HYDROLOGY OF THE OAKLEY FAN AREA, SOUTH-CENTRAL IDAHO

By H.W. Young and G.D. Newton

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CONVERSION FACTORS

For readers who prefer to use metric (International System) units, conversion factors for inch-pound units used in this report are listed below. Constituent concentrations are given in mg/L (milligrams per liter), which is equal to parts per million. Specific conductance is expressed as µS/cm (microsiemens per centimeter at 25 degrees Celsius).

Multiply inch-pound unit	By	To obtain metric unit
acre	4,047	square meter
acre-foot	1,233	cubic meter
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
foot (ft)	0.3048	meter
foot squared per day (ft^2/d)	0.0929	meter squared per day
inch (in.)	25.4	millimeter
kilowatthour (kWh)	3,600,000	joule
mile (mi)	1.609	kilometer
pound per square inch (psi)	6.895	kilopascal

Water temperatures in °C (degrees Celsius) can be converted to °F (degrees Fahrenheit) by the 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), which was derived from a general adjustment of the first-order level nets of both the United States and Canada, and formerly was called "mean sea level of 1929."

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ABSTRACT

The Oakley Fan area is a broad, crescent-shaped lowland along the southern margin of the Snake River Plain in south-central Idaho. Intensive ground-water development for irrigation has resulted in rapid water-level declines and, as a consequence, designation by the State of four Critical Ground-Water Areas.

Principal aquifers are in limestone, rhyolite, basalt, and alluvium. Annual water-level declines range from 3 feet to about 5 feet. Recharge to the ground-water system is from infiltration of surface water used for irrigation, precipitation on the surrounding mountains, infiltration of localized runoff, and upward movement of thermal water. Ground-water pumpage during the period 1979-84 averaged 173,000 acre-feet per year.

Surface and ground water is predominantly a calcium bicarbonate type with variable concentrations of dissolved solids. Comparisons of silica and chloride concentrations and isotopic composition of ground water were useful in determining areal extent of aquifers and movement of ground water.

A three-dimensional mathematical model of the Oakley Fan area was developed. The aquifer system was simulated in three phases: (1) Average 1979-84 hydrologic conditions, (2) 1910 hydrologic conditions, and (3) 1910-84 hydrologic conditions. Model simulation indicated that, for the period 1945-79, subsurface outflow declined from 327,000 acre-feet per year to 215,000 acre-feet per year. Simulated ground-water pumpage during the period 1945-79 was 3,000,000 acre-feet; simulated change in storage was 250,000 acre-feet. Simulations with the model approximate natural conditions and probably can be used to evaluate future changes in the hydrologic system.

INTRODUCTION

Eight areas in southern Idaho have been designated by the Idaho Department of Water Resources as Critical Ground-Water Areas. Areas so designated typically exhibit prominent declines in ground-water levels and are closed to further unrestricted ground-water development. The Oakley Fan in west Cassia and northeastern Twin Falls Counties includes four Critical Ground-Water Areas (pl. 1): (1) Artesian City, established in 1962; (2) Cottonwood, established in 1962; (3) Oakley-Kenyon, established in 1962; and (4) West Oakley Fan, established in 1982.

Ground-water levels in the Oakley Fan area have continued to decline even with restricted ground-water development. Since about 1976, water levels have declined as much as 5 ft/yr. Pumping lifts in the area are commonly about 400 ft, and continued water-level declines could soon render pumping of ground water for irrigation economically unfeasible. Because irrigated agriculture and associated processing of agricultural products are major economic activities in the area, continued water-level declines are of great concern to residents.

As a result of this concern, the Southwest Irrigation District was formed to consider the feasibility of artificially recharging aquifers in the Oakley Fan area. In anticipation of an artificial recharge program, the U.S. Geological Survey, in cooperation with the Southwest Irrigation District, conducted a mass well inventory and water-level measurement program. In March and April of 1984, water levels in about 500 wells were measured as part of this preliminary work; the existing observation-well network in the area was expanded from 15 to 30 wells, and water-level measurements were obtained monthly throughout the rest of 1984.

Results of the mass well inventory and water-level measurement program were published in the summer of 1984 (Young, 1984). These preliminary data indicate that the Oakley Fan area is hydrologically and geologically complex. The ground-water system comprises at least four aquifers, and several faults displace water-bearing rock or act as barriers to the movement of ground water.

A more detailed study was begun to define the geohydrology of the Oakley Fan area so a ground-water model could be developed before an artificial recharge program began.

Purpose and Scope

The U.S. Geological Survey undertook this 2½-year study, results of which are presented in this report, as part of a continuing cooperative program of water-resource investigations in the State of Idaho. The study was designed to meet the needs of the Southwest Irrigation District in considering the feasibility of artificially recharging aquifers in the Oakley Fan area. Specific purposes of the study were to: (1) Examine available data needed to describe geohydrology of the area; and (2) develop a ground-water model that could be used to evaluate effects of present and future water-management practices on the aquifer systems.

The major emphasis of the study was development of the ground-water flow model. Work accomplished during the investigation included: (1) Collection of periodic water-level data from 33 wells; (2) determination of the volume of ground-water pumpage for irrigation; (3) study of the relation between surface- and ground-water systems; (4) appraisal of surface- and ground-water chemistry; (5) geochemical mapping; (6) collection of streamflow data on seven streams; and (7) development and calibration of a ground-water flow model.

Location and Geographic Features

The Oakley Fan area is a broad, crescent-shaped lowland along the southern margin of the Snake River Plain in south-central Idaho (pl. 1). The western part of the fan includes Big Cottonwood and Dry Creeks, which drain the northern part of the Rock Creek Hills and flow into Murtaugh Lake. The central and eastern parts of the fan include the northern part of Goose Creek basin. Goose Creek, a southern tributary to the Snake River, drains parts of northwestern Utah and northeastern Nevada. The flat surface of the Oakley Fan is broken occasionally by broad volcanic domes, called buttes, which rise several hundred feet above the plain.

The fan slopes gently northward from an altitude of 4,584 ft above sea level at Oakley to an altitude of 4,165 ft at Burley on the east and an altitude of 4,082 ft at Murtaugh on the west. The fan is bounded on the southeast by the Albion Mountain Range (pl. 1), which rises to an altitude of 10,339 ft at Cache Peak and, on the southwest, by the Rock Creek Hills (pl. 1), which rise to an altitude of 8,050 ft at Monument Peak. The Snake River is the northern boundary of the fan.

Previous Studies

Numerous reports have been written describing various aspects of ground-water hydrology of the Oakley Fan area. Some of the earliest geologic and hydrologic studies were done by Piper (1923); Anderson (1931); Stearns, Crandall, and Steward (1938); Crosthwaite (1957); and Mundorff, Crosthwaite, and Kilburn (1964). Data on wells from drillers' logs were compiled by West and Fader (1952) and Mower (1953), and unpublished data were collected by the U.S. Geological Survey.

The most recent reports of the Oakley Fan area were those of Crosthwaite (1969), Edwards and Young (1984), Young (1984), and Burrell (1987). Crosthwaite's report included the Goose Creek and Rock Creek basins, which encompass the entire Oakley Fan area. Much of the initial information on ground-water hydrology of the Oakley Fan area used in this report was based on Crosthwaite's investigation. Edwards and Young (1984) described ground-water conditions in the Cottonwood and West Oakley Fan Critical Ground-Water Areas. Young (1984) presented the most current ground-water information available for the Oakley Fan area. This map report includes potentiometric surface contours, directions of ground-water movement, and delineation of perched-water zones. Young (1983) and Young and Norvitch (1984) documented ground-water level trends and rates of water-level declines in the Oakley Fan area. Burrell (1987) developed a computer program to calculate recharge in the Oakley Fan area.

Acknowledgments

We are grateful to the many landowners in the Oakley Fan area who allowed access to their property so water-level measurements could be obtained, and who supplied well construction information and hydrologic data pertaining to their wells. Officials and employees of Idaho Power Company supplied power records needed for computation of pumpage volumes. Special thanks go to Mr. Kent Foster, U.S. Department of Agriculture, Soil Conservation Service, for his help in this study.

U.S. Geological Survey Numbering Systems

The well- and spring-numbering system (fig. 1) used by the U.S. Geological Survey in Idaho indicates the location of wells or springs within the official rectangular subdivision of public lands, with reference to the Boise Meridian and base line. The first two segments of the number desig-

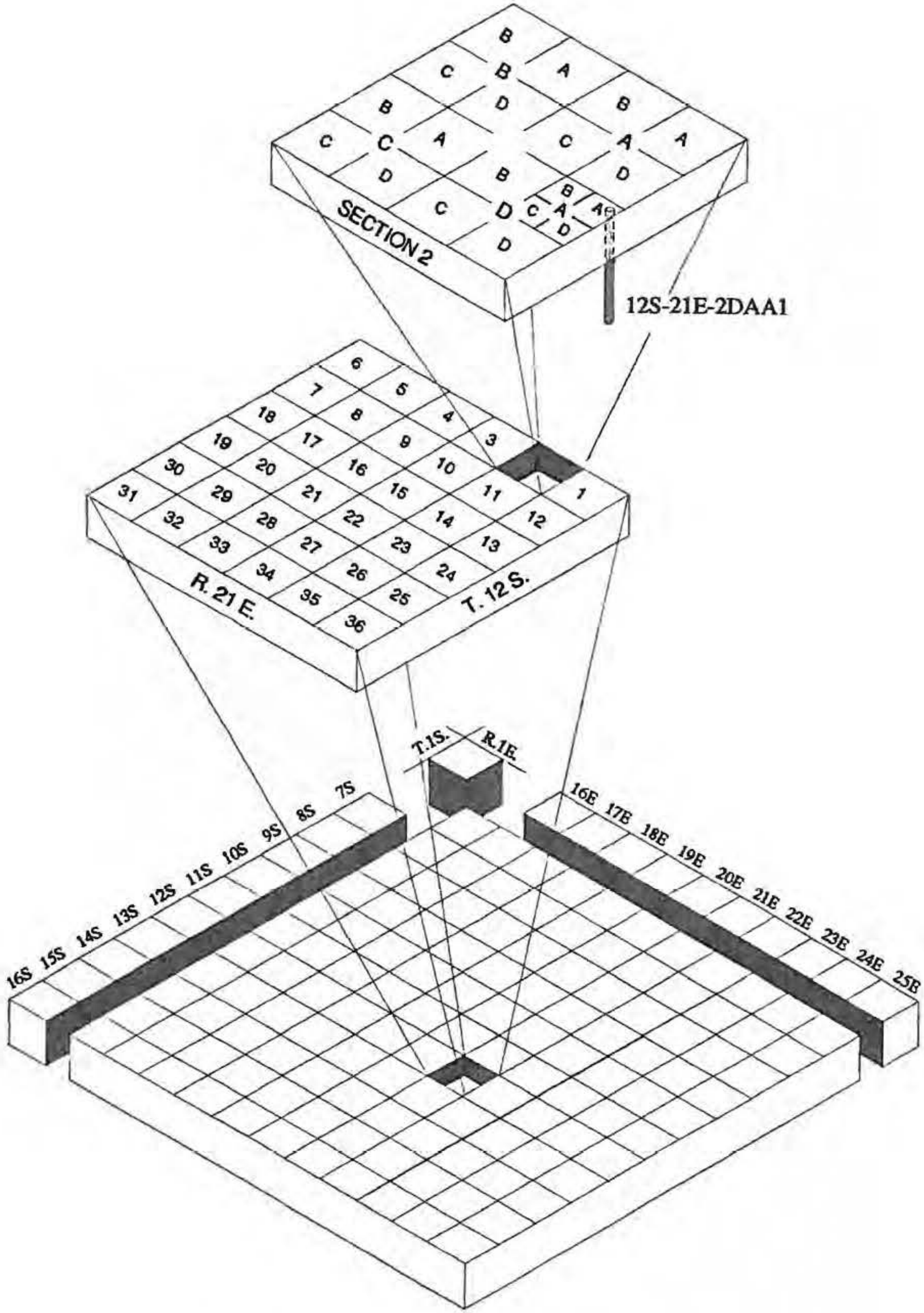


Figure 1.--Well- and spring-numbering system.

nate the township (north or south) and range (east or west). The third segment gives the section number; three letters, which indicate the ¼ section (160-acre tract), ¼-¼ section (40-acre tract), and ¼-¼-¼ section (10-acre tract); and serial number of the well within the tract.

Quarter sections are designated by the letters A, B, C, and D in counterclockwise order from the northeast quarter of each section. Within quarter sections, 40-acre and 10-acre tracts are lettered in the same manner. For example, well 12S-21E-2DAA1 is in the NE¼NE¼SE¼ sec. 2, T. 12 S., R. 21 E., and was the first well inventoried in that tract. Springs are designated by the letter "S" following the last numeral; for example, 13S-23E-8BCC1S.

Each surface-water gaging station has been assigned a number in downstream order in accordance with the permanent numbering system used by the U.S. Geological Survey. Numbers are assigned in a downstream direction along the main stream, and stations on tributaries between main-stream stations are numbered in the order that the tributaries enter the main stream. A similar order is followed on other ranks of tributaries. The complete 8-digit number, such as 13088510, which is used for the station "Big Cottonwood Creek near Oakley," includes the part number "13," which indicates that Big Cottonwood Creek is in the Snake River basin, plus a 6-digit station number.

GEOLOGY

Lithology

Geologic units in the Oakley Fan area are: (1) Undifferentiated pre-Tertiary rocks, (2) Tertiary silicic volcanics (locally called rhyolite), (3) Quaternary and Tertiary basalts, and (4) Quaternary alluvium. Water-bearing characteristics of each unit are discussed in the section, "Ground-Water Hydrology." Areal distribution is shown on plate 2.

Pre-Tertiary rocks consist mostly of dense, massive quartzite, schist, and marble in the Albion Mountain Range, and limestone, shaly, cherty limestone, quartzite, sandstone, and shale in the Rock Creek Hills. Limestone underlies most of the Cottonwood Critical Ground-Water Area. This rock unit also underlies the Tertiary silicic volcanics in the West Oakley Fan Critical Ground-Water Area and is thought to underlie most of the southern half of the study area. Total thickness of the unit is unknown.

Tertiary silicic volcanics consist mostly of welded ash flows, bedded tuffs, and lava flows of rhyolitic and latitic composition. Individual flows are dense; many are massive and commonly vesicular and are generally reddish-brown, gray, or black. Jointing ranges from platy to columnar. The tuffs or ash beds are fine to coarse grained and generally light colored. The silicic volcanics also include some interbedded silt, sand, and gravel beds, and may include some Tertiary sediments of the Miocene and Pliocene Salt Lake Formation. The unit is exposed throughout the Rock Creek Hills and forms a prominent ridge east of Oakley and The Knolls (locally called Churchill Knolls). The silicic volcanics underlie most of West Oakley Fan, Oakley-Kenyon, and Artesian Critical Ground-Water Areas. The unit generally has not been identified in well logs north of the line between townships 11 and 12 south because of lack of deep wells. Total thickness of the unit may exceed 2,500 ft.

Quaternary and Tertiary basalts consist mostly of light to dark gray olivine basalts. Individual flows range from dense to vesicular, aphanitic to porphyritic, and irregular to widely columnar jointed. Thickness of individual flows ranges from a few feet to several tens of feet. Included in the unit are basaltic cinders and rubbly basalt at the bottom and top of individual flows. Some interbedded sediments, mostly clay, sand, and gravel, are included in the unit. The unit is exposed in the northern part of the Oakley Fan area, where it is generally covered by a thin layer of windblown deposits. The basalts overlie the Tertiary silicic volcanics and underlie the Quaternary alluvium. In the northern part of the Oakley Fan area, the basalt flows interfinger with the Quaternary alluvium. Thickness of the unit is variable but generally does not exceed 600 ft.

Quaternary alluvium consists mostly of clay, silt, sand, and gravel. The unit is unconsolidated to well compacted and is poorly sorted. The unit also includes windblown deposits which cover most of the Oakley Fan area. South of Burley, alluvium deposited by the Snake River interfingers with alluvium deposited by Goose Creek. Outwash from streams has created other extensive alluvial deposits along the margins of the Oakley Fan. Neither basalt nor silicic volcanics were encountered in a 1,000-ft well (13S-22E-21CCD2, pl. 1) several miles north of Oakley. Absence of these units may indicate filling of an ancestral channel of Goose Creek by alluvial deposits. Thickness of the Quaternary alluvium is highly variable but generally ranges from less than 1 to 300 ft.

Structure

Several faults strongly influence the movement of ground water in the Oakley Fan (pl. 3). The faults form barriers to lateral movement when permeable rock on one side has been displaced so that it lies opposite less permeable rock on the other side, or when the fractured area along the fault is filled with impermeable material.

The most obvious evidence of faulting is Churchill Knolls, a rhyolitic butte in section 20, T. 12 S., R. 22 E. (pl. 2). The southwest side of the butte is a fault escarpment approximately 100 ft high. Geologic interpretations from drillers' logs indicate that this partially buried fault block has risen more than 300 ft relative to rocks on the other side of the fault. Evidence of the Churchill Knolls fault to the northwest is not present at land surface; however, lithologic discontinuities evident in drillers' logs and variable ground-water levels indicate that the fault may extend to the Snake River. Water levels on the southwest side of the fault are as much as 100 ft higher than those on the northeast side in the vicinity of the Churchill Knolls.

Foothills Road is nearly coincident with the Foothills Road fault, which displaces the limestone downward to the northeast (Anderson, 1931, p. 23-67). Water levels on the southwest side of the fault are as much as 300 ft higher than those on the northeast side of the fault. The Foothills Road fault, which parallels the Churchill Knolls fault, may be truncated by a more westerly trending fault(s) along the base of the foothills south of Murtaugh Lake.

SURFACE-WATER HYDROLOGY

Climate and Precipitation

Climate in the Oakley Fan area ranges from semiarid in the lowlands to subhumid in the mountains. Variation in climatic conditions is caused primarily by topographic relief.

Mean annual temperatures recorded by the National Weather Service are 49.6 °F (9.8 °C) at Burley (altitude 4,146 ft) and 48.7 °F (9.3 °C) at Oakley (altitude 4,600 ft). Mean monthly temperatures at Burley (fig. 2) range from 26.6 °F (-3 °C) in January to 73.8 °F (23.2 °C) in July. Mean monthly temperatures at Oakley (fig. 2) range from 27.5 °F (-2.5 °C) in January to 69.2 °F (20.7 °C) in July. The average frost-free growing season is 123 days at Oakley and 147 days at Burley.

