.	5	115
Clay, red	25	140
Clay and sandstone; water at 149'	9	149
Clay, red	61	210
Clay and gravel, red. . . .	9	219
Sand and gravel; some water	3	222
Clay and gravel; no water .	13	235
Gravel, fused hard rock . .	18	253
(D-4-4) 1ddc-1. Log by Intermountain Drilling Co. Alt. 5,535.		
Topsoil	5	5
Clay.	5	10
Clay and silt	4	14
Clay.	2	16
Boulders.	18	34
Cobbles	7	41
Gravel, sand, and silt. . .	6	47
Gravel and sand	6	53
Boulders.	3	56
Boulders and cobbles. . . .	3	59
Gravel.	3	62
Gravel and silt	13	75
Gravel, sand, and silt. . .	16	91
Cobbles	7	98
Hardpan	3	101
(D-4-4)23aab-1. Log by J.G. Lee Drilling Co., Inc. Alt. 5,500.		
Gravel and clay	10	10
Boulders.	32	42
Gravel and sand	2	44
Clay, brown	7	51
Gravel; water	3	54
Boulders and clay	4	58
Gravel; water	4	62
Gravel and clay; water. . .	16	78
Clay, brown	14	92
Gravel; water.	38	130

Table 7.—*Drillers' logs of selected wells*—Continued

Material	Thickness	Depth
(D-4-4)23aab-1 --Continued		
Clay	30	160
Bedrock	10	170
(D-4-5) 4ccb-1. Log by Wasatch Drilling. Alt. 5,700.		
Topsoil	2	2
Gravel, cobbles, boulders	24	26
Sand and gravel	57	83
Sand	11	94
Clay	22	116
Gravel and cobbles	9	125
Sand and gravel; some water at 150 feet	55	180
Gravel and cobbles; some water	15	195
Sand and gravel; some water	25	220
(D-4-5) 5abb-1. Log by Clearwater Drilling. Alt. 5,640.		
Topsoil	2	2
Gravel, sand, and clay	54	56
Sand and gravel	18	74
Clay and gravel	54	128
Gravel	8	136
Sand and gravel	6	142
Clay and gravel	199	341
Gravel	2	343
Clay, yellow	25	368
Sand, red	2	370
Boulders	5	375
Bedrock, red sandstone; water in fractured areas	119	494
(D-4-5)11abd-1. Log by J.G. Lee Drilling Co. Alt. 6,015.		
Boulders and clay	80	80
Shale, red	8	88
Sandstone	7	95
Conglomerate	30	125
Shale, red	45	170
Shale, green	40	210
Shale, red	17	227
Sandstone	8	235
(D-4-5)11abd-1 --Continued		
Shale, green	40	275
Shale, red	26	301
Sandstone	4	305
Shale, green	10	315
Shale, red	7	322
Limestone	10	332
Shale, green	3	335
Limestone	3	338
Shale, red	34	372
Sandstone	99	471
Shale, gray	21	492
Limestone	47	539
Sandstone, brown	51	590
(D-4-5)16bcc-1. Log by Binning Drilling Co. Alt. 5,805.		
Clay, gravel, cobbles, and boulders	10	10
Gravel and boulders; water at 30 feet	30	40
Clay, cobbles, and boulders	20	60
Clay, gravel, cobbles, and boulders	20	80
Clay and boulders, tan	20	100
Clay, gravel, and boulders	60	160
Clay, gravel, cobbles, and boulders	40	200
Clay, gravel, and cobbles	18	218
Gravel; little water	2	220
Clay, gravel, and boulders	35	255
Clay and gravel; little water	5	260
Conglomerate; water	24	284
(D-5-4) 2cda-1. Log by Petersen Bros. Drilling Co., Inc. Alt. 5,490.		
Silt	20	20
Clay	70	90
Clay and conglomerate	30	120
Bedrock	30	150

Table 7.—*Drillers' logs of selected wells*—Continued

Material	Thickness	Depth
(D-5-4)24baa-1. Log by Eldon Comer. Alt. 6,110.		
Soil and rock	1	1
Clay, tan, and layers of rock	89	90
Clay and layers of rock mixed	80	170
Clay and sand, yellow	123	293
Clay and sand; rock ledges	22	315
Bedrock, lime and quartz; seeps	120	435
(D-5-5)19aac-1. Log by Unzicker and Wells Drilling Co., Inc. Alt. 5,740.		
Topsoil, clay	5	5
Gravel, cobbles, and boulders	135	140
Bedrock, limestone and sandstone layers; water at 211 feet	80	220
(D-5-5)21ccd-1. Log by Petersen Bros. Drilling Co. Alt. 5,960.		
Topsoil	1	1
Gravel and cobbles, brown	19	20
Clay, gravel, and boulders	15	35
Clay and gravel; trace of water	30	65
Bedrock, sandstone	35	100
Bedrock; fractured area with water	23	123
Bedrock, sandstone	7	130
Bedrock; fractured area with water	35	165

Table 8.—*Field measurements of discharge, temperature, and specific conductance at selected surface-water sites*

Location: See explanation of the numbering system for hydrologic-data sites on p. 4; location numbers are listed in approximate downstream order; letter following location number indicates type of site: B, canal or ditch; W, stream.
Discharge: ft³/s, cubic feet per second.
Water temperature: °C, degrees Celsius.
Specific Conductance: µS/cm, microsiemens per centimeter, at 25 degrees Celsius.
--: Indicates no data available.

Location	Date	Discharge (ft³/s)	Water temperature (°C)	Specific conductance (µS/cm)	Site description
(D-3-4)13dda-1B	07-22-88	14.7	24.5	455	River Ditch at head near Midway.
	08-30-88	10.4	12.4	365	
	08-31-88	11.1	13.0	360	
	09-01-88	10.6	12.5	375	
	09-23-88	15.6	--	--	
24aba-1B	08-30-88	10.6	13.1	360	River Ditch near River Road.
	08-31-88	11.2	13.2	370	
	09-01-88	10.2	13.1	365	
24aba-2B	08-31-88	.663	--	--	Diversion from River Ditch.
	09-01-88	1.19	--	--	
24abd-1B	08-30-88	1.21	16.2	340	Diversion from River Ditch.
	08-31-88	1.65	14.6	365	
	09-01-88	[1].10	--	--	
24abc-1B	09-01-88	1.09	13.5	365	Diversion from River Ditch.
23dda-1B	08-30-88	7.92	13.8	360	River Ditch near Dutch Hollow.
	08-31-88	7.97	13.7	365	
	09-01-88	7.30	13.8	365	
23dcd-1B	08-30-88	1.08	14.5	360	Diversion from River Ditch on east side of Burgi Hill.
	08-31-88	1.04	15.0	365	
	09-01-88	.959	14.5	360	
26bdd-1B	08-30-88	5.53	17.4	--	River Ditch south end of Burgi Hill.
	08-31-88	5.17	16.0	380	
	09-01-88	4.41	15.8	380	
26bbc-1B	08-30-88	1.99	--	--	Inflow to River Ditch.
	08-31-88	1.13	19.9	595	
	09-01-88	.823	19.8	--	
26cbb-1B	08-30-88	6.33	--	--	River Ditch just north of Midway.
	08-31-88	5.92	18.7	490	
	09-01-88	5.85	18.8	500	
(D-3-5) 6baa-1B	06-29-88	44.3	20.0	175	Timpanogos Canal at head north of Heber City.
	09-23-88	1.87	--	--	
18bab-1B	06-29-88	84.5	19.0	200	Wasatch Canal at head north of Heber City.
	08-30-88	19.8	12.0	360	
	08-31-88	20.4	--	--	
	09-01-88	19.7	13.0	230	
	09-22-88	33.8	--	--	
18bab-2B	08-31-88	12.8	17.0	--	Rock Creek at head north of Heber City.
	09-01-88	13.3	--	--	
	09-20-88	15.7	9.0	285	
31cdc-1B	07-20-88	18.5	--	--	Sagebrush/Spring Creek Canal west of Heber City.
	09-23-88	13.4	10.5	310	
	12-02-88	2.51	--	--	
	01-05-89	2.12	9.0	410	
	02-10-89	1.74	8.0	400	

Table 8.—*Field measurements of discharge, temperature, and specific conductance at selected surface-water sites*—Continued