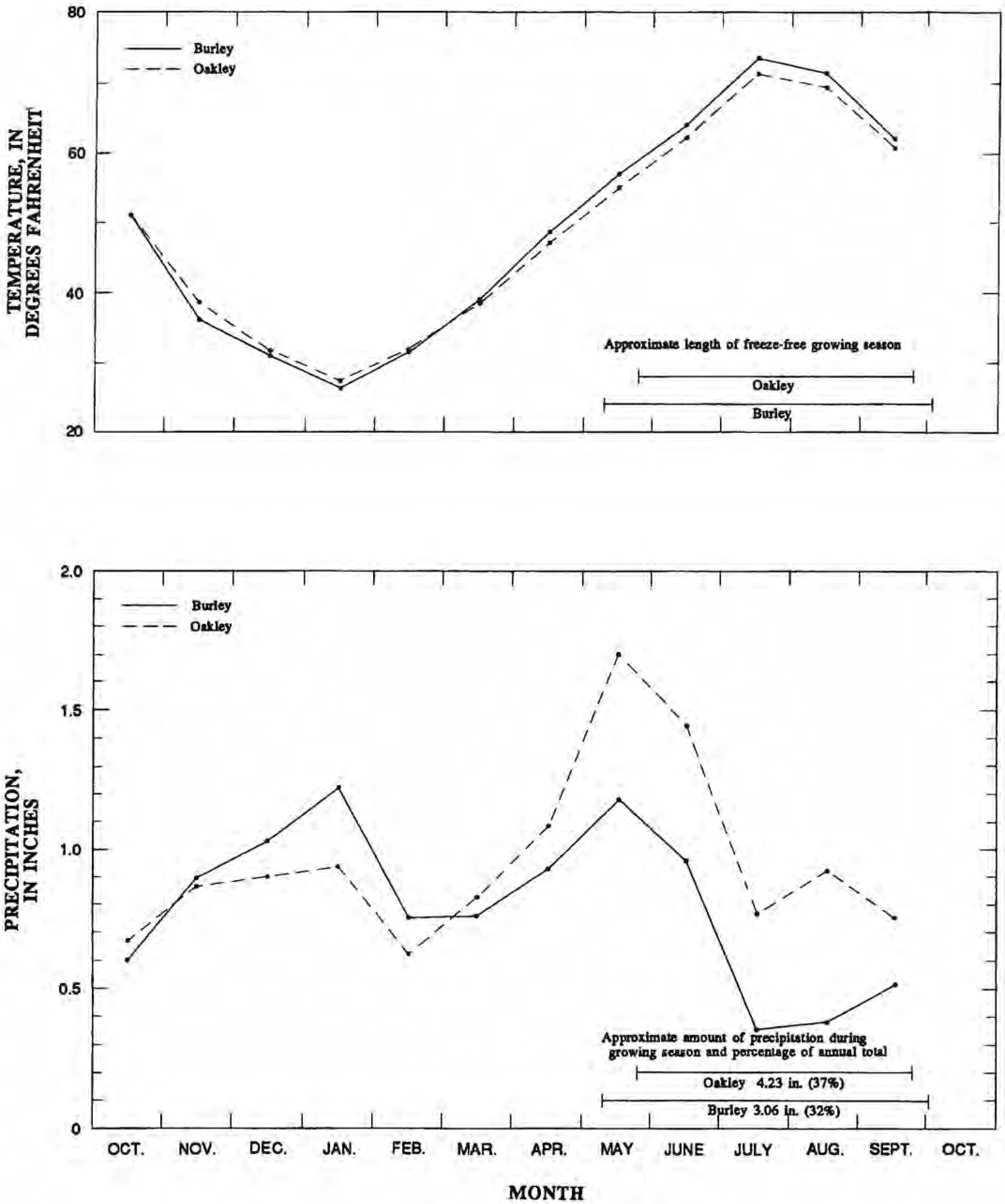


Figure 2.--Mean monthly temperature (1931-60) and precipitation (1951-80) at selected stations.
(Values based on data from National Weather Service)

Mean annual precipitation ranges from about 10 in. on the Oakley Fan to about 55 in. on nearby mountains (Thomas and others, 1963). Months with the highest precipitation (fig. 2) are May and June at Oakley and January and May at Burley. Months with the lowest precipitation are February at Oakley and July at Burley. The amount of precipitation during the frost-free growing season on the Oakley Fan ranges from 4.23 in. at Oakley (37 percent of the mean annual) to 3.06 in. at Burley (32 percent of the mean annual).

Streamflow

All available surface water in the Oakley Fan area is used for irrigation or infiltrates into the ground-water systems. Monthly discharge measurements provide a way of determining a stream's seasonal flow distribution and mean annual runoff. Monthly discharge measurements were made during the period August 1984 to December 1986 on seven streams in the Oakley Fan area. Locations of these sites are shown on plate 1 and measured discharges are listed in table 1.

The monthly measurements were used to estimate the monthly mean discharge for seven sites by a method described by Riggs (1969), which correlates the measured monthly discharge of a stream concurrently with the mean daily discharge at a nearby continuous-recording stream gage. Discharge values from the continuous-recording gage on Trapper Creek were used for correlation with other streams in the Oakley Fan. The resultant estimates of monthly mean discharges for the 1985 water year for the seven selected streams are given in table 2.

The process used to convert the monthly mean discharges for 1985 water year to the mean monthly discharge for each stream in table 2 is as follows: (1) The monthly mean discharges developed by the Riggs method were used to determine annual mean discharge for the 1985 water year; (2) the annual mean discharge then was adjusted to a mean annual discharge by assuming the same relation of 1985 annual mean to mean annual exists at the measurement site and the correlation station; (3) the mean monthly discharge for each month was estimated by a percentage of the mean annual flow for each month as determined by the nearby station record. The mean annual runoff for each stream was computed and is given in table 2. For example, table 2 indicates that highest mean monthly discharge for Big Cottonwood Creek was 21 ft^3/s in May. Mean monthly runoff for Big Cottonwood Creek in May was 1,300 acre-ft and mean annual runoff was 7,200 acre-ft.

Table 1.--Monthly discharge, specific conductance, and water temperature measurements for selected streams, 1984-86

[--, no data available]

Station number (locations shown on pl. 1)	Station name	Date of sample	Discharge, instantaneous (ft^3/s)	Specific conductance ($\mu S/cm$)	Temperature (°C)
13083000	Trapper Creek near Oakley	1-19-84	11	208	5.5
		2-10-84	15	256	4.0
		3-22-84	20	216	9.0
		4-19-84	37	177	9.0
		5-10-84	66	169	10.0
		5-15-84	146	153	6.0
		6-12-84	72	144	9.5
		7-18-84	27	179	18.0
		8-22-84	13	255	17.0
		10- 1-84	13	255	12.5
		11- 6-84	17	268	7.0
		12-12-84	16	236	1.5
		1-15-85	16	262	.5
		3- 6-85	16	264	6.5
		4- 2-85	20	239	11.0
		5- 8-85	37	176	10.5
		6-12-85	17	193	14.0
		7-31-85	13	261	15.0
		8-21-85	11	259	21.5
		8-26-85	12	297	16.0
		9-10-85	13	254	12.0
		10-17-85	14	275	6.5
		12- 5-85	14	258	4.0
		1-15-86	13	273	4.0
		2-18-86	49	166	6.0
		3- 3-86	36	201	6.0
		4- 8-86	44	182	7.5
		5-13-86	41	168	9.0
		7- 2-86	13	250	17.5
		8-11-86	13	240	18.0
13084400	Birch Creek above Feeder Canal near Oakley	8-14-84	8.9	353	17.5
		9-17-84	6.0	375	17.5
		10-18-84	7.8	397	5.0
		11-20-84	6.0	377	4.0
		12-19-84	6.3	367	--
		1-22-85	6.2	333	3.5

Table 1.--Monthly discharge, specific conductance, and water temperature measurements for selected streams, 1984-86--Continued

Station number (locations shown on pl. 1)	Station name	Date of sample	Discharge, instantaneous (ft ^{3}/s)	Specific conductance (µS/cm)	Temperature (°C)
13084400	Continued	2-12-85	6.5	364	4.0
		3-20-85	12	360	6.0
		4-16-85	23	263	13.0
		5-14-85	17	252	8.0
		6-11-85	11	286	16.0
		7-17-85	4.2	334	25.0
		8-13-85	3.1	353	19.5
		9-19-85	3.9	310	19.0
		10-17-85	4.4	379	9.0
		11-18-85	5.4	384	.5
		12-11-85	4.9	393	0
		1-23-86	6.3	359	2.0
		2-12-86	5.9	355	2.0
		3-18-86	15	273	6.5
		4-15-86	36	234	10.5
		5-20-86	32	229	15.0
		6-19-86	13	274	18.0
		7-17-86	6.8	341	—
		8-20-86	4.7	379	19.0
		9-18-86	5.7	355	—
13084630	Land Creek near Burley	8-16-84	1.6	298	14.0
		9-18-84	1.3	294	17.0
		10-18-84	1.2	314	4.0
		11-20-84	1.3	279	4.0
		12-19-84	1.2	283	0
		1-22-85	1.1	221	3.5
		2-12-85	1.6	252	3.0
		3-20-85	4.3	150	5.5
		4-16-85	9.1	125	10.0
		5-14-85	3.8	161	7.5
		6-11-85	2.3	216	11.5
		7-17-85	1.1	235	21.0
		8-13-85	.88	270	15.0
		9-19-85	.92	237	11.5
		10-17-85	.83	335	9.5
		11-14-85	.93	299	3.0
		12-10-85	1.0	226	0
		1-23-86	1.2	240	2.5
		2-12-86	1.8	205	3.0
		3-18-86	3.4	169	8.5

Table 1.--Monthly discharge, specific conductance, and water temperature measurements for selected streams, 1984-86--Continued

Station number (locations shown on pl. 1)	Station name	Date of sample	Discharge, instantaneous (ft^3/s)	Specific conductance (µS/cm)	Temperature (°C)
13084630	Continued	4-15-86	5.2	125	9.0
		5-20-86	9.8	129	14.0
		6-20-86	3.7	216	10.0
		7-17-86	1.5	248	—
		8-20-86	1.3	294	13.5
		9-18-86	.77	283	—
13088400	Dry Creek near Artesian City	8-15-84	3.2	136	20.0
		9-17-84	1.8	123	17.5
		10-19-84	2.6	138	6.0
		11-21-84	3.1	137	6.0
		12-20-84	2.6	122	1.0
		1-23-85	2.2	119	3.0
		2-13-85	2.2	118	4.0
		3-21-85	18	120	4.5
		4-17-85	89	88	7.0
		5-14-85	28	84	6.5
		6-12-85	7.3	97	11.0
		7-18-85	1.5	113	15.5
		8-16-85	.6	130	18.0
		9-18-85	.93	109	13.0
		10-15-85	1.4	157	11.5
		11-15-85	.95	133	6.0
		12-12-85	1.6	128	3.0
		1-24-86	8.2	121	3.0
		2-12-86	5.0	119	5.0
		3-18-86	19	108	2.5
		4-16-86	47	—	8.0
		5-20-86	41	—	10.0
		6-19-86	7.3	108	17.0
		7-17-86	2.1	119	—
		8-20-86	.66	133	15.0
		9-19-86	1.5	129	21.0
		11-18-86	1.8	—	—
		12-17-86	3.6	113	—
13088525	Big Cedar Creek near Oakley	8-16-84	.03	282	14.0
		4-16-85	6.9	149	1.0
		5-13-85	3.7	130	12.0
		6-11-85	.76	144	16.5
		3-18-86	1.1	163	3.0
		4-16-86	3.4	128	5.5
		5-20-86	2.6	129	13.0
		6-19-86	.36	149	18.0
13084590	Mill Creek near Basin	8-15-84	—	140	14.0
		9-18-84	.78	191	15.0

Table 1.--Monthly discharge, specific conductance, and water temperature measurements for selected streams, 1984-86--Continued

Station number (locations shown on pl. 1)	Station name	Date of sample	Discharge, instantaneous (ft^3/s)	Specific conductance ($\mu S/cm$)	Temperature (°C)
13084590	Continued	10-18-84	1.8	163	1.5
		11-20-84	1.5	161	1.5
		12-19-84	1.2	161	0
		1-22-85	1.1	156	1.5
		2-12-85	.49	161	1.5
		3-20-85	.96	161	3.0
		4-16-85	8.2	114	7.5
		5-14-85	9.9	75	5.0
		6-11-85	9.7	69	8.0
		7-17-85	1.8	116	20.0
		8-13-85	.72	131	15.0
		8-22-85	.70	141	12.0
		9-19-85	.76	123	10.0
		10-17-85	1.0	167	5.5
		11-14-85	.94	160	0
		12-10-85	.92	147	0
		1-23-86	.83	152	0
		2-12-86	.74	155	0
		3-18-86	2.1	139	3.0
		4-15-86	6.6	127	7.0
		5-20-86	20	97	11.0
		6-19-86	22	59	11.0
		7-18-86	2.3	113	--
		8-20-86	.66	157	15.0
		9-18-86	1.4	141	--
13088510	Big Cottonwood Creek near Oakley	8-14-84	6.1	139	14.0
		9-17-84	2.3	164	17.5
		10-18-84	3.4	121	6.0
		11-19-84	3.6	137	5.0
		12-19-84	2.9	135	.5
		1-22-85	2.1	128	3.0
		2-13-85	2.5	123	3.0
		3-20-85	4.5	116	7.0
		4-16-85	57	72	10.0
		5-13-85	50	72	10.5
		6-11-85	15	84	15.0
		7-18-85	4.	112	21.0
		8-16-85	1.7	133	18.0
		9- 4-85	.5	171	13.5
		9-17-85	2.2	121	13.0
		10-16-85	2.3	129	11.0
		11-18-85	2.9	142	3.0
		12-11-85	1.2	138	1.0
		1-22-86	2.5	119	3.0
		2-11-86	2.7	117	2.0

Table 1.--Monthly discharge, specific conductance, and water temperature measurements for selected streams, 1984-86--Continued

Station number (locations shown on pl. 1)	Station name	Date of sample	Discharge, instantaneous (ft^3/s)	Specific conductance (μS/cm)	Temperature (°C)
13088510	Continued	3-18-86	12	93	5.0
		4-15-86	62	71	9.0
		5-20-86	78	65	12.5
		7-22-86	3.4	115	—
		8-19-86	1.6	138	18.5
		9-18-86	1.7	129	—
		11-18-86	2.6	—	—
		12-16-86	1.8	112	—
13084650	Willow Creek near Burley	8-16-84	3.9	94	11.5
		9-18-84	3.2	94	17.5
		10-19-84	5.6	94	5.0
		11-20-84	4.5	97	3.5
		12-19-84	4.8	91	1.0
		1-22-85	4.4	87	3.5
		2-12-85	4.2	92	4.0
		3-20-85	3.4	101	4.5
		4-16-85	5.1	116	9.0
		5-14-85	5.2	101	6.0
		6-11-85	8.3	73	8.0
		7-17-85	5.1	80	13.0
		8-13-85	4.2	88	11.0
		8-22-85	4.4	88	8.0
		9-19-85	3.3	74	11.0
		10-17-85	2.8	103	9.5
		11-14-85	3.0	99	2.0
		12-10-85	4.0	87	0
		1-23-86	3.8	89	3.5
		2-12-86	4.0	93	3.0
		3-18-86	3.7	96	7.0
		4-15-86	3.7	96	7.0
		5-22-86	7.3	94	5.0
		6-20-86	14	72	8.0
		7-17-86	7.7	82	—
		8-20-86	5.9	89	10.0
		9-18-86	5.4	86	—
		11-19-86	3.8	—	—
		12-17-86	3.6	78	—

Table 2.--Monthly mean and mean monthly discharge and mean monthly runoff for selected streams, 1985 water year

[Discharge in cubic feet per second; runoff in acre-feet]

Station number and name (locations shown on pl. 1)			Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Annual 1985	Mean annual	Mean annual runoff (rounded)
13084400	Birch Creek above feeder canal near Oakley	Monthly mean 1985	7.2	6.0	6.6	6.5	6.9	11	19	16	11	5.1	3.2	4.0	8.5		
		Mean monthly	5.2	5.5	5.4	5.5	6.7	7.2	11	16	12	6.2	4.9	4.9		7.5	
		Mean monthly runoff	320	330	330	340	370	440	640	960	690	380	300	290			5,400
13084590	Mill Creek near Basin	Monthly mean 1985	1.6	1.6	1.3	1.2	.52	.90	6.6	9.4	9.6	2.1	.73	.78	3.0		
		Mean monthly	1.8	2.0	1.9	1.9	2.4	2.5	3.8	5.5	4.1	2.2	1.7	1.7		2.6	
		Mean monthly runoff	110	120	120	120	130	160	230	340	240	130	110	100			1,900
13084630	Land Creek near Burley	Monthly mean 1985	1.1	1.3	1.3	1.2	1.6	4.0	6.5	3.6	2.2	1.4	.90	.95	2.2		
		Mean monthly	1.3	1.4	1.4	1.4	1.7	1.9	2.8	4.1	3.0	1.6	1.3	1.3		1.9	
		Mean monthly runoff	82	86	86	87	97	110	170	250	180	98	78	76			1,400
13084650	Willow Creek near Burley	Monthly mean 1985	5.2	4.5	4.9	4.6	4.5	3.2	4.1	5.0	8.3	6.2	4.3	3.4	4.8		
		Mean monthly	2.9	3.1	3.0	3.0	3.7	4.0	6.0	8.7	6.4	3.4	2.7	2.7		4.2	
		Mean monthly runoff	180	180	180	190	210	250	360	530	380	210	170	160			3,000
13088400	Dry Creek near Artesian City	Monthly mean 1985	2.4	3.2	2.4	2.4	2.3	16	70	27	7.3	1.6	.61	.89	11		
		Mean monthly	6.9	7.4	7.2	7.3	9.0	9.6	14	21	15	8.2	6.5	6.6		10	
		Mean monthly runoff	420	440	440	450	500	590	860	1,300	920	500	400	390			7,200
13088510	Big Cottonwood Creek near Oakley	Monthly mean 1985	3.1	3.6	3.0	2.2	2.7	4.2	46	46	14	4.4	1.7	2.3	11		
		Mean monthly	6.8	7.4	7.2	7.3	8.9	9.4	17	21	15	8.2	6.5	6.6		9.9	
		Mean monthly runoff	420	440	440	450	500	590	860	1,300	920	500	400	390			7,200
13088525	Big Cedar Creek near Oakley	Monthly mean 1985	0	0	0	0	0	0	5.6	3.4	.76	0	0	0	.81		
		Mean monthly	0	0	0	0	0	0	2.4	3.6	2.6	0	0	0		.72	
		Mean monthly runoff	0	0	0	0	0	0	150	220	160	0	0	0			520

GROUND-WATER HYDROLOGY

Occurrence and Movement

Principal aquifers in the Oakley Fan area are limestone (pre-Tertiary rocks map unit, undifferentiated); rhyolite (Tertiary silicic volcanics map unit); basalt (Quaternary and Tertiary basalts map unit); and alluvium (Quaternary alluvium map unit). Ground water is present primarily under confined conditions in the limestone and rhyolite, under unconfined conditions in the basalt, and in unconfined perched zones in the alluvium. Water is contained in fractures and weathered zones in the limestone; in fractures, voids, joints, and sedimentary interbeds in the rhyolite and basalt; and in intergranular spaces in the alluvium.

The general direction of ground-water movement can be inferred from the potentiometric surface. Movement is down the hydraulic gradient and roughly perpendicular to the potentiometric contours, from areas of recharge to areas of discharge. The potentiometric surface includes the surface of the water table where ground water is unconfined and includes the head in areas where ground water is confined.

Plate 3 shows potentiometric-surface contours and the general direction of ground-water movement in the Oakley Fan area (Young, 1984). The potentiometric surface was based on water levels measured in about 500 wells in March and April of 1984.

Water-Level Fluctuations

Ground-water levels decline in response to discharge from aquifers and rise in response to recharge. Fluctuations are significant on both short-term (seasonal) and long-term (yearly) bases. Hydrographs of seasonal water-level fluctuations can reveal the kinds of stresses on an aquifer, and hydrographs of long-term fluctuations can reveal the balance or imbalance between recharge and discharge.

Under natural conditions (no influence from pumping or irrigation), water levels are either relatively stable or start to rise in the spring in response to infiltration of snowmelt. This rise continues until early summer, then water levels gradually decline. The decline continues throughout fall and winter when recharge is insignificant.

The seasonal character of water-level fluctuations in agricultural areas is superimposed over natural fluctuations and depends on whether ground water or surface water is the principal source for irrigation. Where surface water is the source, ground-water levels start to rise after the beginning of an irrigation season, as some of the applied water percolates to the saturated zone. Water levels generally begin to decline shortly after the end of the irrigation season and continue to decline until the start of the next season. Where ground water is the principal source, water levels start to decline at the beginning of the irrigation season in response to pumping. The decline continues through the season until pumping ceases, then water levels generally recover gradually.

Hydrographs of water levels in selected wells are shown in figures 3 and 4. Well locations are shown on plate 1. The hydrographs in figure 3 show seasonal fluctuations for the period of study, whereas those in figure 4 indicate long-term trends.

Water-level fluctuations in the Oakley Fan area generally reflect ground-water pumping for irrigation. Hydrographs of wells 11S-22E-14DAC1, 13S-21E-4CCC1, and 13S-21E-6DAD1 (fig. 3) show seasonal fluctuations in an area of ground-water irrigation and are typical of wells completed in the basalt, rhyolite, and limestone aquifers, respectively. In contrast, well 13S-22E-32CCB1 shows fluctuations in an area of predominantly surface-water irrigation and is typical of wells completed in the perched alluvial aquifer near Oakley.