Location	Date	Discharge (ft^3/s)	Water temperature (°C)	Specific conductance (µS/cm)	Site description
(D-3-5)31aaa-1B	03-08-89	7.94	10.0	370	Sagebrush/Spring Creek Canal (measurement taken at new location further north on the Sagebrush/ Spring Creek Canal).
	04-10-89	4.56	15.5	390	
	05-03-89	6.70	11.0	390	
	06-06-89	6.97	14.5	410	
	07-07-89	8.27	13.5	395	
	08-02-89	6.45	15.0	420	
(D-4-4)14bba-1B	07-20-88	8.09	--	--	Lower Charleston Canal near Charleston.
	09-23-88	5.64	14.0	460	
	12-02-88	3.73	--	--	
	01-05-89	3.28	7.0	435	
	02-10-89	7.56	6.0	425	
	03-08-89	11.3	9.0	445	
	04-10-89	3.80	15.0	370	
	05-02-89	7.36	13.5	385	
	06-06-89	14.6	13.5	440	
	07-07-89	14.5	13.5	425	
	08-03-89	10.7	18.0	425	
(D-2-5)31cdc-1W	08-30-88	48.4	13.5	370	Provo River below Jordanelle damsite U.S. Bureau of Reclamation station No. 1004.
	08-31-88	51.5	14.0	380	
	09-01-88	50.2	13.5	375	
(D-3-5) 6bbd-1W	08-30-88	6.04	13.7	365	Diversion from Provo River.
	08-31-88	6.25	13.4	370	
	09-01-88	6.01	13.1	370	
6cbb-1W	08-30-88	.199	13.6	330	Inflow to Provo River.
	08-31-88	.065	13.6	330	
	09-01-88	.079	13.4	330	
7bba-1W	08-30-88	50.5	18.0	--	Provo River.
	08-31-88	55.9	15.0	375	
	09-01-88	44.8	15.0	370	
7bca-1W	08-30-88	.538	15.9	335	Inflow to Provo River.
	08-31-88	.509	15.2	330	
	09-01-88	.570	14.0	330	
7cab-1W	08-30-88	1.18	--	--	Diversion from Provo River.
	08-31-88	1.35	14.4	365	
	09-01-88	1.32	13.8	365	
7cdb-1W	08-30-88	11.1	--	--	Diversion from Provo River.
	08-31-88	10.7	14.8	365	
	09-01-88	11.2	14.0	365	
18bbb-1W	08-30-88	13.3	17.8	360	Provo River north of Heber City.
	08-31-88	10.4	16.9	365	
	09-01-88	11.7	15.5	360	
18bbb-2W	08-30-88	11.3	--	--	Provo River.
	08-31-88	11.2	17.9	360	
	09-01-88	11.7	15.5	360	
(D-3-4)13ada-1W	08-30-88	1.55	--	--	Inflow to Provo River.
	08-31-88	1.72	15.6	365	
	09-01-88	1.49	14.2	365	
(D-3-5)18ccb-1W	08-30-88	11.5	--	--	Diversion from Provo River.
	08-31-88	11.1	21.1	350	
	09-01-88	11.6	17.7	355	

Table 8.—*Field measurements of discharge, temperature, and specific conductance at selected surface-water sites*—Continued

Location	Date	Discharge (ft³/s)	Water temperature (°C)	Specific conductance (µS/cm)	Site description
(D-3-5)18ccb-2W	08-30-88	12.9	22.5	350	Provo River at River Road bridge.
	08-31-88	12.9	18.5	--	
	09-01-88	12.4	17.5	365	
(D-3-4)24acd-1W	08-30-88	.839	--	--	Diversion from Provo River.
	08-31-88	.718	24.7	320	
	09-01-88	.530	23.0	325	
24cdd-1W	08-30-88	.086	--	--	Diversion from Provo River.
	08-31-88	.147	21.8	300	
	09-01-88	.170	20.8	315	
24cdd-2W	08-30-88	1.12	24.0	310	Provo River near Berkenshaw Creek.
	08-31-88	1.31	21.5	320	
	09-01-88	1.45	22.0	320	
36bcc-1W	08-30-88	1.07	17.5	860	Inflow to Provo River.
	08-31-88	1.05	17.7	845	
	09-01-88	1.25	17.3	850	
36cbb-1W	08-30-88	4.48	22.1	645	Inflow to Provo River.
	08-31-88	4.67	20.2	645	
	09-01-88	4.87	20.2	670	
36ccb-1W	08-30-88	3.22	18.0	925	Inflow to Provo River.
	09-01-88	3.08	--	--	
36ccd-1W	07-22-88	7.98	20.5	735	Diversion from Provo River at head of Island Ditch.
	08-30-88	10.6	--	--	
	08-31-88	10.5	--	--	
	09-01-88	11.3	--	--	
36ccd-2W	08-30-88	.620	21.5	690	Provo River near head of Island Ditch.
	08-31-88	.877	22.0	700	
	09-01-88	.908	--	700	
(D-4-4) 1bdc-1W	08-30-88	1.18	--	--	Inflow to Provo River.
	08-31-88	1.31	16.5	350	
	09-01-88	2.53	--	--	
1bdc-2W	08-30-88	.222	--	--	Diversion from Provo River.
	08-31-88	.218	--	--	
	09-01-88	.358	--	--	
1cab-1W	08-30-88	1.50	--	--	Groundwater inflow to Provo River.
	08-31-88	1.70	15.5	340	
	09-01-88	1.56	--	--	
1cbd-1W	08-30-88	.620	12.5	520	Groundwater inflow to Provo River.
	08-31-88	.821	12.5	360	
	09-01-88	.841	--	--	
1cca-1W	08-30-88	1.40	15.0	440	Groundwater inflow to Provo River.
	08-31-88	1.64	15.0	355	
	09-01-88	1.64	--	--	
1ccc-1W	08-30-88	4.08	15.0	405	Groundwater inflow to Provo River.
	08-31-88	2.97	15.0	350	
	09-01-88	3.09	--	--	
11aaa-1W	08-30-88	2.59	15.0	365	Groundwater inflow to Provo River.
	08-31-88	2.48	--	--	
	09-01-88	2.62	--	--	

Table 8.—*Field measurements of discharge, temperature, and specific conductance at selected surface-water sites*—Continued

Location	Date	Discharge (ft³/s)	Water temperature (°C)	Specific conductance (µS/cm)	Site description
(D-4-4)11acc-1W	08-30-88	0.374	24.5	545	Groundwater inflow to Provo River.
	08-31-88	.463	20.5	465	
	09-01-88	.318	--	--	
11acc-2W	08-30-88	5.91	19.5	645	Inflow to Provo River.
	08-31-88	2.46	19.5	520	
	09-01-88	1.82	--	--	
11caa-1W	08-31-88	22.0	17.0	390	Provo River above Deer Creek Reservoir U.S. Bureau of Reclamation station No. 1008.
	09-01-88	21.6	18.5	390	
(D-5-5)18acb-1W	07-05-88	3.00	17.5	590	Wallsburg Spring Creek in Wallsburg.
	08-04-88	3.12	13.0	600	
	09-23-88	2.56	11.0	605	
	10-17-88	2.41	11.5	570	
	12-05-88	2.99	10.5	590	
	01-05-89	2.71	11.0	580	
	02-10-89	3.02	10.0	605	
	03-08-89	3.21	11.5	600	
	04-10-89	2.87	11.0	585	
	05-02-89	2.88	11.0	585	
	06-06-89	3.01	11.0	595	
	07-07-89	2.66	11.5	595	
	08-03-89	2.27	11.5	590	
28dcd-1W	05-05-89	.65	13.5	200	Maple Creek in Round Valley.
32aba-1W	05-01-89	.31	--	--	Tributary of the Right Fork of Little Hobble Creek.
32bdc-1W	05-01-89	6.40	9.5	300	Right Fork of Little Hobble Creek.

[1] Estimated

Table 9.--*Water levels in selected wells*

Location: See explanation of the numbering system for hydrologic-data sites on p. 4.
Altitude: Altitude of land surface in feet above sea level.
Water levels are in feet below or above (+) land surface.
Letters appearing after measurements: R, reported.

(D-3-4)24abd-1

Altitude 5,670

Date	Water level	Date	Water level	Date	Water level	Date	Water level
AUG 17, 1988	48.25	NOV 30, 1988	80.55	MAR 06, 1989	80.81	JUN 01, 1989	47.24
SEP 08	59.41	JAN 03, 1989	81.62	APR 11	80.61	JUL 06	51.71
OCT 06	49.34	FEB 07	81.63	MAY 01	50.64	31	64.08

(D-3-4)24aca-1

Altitude 5,660

Date	Water level	Date	Water level	Date	Water level	Date	Water level
JUL 08, 1988	24.90	DEC 05, 1988	57.56	JAN 15, 1989	58.81	MAR 10, 1989	57.23
AUG 17	25.51	10	57.64	20	58.72	APR 11	58.35
SEP 08	36.76	15	57.84	25	58.39	MAY 01	38.00
OCT 06	26.62	20	58.34	31	58.82	JUN 01	24.65
NOV 03	40.55	25	58.52	FEB 05	58.71	02	26.27
19	56.39	31	58.72	08	58.97	JUL 06	29.08
20	56.71	JAN 03, 1989	58.86	28	58.14	31	41.42
25	57.58	05	58.59	MAR 05	57.92		
30	57.75	10	58.60	06	58.04		

(D-3-4)26dba-1

Altitude 5,580

Date	Water level	Date	Water level	Date	Water level	Date	Water level
JUL 08, 1988	12.55	NOV 03, 1988	12.88	MAR 06, 1989	16.50	JUL 06, 1989	12.22
AUG 17	12.83	30	15.19	APR 11	16.72	AUG 02	12.45
SEP 08	12.81	JAN 03, 1989	16.16	MAY 01	13.53		
OCT 06	12.49	FEB 07	17.16	JUN 01	12.33		

(D-3-5) 7cdb-1

Altitude 5,759

Date	Water level	Date	Water level	Date	Water level	Date	Water level
SEP 13, 1966	6.23	JUL 19, 1967	6.19	JUL 16, 1968	5.18	JAN 03, 1989	4.14
OCT 12	12.18	AUG 21	8.84	AUG 13	4.67	FEB 07	4.45
NOV 14	17.44	SEP 28	10.03	SEP 12	6.68	MAR 06	2.71
DEC 15	18.79	OCT 11	19.08	JUL 19, 1988	6.21	APR 10	4.74
JAN 10, 1967	19.63	NOV 09	18.17	AUG 17	6.31	MAY 01	3.47
MAR 20	23.89	FEB 01, 1968	19.93	SEP 08	6.33	JUN 01	3.52
APR 20	20.19	MAR 12	20.69	OCT 06	5.64	JUL 06	5.30
MAY 17	7.48	MAY 08	4.93	NOV 03	4.32	31	6.14
JUN 12	5.55	JUN 06	3.17	30	3.45		

(D-3-5)18cba-1

Altitude 5,700

Date	Water level	Date	Water level	Date	Water level	Date	Water level
OCT 17, 1988	15.00	JAN 03, 1989	22.07	APR 11, 1989	17.70	JUL 06, 1989	24.16
NOV 03	18.77	FEB 07	24.75	MAY 01	14.39	AUG 02	28.24
30	22.12	MAR 06	20.15	JUN 01	20.77		

(D-3-5)18dcc-1

Altitude 5,695

Date	Water level	Date	Water level	Date	Water level	Date	Water level
AUG 17, 1988	91.41	DEC 01, 1988	98.14	APR 12, 1989	98.62	AUG 01, 1989	94.14
SEP 08	94.06	JAN 04, 1989	98.42	MAY 02	92.57		
OCT 06	91.53	FEB 07	98.79	JUN 01	89.41		
NOV 03	93.68	MAR 07	97.97	JUL 01	91.53		

Table 9.--*Water levels in selected wells*--Continued

(D-3-5)19aba-1

Altitude 5,690

Date	Water level	Date	Water level	Date	Water level	Date	Water level
SEP 03, 1949	17.10 R	JAN 28, 1950	31.70 R	JUN 02, 1950	15.00 R	OCT 02, 1950	18.60 R
OCT 01	17.00 R	MAR 04	32.04 R	JUL 03	13.06 R		
NOV 01	24.20 R	APR 03	29.52 R	AUG 03	15.60 R		
DEC 01	30.25 R	MAY 03	28.50 R	SEP 06	17.84 R		

(D-3-5)19cbb-1

Altitude 5,650

Date	Water level	Date	Water level	Date	Water level	Date	Water level
JUL 20, 1988	9.95	NOV 03, 1988	10.27	MAR 06, 1989	10.22	JUL 06, 1989	9.51
AUG 17	9.99	DEC 01	10.35	APR 12	11.63	AUG 03	9.82
SEP 08	10.21	JAN 03, 1989	11.39	MAY 02	9.41		
OCT 06	10.24	FEB 07	10.93	JUN 01	8.66		

(D-3-5)29cac-1

Altitude 5,608

Date	Water level	Date	Water level	Date	Water level	Date	Water level
OCT 27, 1936	4.68	APR 06, 1950	10.28	NOV 16, 1966	8.18	MAR 13, 1978	8.68
JUN 30, 1937	1.63	DEC 12	7.22	DEC 15	8.67	SEP 11	2.16
OCT 11	4.01	APR 04, 1951	10.49	JAN 10, 1967	8.84	MAR 29, 1979	8.82
APR 05, 1938	10.15	DEC 27	7.90	MAR 20	9.83	SEP 25	5.29
JUN 01	1.45	APR 17, 1952	3.51	APR 12	9.07	MAR 19, 1980	7.53
AUG 27	2.05	DEC 29	7.96	MAY 17	7.16	SEP 05	3.10
OCT 23	2.94	APR 03, 1953	10.15	JUN 12	4.02	MAR 30, 1981	11.13
DEC 13	5.48	DEC 09	6.95	JUL 19	7.13	SEP 28	3.46
MAR 21, 1939	7.02	APR 19, 1954	10.32	AUG 21	3.14	MAR 25, 1982	7.75
MAY 21	1.96	DEC 08	8.42	SEP 28	4.20	SEP 30	6.19
JUN 22	1.25	MAR 31, 1955	10.10	OCT 11	4.93	MAR 31, 1983	8.29
AUG 29	3.95	DEC 12	7.63	NOV 09	8.23	SEP 28	2.80
OCT 30	4.85	DEC 20, 1956	8.42	FEB 01, 1968	9.74	MAR 29, 1984	9.06
JAN 08, 1940	8.86	MAR 25, 1957	10.20	MAR 12	10.11	SEP 21	3.29
FEB 14	9.85	DEC 09	6.79	APR 12	9.07	MAR 29, 1985	8.23
APR 03	9.78	MAR 17, 1958	9.77	MAY 08	5.90	SEP 20	1.97
JUN 23	2.61	DEC 18	7.87	JUN 06	2.68	MAR 20, 1986	6.65
NOV 30	7.52	MAR 20, 1959	10.61	JUL 16	1.57	SEP 15	3.45
MAR 14, 1941	9.83	DEC 09,	6.85	AUG 13	2.01	MAR 23, 1987	10.86
SEP 27	4.77	MAR 21, 1960	9.71	SEP 18	1.79	SEP 18	3.63
NOV 24	7.90	NOV 30	7.10	MAR 24, 1969	9.40	MAR 31, 1988	11.00
MAR 09, 1942	10.92	MAR 21, 1961	8.62	SEP 18	3.37	AUG 09	2.79
JUL 24	.61	JAN 12, 1962	10.41	MAR 19, 1970	10.51	SEP 08	3.56
OCT 24	4.60	MAR 08	8.48	AUG 21	3.45	23	3.43
DEC 12	6.68	DEC 18	8.16	MAR 25, 1971	9.68	OCT 06	4.77
MAR 31, 1943	9.57	MAR 06, 1963	10.79	SEP 10	4.20	NOV 03	4.32
APR 04, 1944	9.54	AUG 30	3.49	MAR 14, 1972	9.66	DEC 01	4.90
DEC 13	7.39	DEC 09	7.59	SEP 29	3.97	JAN 03, 1989	8.22
MAR 21, 1945	8.01	MAR 04, 1964	10.60	MAR 19, 1973	8.24	FEB 07	9.16
MAR 30, 1946	8.98	OCT 20	5.19	SEP 11	2.92	MAR 06	8.64
DEC 12	6.33	DEC 10	7.00	MAR 21, 1974	9.12	APR 12	9.96
APR 02, 1947	9.57	MAR 08, 1965	9.74	SEP 13	.18	MAY 02	5.47
DEC 15	6.65	JUL 27	1.21	MAR 19, 1975	9.61	JUN 01	2.82
MAR 26, 1948	9.16	OCT 18	5.30	SEP 09	2.20	JUL 06	2.43
JAN 12, 1949	8.38	DEC 13	1.89	MAR 03, 1976	8.98	AUG 01	3.45
APR 04	6.99	MAR 16, 1966	4.67	SEP 07	2.99	SEP 18	6.85
JUN 24	.80	SEP 16	2.72	MAR 07, 1977	10.71		
DEC 06	8.15	OCT 12	7.83	SEP 08	4.25		