Hydrographs in figure 4 show long-term water-level records for selected wells. These long-term hydrographs indicate the imbalance between recharge and discharge in the aquifers underlying ground-water irrigated areas in the Oakley Fan. For the period 1976-83, water levels in the basalt aquifer (wells 11S-22E-32CCC1 and 11S-23E-34CDC1) declined about 3.5 to 3.0 ft/yr. Water levels in the rhyolite aquifer (well 12S-21E-2DAA1) declined about 4.5 ft/yr during the same period. Declines in the limestone aquifer (well 13S-21E-18BBC1) were about 25 ft/yr from 1961 to about 1969. Since then, the Idaho Department of Water Resources has regulated the amount of withdrawals and the rate of decline was about 5 ft/yr during the period 1976-83.

In about 1984, all hydrographs show a sharp break in the downward trends of the late 1970's and early 1980's (fig. 4), probably the result of above-normal precipitation in 1983-84. In addition to supplying more recharge to the aquifers, this above-normal precipitation caused a reduction

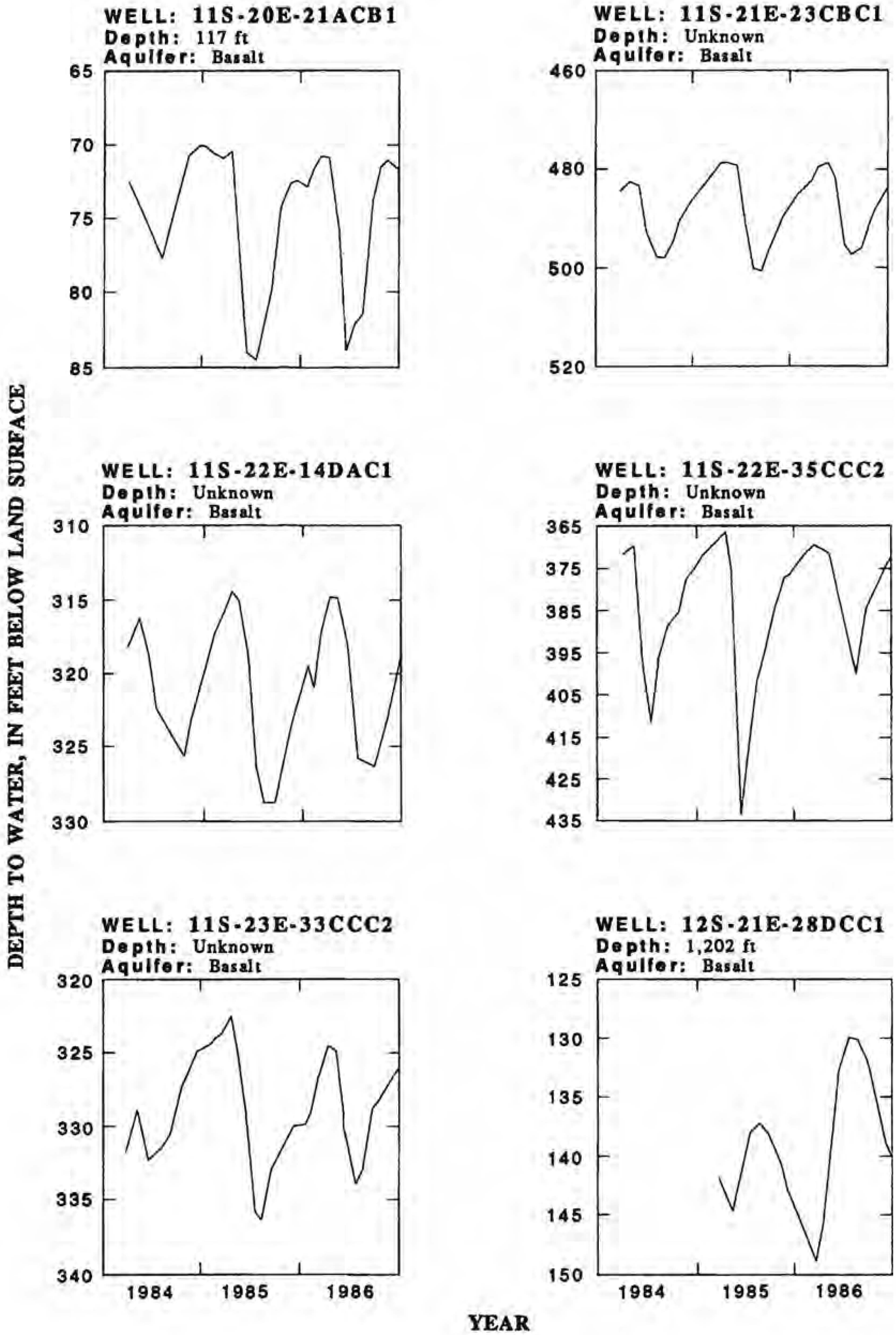


Figure 3.--Hydrographs of ground-water levels showing short-term fluctuations in selected wells. (Locations of wells shown on plate 1)

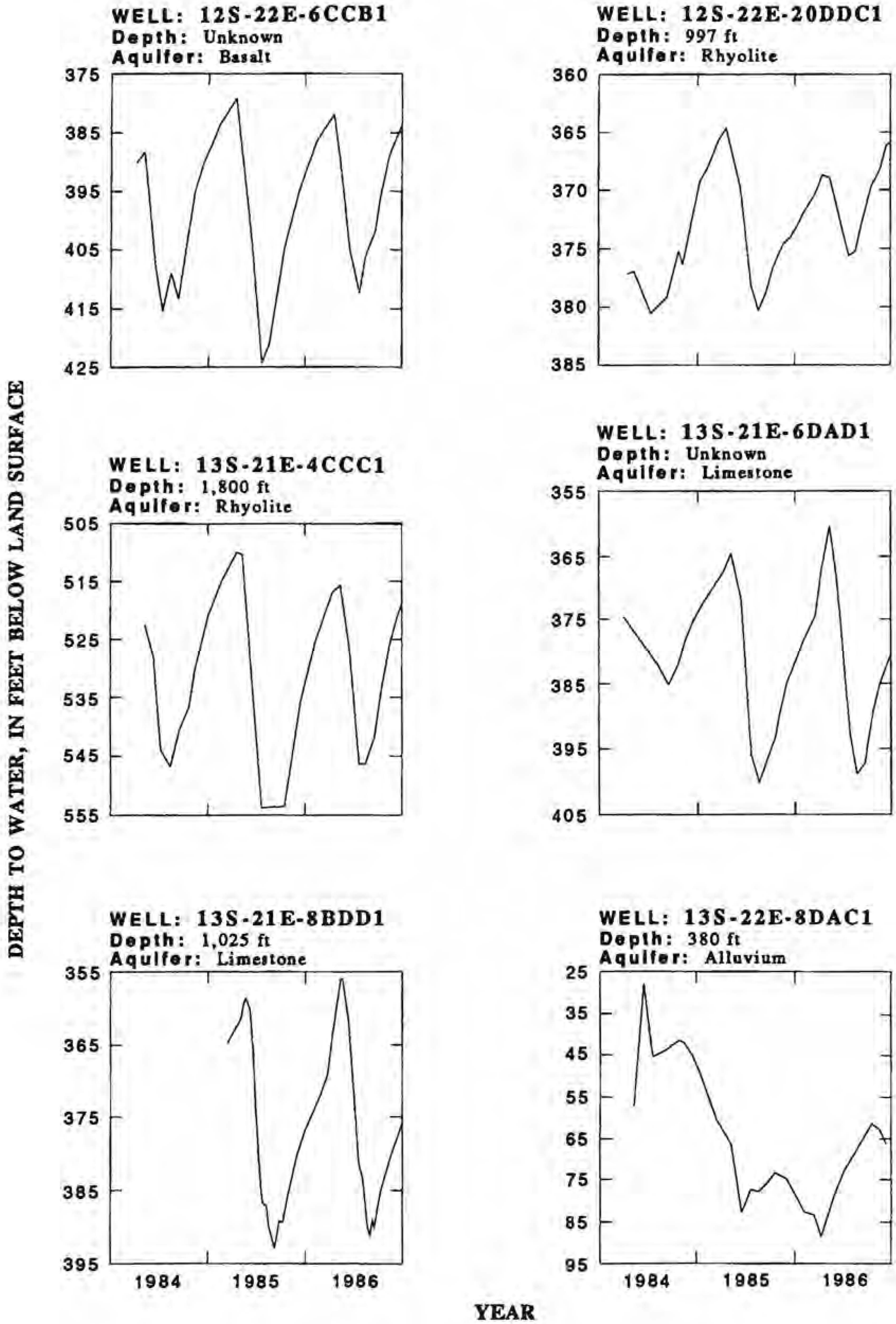


Figure 3.--Hydrographs of ground-water levels showing short-term fluctuations in selected wells--Continued.
(Locations of wells shown on plate 1)

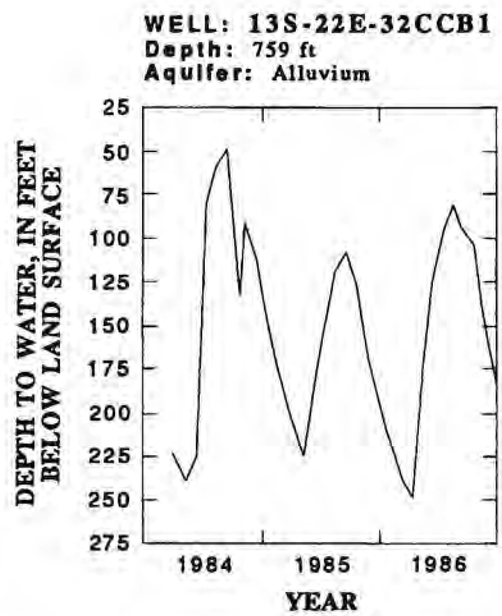


Figure 3.--Hydrographs of ground-water levels showing short-term fluctuations in selected wells--Continued.
(Locations of wells shown on plate 1)

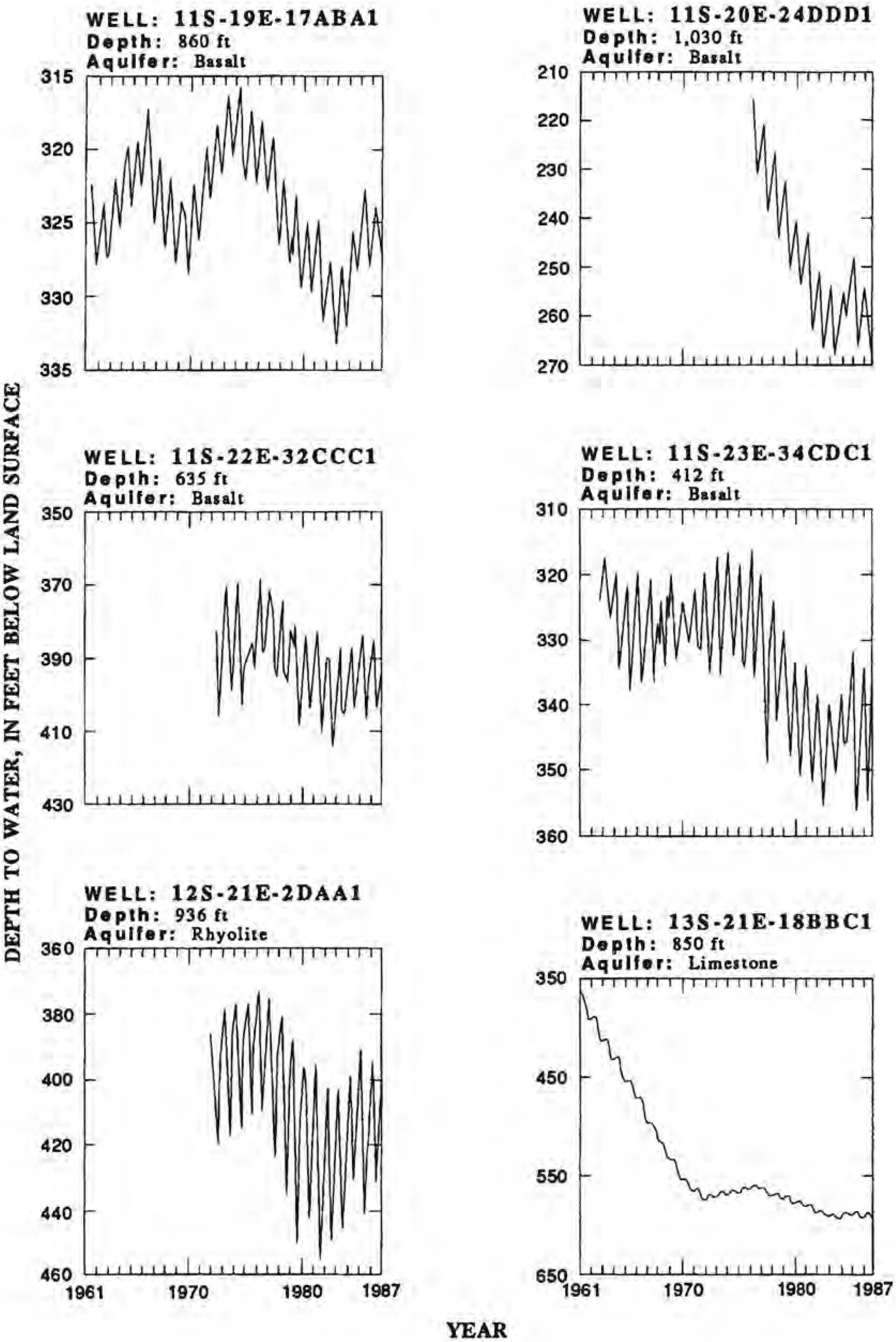


Figure 4.--Hydrographs of ground-water levels showing long-term fluctuations in selected wells.
(Locations of wells shown on plate 1)

in the amount of ground water pumped for irrigation (see section, "Pumpage"). However, it is apparent in hydrographs shown in figures 3 and 4 that by 1985, downward trends similar to those prior to 1983 had resumed.

Recharge

The main sources of recharge to aquifers in the Oakley Fan area are infiltration of surface water, which includes water used for irrigation and losses through drainage channels, streams, and lakebeds; precipitation on the surrounding mountains; and local runoff. An unknown but probably limited amount of recharge is from upward movement of thermal water.

The ground-water system underlying the northern part of the study area is recharged principally by irrigation water diverted from the Snake River. In the Burley Irrigation District, recharge is from leakage from the many irrigation canals, laterals, and ditches that cross the district and from downward percolation of applied irrigation water. Some downward-percolating water has encountered less permeable rock and has created several local perched-water zones in the Burley Irrigation District. Percolation of water that continues downward from these zones recharges the regional ground-water system.

Estimates of monthly ground-water recharge were made by Burrell (1987, p. 63-82) on the basis of data on surface-water diversions and ground-water pumpage, crop distribution, climate, canal and stream losses, and soil characteristics. An average annual recharge rate of 390,000 acre-ft was computed from Burrell's data for the period 1979-84. This estimate is similar to the estimate of 400,000 to 500,000 acre-ft obtained by Crosthwaite (1969, p. 27). Deep percolation was computed as a residual from surface-water gains and losses which accounted for flow in the unsaturated zone during periods of soil-moisture depletion. Table 3 summarizes annual recharge from irrigation and streamflow for the area south of the Snake River. Recharge data for the area north of the Snake River were modified from a report by Garabedian (in press). Most recharge is within the boundaries of the Burley and Milner Low-Lift Irrigation Districts (pl. 1).

Seepage from Murtaugh Lake also recharges the ground-water system. Seepage losses from Murtaugh Lake and a 2-mi reach of the J Canal were measured three times during the study. The following table summarizes the results:

Table 3.--Summary of recharge data in the study area south of the Snake River, 1979-84

Year	Pumpage (acre-feet)	Recharge (acre-feet)[1]	Net recharge (acre-feet)
1979	218,000	412,000	194,000
1980	159,000	390,000	231,000
1981	214,000	360,000	146,000
1982	183,000	388,000	205,000
1983	153,000	390,000	237,000
1984	127,000	400,000	273,000
Average	176,000	390,000	214,000

[1]Recharge was determined by Burrell, (1987, p. 64, 65).

Date	Seepage (ft^3/s)	Seepage for irrigation season (199 days) (acre-ft)	Inflow to Murtaugh Lake or flow in canal (ft^3/s)
		Murtaugh Lake	
6-18-85	21.4	8,450	3,530
8-17-85	24.3	9,590	3,640
9-18-84	49.4	19,500	2,720
		J Canal	
6-19-85	14.4	5,680	390
8-17-85	14.7	5,800	310
9-19-84	12.6	4,970	139

Seepage from Murtaugh Lake, in part, is related to ground-water pumpage. As ground-water levels decline during the irrigation season, seepage from the lake increases. Seepage from the J Canal also is controlled to some degree by the amount of water in the canal.

The Snake River gains from and loses to the ground-water system from Lake Walcott to near Murtaugh; however, the overall result is zero net gain or loss. The river from near Burley upstream to Lake Walcott gains from the perched ground-water system underlying the Burley Irrigation District and loses to the ground-water system downstream to near Murtaugh. Downstream from Murtaugh, the river enters a deep canyon and gains ground water.

The pre-Tertiary rocks and the Tertiary silicic volcanics exposed in the catchment areas of the surrounding mountains also compose the principal aquifers underlying the southern part of the study area. The principal source of recharge to these aquifers is precipitation in the mountains. The pre-Tertiary rocks and the Tertiary silicic volcanics accept snowmelt through fractures, joints, and other connected pores that eventually transmit water to the aquifers underlying the fan. Another source of recharge to the four principal aquifers of the Oakley Fan area is infiltration of runoff from many streams that drain the surrounding mountains.

Pumpage

Ground water is pumped for irrigation, municipal, rural domestic, and stock uses. Although pumpage for municipal, rural domestic, and stock uses was not computed as part of this study, the total quantity is negligible compared with quantity pumped for irrigation.

During most years, about 500 wells are pumped with electric motors to irrigate croplands in the Oakley Fan area. To calculate irrigation use, power records were obtained from the Idaho Power Company. By using the power-consumption data and by either measuring or estimating depth to water and the dynamic pressure head while the well is pumping, total seasonal pumpage can be computed by the equation:

$$Q_t = \frac{kWh}{1.8 \times (H + P)}$$

where

Q_t = total seasonal pumpage, in acre-feet;

kWh = total seasonal power consumed, in kilowatthours;

H = average depth to pumping water level, in feet;

P = average pressure head at the well, in feet of water; and

1.8 = the average amount of power, in kilowatthours, to lift 1 acre-ft of water 1 ft.

Water levels in about 30 wells were measured monthly during the 1984 irrigation season to determine pumping water levels and drawdown. On the basis of estimated drawdown values and nonpumping water-level measurements reported by Young (1984), values for pumping water levels were assigned to all wells in the study area. Pressure heads at the wells were estimated on the basis of water application method. Hand-line sprinkler systems were estimated at 70 psi, or 162 ft of water, at the well head, and pivot sprinkler systems were estimated at 90 psi, or 210 ft of water.

Ground-water pumpage for irrigation in the study area for the period 1979-84 is shown in table 4. Pumpage ranged from 218,000 acre-ft in 1979 to 127,000 acre-ft in 1984. The amount of annual pumpage directly affects long-term water-level fluctuations shown in figure 4. When pumpage is small, water levels are high; when pumpage is large, water levels are low.

Table 4.--Ground-water pumpage, 1979-84

[Values are in acre-feet]

Year	Critical Ground-Water Area: Oakley-Kenyon	West Oakley Fan	Artesian City	Cottonwood	Total (rounded)
1979	107,000	53,000	52,400	5,120	218,000
1980	69,800	40,900	45,300	3,400	159,000
1981	104,000	47,600	57,200	4,990	214,000
1982	84,200	45,200	49,200	4,710	183,000
1983	67,500	39,500	41,600	4,300	153,000
1984	53,900	31,100	39,700	2,280	127,000

WATER CHEMISTRY

Surface Water

Water samples were collected from five streams in the Oakley Fan area to define the chemistry of the local surface water. The samples were collected in August and September when streamflows were lowest. Chemical analyses are shown in table 5. Monthly specific conductance measurements for the period of study also are included in table 1.