(D-3-5)30bcc-1

Altitude 5,594

Date	Water level	Date	Water level	Date	Water level	Date	Water level
DEC 01, 1988	2.12	MAR 06, 1989	0.27	JUN 02, 1989	0.89		
JAN 03, 1989	2.77	APR 12	2.70	JUL 06	2.50		
FEB 09	2.77	MAY 02	.96	AUG 03	2.55		

Table 9.--*Water levels in selected wells*--Continued

(D-3-5)31dcd-1

Altitude 5,557

Date	Water level	Date	Water level	Date	Water level	Date	Water level
SEP 03, 1949	3.77 R	JAN 28, 1950	8.27 R	JUN 02, 1950	4.57 R	OCT 02, 1950	4.17 R
OCT 01	4.73 R	MAR 04	7.33 R	JUL 03	3.57 R		
NOV 01	6.77 R	APR 03	6.57 R	AUG 03	3.39 R		
DEC 01	8.43 R	MAY 03	6.62 R	SEP 06	3.61 R		

(D-3-5)32dcd-1

Altitude 5,636

Date	Water level	Date	Water level	Date	Water level	Date	Water level
SEP 03, 1949	4.40 R	FEB 03, 1950	16.80 R	JUN 02, 1950	4.85 R	OCT 02, 1950	8.54 R
OCT 01	8.26 R	MAR 04	14.86 R	JUL 03	3.60 R		
NOV 01	12.36 R	APR 03	15.50 R	AUG 03	3.66 R		
DEC 01	14.80 R	MAY 03	10.25 R	SEP 06	4.80 R		

(D-4-4) 3ada-1

Altitude 5,490

Date	Water level	Date	Water level	Date	Water level	Date	Water level
JUL 09, 1988	54.75	NOV 30, 1988	57.01	APR 12, 1989	56.87	AUG 01, 1989	55.61
SEP 08	55.94	JAN 03, 1989	57.54	MAY 01	55.91		
OCT 06	56.23	FEB 07	58.15	JUN 01	54.58		
NOV 03	56.91	MAR 06	57.35	JUL 06	55.03		

(D-4-4) 3dcd-1

Altitude 5,475

Date	Water level	Date	Water level	Date	Water level	Date	Water level
JUL 21, 1988	12.48	OCT 06, 1988	12.38	MAR 06, 1989	13.49	JUN 01, 1989	11.56
AUG 17	12.36	NOV 03	12.44	APR 13	13.69	JUL 06	11.41
SEP 08	12.59	30	12.89	MAY 01	12.81	AUG 01	12.78

(D-4-4)10daa-1

Altitude [1]5,430.17

Date	Water level	Date	Water level	Date	Water level
NOV 30, 1988	3.33	MAR 06, 1989	3.17	JUN 02, 1989	2.40
JAN 03, 1989	3.56	APR 13	3.44	JUL 06	2.88
FEB 08	3.50	MAY 01	3.31	AUG 01	3.67

(D-4-4)10daa-2

Altitude 5,430

Date	Water level	Date	Water level	Date	Water level
NOV 30, 1988	2.89	MAR 06, 1989	2.55	JUN 02, 1989	2.95
JAN 03, 1989	3.10	APR 13	3.23	JUL 06	3.40
FEB 08	2.97	MAY 01	3.14	AUG 01	3.88

(D-4-4)11dcd-1

Altitude 5,470

Date	Water level	Date	Water level	Date	Water level	Date	Water level
OCT 01, 1949	13.01 R	AUG 10, 1966	17.28	JAN 01, 1967	21.31	APR 09, 1967	23.05
NOV 01	15.57 R	SEP 13	17.45	08	21.62	16	23.15
DEC 01	16.74 R	OCT 10	17.34	15	21.81	23	23.22
JAN 01, 1950	17.22 R	23	18.33	22	21.97	30	22.49
FEB 01	17.80 R	30	17.99	29	22.09	MAY 14	16.47
MAR 01	17.38 R	NOV 06	17.91	FEB 05	22.20	21	13.26
APR 01	17.58 R	13	18.17	19	22.51	25	11.85
MAY 04	14.12 R	20	18.50	26	22.70	JUL 19	4.72
JUN 01	7.35 R	27	18.87	MAR 05	22.78	AUG 02	4.99
JUL 01	1.35 R	DEC 04	19.22	12	21.92	06	5.68
AUG 01	3.71 R	11	19.59	19	22.07	13	5.55
SEP 01	8.61 R	18	20.21	26	22.50	21	5.95
OCT 01	8.38 R	25	20.88	APR 02	22.80	SEP 30	15.69

Table 9.--*Water levels in selected wells*--Continued

Date	Water level	Date	Water level	Date	Water level	Date	Water level
			(D-4-4)11dcd-1--Continued				
OCT 08, 1967	16.53	SEP 12, 1968	6.23	MAR 05, 1989	21.43	MAY 20, 1989	13.70
15	18.13	JUL 06, 1988	13.53	06	21.34	25	12.80
22	18.57	AUG 23	18.40	10	19.41	31	12.50
29	16.60	SEP 08	18.94	15	20.47	JUN 02	12.62
NOV 09	15.83	OCT 06	20.43	20	21.68	05	12.20
19	16.45	NOV 03	19.81	25	22.33	25	11.05
26	16.83	20	18.54	31	22.71	30	10.58
DEC 03	17.10	25	18.53	APR 05	22.91	JUL 05	11.57
FEB 01, 1968	20.45	30	19.08	10	22.50	06	11.69
11	20.91	DEC 05	19.75	13	22.38	10	11.41
18	21.22	10	20.47	15	22.30	15	12.97
25	21.35	JAN 03, 1989	22.22	20	21.90	20	13.05
MAR 12	21.46	20	22.77	25	20.50	25	14.61
18	19.61	FEB 08	23.21	30	18.70	31	14.52
MAY 10	20.06	15	23.27	MAY 03	17.80	AUG 01	15.12
JUN 12	6.44	20	23.25	05	16.70		
JUL 16	8.48	25	23.10	10	15.50		
AUG 13	7.16	28	22.79	15	14.30		
			(D-4-4)12dcc-1				
Altitude 5,535							
SEP 03, 1949	36.40 R	FEB 03, 1950	57.00 R	JUN 02, 1950	32.50 R	OCT 02, 1950	35.05 R
OCT 01	42.50 R	MAR 04	56.00 R	JUL 03	23.00 R	APR 14, 1989	66.30
NOV 01	47.25 R	APR 03	54.80 R	AUG 03	28.30 R		
DEC 01	51.04 R	MAY 03	50.60 R	SEP 06	35.46 R		
			(D-4-4)13cbb-1				
Altitude 5,530							
SEP 03, 1949	44.40 R	FEB 03, 1950	60.76 R	JUN 02, 1950	36.08 R	OCT 02, 1950	42.00 R
OCT 01	48.20 R	MAR 04	59.30 R	JUL 03	27.24 R		
NOV 01	51.90 R	APR 03	56.50 R	AUG 03	32.40 R		
DEC 01	55.06 R	MAY 03	49.00 R	SEP 06	41.84 R		
			(D-4-4)14bbc-1				
Altitue 5,426							
SEP 03, 1949	9.93 R	FEB 03, 1950	13.63 R	JUN 02, 1950	4.75	OCT 02, 1950	10.66 R
OCT 01	11.53 R	MAR 04	13.55 R	JUL 03	3.33		
NOV 01	12.83 R	APR 01	13.83 R	AUG 03	5.79		
DEC 01	13.43 R	MAY 03	11.89 R	SEP 06	9.43		
			(D-4-4)15daa-1				
Altitude 5,430							
JUL 05, 1988	8.85	AUG 16, 1988	16.60	SEP 08, 1988	18.88		
			(D-4-4)15ddd-1				
Altitude 5,420							
DEC 05, 1988	15.77	MAR 06, 1989	13.04	JUN 02, 1989	+0.33		
JAN 03, 1989	15.98	APR 13	8.02	JUL 06	1.17		
FEB 08	14.86	MAY 01	5.21	AUG 03	7.96		

Table 9.--*Water levels in selected wells*--Continued

(D-4-4)15ddd-2

Altitude [1]5,420.46

Date	Water level	Date	Water level	Date	Water level	Date	Water level
DEC 05, 1988	17.82	MAR 06, 1989	16.87	JUN 02, 1989	1.60		
JAN 03, 1989	18.29	APR 13	11.30	JUL 06	2.37		
FEB 08	16.95	MAY 01	6.99	AUG 03	9.39		

(D-4-4)23bbb-2

Altitude 5,426

Date	Water level	Date	Water level	Date	Water level	Date	Water level
JUL 05, 1988	9.20	NOV 03, 1988	19.65	MAR 06, 1989	22.30	JUL 06, 1989	7.85
AUG 23	17.92	DEC 01	20.99	APR 13	19.29	AUG 02	13.86
SEP 08	17.32	JAN 03, 1989	21.86	MAY 01	11.41		
OCT 05	18.69	FEB 07	23.37	JUN 01	8.99		

(D-4-4)23bbc-1

Altitude 5,425

Date	Water level	Date	Water level	Date	Water level	Date	Water level
SEP 03, 1949	13.33 R	FEB 03, 1950	19.98 R	JUN 02, 1950	6.40 R	OCT 02, 1950	14.24 R
OCT 01	14.24 R	MAR 04	18.10 R	JUL 03	4.50 R		
NOV 01	17.20 R	APR 03	18.32 R	AUG 03	7.92 R		
DEC 01	18.10 R	MAY 03	10.46 R	SEP 06	12.06 R		

(D-4-5) 2ccc-1

Altitude 5,930

Date	Water level	Date	Water level	Date	Water level	Date	Water level
SEP 03, 1949	27.50 R	FEB 23, 1950	34.90 R	JUN 02, 1950	8.80 R	OCT 02, 1950	30.66 R
OCT 01	29.84 R	MAR 04	33.00 R	JUL 03	15.75 R	APR 20, 1989	23.53
NOV 01	31.04 R	APR 03	31.52 R	AUG 03	20.70 R		
DEC 01	31.32 R	MAY 03	24.10 R	SEP 06	27.40 R		

(D-4-5) 3dcc-1

Altitude 5,880

Date	Water level	Date	Water level	Date	Water level	Date	Water level
JUL 06, 1988	16.45	NOV 04, 1988	29.60	MAR 07, 1989	29.58	JUL 06, 1989	17.20
AUG 16	22.07	DEC 05	31.88	APR 14	19.45	AUG 01	19.83
SEP 08	24.69	JAN 04, 1989	34.06	MAY 03	20.29		
OCT 06	27.37	FEB 09	33.12	JUN 06	19.27		

(D-4-5) 4ddd-1

Altitude 5,798

Date	Water level	Date	Water level	Date	Water level	Date	Water level
JUL 08, 1939	17.30	DEC 08, 1954	31.02	DEC 10, 1964	35.31	APR 12, 1968	34.10
SEP 03, 1949	19.50	MAR 31, 1955	42.78	MAR 08, 1965	40.79	MAY 08	24.63
OCT 01	25.66	DEC 12	34.00	OCT 18	20.38	JUN 06	21.27 R
NOV 01	29.50	DEC 20, 1956	33.41	DEC 13	28.37	JUL 16	33.27 R
DEC 01	31.20	MAR 25, 1957	35.09	MAR 16, 1966	39.24	AUG 13	31.17 R
FEB 03, 1950	36.10	DEC 09	33.10	SEP 13	24.68	SEP 18	34.31
MAR 04	39.00	MAR 17, 1958	45.55	OCT 12	27.27	MAR 24, 1969	38.94
APR 03	33.50	DEC 18	34.37	NOV 14	43.18	SEP 18	18.89
MAY 03	26.80	MAR 20, 1959	40.20	DEC 15	36.42	MAR 19, 1970	42.73
JUN 02	10.50	DEC 09	36.22	JAN 10, 1967	38.76	AUG 20	11.21
JUL 03	7.64	MAR 21, 1960	36.44	MAR 20	42.12	MAR 25, 1971	41.92
AUG 03	10.60	NOV 30	29.84	APR 12	34.10	SEP 10	17.91
SEP 06	18.50	MAR 21, 1961	40.37	MAY 17	35.86	MAR 14, 1972	39.36
OCT 02	22.84	JAN 12, 1962	45.45	JUN 12	43.23	SEP 29	24.99
SEP 11, 1951	19.80	MAR 08	45.10	JUL 19	45.54	MAR 19, 1973	47.12
DEC 27	35.17	DEC 18	45.26	AUG 21	38.82	SEP 11	16.50
APR 17, 1952	26.79	MAR 06, 1963	41.47	SEP 28	28.84	MAR 21, 1974	37.56
DEC 29	38.10	AUG 30	19.60	OCT 11	37.20	SEP 13	19.46
APR 03, 1953	36.85	DEC 09	32.06	NOV 09	29.81	MAR 19, 1975	43.72
DEC 09	32.46	MAR 04, 1964	45.64	FEB 01, 1968	39.94	SEP 09	14.44
APR 19, 1954	30.94	OCT 20	24.13	MAR 12	37.42	MAR 03, 1976	41.52

Table 9.--*Water levels in selected wells*--Continued

(D-4-5) 4ddd-1--Continued

Date	Water level	Date	Water level	Date	Water level	Date	Water level
SEP 07, 1976	19.45	SEP 28, 1981	23.76	SEP 15, 1986	23.15	JAN 04, 1989	41.44
MAR 07, 1977	42.24	MAR 25, 1982	27.40	MAR 23, 1987	40.70	FEB 09	44.03
SEP 08	22.70	SEP 30	28.26	SEP 18	26.35	MAR 07	42.41
MAR 13, 1978	46.49	MAR 31, 1983	18.80	MAR 31, 1988	41.30	APR 14	23.24
SEP 11	19.17	SEP 28	20.54	AUG 16	24.56	MAY 03	16.88
MAR 29, 1979	34.13	MAR 29, 1984	25.44	SEP 07	28.53	JUL 06	17.65
SEP 25	25.94	SEP 21	18.57	23	30.69	AUG 01	22.42
MAR 19, 1980	28.77	MAR 29, 1985	26.04	OCT 06	32.61	SEP 18	28.52 R
SEP 05	17.77	SEP 20	21.50	NOV 04	24.62		
MAR 30, 1981	34.28	MAR 20, 1986	18.76	DEC 05	29.82		

(D-4-5) 6bba-1

Altitude 5,526

Date	Water level	Date	Water level	Date	Water level	Date	Water level
MAR 24, 1969	6.54	MAR 04, 1976	5.51	MAR 31, 1983	0.15	NOV 03, 1988	1.53
SEP 18	1.60	SEP 07	5.69	SEP 28	.42	DEC 01	1.59
MAR 12, 1970	6.30	MAR 07, 1977	5.89	MAR 29, 1984	.82	JAN 04, 1989	1.70
AUG 21	3.03	SEP 08	5.91	SEP 21	.11	FEB 07	1.82
MAR 25, 1971	6.38	MAR 13, 1978	6.09	MAR 29, 1985	.49	MAR 07	1.92
SEP 10	6.01	SEP 11	5.97	SEP 20	.32	APR 14	2.04
MAR 24, 1972	6.28	MAR 29, 1979	6.32	MAR 20, 1986	.17	MAY 02	2.07
SEP 29	6.11	SEP 25	6.20	MAR 23, 1987	.80	JUN 01	2.08
MAR 19, 1973	6.12	MAR 19, 1980	6.36	SEP 18	.26	JUL 06	2.11
SEP 11	6.13	SEP 05	.28	MAR 31, 1988	.87	AUG 02	2.12
MAR 21, 1974	6.25	MAR 30, 1981	1.06	AUG 23	1.17	SEP 15	1.86
SEP 13	6.11	SEP 28	1.38	SEP 08	1.44		
MAR 19, 1975	6.18	MAR 25, 1982	1.90	23	1.50		
SEP 09	6.15	SEP 30	1.53	OCT 06	1.46		