Patterns for chemical composition of sampled streams are shown on plate 4. In addition, values of dissolved-solids concentrations are given above each pattern. Differences and similarities among selected water chemistries can be illustrated using a pattern method developed by Stiff (1951). In this method, three parallel horizontal axes extend on each side of a vertical central axis. Concentrations of the three principal cations (Na, K, Mg) are plotted, one on each horizontal axis to the left; likewise, concentrations of the three principal anions (Cl, HCO_3, SO_4) are plotted, one on each horizontal axis to the right. The concentrations are expressed in milliequivalents per liter. The resulting points are connected to form an irregular polygon, which is a distinctive identifier of water chemistry. The overall area of the polygon indicates the relative dissolved-solids concentration.

Plate 4 shows that surface water in the Oakley Fan area is chemically similar; dissolved-solids concentrations range from 55 mg/L at Willow Creek (station 13084650) to 240 mg/L at Birch Creek (station 13084400).

Ground Water

Samples were collected from 41 wells and 6 springs during this study (table 6) to define the chemistry of water underlying the Oakley Fan area. Chemical analyses of water from 12 wells sampled during previous studies also are included in table 6.

The chemical character of ground water in the Oakley Fan area, shown diagrammatically on plate 4, indicates that the majority of sampled water in the study area is a calcium bicarbonate type with varying concentrations of dissolved solids. There are exceptions in the basalt aquifer in the northern part of the study area, where sodium sulfate and sodium bicarbonate type water is evident near Murtaugh Lake and calcium chloride type water is evident south of Burley.

Table 5.--Chemical analyses of water for selected streams

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

Station number (locations shown on pl. 1)	Station name	Date of sample	Discharge, instantaneous (ft^3/s)	Specific conductance ($\mu S/cm$)	pH (standard units)	Temperature (°C)	Hardness (mg/L as $CaCO_3$)
13083000	Trapper Creek near Oakley	8-21-85	11	259	--	21.5	120
13084400	Birch Creek above Feeder Canal near Oakley	9- 4-85	3.5	375	8.40	12.5	150
13084590	Mill Creek near Basin	8-22-85	.7	141	8.20	12.0	55
13084650	Willow Creek near Burley	8-22-85	4.4	88	8.00	8.0	37
13088510	Big Cottonwood Creek near Oakley	9- 4-85	.5	171	7.90	13.5	69

Station number	Date of sample	Hardness, noncarbonate, total field (mg/L as $CaCO_3$)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Percent sodium	Sodium adsorption ratio	Potassium, dissolved (mg/L as K)	Bicarbonate, total field (mg/L as HCO_3)	Carbonate, total field (mg/L as CO_3)	Alkalinity, total field (mg/L as $CaCO_3$)
13083000	8-21-85	0	41	4.7	5.8	9	0.2	2.7	140	6	130
13084400	9- 4-85	8	45	8.7	23	25	.9	3.1	180	1	140
13084590	8-22-85	0	17	3.1	6.7	20	.4	1.9	76	0	62
13084650	8-22-85	0	12	1.6	2.4	12	.2	0.9	53	0	42
13088510	9- 4-85	0	23	2.7	7.0	17	.4	5.8	95	0	78

Station number	Date of sample	Carbon dioxide, dissolved (mg/L as CO_2)	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)	Solids, sum of constituents, dissolved (mg/L)	Nitrogen, NO_2+NO_3 dissolved (mg/L as N)	Phosphorus, total (mg/L as P)	Phosphorus, total (mg/L as PO_4)
13083000	8-21-85	--	5.8	4.2	0.1	22	160	0.10	0.03	0.09
13084400	9- 4-85	1.1	12	27	.3	35	240	.13	.06	.18
13084590	8-22-85	.8	7.4	2.8	.2	15	91	.21	.02	.06
13084650	8-22-85	.8	1.9	1.4	.1	55	55	.51	.03	.09
13088510	9- 4-85	1.9	3.7	6.3	.1	47	140	.10	.05	.15

Table 6.—Chemical and stable isotope analyses of water from selected wells and springs

[tot fld, total field; —, no data available; <, less than]

Ref. number (fig. 5)	Well or spring location (pl. 4)	Major aquifer	Date of sample	Specific conductance (µS/cm)	pH (standard units)	Temperature (° C)	Hardness (mg/L as $CaCO_3$)	Hardness, noncarbonate, tot fld (mg/L as $CaCO_3$)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)
1	10S-21E-35CCC1	Basalt	5-23-86	538	7.40	17.5	210	56	61	13
2	10S-22E-26CCB1	Basalt	5-19-86	990	7.60	13.0	260	0	58	28
	10S-22E-31DDC1	Basalt	5-21-86	809	7.60	15.5	320	110	97	19
3	10S-23E-20DCC2	Basalt	6- 6-86	808	7.60	16.0	350	230	100	25
	11S-19E-33CDD1	Rhyolite	9-23-81	246	8.00	32.0	76	0	24	3.9
	11S-19E-35BDD1	Rhyolite	9-23-81	348	7.60	25.0	110	9	34	5.4
	11S-20E-10DBC3	Basalt	5-30-86	877	7.70	14.0	280	0	48	38
	11S-20E-22CCB1	Basalt	7-10-85	2,070	7.70	14.5	700	410	180	61
4	11S-20E-26BAA1	Basalt	7-10-85	591	7.70	17.5	250	110	77	14
	11S-21E- 5DAD1	Basalt	5-19-86	559	7.80	17.5	210	68	52	19
	11S-21E- 9DDD1	Basalt	6-30-82	433	7.90	17.5	170	61	42	16
5	11S-21E-26DAD1	Basalt	5-22-86	469	7.50	17.0	180	48	56	9.3
6	11S-21E-28BBB1	Basalt	6-30-82	880	7.60	16.0	350	150	110	19
	11S-22E- 3CCC1	Basalt	7- 8-85	725	7.70	14.0	310	75	91	19
7	11S-22E-14DAC1	Basalt	7- 8-85	646	7.70	15.0	280	78	85	16
			5-20-86	631	7.30	14.5	—	—	—	—
8	11S-22E-19CBC1	Basalt	7- 9-85	686	7.80	18.5	280	120	86	15
	11S-22E-27BCB1	Rhyolite	5-22-86	558	7.50	18.5	230	67	71	12
	11S-23E- 4CBB1	Basalt	5-19-86	747	7.40	13.0	250	32	76	15
	11S-23E- 4DDA1	Alluvium	5-22-86	876	7.30	13.0	310	2	92	20
	11S-23E-26CDC1	Basalt	7- 9-85	628	7.70	16.5	250	110	70	18
			5-29-86	—	—	—	—	—	—	—
9	11S-23E-32ABC1	Basalt	7- 9-85	712	7.80	15.5	290	160	91	16
	12S-19E- 2DAA1	Limestone	9-23-81	359	8.00	36.0	100	0	30	6.5
10	12S-19E-24BBA1	Rhyolite	7- 1-86	247	7.80	38.0	70	0	22	3.7
11	12S-20E- 3CDD1	Limestone	9-23-81	353	7.80	32.0	150	0	42	11
			8-20-85	—	—	—	—	—	—	—
12	12S-20E- 6BAC1	Limestone	8-20-85	324	8.00	40.0	100	0	31	5.9
13	12S-20E-13DCC1	Rhyolite	6- 9-82	285	7.80	25.0	110	0	38	4.8
14	12S-20E-25BCA1	Limestone	6- 8-82	271	7.80	20.5	130	9	38	8.4
15	12S-21E- 5BCB1	Rhyolite	7-10-85	325	7.70	19.5	140	8	45	6.3
16	12S-21E-10DCC1	Rhyolite	6-30-82	181	8.10	21.0	67	0	23	2.3
	12S-21E-11ADD1	Rhyolite	7-10-85	199	8.00	28.0	49	0	18	0.97
			5-21-86	199	8.00	29.0	—	—	—	—
17	12S-21E-14CCB1	Rhyolite	7-10-85	297	7.90	48.5	76	0	28	1.4
			10- 7-86	—	—	—	—	—	—	—
18	12S-21E-16CCD1	Alluvium	7-10-85	536	7.50	13.0	210	73	69	10
19	12S-21E-19DCC2	Limestone	6-10-82	278	7.60	39.5	120	0	37	6.9

Table 6.--Chemical and stable isotope analyses of water from selected wells and springs--Continued

Date of sample	Sodium, dis- solved (mg/L as Na)	Percent sodium	Sodium ad- sorp- tion ratio	Potas- sium, dis- solved (mg/L as K)	Bicar- bonate, total field (mg/L as HCO_3)	Car- bonate, total field (mg/L as CO_3)	Alka- linity, total field (mg/L as $CaCO_3$)	Carbon dioxide, dis- solved (mg/L as CO_2)	Sulfate, dis- solved (mg/L as SO_4)
5-23-86	20	17	0.6	6.8	180	0	150	11	40
5-19-86	110	47	3	8.8	270	0	270	11	93
5-21-86	28	16	.7	7.8	250	0	210	10	75
6- 6-86	25	13	.6	9.0	150	0	120	6.0	74
9-23-81	15	27	.8	8.5	100	0	82	1.6	12
9-23-81	21	28	.9	9.9	120	0	98	4.8	22
5-30-86	74	36	2	4.6	380	0	310	12	73
7-10-85	140	30	2	11	350	--	290	11	430
7-10-85	16	12	.5	6.2	160	0	140	5.1	51
5-19-86	26	21	.8	6.2	170	0	140	4.3	58
6-30-82	17	17	.6	4.2	140	0	110	2.8	36
5-22-86	15	15	.5	6.1	160	0	130	8.0	26
6-30-82	35	17	.8	8.4	250	0	200	10	86
7- 8-85	31	18	.8	7.5	280	0	230	8.9	58
7- 8-85	19	13	.5	7.2	240	0	200	7.6	45
5-20-86	--	--	--	--	230	0	190	18	--
7- 9-85	22	14	.6	7.7	190	0	160	4.8	56
5-22-86	21	16	.6	8.4	190	0	160	9.5	36
5-19-86	59	33	2	8.0	260	0	220	16	57
5-22-86	64	30	2	9.0	380	0	310	30	55
7- 9-85	24	17	.7	5.1	170	0	140	5.4	39
5-29-86	--	--	--	--	--	--	--	--	--
7- 9-85	17	11	.4	5.5	160	0	130	4.0	34
9-23-81	33	38	1	12	210	0	170	3.3	9
7- 1-86	17	32	.9	7.3	120	0	96	3.0	13
9-23-81	14	16	.5	6.5	200	0	160	5.0	16
8-20-85	--	--	--	--	--	--	--	--	--
8-20-85	23	31	1	9.0	170	0	140	2.7	16
6- 9-82	13	19	.6	6.4	150	0	120	3.8	14
6- 8-82	10	14	.4	2.6	140	0	120	3.5	11
7-10-85	13	16	.5	5.3	160	0	130	5.1	13
6-30-82	8.4	20	.5	5.3	88	0	72	1.1	6
7-10-85	19	41	1	7.6	--	0	79	1.5	6.6
5-21-86	--	--	--	--	96	0	79	1.5	--
7-10-85	27	40	1	11	150	0	120	3.0	13
10- 7-86	--	--	--	--	--	--	--	--	--
7-10-85	22	18	.7	4.6	170	0	140	8.5	34
6-10-82	11	16	.5	4.4	150	0	130	6.0	15

Table 6.--Chemical and stable isotope analyses of water from selected wells and springs--Continued

Date of sample	Chloride, dissolved (mg/L as Cl)	Fluoride, dissolved (mg/L as F)	Silica dissolved (mg/L as SiO_2)	Solids, sum of constituents, dissolved (mg/L)	Nitrogen, NO_2+NO_3 dissolved (mg/L as N)	Phosphorus, total (mg/L as P)	Phosphorus, total (mg/L as PO_4)	$^2H/H$ stable-isotope ratio (permil)	$^{18}O/^{16}O$ stable-isotope ratio (permil)
5-23-86	46	0.3	48	320	1.90	0.03	—	-126	-16.9
5-19-86	52	.4	44	530	10.00	.06	—	-128	-16.5
5-21-86	87	.2	44	480	2.90	.03	—	-128	-16.8
6- 6-86	71	.2	52	430	3.90	.03	—	-127	-16.2
9-23-81	23	.4	66	200	.69	.01	.03	—	—
9-23-81	28	.6	70	250	1.10	.01	.03	—	—
5-30-86	30	.5	47	500	5.20	.03	—	-128	-16.7
7-10-85	290	.2	45	1,300	4.10	<.01	—	—	—
7-10-85	66	.2	52	360	1.20	.01	.03	-126	-17.1
5-19-86	52	.2	45	340	1.90	.01	—	-131	-17.2
6-30-82	43	.2	41	270	1.70	.04	.12	—	—
5-22-86	49	.2	49	290	2.30	.04	—	-130	-17
6-30-82	110	.2	45	540	4.10	.04	.12	-126	-16.5
7- 8-85	56	.2	45	450	3.20	.02	.06	—	—
7- 8-85	59	.2	45	390	3.00	.03	.09	-129	-16.5
5-20-86	—	—	—	—	—	—	—	—	—
7- 9-85	87	.2	49	420	2.20	.11	.34	-129	-16.7
5-22-86	48	.3	58	350	2.00	.07	—	-127	-16.7
5-19-86	42	.2	44	430	6.20	.09	—	-128	-16.5
5-22-86	34	.2	48	510	15.0	.10	—	-128	-16.7
7- 9-85	88	.2	44	370	2.30	.04	.12	—	—
5-29-86	—	—	—	—	—	—	—	-126	-16.5
7- 9-85	120	.2	41	400	4.60	.02	.06	-125	-16.3
9-23-81	4.1	.9	21	220	.13	.01	.03	—	—
7- 1-86	8.7	.7	45	180	.22	.01	—	-124	-16.3
9-23-81	5.2	.5	18	210	.11	.01	.03	—	—
8-20-85	—	—	—	—	—	—	—	-135	-17.8
8-20-85	6.1	.8	19	190	<.10	<.01	—	-132	-17.6
6- 9-82	9.8	.3	64	220	.24	.04	.12	-132	-17.5
6- 8-82	7.5	.2	20	170	.24	.02	.06	-131	-17.5
7-10-85	11	.3	69	240	.39	<.01	—	-133	-17.4
6-30-82	8.5	.2	59	160	.43	.04	.12	-128	-17.2
7-10-85	8.2	.7	69	180	.25	.01	.03	—	—
5-21-86	—	—	—	—	—	—	—	-133	-17.7
7-10-85	5.8	.8	80	240	.10	.02	.06	-138	-18
10- 7-86	—	—	—	—	—	—	—	—	—
7-10-85	57	.2	23	300	2.50	<.01	—	-130	-17
6-10-82	5.3	.3	19	170	<.10	.02	.06	-133	-17.8

Table 6.--Chemical and stable isotope analyses of water from selected wells and springs--Continued

Ref. number (fig. 5)	Well or spring location (pl.4)	Major aquifer	Date of sample	Specific conductance (µS/cm)	pH (standard units)	Temperature (°C)	Hardness (mg/L as $CaCO_3$)	Hardness, noncarbonate, tot fld (mg/L as $CaCO_3$)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)
20	12S-21E-25CCC1	Rhyolite	7-10-85	256	7.70	25.0	92	2	33	2.3
21	12S-21E-27BCC1	Limestone	6-10-82	261	8.60	23.5	120	1	37	7.0
	12S-21E-28CCB1	Rhyolite	7-10-85	199	7.90	22.0	82	0	28	2.9
22	12S-22E- 3CCC1	Basalt	7- 8-85	528	7.60	20.0	210	55	64	11
23	12S-22E- 6BBB1	Basalt	8-20-85	347	7.90	32.0	82	0	29	2.3
24	12S-22E- 7ADD1	Basalt	7- 9-85	565	7.50	18.0	220	51	72	10
	12S-22E-13DCC1	Basalt	5-22-86	474	7.30	17.0	200	30	62	11
	12S-22E-16CAA1	Basalt	7- 9-85	489	7.40	18.0	190	50	60	9.7
	12S-22E-18DDD1	Alluvium	5-29-86	979	7.20	11.5	400	160	130	19
25	12S-22E-26CCC1	Basalt	7- 9-85	439	7.50	18.0	170	61	54	8.8
	12S-22E-30AAA1	Rhyolite	5-22-86	640	7.10	12.0	260	19	84	12
	12S-22E-32ACD1	Basalt	5-29-86	457	7.20	16.5	170	16	54	7.6
	12S-23E- 6DCC1	Basalt	5-21-86	873	7.20	14.0	390	220	120	21
26	12S-23E-15CCD1	Basalt	5-29-86	303	7.00	16.5	110	31	34	6.7
	125-24E-31CDC1S	--	8-20-85	164	7.40	10.0	74	0	25	2.7
27	13S-20E- 8DCA1S	--	6- 8-82	--	6.80	7.5	--	--	--	--
			8-21-85	206	7.00	8.0	51	0	15	3.2
	13S-21E- 5CBC1	Limestone	4-27-82	270	--	24.0	130	10	40	7.4
28	13S-21E- 8BAD1	Limestone	9- 4-85	305	8.00	24.0	140	7	42	7.7
29	13S-22E- 2DDC2	Basalt	7- 9-85	503	7.60	17.0	200	0	61	12
	13S-22E- 8BAD1	Rhyolite	7- 9-85	431	7.40	15.0	170	22	56	7.8
30	13S-22E- 9DDC1	Alluvium	7-10-85	527	7.20	11.5	230	53	75	11
			5-20-86	627	7.20	11.0	--	--	--	--
	13S-22E-33DDA2	Alluvium	7-10-85	521	7.00	10.5	210	3	64	13
31	13S-23E- 8BCC1S	--	5-30-86	534	7.40	16.0	230	33	72	13
32	14S-19E-24DBC1S	--	6-29-82	40	7.30	5.0	--	--	--	--
			8-21-85	44	6.40	6.0	10	0	3.0	.65
33	14S-23E- 2CCC1S	--	8-22-85	279	7.60	7.5	140	0	36	12
	15S-23E- 2DBD1S	--	8-22-85	44	5.90	5.0	15	0	4.0	1.3

Table 6.--Chemical and stable isotope analyses of water from selected wells and springs--Continued

Date of sample	Sodium, dis-solved (mg/L as Na)	Percent sodium	Sodium ad-sorp-tion ratio	Potas-sium, dis-solved (mg/L as K)	Bicar-bonate, total field (mg/L as HCO_3)	Car-bonate, total field (mg/L as CO_3)	Alka-linity, total field (mg/L as $CaCO_3$)	Carbon dioxide, dis-solved (mg/L as CO_2)	Sulfate, dis-solved (mg/L as SO_4)
7-10-85	14	23	0.7	7.1	110	0	90	3.5	12
6-18-82	9.9	15	.4	3.6	130	5	120	.5	15
7-10-85	7.9	16	.4	4.2	100	0	83	2.0	8
7- 8-85	20	17	.6	6.4	180	0	150	7.2	31
8-20-85	37	46	2	9.2	160	0	140	3.2	15
7- 9-85	23	18	.7	4.0	200	0	170	10	27
5-22-86	14	13	.4	4.3	180	0	170	14	19
7- 9-85	18	17	.6	6.5	170	0	140	11	21
5-29-86	26	12	.6	6.9	290	0	240	29	56
7- 9-85	16	16	.6	5.9	140	0	110	7.0	16
5-22-86	22	15	.6	6.6	300	0	240	38	30
5-29-86	17	18	.6	6.0	180	0	150	18	20
5-21-86	19	10	.4	4.7	110	0	170	21	40
5-29-86	11	17	.5	2.7	99	0	81	16	11
8-20-85	3.6	9	.2	1.3	92	0	76	5.8	2.7
6- 8-82	--	--	--	--	66	0	54	17	--
8-21-85	16	36	1	8.2	75	0	61	12	18
4-27-82	7.2	10	.3	3.8	--	--	--	--	15
9- 4-85	12	16	.5	3.9	160	0	130	2.5	18
7- 9-85	20	17	.6	6.4	310	0	260	12	30
7- 9-85	18	18	.6	6.7	190	0	150	12	19
7-10-85	22	17	.7	3.9	220	0	180	22	24
5-20-86	--	--	--	--	180	0	150	18	--
7-10-85	26	20	.8	10	260	0	210	41	19
5-30-86	21	16	.6	3.7	240	0	200	15	26
6-29-82	--	--	--	--	21	0	17	1.7	--
8-21-85	2.9	31	.4	2.9	20	0	16	13	3.6
8-22-85	3.5	5	.1	.8	180	0	140	7.2	2.1
8-22-85	2.9	28	.3	.6	18	0	15	36	6.8

Table 6.--Chemical and stable isotope analyses of water from selected wells and springs--Continued

Date of sample	Chloride, dissolved (mg/L as Cl)	Fluoride, dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO_2)	Solids, sum of constituents, dissolved (mg/L)	Nitrogen, NO_2+NO_3 dissolved (mg/L as N)	Phosphorus, total (mg/L as P)	Phosphorus, total (mg/L as PO_4)	$^2H/H$ stable-isotope ratio (permil)	$^{18}O/^{16}O$ stable-isotope ratio (permil)
7-10-85	15	0.4	71	210	0.56	<0.01	--	-133	-17.4
6-10-82	6.5	.2	16	170	<.10	.02	0.06	-131	-17.6
7-10-85	7.3	.2	54	160	.13	.01	.03	--	--
7- 8-85	50	.4	49	320	2.10	.03	.09	-128	-16.7
8-20-85	17	1.3	69	260	.64	<.01	--	-131	-17.4
7- 9-85	41	.4	48	320	2.70	.02	.06	-129	-16.7
5-22-86	43	.2	43	290	1.30	.07	--	-125	-16.6
7- 9-85	51	.3	51	300	1.60	.02	.06	-130	-17
5-29-86	96	.2	38	510	5.80	.04	--	-124	-16
7- 9-85	47	.3	50	270	1.20	.03	.09	-128	-16.7
5-22-86	29	.2	37	370	5.20	.07	--	-123	-16
5-29-86	27	.3	55	280	1.20	.04	--	-129	-16.9
5-21-86	140	.1	37	490	6.10	.09	--	-123	-16.2
5-29-86	24	.2	37	180	.81	.01	--	-126	-16.8
8-20-85	1.8	<.1	11	93	.73	.02	.06	-123	-17
6- 8-82	--	--	--	--	--	--	--	-123	-16.7
8-21-85	13	.2	55	170	.64	.02	.06	--	--
4-27-82	6.3	.3	16	170	<.10	<.01	--	--	--
9- 4-85	8.8	.2	16	190	.15	<.01	--	-133	-17.8
7- 9-85	42	.3	47	370	.39	.02	.06	-126	-16.6
7- 9-85	28	.3	56	290	1.20	.03	.09	--	--
7-10-85	40	.1	30	310	4.60	.04	.12	-126	-16.3
5-20-86	--	--	--	--	--	--	--	--	--
7-10-85	29	.3	38	330	.85	<.01	--	--	--
5-30-86	36	.2	35	320	1.40	.02	--	-124	-16.6
6-29-82	--	--	--	--	--	--	--	-126	-17
8-21-85	1.5	<.1	45	69	.41	.03	.09	--	--
8-22-85	2.8	.2	11	160	.59	.01	.03	-123	-16.4
8-22-85	1.5	.1	15	41	.11	.06	.18	-122	-16.9

Another exception is in the limestone aquifer near Dry Creek and the rhyolite aquifer northwest of Churchill Knolls, where sodium bicarbonate type water is evident. However, these samples are from wells that produce thermal water.

The chemical character of water from sampled springs issuing from the Rock Creek Hills west of the Oakley Fan is a sodium bicarbonate type; water from springs issuing from the Albion Mountain Range east of the Oakley Fan is a calcium bicarbonate type.

The cation and anion balance of water in the basalt, rhyolite, and limestone aquifers is shown on a trilinear plot on plate 4. The composition of the water is expressed as a percentage of the total milliequivalents per liter of the ions shown. The grouping of selected water samples from the various aquifers shows the chemical similarities of the water within each system.

Distribution and Concentrations of Selected Chemical Constituents

Several chemical constituents were useful in determining the areal extent of different aquifers and evaluating the effect of faults on ground-water movement in the Oakley Fan area. Generally, silica concentrations less than 25 mg/L indicate a limestone aquifer, 40-60 mg/L, a basalt aquifer, and greater than 60 mg/L, a rhyolite aquifer. Chloride concentrations less than 20 mg/L are indicative of a limestone or rhyolite aquifer, and chloride concentrations greater than 40 mg/L are indicative of a basalt aquifer. Silica and chloride concentrations from selected wells are shown on plate 3.

The areal extent of the limestone aquifer near Artesian City is defined on the basis of silica concentrations generally less than 25 mg/L and chloride concentrations generally less than 20 mg/L. Concentrations of silica and chloride greater than 25 and 20 mg/L are in water from wells open to the rhyolite and/or perched-water aquifers. Separation of the rhyolite and limestone aquifers by the Foothills Road fault is substantiated by the contrasting silica concentrations. The only exceptions are wells 12S-21E-19DCC2 and 27BCC1 northeast of the fault. These wells produce thermal water from limestone.

Separation of the rhyolite and basalt aquifers by the Churchill Knolls fault and the influence of the fault on the direction of ground-water movement may be inferred from the concentrations of silica and chloride shown on plate 3. Northeast of the fault in the basalt aquifer, silica concentrations are generally less than 60 mg/L and chloride concentrations are generally greater than 40 mg/L. Southwest of the fault in the rhyolite aquifer, silica concentrations are generally greater than 60 mg/L and chloride concentrations are generally less than 20 mg/L. South of the Churchill Knolls fault, mixing of downward percolating water from the perched zones north of Oakley also is indicated by the lower silica and higher chloride concentrations in the rhyolite aquifer. Near the mapped northern extent of the fault (pl. 3), movement of ground water across the fault also is indicated by decreasing silica concentrations and increasing chloride concentrations.

Stable Isotopes

The stable isotopes D (deuterium), or ^{2}H (hydrogen-2), and ^{18}O (oxygen-18) can provide valuable information about the source, relative age, and environment of ground water. Basically, the D and ^{18}O composition of water decreases with decreasing temperature at the time of condensation (precipitation). Thus, isotopic compositions of water samples from different sources can be compared, and inferences can be drawn as to climatic conditions at the time of precipitation (Young, 1985).

Stable isotope concentrations are expressed in delta units (δ) and are reported in parts per thousand, commonly abbreviated permil (^{o}/oo). These units are defined as:

$$\delta = \left[\frac{R\ sample - R\ standard}{R\ standard}\right] \times 1{,}000$$

where
R sample = ratio of isotopic concentrations ($^{18}O/^{16}O$ or D/H) for the sample, and
R standard = ratio of isotopic concentrations for the standard, which is referred to as SMOW (Standard Mean Ocean Water).

A worldwide study of freshwater samples showed that isotopic compositions of cold meteoric water were related by the equation $\delta D = 8\delta^{18}O + 10$ (Craig, 1963). This straight line commonly is referred to as the meteoric water line (fig. 5); the slope and intercept of the line may vary regionally. Values for water affected by extensive nonequilibrium evaporation, as in inland basins, lie off the meteoric line. However, at ordinary air temperatures, evaporated surface water is connected approximately to the original precipitation composition of $\delta^{18}O_O$ and δD_O by a line having the equation $\delta D = 5\ (\delta^{18}O - \delta^{18}O_O) + D_O$ (Ellis and Mahon, 1977, p. 75).

Water samples from 41 wells and 6 springs were collected for isotope analyses from various points in the ground-water flow systems, including the suspected recharge areas. The isotopic compositions are given in table 6; locations of the sampling sites are shown on plate 4 and δD values are shown on plate 3. Comparison of isotopic compositions in selected water samples from different aquifers is shown in figure 5.

All the samples cluster near the meteoric line and differ only in their position up- or downslope. The more depleted the sample in ^{18}O and D, the farther downslope the plot (to the left in fig. 5). Samples from wells completed in the basalt aquifers, perched-water zones, and springs in the surrounding mountains cluster near the meteoric line and upslope to the right). Samples from wells completed in the rhyolite and limestone aquifers cluster near the meteoric line and downslope. The only exceptions are samples 10, 16, and 18. Sample 10 is thermal water from a well near Dry Creek (pl. 3) and plots in the cluster to the right in figure 5. The upslope plot of this sample is not understood at this time. Sample 16 plots between the two sample clusters. Although this well is completed in rhyolite, it is downgradient (pl. 3) from the perched-water zone near Big Cottonwood Creek and could indicate mixed water. Sample 18 is from a well completed in the perched-water zone near Big Cottonwood Creek (pl. 3) and also plots between the two previously mentioned clusters.

The significant depletion of δD values relative to $\delta^{18}O$ values for water from the rhyolite and limestone aquifers compared with values of samples from cold springs in the surrounding mountains, along with the higher water temperatures, indicates that the samples from rhyolite and limestone aquifers represent water with longer circulation times. For a more complete discussion of circulation times of thermal water in Idaho, refer to reports by Young and Lewis (1982) and Young (1985).

The comparability of the isotopic compositions of water samples is shown on plate 3. In most cases, values of δD are correlative to indicated ground-water flowpaths, as shown by the potentiometric-surface contours.

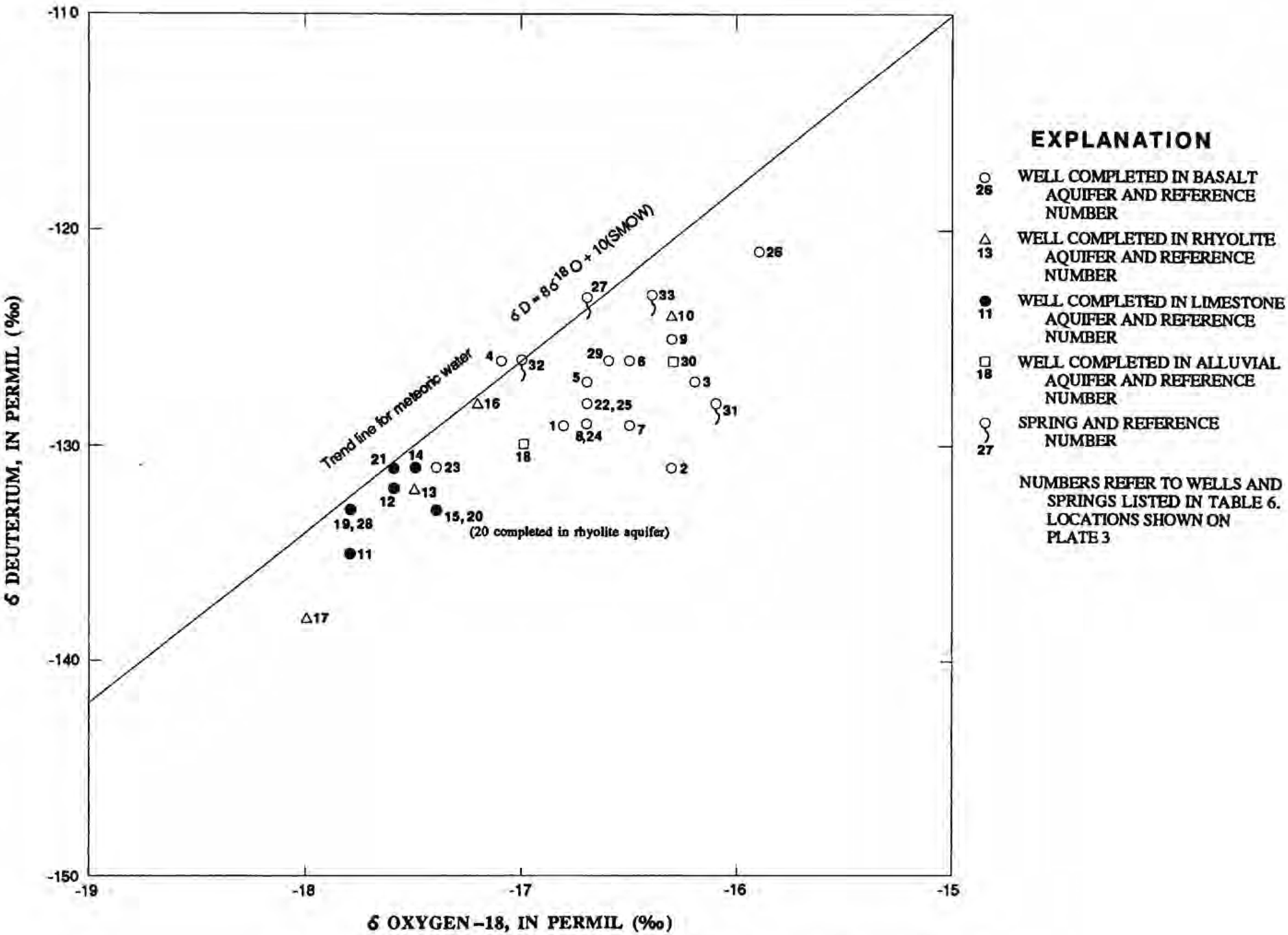


Figure 5.--Relation between concentrations of deuterium and oxygen-18.

MATHEMATICAL MODEL

Assumptions and Limitations

Simulation of a ground-water flow system is subject to limitations inherent in the technique used. A mathematical model is essentially a set of equations that describe an idealized system having properties similar to a real ground-water system. If the model adequately describes a real ground-water system, then the response of the model to imposed stresses, such as ground-water pumping, will approximate the response of the real system if it were to undergo the same stresses. The degree to which a model can accurately simulate a real system is limited by characteristics of both the model and the system being simulated and by availability of reliable data used in the model.

The simplifying assumptions and generalizations that are incorporated into a model affect the output. The model cannot represent the real system exactly. The more complex the real system is, the more simplification that must be made in the model and the less accurate the model representation. If the real system is complex, the model can be used to make only general statements about the response of the real system to imposed stresses.

Information on aquifer characteristics and hydraulic heads often is unavailable, especially for undeveloped areas, and must be estimated on the basis of what few data are available. Errors in these estimates may significantly affect model results. For some data, the range of possible values is small but, for others, the range may be within several orders of magnitude. The model is more sensitive to the variation of some data than others; therefore, a sensitivity analysis is performed to test the response of the model to a range of values.

Nearly identical water-level configurations with numerous different combinations of parameters are possible. Therefore, computed solutions are not unique and a match between observed and modeled conditions does not guarantee that the model parameters and the real system parameters are identical. However, if the parameters used are generally compatible with known information, errors caused by non-uniqueness can be minimized.

Model Description

The flow of ground water in a porous medium in three dimensions may be expressed as a mathematical equation. This equation may be solved for the head in the aquifer at any particular time. Because solution of the equation is complex, a computer program is used to solve a finite-difference approximation of the equation. The computer program used in this study was written by McDonald and Harbaugh (1984).

For the finite-difference method of solution, the aquifer system is divided into layers. Each layer is divided into three-dimensional cells, and values of hydraulic head, transmissivity, and storage capacity are assigned to the center of each cell.

Oakley Fan ground-water system was modeled using the finite-difference method of solution and divided into two layers of cells, each with 65 rows and 80 columns. The area of the top face of each cell is 160 acres. For simplification of data input and calibration, cells were grouped into zones with similar aquifer properties.

Figure 6 is a conceptualization of the ground-water system in the Oakley Fan area. The northern edge of the system was extended about 15 mi north of the Snake River to include areas of probable subsurface inflow and outflow.

Layer 1 represents the "shallow" ground-water system where recharge and ground-water pumping are most active. Water is present under both confined and unconfined conditions; in both instances, head generally decreases with depth because of recharge from irrigation. The shallow aquifer system gains water from or loses water to the Snake River, depending on where the river intersects the water table.

Layer 2 represents the "deep" ground-water system where water is generally under confined conditions. Leakage from layer 1 and subsurface inflow recharge the deep system. Subsurface inflow moves southwestward from the Snake River Plain and from the surrounding mountains. Ground water is discharged by pumping and as subsurface outflow to the Snake River Plain.

The upward movement of thermal water was not considered in the model. Although the quantity of thermal water entering the deep system is unknown, it is probably small compared to other sources of inflow.

The limestone unit at the western boundary of the study area was not included in the model. Known areal extent of this unit is small and its effects on the rest of the system would be negligible. More information about recharge distribution along the western boundary of the limestone unit is neeed for accurate modeling.

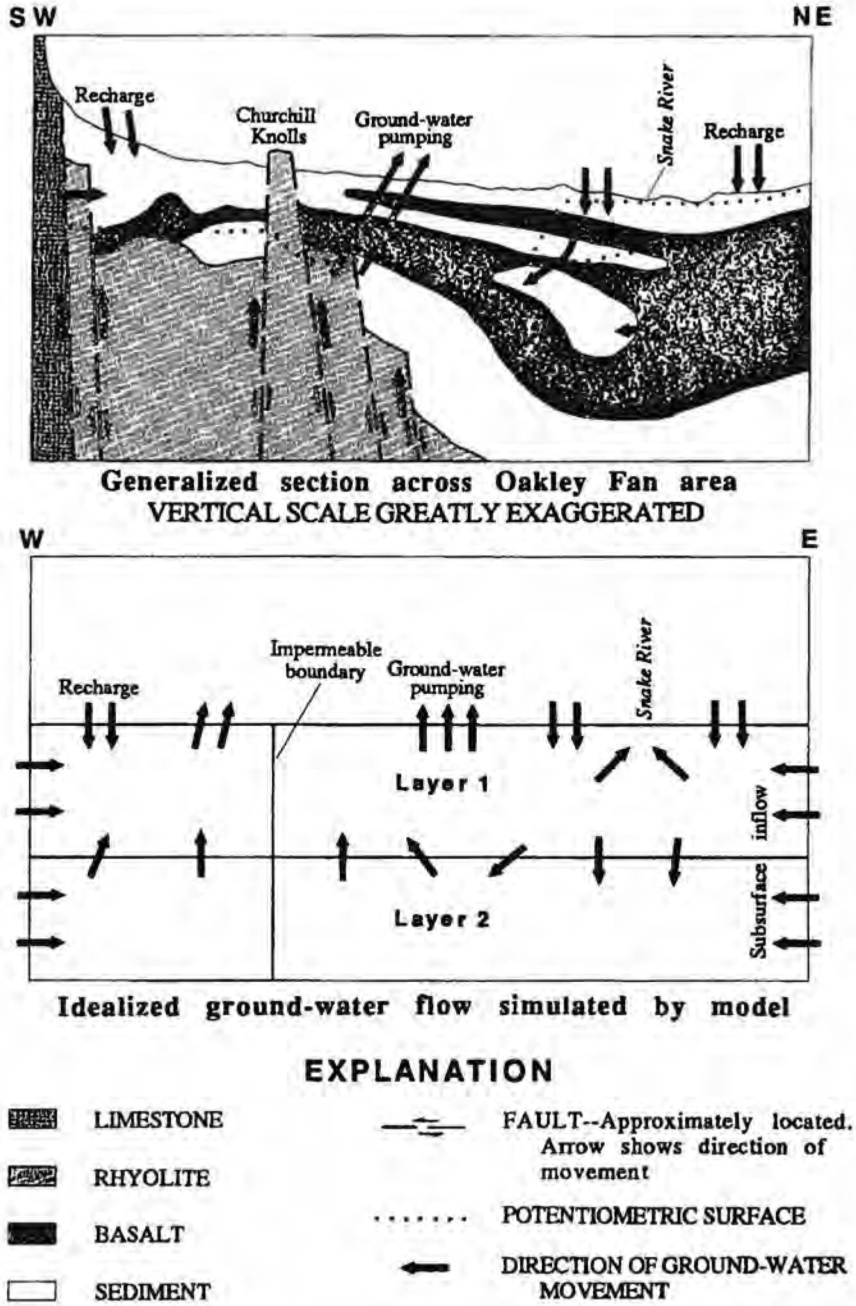


Figure 6.--Conceptualization of the ground-water flow system.