(D-4-5) 8bbb-1

Altitude 5,636

Date	Water level	Date	Water level	Date	Water level	Date	Water level
SEP 03, 1949	48.70 R	FEB 02, 1950	106.20 R	JUN 02, 1950	92.16 R	OCT 02, 1950	65.30 R
OCT 01	61.40 R	MAR 04	110.20 R	JUL 03	57.08 R		
NOV 01	78.10 R	APR 03	112.00 R	AUG 03	50.30 R		
DEC 01	94.10 R	MAY 03	110.70 R	SEP 06	56.90 R		

(D-4-5)11bcd-1

Altitude 5,930

Date	Water level	Date	Water level	Date	Water level	Date	Water level
JUL 06, 1988	10.43	OCT 06, 1988	18.27	JAN 04, 1989	19.90	APR 14, 1989	15.40
AUG 16	13.90	NOV 04	19.97	FEB 08	18.91	MAY 03	14.64
SEP 07	16.14	DEC 05	20.25	MAR 07	17.65	JUL 06	10.15

(D-4-5)14aac-1

Altitude 6,020

Date	Water level	Date	Water level	Date	Water level	Date	Water level
JUL 06, 1988	9.33	NOV 04, 1988	11.61	MAR 07, 1989	11.57	JUL 06, 1989	5.63
AUG 16	9.81	DEC 05	11.66	APR 14	11.19	AUG 01	8.63
SEP 07	10.27	JAN 04, 1989	11.64	MAY 03	10.76		
OCT 06	11.34	FEB 08	11.60	JUN 02	7.98		

Table 9.--*Water levels in selected wells*--Continued

(D-4-5)15aab-1

Altitude 5,900

Date	Water level	Date	Water level	Date	Water level	Date	Water level
JUL 07, 1988	18.31	JAN 15, 1989	19.39	MAR 31, 1989	18.76	JUN 05, 1989	5.70
AUG 16	19.77	20	19.46	APR 05	18.73	10	15.90
SEP 07	19.05	25	19.55	10	18.74	15	15.80
OCT 06	19.48	31	19.68	14	18.61	20	16.00
NOV 04	20.20	FEB 05	19.89	15	18.80	25	16.10
20	20.16	08	19.91	20	18.70	30	16.20
25	19.99	10	20.12	25	18.80	JUL 05	16.00
30	19.71	15	20.37	30	18.90	06	16.57
DEC 05	19.53	20	19.91	MAY 03	18.65	10	16.10
10	19.41	25	19.82	05	18.80	15	16.30
15	19.72	28	19.78	10	16.80	20	16.60
20	19.41	MAR 05	19.56	15	16.40	25	17.00
25	19.47	07	19.43	20	16.10	31	17.30
31	18.89	10	18.73	25	15.80	AUG 01	17.32
JAN 04, 1989	18.62	15	18.64	31	15.90		
05	18.90	20	18.71	JUN 02	15.69		
10	19.26	25	18.72	03	15.70		

(D-4-5)15bab-1

Altitude 5,850

Date	Water level	Date	Water level	Date	Water level	Date	Water level
JUL 07, 1988	127.25	NOV 04, 1988	127.46	MAR 07, 1989	135.48	JUL 06, 1989	126.64
AUG 16	129.19	DEC 05	130.82	APR 14	132.37	AUG 02	125.49
SEP 07	129.45	JAN 04, 1989	131.72	MAY 03	131.12		
OCT 06	127.28	FEB 08	134.45	JUN 02	126.81		

(D-4-5)16ccd-1

Altitude 5,850

Date	Water level	Date	Water level	Date	Water level	Date	Water level
OCT 17, 1988	88.40	FEB 08, 1989	94.73	MAY 03, 1989	84.01	JUL 06, 1989	91.34
DEC 08	95.16	MAR 07	94.33	JUN 02	83.93	AUG 01	88.67
JAN 04, 1989	94.53	APR 14	94.55				

(D-5-4) 1bcb-1

Altitude 5,560

Date	Water level	Date	Water level	Date	Water level	Date	Water level
OCT 05, 1988	25.02	JAN 04, 1989	25.15	APR 10, 1989	25.34	JUL 07, 1989	25.22
NOV 04	24.95	FEB 07	25.62	MAY 02	25.63	AUG 02	25.45
DEC 01	25.06	MAR 08	25.75	JUN 06	25.27		

(D-5-4) 2cca-1

Altitude 5,470

Date	Water level	Date	Water level	Date	Water level	Date	Water level
AUG 03, 1988	20.31	DEC 01, 1988	23.49	APR 10, 1989	23.47	AUG 02, 1989	19.50
SEP 07	20.84	JAN 04, 1989	23.96	MAY 02	22.90		
OCT 05	22.07	FEB 07	24.03	JUN 06	19.74		
NOV 04	22.93	MAR 08	23.39	JUL 07	19.40		

(D-5-4)12baa-1

Altitude 5,540

Date	Water level	Date	Water level	Date	Water level	Date	Water level
AUG 05, 1988	4.74	NOV 04, 1988	4.56	APR 10, 1989	4.53	JUL 07, 1989	5.63
SEP 07	4.88	DEC 01	4.98	MAY 02	4.00	AUG 03	5.75
OCT 05	4.90	MAR 08, 1989	4.39	JUN 06	4.25		

Table 9.--*Water levels in selected wells*--Continued

Date	Water level	Date	Water level	Date	Water level	Date	Water level
				(D-5-4)12cad-1			
Altitude [1]5,540.29							
SEP 28, 1988	2.88	JAN 04, 1989	2.55	APR 10, 1989	2.68	JUL 07, 1989	3.29
NOV 04	2.83	FEB 09	2.35	MAY 02	2.82	AUG 02	3.75
DEC 01	2.56	MAR 07	1.37	JUN 06	2.28		
				(D-5-4)12cad-2			
Altitude 5,540							
DEC 01, 1988	1.88	MAR 07, 1989	.86	MAY 02, 1989	2.12	JUL 07, 1989	2.31
JAN 04, 1989	1.90	APR 10	2.10	JUN 06	1.60	AUG 02	2.65
FEB 09	1.73						
				(D-5-5)18aba-1			
Altitude 5,725							
AUG 04, 1988	83.78	DEC 01, 1988	82.36	APR 10, 1989	81.08	AUG 03, 1989	81.96
SEP 07	82.10	JAN 04, 1989	81.64	MAY 02	81.04		
OCT 05	82.18	FEB 09	81.34	JUN 06	81.09		
NOV 04	82.59	MAR 07	81.11	JUL 07	81.49		
				(D-5-5)18dcb-1			
Altitude 5,680							
AUG 04, 1988	10.58	NOV 04, 1988	11.51	FEB 09, 1989	8.53	MAY 02, 1989	8.53
SEP 07	11.09	DEC 01	9.52	MAR 07	8.33	JUN 06	8.57
OCT 05	11.09	JAN 04, 1989	8.72	APR 10	8.25	JUL 07	9.78
						AUG 02	10.75
				(D-5-5)20cad-1			
Altitude 5,850							
NOV 04, 1988	15.46	FEB 09, 1989	12.06	MAY 02, 1989	6.27	AUG 02, 1989	68.12
DEC 01	12.66	MAR 07	11.19	JUN 01	7.54		
JAN 04, 1989	11.58	APR 10	10.77	JUL 07	14.02		
				(D-5-5)21ccd-1			
Altitude 5,960							
AUG 30, 1988	29.88	DEC 01, 1988	29.81	MAR 07, 1989	31.74	JUN 01, 1989	21.29
OCT 05	31.29	JAN 04, 1989	32.54	APR 10	29.87	JUL 07	23.06
NOV 04	26.77	FEB 09	32.90	MAY 01	24.23	AUG 03	28.73

[1] Altitudes reported to the nearest 0.01 foot are not necessarily true altitudes. These altitudes represent the difference in land surface between two wells that are located next to each other.

Table 10.—*Chemical analyses of water from*

[mg/L, milligrams per liter; µg/L, micrograms per liter;

Location: See explanation of the numbering system for hydrologic-data sites on p. 4.
Specific conductance: µS/cm, microsiemens per centimeter, at 25 degrees Celsius.
Water temperature: °C, degrees Celsius.
Solids, dissolved: Sum of constituents except R, residue on evaporation at 180 °C.

Location	Date of sample	Specific conductance (µS/cm)	pH (standard units)	Water temperature (°C)	Hardness (mg/L as $CaCO_3$)	Hardness, noncarbonate (mg/L as $CaCO_3$)	Alkalinity, total (mg/L as $CaCO_3$)	Solids, sum of constituents, dissolved (mg/L)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)
(D-3-4)21bbb-S1	07-29-63	760	7.9	—	365	71	—	488R	97	30	24	2.1
(D-3-4)21dcd-S1	09-12-68	520	7.3	—	275	36	239	299	61	30	7.3	1.1
(D-3-4)22bcc-S1	06-15-89	500	7.6	12.0	—	—	226	285	63	23	6.8	1.2
(D-3 4)23daa-1	06-14-89	690	7.4	14.5	—	—	262	403	79	25	26	1.3
(D-3-4)26cca-S1	09-28-66	2,200	7.3	39.5	1,110	553	—	1,670	331	68	114	25.0
(D-3-4)26dba-1	05-17-67	950	8.0	11.5	434	177	—	625	118	34	37	7.0
	06-14-89	850	7.5	12.5	—	—	268	521	110	27	29	7.0
(D-3-4)27baa-S1	09-13-67	2,410	7.5	45.0	1,200	672	—	1,810	345	83	148	16.0
	06-13-89	2,260	6.7	45.5	—	—	580	1,950	360	70	140	34.0
(D-3-4)27bad-S1	09-28-66	2,560	7.3	39.5	1,270	673	—	1,990	389	73	151	31.0
	05-16-67	2,490	7.8	40.0	1,260	689	—	2,000	361	88	152	32.0
(D-3-4)27cbd-S1	09-28-66	2,330	7.4	29.0	1,180	589	—	1,770	353	72	125	28.0
	05-16-67	2,280	7.8	29.0	960	570	—	1,570	228	95	130	28.0
	05-23-67	2,280	—	30.0	—	—	—	—	—	—	—	—
(D-3-4)27cbd-S2	09-28-66	2,180	7.7	29.5	1,110	545	—	1,640	329	70	111	25.0
	05-15-67	2,120	7.9	32.0	1,000	531	—	1,510	279	74	114	26.0
	05-23-67	2,170	—	34.5	—	—	—	—	—	—	—	—
(D-3-4)27cbd-S3	05-16-67	2,610	7.7	28.5	1,180	701	—	1,880	329	88	163	33.0
	05-23-67	2,490	—	19.0	—	—	—	—	—	—	—	—
(D-3-4)33aad-1	06-14-89	980	7.4	11.0	—	—	285	626	120	42	30	1.1
(D-3-4)35dab-1	05-17-67	1,530	7.8	15.0	770	360	—	1,110	220	54	66	15.0
(D-3-5) 6bab-2	08-15-67	305	7.1	15.5	—	—	—	—	42	9.7	4.4	1.5
	08-15-67	305	7.1	15.5	—	—	—	—	42	9.7	4.4	1.5
(D-3-5)19add-1	05-17-67	375	7.9	13.0	172	8	—	252	48	13	13	3.2
(D-3-5)20ccd-S1	06-15-89	300	7.5	12.0	—	—	128	197	37	7.9	9.1	3.0
(D-3-5)30bcc-1	05-23-89	630	7.0	12.0	—	—	160	351	66	18	16	28.0
(D-3-5)32bad-S1	06-14-89	395	7.6	13.0	—	—	180	237	55	12	9.0	2.0
(D-4-4) 2cbb-S1	12-07-62	995	7.7	14.0	484	199	—	682R	—	—	[2]36	—
(D-4-4) 3ada-1	06-13-89	1,440	7.1	16.5	—	—	360	934	190	43	55	12.0
(D-4-4)10daa-1	05-23-89	610	7.7	11.0	—	—	148	355	64	18	29	4.1
(D-4-4)10daa-2	05-23-89	880	7.5	9.0	—	—	285	540	110	30	34	6.4
(D-4-4)13ada-1	06-12-89	510	7.2	12.0	—	—	200	247	60	17	8.6	1.4
(D-4-4)13cba-1	08-17-67	405	7.5	13.0	212	22	—	236	56	18	4.7	.3
(D-4-4)15dbc-S1	10-21-88	455	7.9	11.0	—	—	[1]195	255	57	17	11	2.1
(D-4-4)15dbc-S2	10-21-88	450	7.9	14.0	—	—	[1]187	249	56	16	8.9	2.3
(D-4-5) 2acb-1	06-01-89	680	7.6	11.0	—	—	233	389	58	30	36	3.4
(D-4-5) 4aab-S1	03-03-48	—	—	—	170	18	—	215R	49	12	[2]5.0	—
(D-4-5) 5ccc-1	05-20-66	370	7.5	—	170	21	150	234R	52	10	7.0	1.0
(D-4-5) 7aac-1	07-30-63	365	7.3	—	190	19	172	268R	59	10	6.4	2.2
(D-4-5) 7ada-1	08-17-67	495	7.5	12.0	256	17	—	305	75	17	8.2	.8
(D-4-5) 7daa-1	06-12-89	510	7.5	12.0	—	—	238	294	71	17	10	1.8
(D-4-5) 9bcc-1	06-01-89	500	7.2	11.0	—	—	205	291	70	14	11	2.4
(D-4-5)10baa-2	08-30-89	415	—	13.0	—	—	—	—	—	—	—	—
(D-4-5)11aaa-1	06-01-89	440	7.0	10.0	—	—	205	263	70	8.3	7.5	2.7
(D-4-5)14aac-1	08-17-67	705	7.9	16.0	324	16	—	451	89	26	31	1.7

selected wells and springs

--, no data available; < , less than]

Bicarbonate water (mg/L as HCO_3)	Sulfate, dissolved (mg/L as SO_4)	Chloride, dissolved (mg/L as Cl)	Fluoride, dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO_2)	Nitrogen, Nitrate, dissolved (mg/L as NO_3)	Nitrogen, NO_2+NO_3, dissolved (mg/L as N)	Nitrogen, Ammonia, dissolved (mg/L as N)	Phosphorus, ortho, dissolved (mg/L as P)	Phosphate, ortho, dissolved (mg/L as PO_4)	Boron, dissolved (µg/L as B)	Iron, dissolved (µg/L as Fe)	Manganese, dissolved (µg/L as Mn)	Zinc, dissolved (µg/L as Zn)
359	96	17	0.2	13	0	—	—	—	—	160	—	—	—
292	39	7.0	.6	7.0	2.0	—	—	—	—	30	—	—	—
—	38	6.7	.2	9.8	—	0.40	<0.01	<0.01	—	40	3	<1	—
—	62	27	.2	25	—	.44	< .01	.03	—	50	<3	2	—
674	661	108	2.2	23	.1	—	—	—	0.24	670	—	—	—
314	219	34	1.1	17	3.6	—	—	—	—	160	—	—	—
—	140	26	.7	20	—	2.40	.02	.03	—	120	3	<1	—
644	742	132	2.5	27	.4	—	—	—	—	640	—	—	—
—	820	130	2.6	29	—	< .10	.25	< .01	—	—	120	65	37
728	820	138	2.5	28	.1	—	—	—	.04	790	—	—	—
696	853	140	3.1	28	0	—	—	—	—	830	—	—	20
716	702	115	2.1	21	.1	—	—	—	.07	700	—	—	—
476	719	115	2.3	22	.1	—	—	—	—	710	—	—	10
—	—	—	—	—	—	—	—	—	—	—	—	—	—
686	643	103	2.2	19	.1	—	—	—	.02	640	—	—	—
572	611	105	2.4	17	0	—	—	—	—	640	—	—	20
—	—	—	—	—	—	—	—	—	—	—	—	—	—
584	805	150	2.7	21	0	—	—	—	—	800	—	—	20
—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	230	16	.3	18	—	1.50	.02	.02	—	30	10	<1	—
500	424	62	2.2	19	1.3	—	—	—	—	360	—	—	—
128	44	5.2	—	14	—	—	—	—	—	—	—	—	—
120	44	5.2	—	14	—	—	—	—	—	—	—	—	—
200	26	6.2	.4	43	1.4	—	—	—	—	20	—	—	—
—	12	7.4	.2	45	—	.52	< .01	.06	—	20	<3	<1	—
—	63	48	.3	16	—	3.60	.16	.03	—	20	12	490	—
—	15	7.3	.1	29	—	.88	< .01	.04	—	20	<3	3	—
348	223	30	—	—	2.6	—	—	—	—	—	—	—	—
—	340	53	1.4	21	—	1.20	.03	< .01	—	360	51	2	—
—	74	38	.3	27	—	.67	.02	.02	—	50	20	51	—
—	140	29	.6	21	—	< .10	.12	< .01	—	160	9	170	—
—	13	14	.1	16	—	1.80	< .01	.02	—	30	47	6	—
232	18	7.3	.2	12	5.4	—	—	—	—	0	—	—	—
—	23	11	.1	20	—	1.40	.04	.04	—	30	8	<1	—
—	21	11	.1	20	—	1.40	.04	.05	—	30	6	12	—
—	30	54	.4	38	—	2.40	.01	.01	—	100	13	2	—
185	10	11	.3	25	0	—	—	—	—	—	—	—	—
182	16	11	.2	30	12	—	—	—	.01	50	—	—	100
209	13	10	.1	24	8.6	—	—	—	.06	70	—	—	500
292	17	7.8	.2	29	5.9	—	—	—	—	0	—	—	—
—	16	10	.1	26	—	2.10	.01	.02	—	40	15	9	—
—	19	11	.1	28	—	2.00	.02	.05	—	30	15	1	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	10	8.2	.1	34	—	2.00	.02	.03	—	30	11	72	—
376	38	35	.5	43	4.0	—	—	—	—	50	—	—	—