Model Boundary Conditions

The finite-difference approximation, together with specification of flow and head conditions at the boundaries of an aquifer system, initial head conditions, ground-water recharge and discharge, and aquifer characteristics constitute a mathematical model of ground-water flow.

The mathematical model requires that either the head or the flux (volumetric flow rate per unit area) be specified along a boundary (fig. 7). The head for a specified-head boundary is not affected by changes in the ground-water system, but the flux across the boundary may vary. The flow across a specified-flux boundary is not affected by changes in the ground-water system, but the head may vary.

The area north of the Snake River was modeled as a specified-head boundary. Heads assigned to this boundary were estimated from water-level measurements. The area south of the Snake River was modeled as a specified-flux boundary. The source of the water is precipitation on the surrounding mountains. Crosthwaite (1969, p. 23) estimated that subsurface inflow from Rock Creek, Dry Creek, and Goose Creek basins was 45,000 acre-ft/yr and, from Birch Creek, 2,000 acre-ft/yr. The remaining subsurface inflow was estimated and values were assigned to cells along the boundary for both layers (fig. 7). The Snake River and Murtaugh Lake were modeled as specified-head boundaries in layer 1. Ground-water inflow and outflow to the river were modeled as a function of head in the aquifer and river stage.

Model Input and Calibration

Recharge values were assigned to each cell in layer 1. Monthly recharge values were computed for the transient simulation.

Ground water moving northward beneath the Snake River discharges to the Snake River Plain north of the study area and eventually crosses the specified-head boundary in the northern part of the modeled area. Ground-water pumpage was computed for each cell and was distributed proportionally between the model layers on the basis of reported well depth.

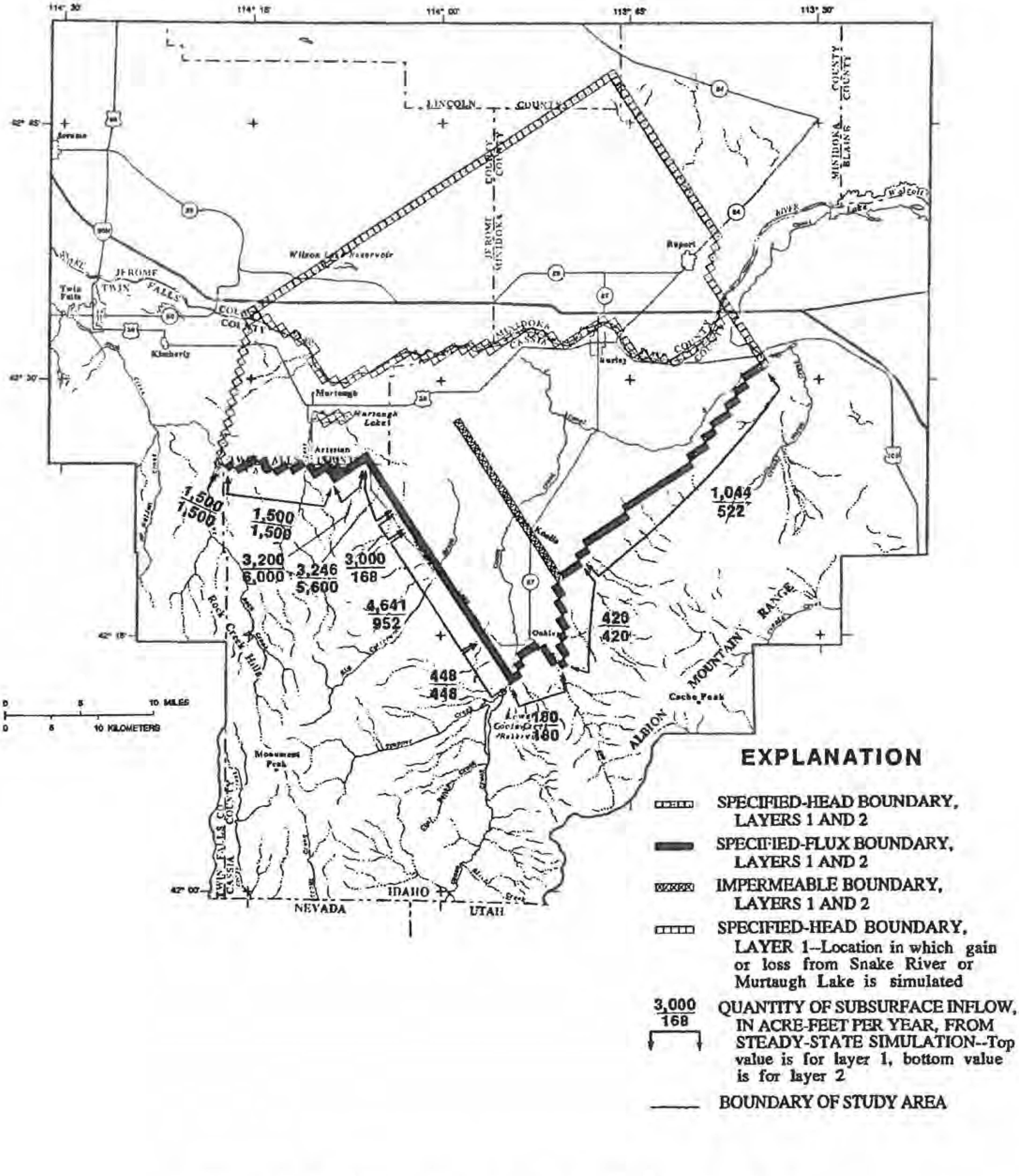


Figure 7.--Model boundary conditions and subsurface inflow.

Accurate specification of aquifer characteristics based on measured or known values is generally not possible because necessary data usually are not obtainable or are not consistent with other model assumptions. The process of determining values for aquifer characteristics is referred to as model calibration. The model must be calibrated before present or future ground-water conditions can be simulated.

Calibration of the Oakley Fan ground-water model involved input of aquifer characteristics until an acceptable match was achieved between measured water levels and water levels simulated by the model. Comparisons also were made between simulated and measured stream discharge (gains or losses), head gradient, known discharge areas, or any relatively well-documented aspect of the ground-water system. Aquifer characteristics were varied within reasonable limits on the basis of known geologic and hydrologic characteristics of the system.

Steady-State Simulation of Average 1979-84 Hydrologic Conditions

Steady-state simulation permits evaluation of several important aspects of the Oakley Fan ground-water system: (1) The values of the aquifer characteristics, (2) subsurface inflow and outflow, (3) ground-water discharge to the Snake River, and (4) seepage from Murtaugh Lake.

The period 1979-84 was used for steady-state simulation because data were the most complete and hydrologic conditions were considered to approach steady state. Water levels during this period fluctuate seasonally and from year to year, with areas of both water-level rise and decline (fig. 4). However, the change in volume of ground water in storage because of these fluctuations is small. The study area south of the Snake River consists of about 217,000 acres. Most water-level changes are in the confined system; aquifer tests indicate the storage coefficient is about 0.001. Because the average water-level change is about 3 ft/yr (excluding the limestone unit), the change in storage is only about 650 acre-ft/yr, or about 0.2 percent of the total recharge; therefore, change in storage was ignored during steady-state calibration.

For steady-state simulation, the head at each cell must be assigned an initial value. The choice of values affects the time required for computing the steady-state solution but not the final head values. However, the initial conditions must approximate a valid solution so the computer algorithm will work properly and the solution time will be reasonable. Initial conditions for steady-state simulation were approximated from March 1984 water levels.

Figures 8 and 9 show contours of the simulated steady-state potentiometric surface for layers 1 and 2. Values of horizontal and vertical hydraulic conductivity were adjusted during calibration until the mean absolute difference between historical (pre-1984) and simulated water levels was minimized. Simulated heads were interpolated at the locations of historical heads. During calibration, recharge and boundary conditions also were adjusted when satisfactory results could not be achieved by adjusting aquifer characteristics alone within limits based on the types of aquifer material.

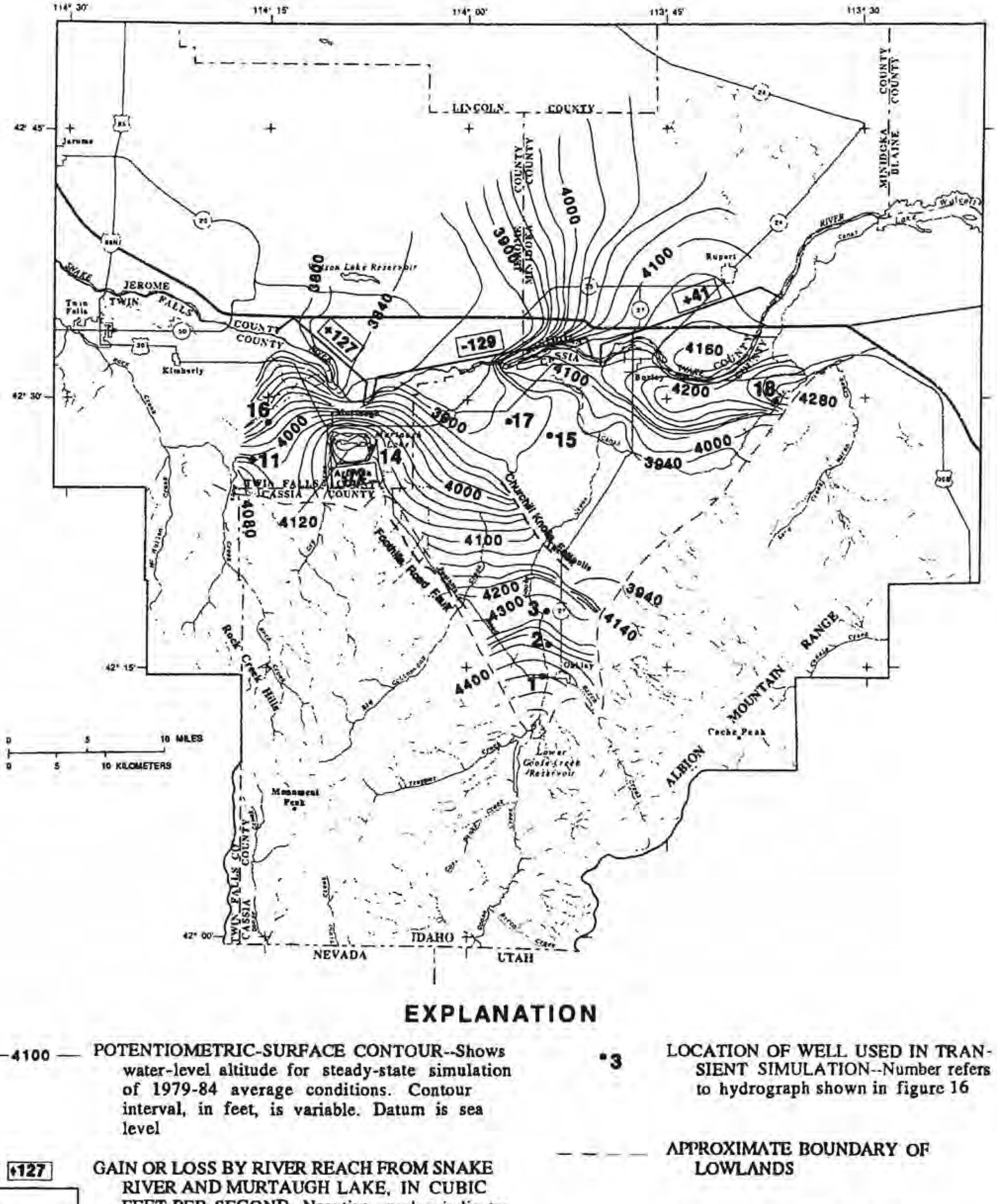
Figure 10 shows simulated hydraulic conductivity values for layer 1. The values range from 4 to 55 ft/d for alluvium and from 17 to about 4,200 ft/d for basalt.

Figure 11 shows simulated transmissivity values for layer 2. The values range from about 1,700 to about 3,110,000 ft^2/d for basalt and from about 2,590 to 8,390 ft^2/d for rhyolite.

Leakage between layers 1 and 2 is limited by thick layers of fine-grained sediments. These sediments are thickest near Burley, where they were deposited to depths of about 200 ft in a large lake that formed behind lava flows across the Snake River. Sediment accumulations are thinnest between Churchill Knolls and the Snake River. Simulated vertical hydraulic conductivity between layers 1 and 2 ranges from 0.4 to 30 ft/d for alluvium and from 28 to 56 ft/d for basalt (fig. 12).

Ground water is discharged to wells, to the Snake River, and as underflow northward beneath the Snake River. The river is a partially penetrating stream; that is, the stream intersects only part of the saturated zone. Thus, water can move through the aquifer beneath the river without discharging into the stream. The stage of the Snake River is above the water table from near Burley downstream to near Murtaugh, where the river enters a deep basalt canyon that intersects the water table.

Steady-state simulation indicates that the Snake River gains water above Burley and below Murtaugh and loses water



EXPLANATION

—4100— POTENTIOMETRIC-SURFACE CONTOUR--Shows water-level altitude for steady-state simulation of 1979-84 average conditions. Contour interval, in feet, is variable. Datum is sea level

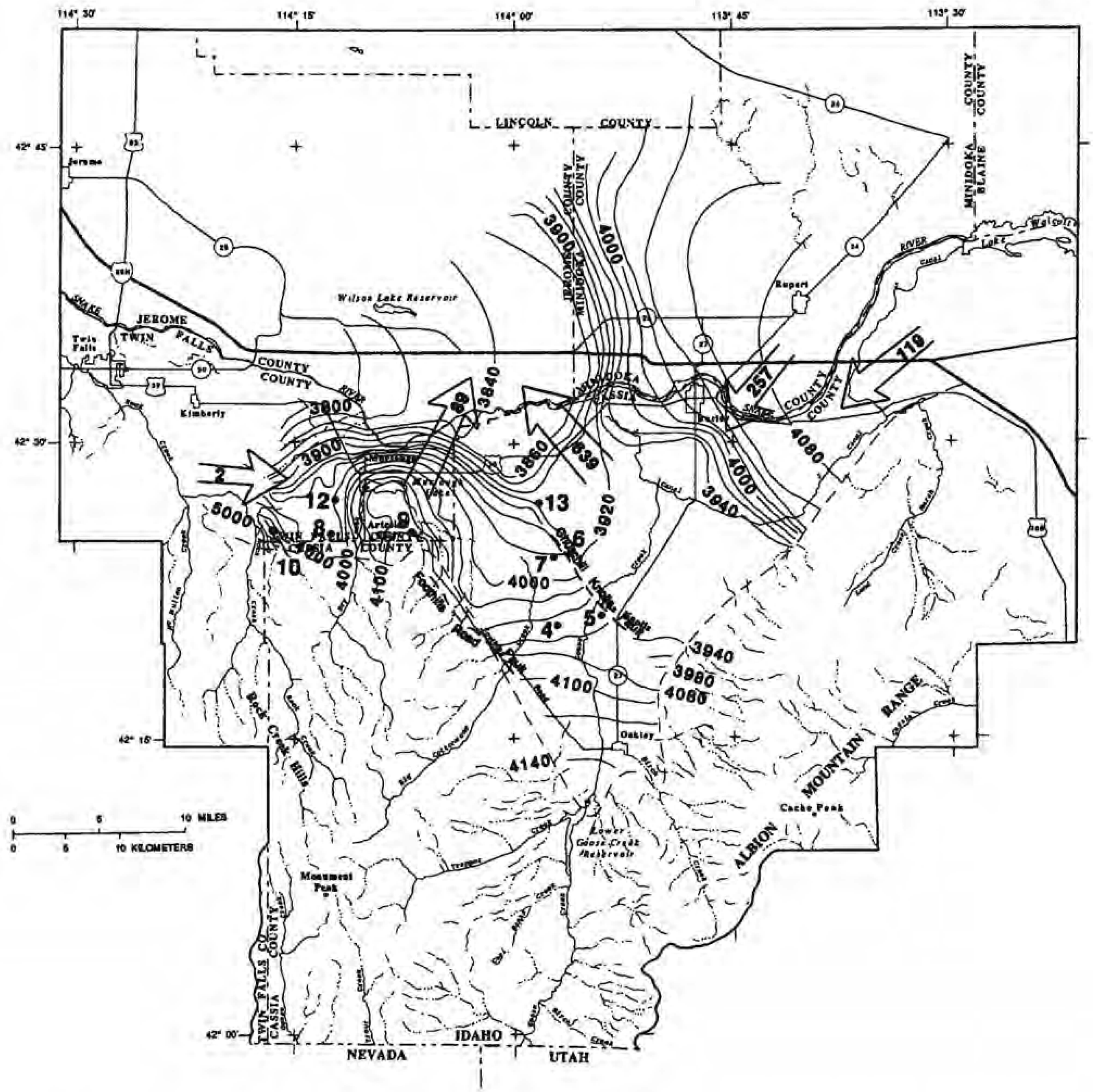
+127 GAIN OR LOSS BY RIVER REACH FROM SNAKE RIVER AND MURTAUGH LAKE, IN CUBIC FEET PER SECOND--Negative number indicates losing reach, positive number indicates gaining reach

•3 LOCATION OF WELL USED IN TRANSIENT SIMULATION--Number refers to hydrograph shown in figure 16

— — — APPROXIMATE BOUNDARY OF LOWLANDS

——— BOUNDARY OF STUDY AREA

Figure 8.--Simulated steady-state potentiometric surface, layer 1, and gains or losses by river reach, 1979-84.



EXPLANATION

—4100— POTENTIOMETRIC-SURFACE CONTOUR--Shows water-level altitude for steady-state simulation of 1979-84 average conditions. Contour interval 20 feet. Datum is sea level

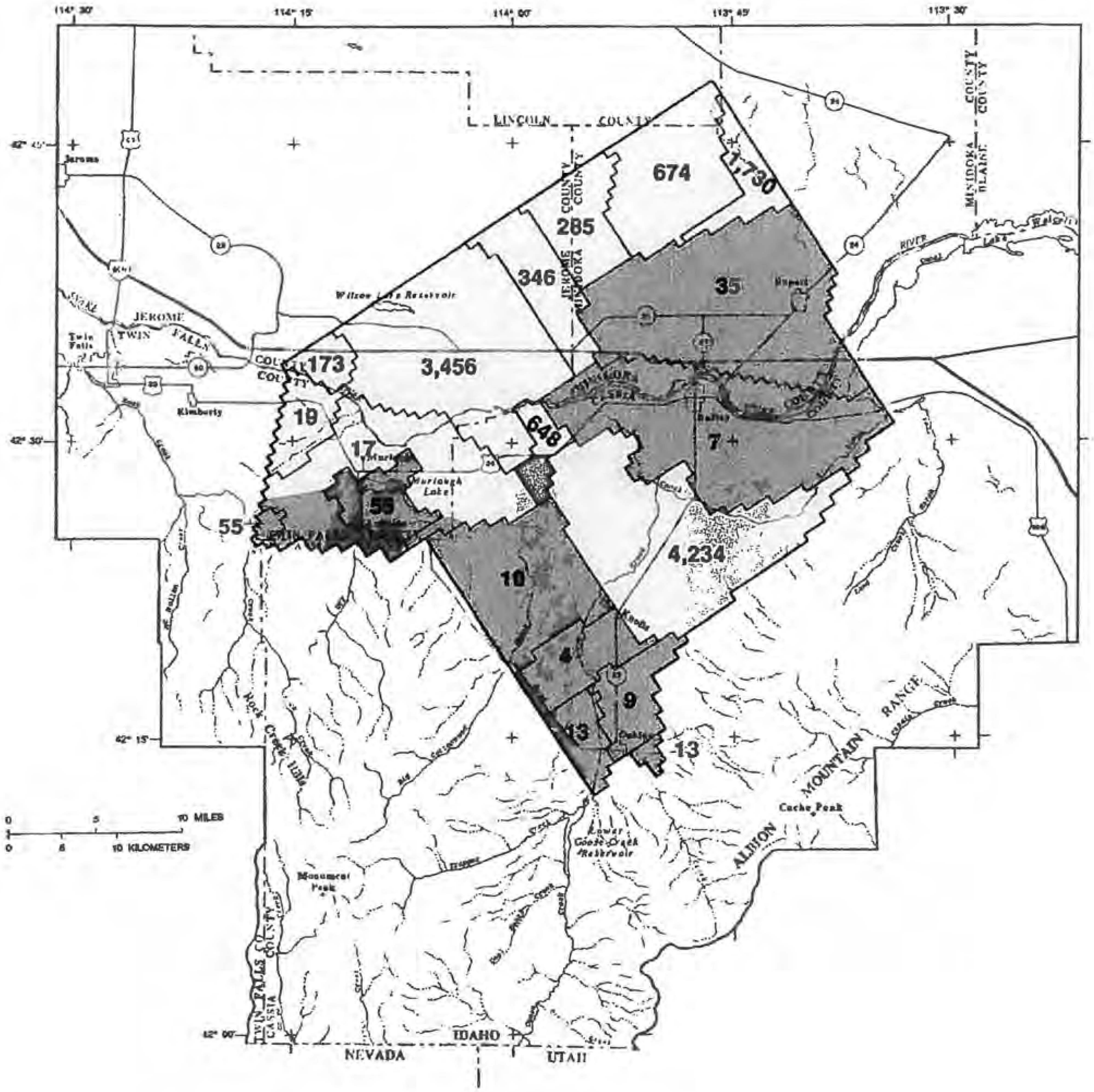
639 SIMULATED SUBSURFACE INFLOW AND OUTFLOW--Number is discharge, in cubic feet per second, in direction indicated by arrow

• 9 LOCATION OF WELL USED IN TRANSIENT SIMULATION--Number refers to hydrograph shown in figure 16

— — — — APPROXIMATE BOUNDARY OF LOWLANDS

———— BOUNDARY OF STUDY AREA

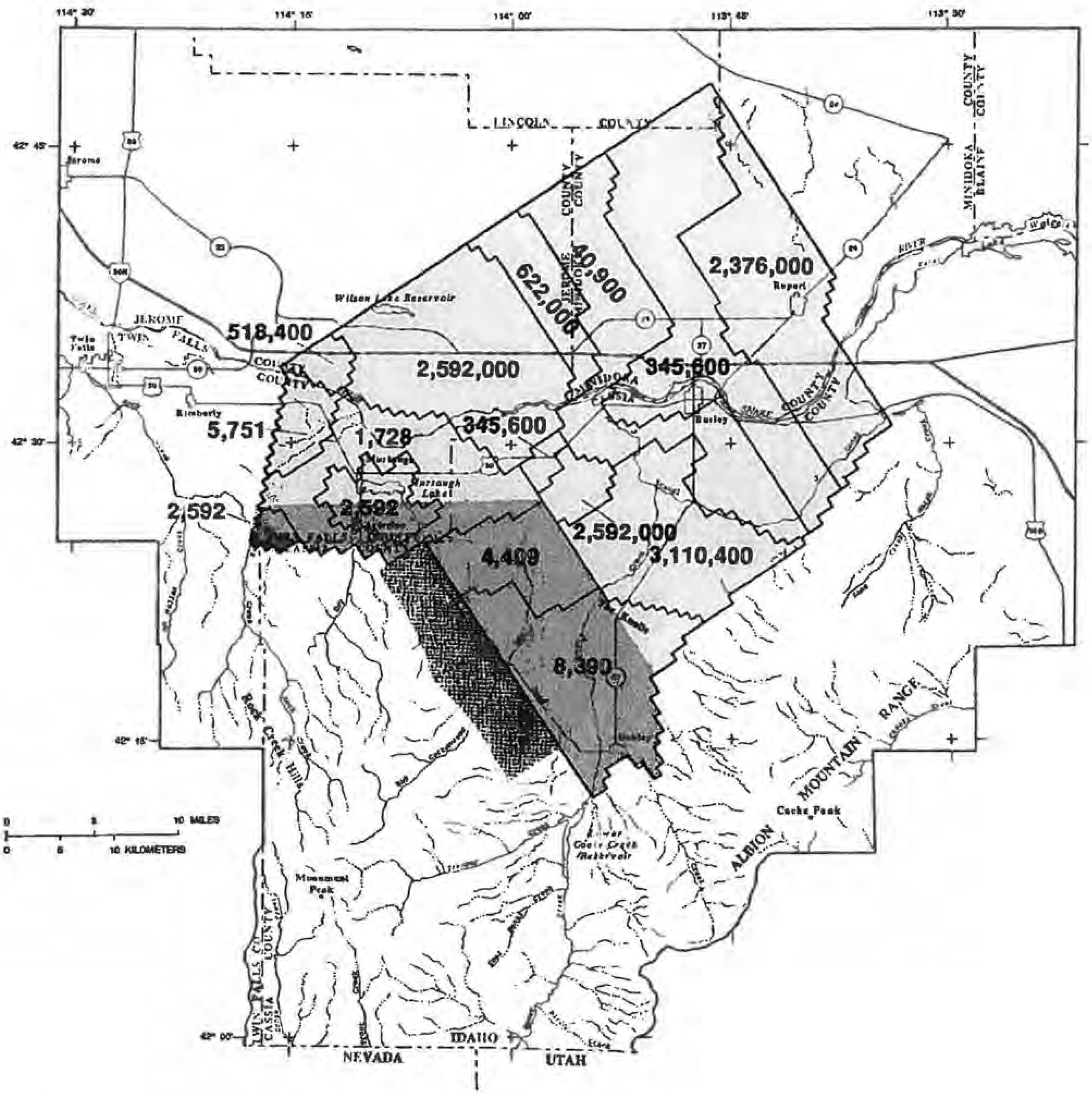
Figure 9.--Simulated steady-state potentiometric surface, layer 2, and subsurface inflow and outflow, 1979-84.



EXPLANATION

APPROXIMATE AREA OF ALLUVIUM AQUIFER	BOUNDARY OF ZONE
APPROXIMATE AREA OF BASALT AQUIFER	BOUNDARY OF MODEL AREA
648 VALUE OF SIMULATED HYDRAULIC CONDUCTIVITY FOR ZONE, IN FEET PER DAY	BOUNDARY OF STUDY AREA

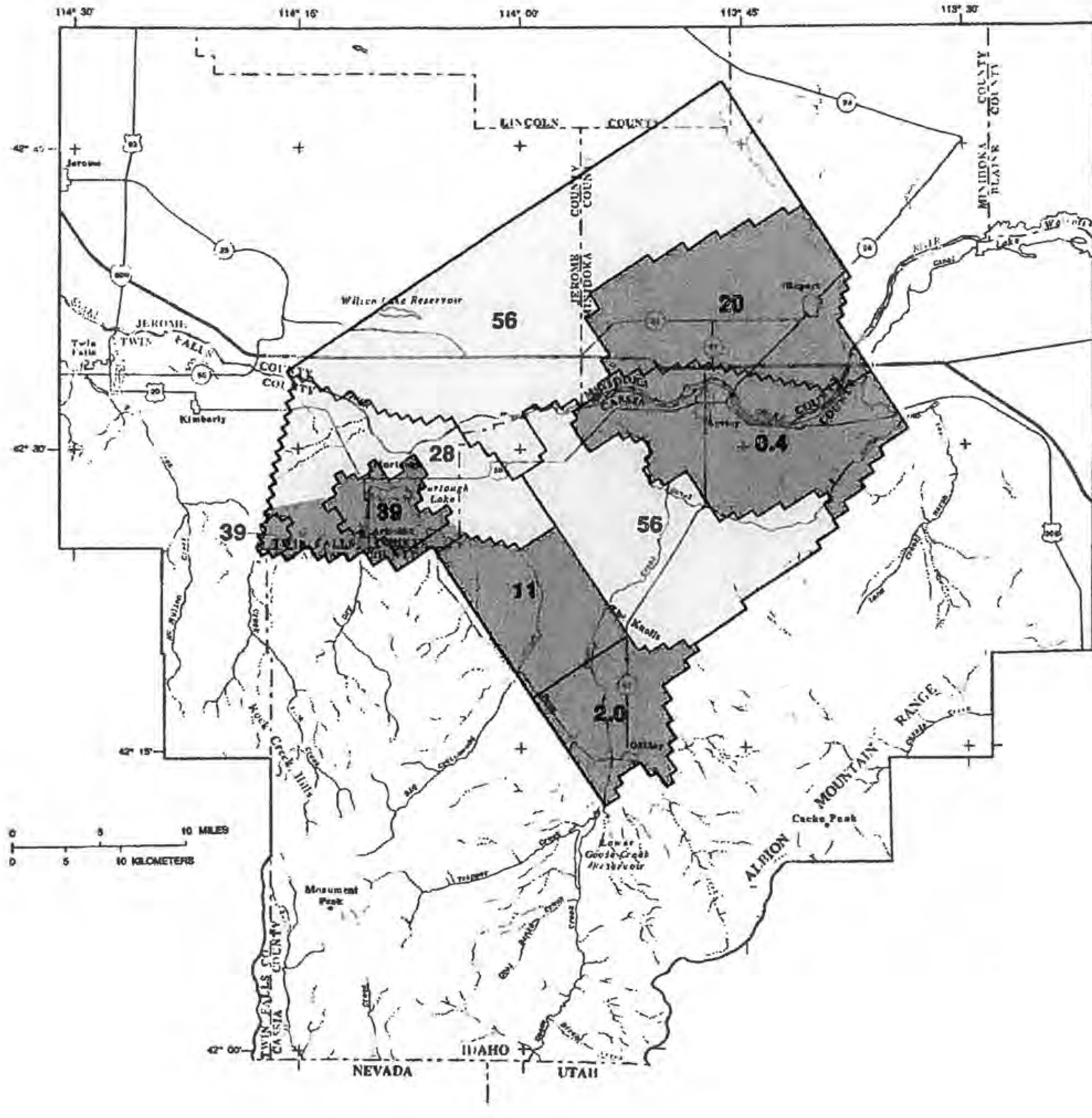
Figure 10.--Distribution of simulated hydraulic conductivity, layer 1.



EXPLANATION

(light shading)	APPROXIMATE AREA OF BASALT AQUIFER
(medium shading)	APPROXIMATE AREA OF RHYOLITE AQUIFER
(patterned shading)	APPROXIMATE AREA OF LIMESTONE AQUIFER
4,409	VALUE OF SIMULATED TRANSMISSIVITY FOR ZONE, IN FEET SQUARED PER DAY
(line)	BOUNDARY OF ZONE
(line)	BOUNDARY OF MODEL AREA
(line)	BOUNDARY OF STUDY AREA

Figure 11.--Distribution of simulated transmissivity, layer 2.



EXPLANATION

APPROXIMATE AREA OF ALLUVIUM

APPROXIMATE AREA OF BASALT

11 VALUE OF VERTICAL HYDRAULIC CONDUCTIVITY, IN FEET PER DAY, BETWEEN LAYERS 1 AND 2

BOUNDARY OF ZONE

BOUNDARY OF MODEL AREA

BOUNDARY OF STUDY AREA

Figure 12.--Distribution of simulated vertical hydraulic conductivity between layers 1 and 2.

between Murtaugh and Burley (fig. 8). Simulated losses from Murtaugh Lake are about 72 ft^3/s, based on a seepage coefficient of 0.045 ft/d (Burrell, 1987, p. 50). Seepage rates from Murtaugh Lake are sensitive to aquifer transmissivity values assigned to the area surrounding the lake. Higher values increase the modeled seepage rate, whereas lower values decrease the rate. Hydraulic conductivity and seepage from the lake also were sensitive to the changing water levels near the lake.

Figure 13 illustrates the relation between March 1984 water levels and simulated heads. The mean absolute difference between historical and simulated heads for all cells was 20 ft in layer 1 and 13 ft in layer 2. Based on this difference, the model seems to be well calibrated and adequately simulates the real system for most applications.

Steady-State Simulation of 1910 Hydrologic Conditions

Initial conditions for transient simulation of water levels for the period 1910-79 were estimated using a steady-state simulation of hydrologic conditions preceding 1910. Prior to 1910, natural hydrologic conditions were unaffected by man's activities. Recharge from surface-water and ground-water irrigation prior to 1910 was negligible. Therefore, it was assumed that hydrologic conditions at the start of 1910 could be reasonably approximated by a steady-state simulation of preirrigation water levels. Model input for the simulation of preirrigation conditions was the same as for the steady-state simulation of 1979-84 average conditions except that recharge from surface-water irrigation and ground-water pumpage were removed. Contours of the simulated 1910 potentiometric surface for layer 1 are shown in figure 14. Water-level data for 1910 were not available. Therefore, it was not possible to compare simulated water levels with measured water levels. However, the simulated water levels are consistent with known hydrologic conditions. Simulated water levels were not above land surface and ground-water discharge to rivers was within reasonable limits, as indicated by historical records of streamflow.

Transient Simulation of 1910-84 Hydrologic Conditions

Because data on recharge and water levels are lacking for the period 1910 to about 1972, it is difficult to check the accuracy of the simulation for that period. However, the simulation provides a view of the past which can at

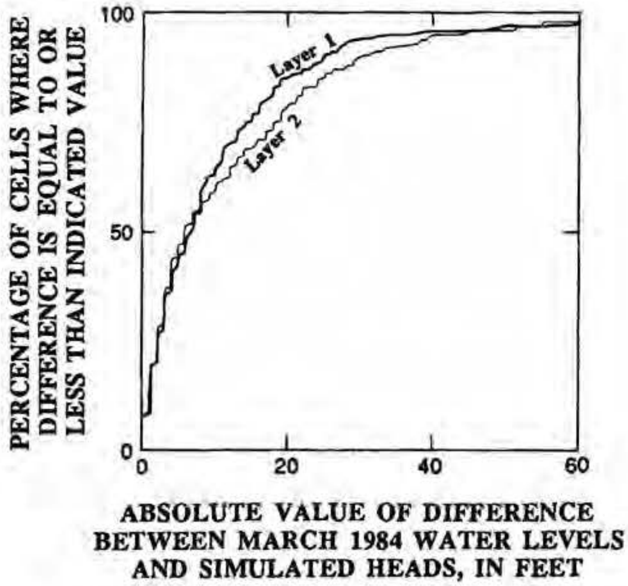
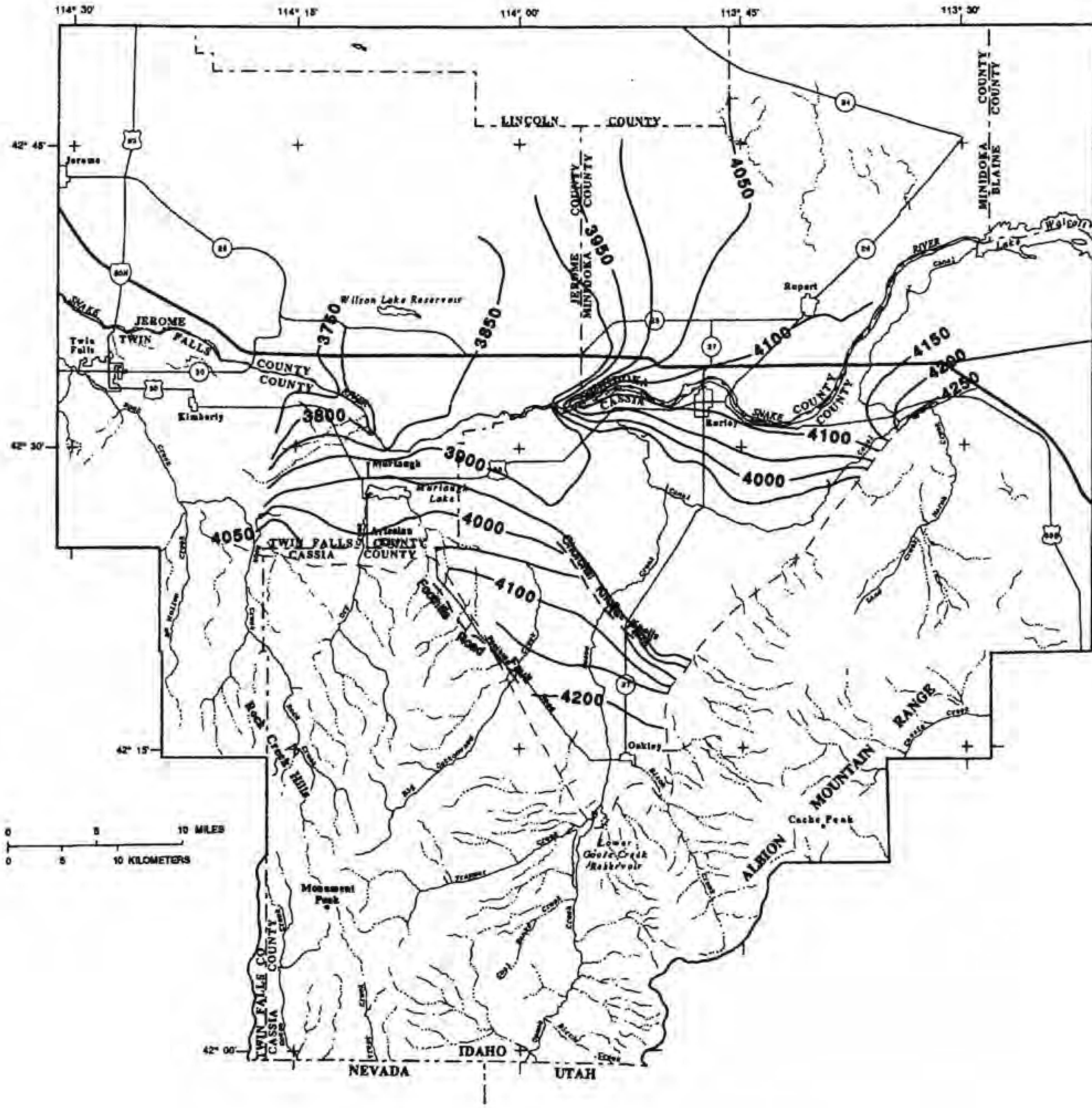


Figure 13.--Relation between March 1984 water levels and simulated heads for average 1979-84 hydrologic conditions.



EXPLANATION

—— 4000 —— POTENTIOMETRIC-SURFACE CONTOUR--Shows water-level altitude for simulation of 1910 hydrologic conditions. Contour interval 50 feet. Datum is sea level

– – – – APPROXIMATE BOUNDARY OF LOWLANDS

———— BOUNDARY OF STUDY AREA

Figure 14.--Simulated 1910 potentiometric surface, layer 1.

least be checked for its consistency with known general hydrologic conditions. Simulation provides an additional check on the degree to which the model can duplicate changes in the system during the period 1910-79.

Information on construction dates from drillers' logs and previous reports indicates that pumping during the period 1910-45 was negligible. In 1910, surface-water diversions began with the construction of Milner Dam and Lake Walcott. Average number of acres irrigated and amount of diversions remained about the same from 1919 to 1984; therefore, recharge was assumed to be the same. Information on pumping during the period 1945-79 is sparse but indicates that pumping increased gradually from none in 1945 to 176,000 acre-ft, the 1979-84 average (table 3).