Location	Date of sample	Specific conductance (µS/cm)	pH (standard units)	Water temperature (°C)	Hardness (mg/L as $CaCO_3$)	Hardness, noncarbonate (mg/L as $CaCO_3$)	Alkalinity, total (mg/L as $CaCO_3$)	Solids, sum of constituents, dissolved (mg/L)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)
(D-4-5)14bbb-1	05-31-89	485	7.1	9.5	—	—	265	339	82	20	10	5.3
(D-4-5)15bbb-1	06-01-89	660	7.3	11.0	—	—	297	391	82	24	24	2.1
(D-4-5)16bca-1	06-01-89	520	7.6	12.0	—	—	225	294	58	24	17	1.2
(D-4-5)17bcb-2	06-13-89	455	7.4	12.0	—	—	193	250	58	18	11	.9
(D-4-5)17dda-1	06-12-89	480	7.7	13.5	—	—	228	266	60	23	6.6	1.1
(D-4-5)18ccc-1	06-12-89	475	7.5	10.0	—	—	214	261	60	18	11	1.3
(D-4-5)21adb-1	06-12-89	500	7.5	12.0	—	—	202	282	60	23	12	1.3
(D-4-5)35dcc-S1	06-22-54	—	7.6	—	226	—	—	259R	—	—	—	—
(D-5-4) 2cdc-1	06-12-89	680	7.5	12.0	—	—	324	395	83	27	19	3.6
(D-5-4)12abd-1	06-13-89	540	7.8	11.5	—	—	240	287	61	21	18	1.7
(D-5-4)12cad-1	06-09-89	630	7.3	9.5	—	—	292	362	82	26	14	3.0
(D-5-4)12cad-2	05-24-89	640	7.2	9.0	—	—	288	355	81	25	14	2.8
(D-5-4)13adc-1	06-13-89	425	7.3	12.0	—	—	177	234	56	9.7	15	1.2
(D-5-5)17abc-S1	05-13-41	—	—	13.0	238	36	—	298R	65	18	[2]13	—
(D-5-5)17aca-1	05-25-89	465	7.4	12.0	—	—	210	249	59	16	10	1.0
(D-5-5)18aca-S1	05-25-89	600	7.4	11.5	—	—	256	331	75	22	17	2.0
(D-5-5)19aac-1	05-30-89	415	7.2	10.5	—	—	180	228	59	11	7.0	1.1
(D-5-5)19bca-1	05-30-89	420	6.8	11.0	—	—	140	242	48	10	20	.9
(D-5-5)20abb-1	05-26-89	460	7.5	11.5	—	—	208	265	65	15	12	1.1
(D-5-5)20add-3	06-13-89	390	7.8	12.0	—	—	172	217	48	12	10	1.9
(D-5-5)21aca-1	05-25-89	400	7.7	12.5	—	—	182	215	53	13	7.8	1.0
(D-5-5)33abd-1	05-25-89	495	7.6	10.0	—	—	210	280	70	15	9.5	1.7

[1] Laboratory measurement of alkalinity.
[2] Na and K dissolved (mg/L as Na).

Bicarbonate water (mg/L as HCO_3)	Sulfate, dissolved (mg/L as SO_4)	Chloride, dissolved (mg/L as Cl)	Fluoride, dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO_2)	Nitrogen, Nitrate, dissolved (mg/L as NO_3)	Nitrogen, NO_2+NO_3, dissolved (mg/L as N)	Nitrogen, Ammonia, dissolved (mg/L as N)	Phosphorus, ortho, dissolved (mg/L as P)	Phosphate, ortho, dissolved (mg/L as PO_4)	Boron, dissolved (µg/L as B)	Iron, dissolved (µg/L as Fe)	Manganese, dissolved (µg/L as Mn)	Zinc, dissolved (µg/L as Zn)
—	24	15	0.2	21	—	2.90	0.02	.12	—	30	20	3	—
—	25	18	.2	36	—	2.20	.01	.04	—	70	19	2	—
—	23	14	.3	19	—	1.30	.02	.01	—	40	10	<1	—
—	13	18	.2	16	—	1.40	< .01	< .01	—	30	6	5	—
—	20	8.2	.2	11	—	.21	.01	< .01	—	20	7	6	—
—	12	17	.1	14	—	.67	< .01	< .01	—	40	25	23	—
—	31	20	.2	12	—	.65	.02	< .01	—	30	19	6	—
264	12	12	.0	—	2.0	—	—	—	—	—	—	—	—
—	23	19	.1	26	—	.91	< .01	.17	—	50	8	<1	—
—	19	14	.1	20	—	2.00	< .01	.02	—	30	<3	<1	—
—	22	16	.2	21	—	< .10	.03	< .01	—	50	2,000	470	—
—	22	18	.2	20	—	< .10	.05	< .01	—	30	690	200	—
—	12	16	.1	19	—	1.40	< .01	.04	—	20	14	<1	—
246	41	14	.0	13	—	—	—	—	—	—	—	—	—
—	7	12	.1	17	—	.73	< .01	.01	—	20	7	<1	—
—	20	23	.1	19	—	2.10	.02	.03	—	40	9	<1	—
—	20	7.7	.2	13	—	.19	.02	.02	—	10	11	1	—
—	20	32	.1	28	—	< .10	< .01	.01	—	20	87	9	—
—	16	14	.1	17	—	.55	.01	< .01	—	20	8	3	—
—	14	9.8	.2	21	—	.36	< .01	< .01	—	30	5	17	—
—	6	10	.1	16	—	.68	.02	< .01	—	20	7	2	—
—	24	18	.1	17	—	.38	.02	.04	—	20	16	2	—

2M 12/90

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Base from U.S. Geological Survey 1:24,000 quadrangles, Aspen Grove, Brighton, Center Creek, Charleston, Francis, Heber City, Twin Peaks, and Wallsburg Ridge, Utah

1 0 1 2 MILES
1 0 1 2 KILOMETERS
CONTOUR INTERVAL 200 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

Hydrology by D.M. Roark and H.K. Shlosar, 1988-90.

MAP SHOWING POTENTIOMETRIC SURFACE IN THE UNCONSOLIDATED VALLEY-FILL DEPOSITS AND LOCATION OF DATA-COLLECTION SITES, HEBER AND ROUND VALLEYS, UTAH