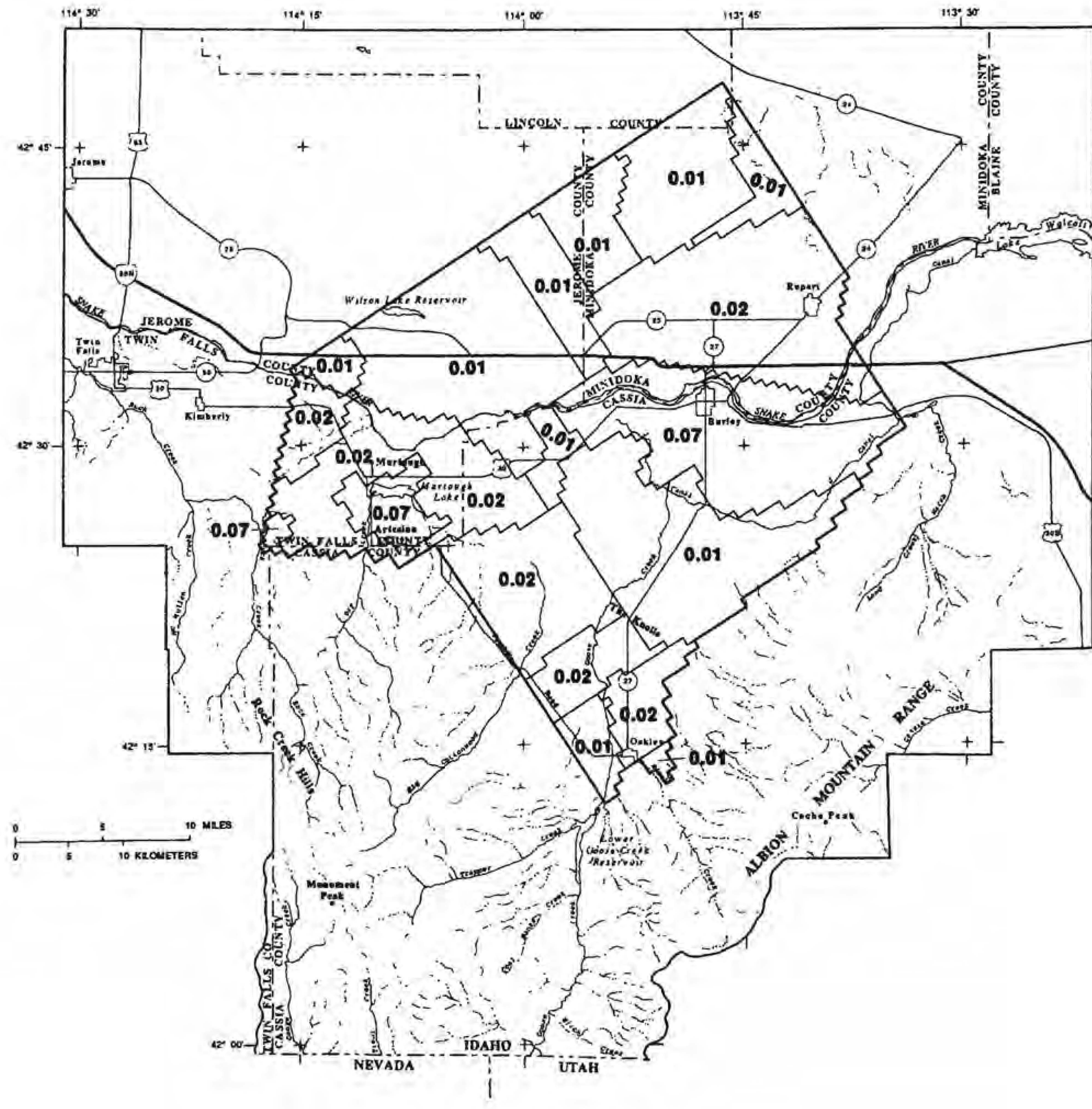
The period from 1910 to 1979 was simulated using 10-year time periods. The period 1979-84 was simulated using monthly time periods so that seasonal head changes could be modeled.

During transient calibration, the specific yield of layer 1 was assigned values from 0.01 to 0.07 (fig. 15). These values are in the low range for specific yield but are typical of clay, silt, limestone, and basalt (Walton, 1984, p. 21). The storage coefficient for layer 2 (fig. 16) was assigned values from 0.001 to 0.006 (Walton, 1984, p. 22).

Figure 17 shows the simulated 1945 potentiometric surface for layer 1. Figure 18 shows simulated rises in water levels for layer 1 for the period 1910-45. During this period, simulated water levels rose as much as 400 ft in some areas. Data are inadequate for comparison of historical and simulated water-level fluctuations for this period; however, the large increases in water levels would be expected as a result of the large amount of irrigation water applied.

Figure 19 shows the simulated 1979 potentiometric surface for layer 2. Figure 20 shows simulated declines in water levels for layer 2 for the period 1945-79. Simulated declines were as large as 140 ft near Murtaugh Lake and 180 ft near Big Cottonwood Creek.

Changes in subsurface outflow resulting from ground-water pumping were evaluated by using the model (fig. 9). Ground-water pumping has captured only a part of the subsurface outflow. Beginning in 1945, before most pumping, simulated net subsurface outflow was 451 ft^3/s. Simulated



EXPLANATION

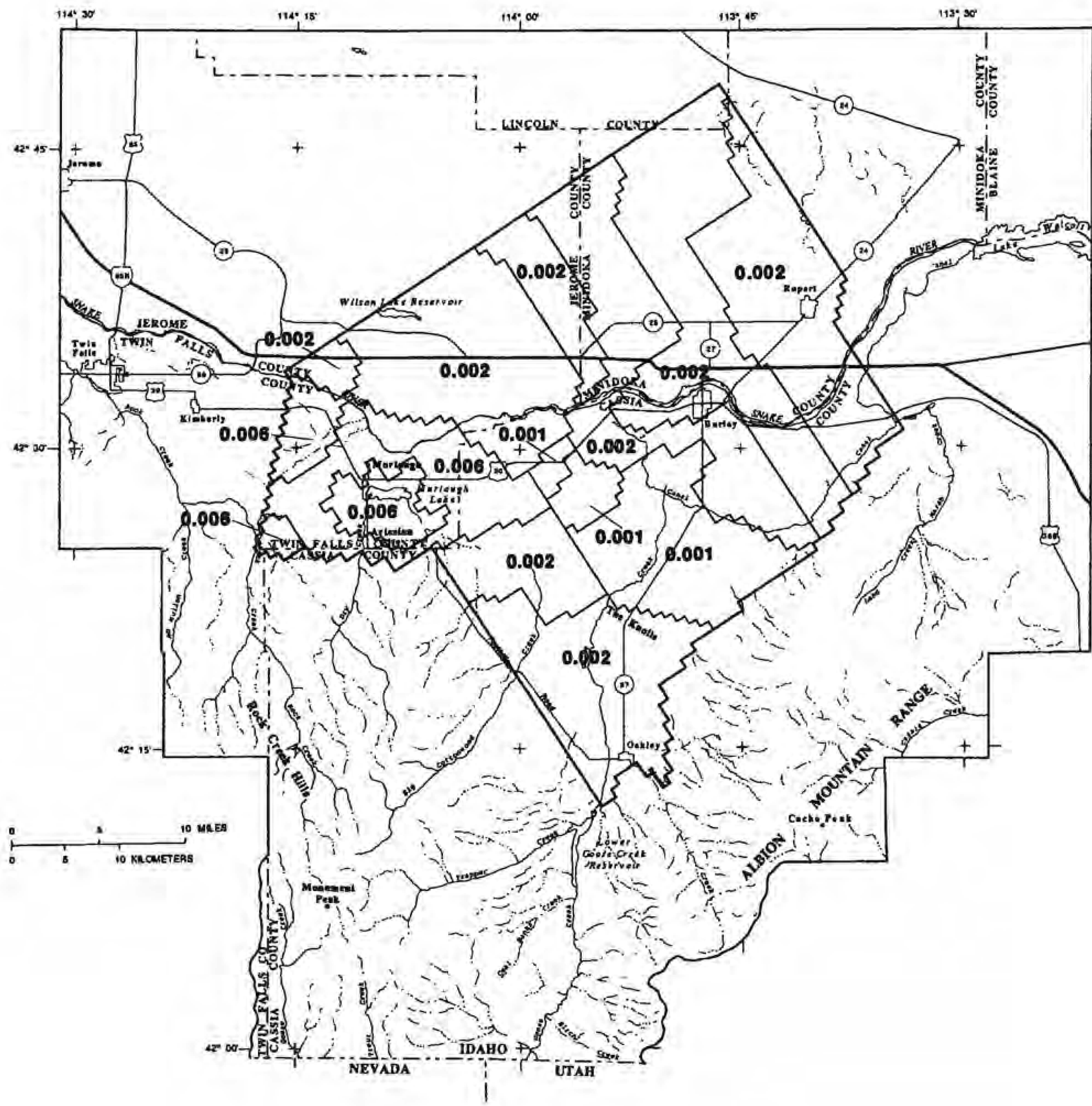
0.01 VALUE OF SPECIFIC YIELD FOR ZONE

BOUNDARY OF ZONE

BOUNDARY OF MODEL AREA

BOUNDARY OF STUDY AREA

Figure 15.--Distribution of specific yield, layer 1.



EXPLANATION

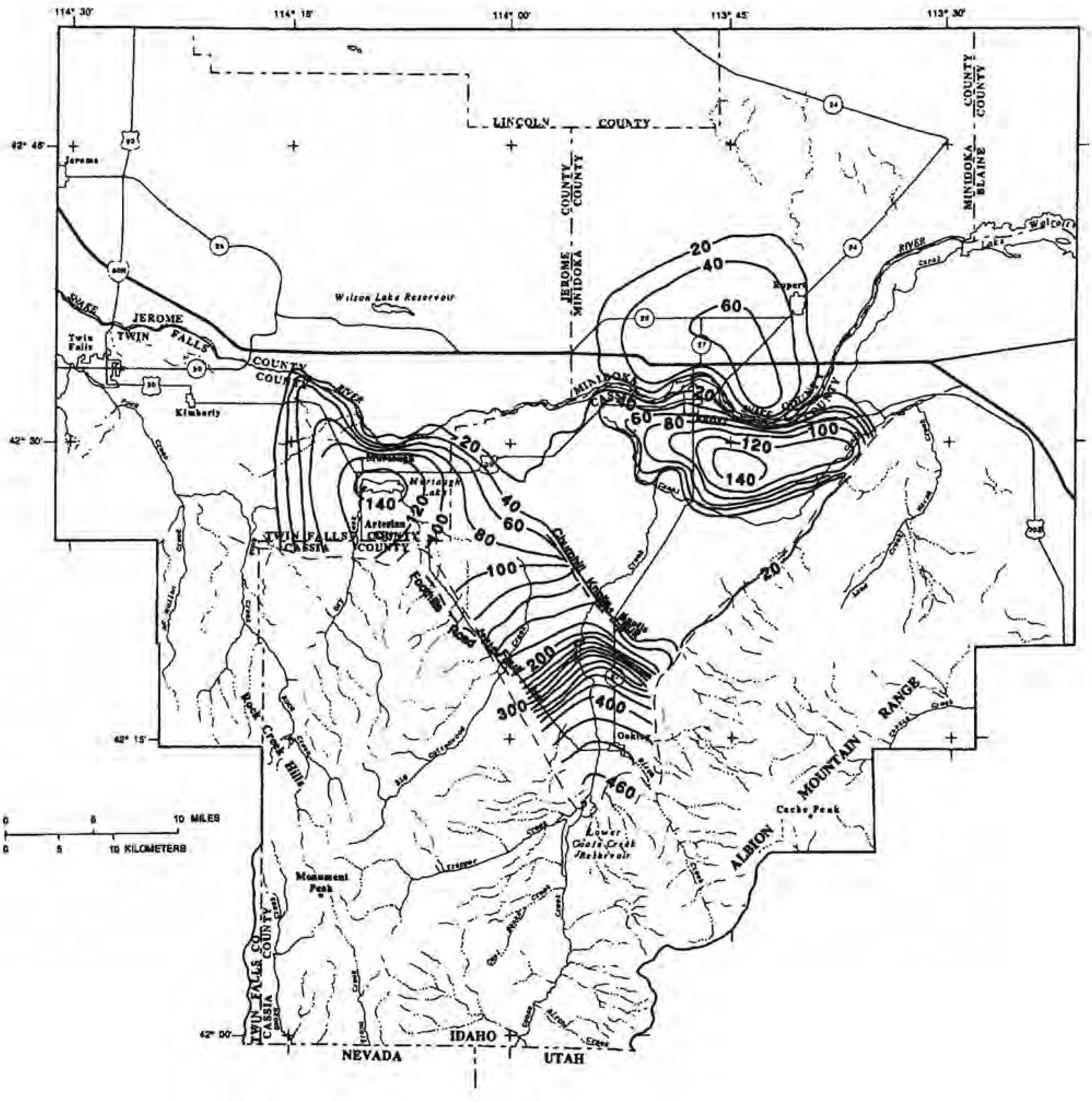
0.006 VALUE OF STORAGE COEFFICIENT FOR ZONE

BOUNDARY OF ZONE

BOUNDARY OF MODEL AREA

BOUNDARY OF STUDY AREA

Figure 16.--Distribution of storage coefficient, layer 2.

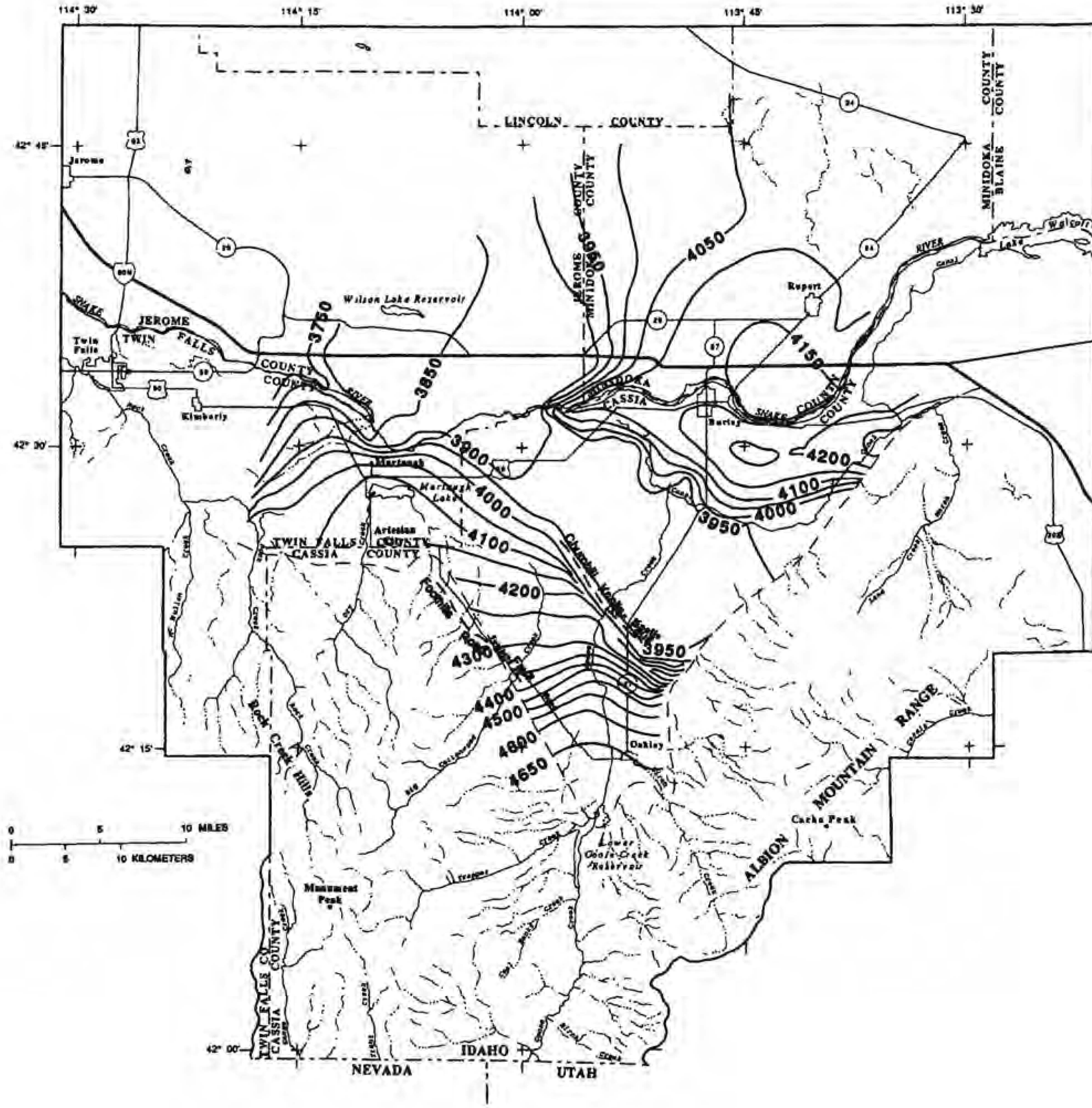


— 200 — WATER-LEVEL CHANGE CONTOUR--Shows simulated rise in water levels, 1910-45. Contour interval 20 feet

- - - - APPROXIMATE BOUNDARY OF LOWLANDS

——— BOUNDARY OF STUDY AREA

Figure 18.--Simulated rises in water levels for layer 1, 1910-45.



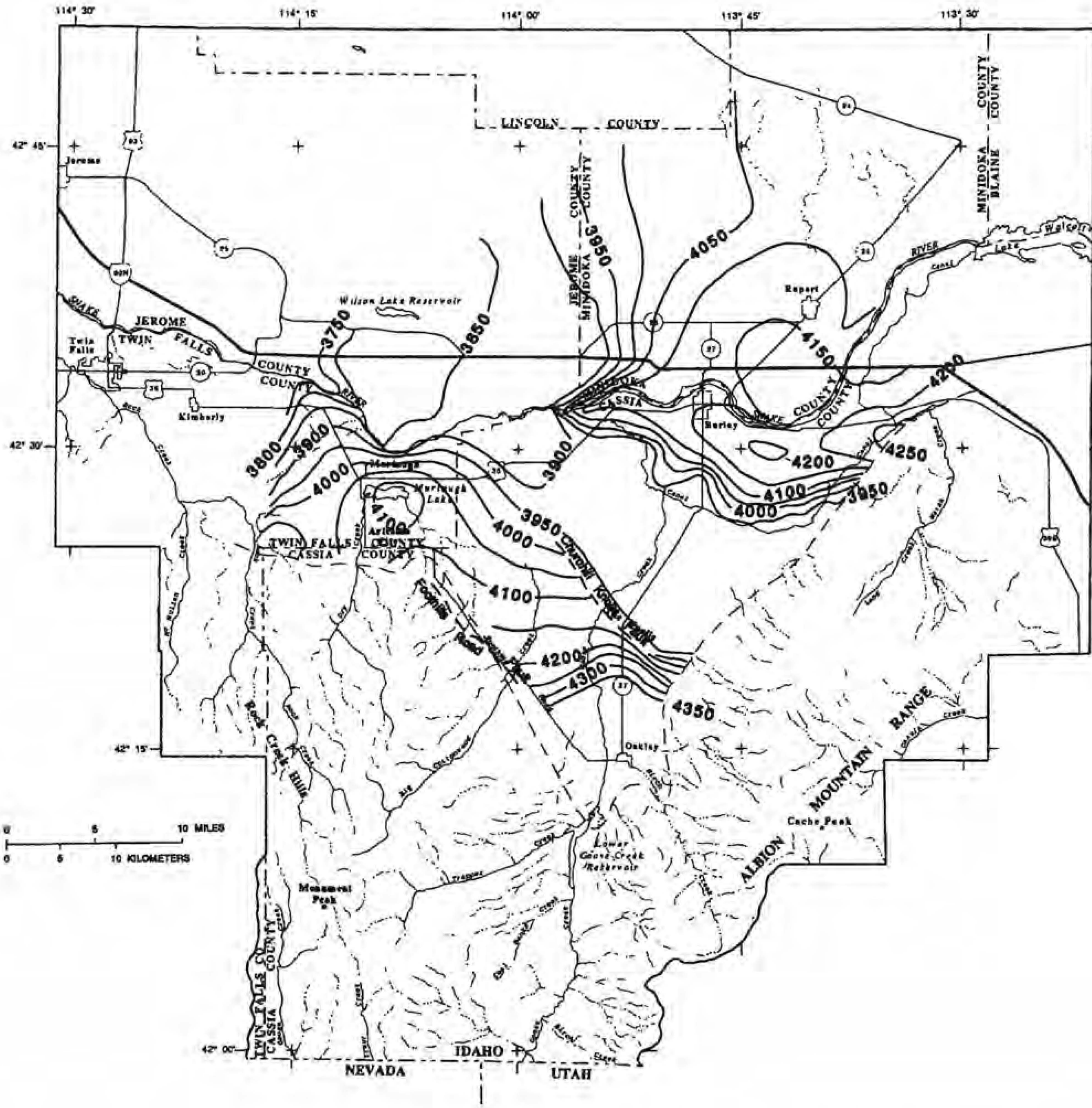
EXPLANATION

— 4200 — POTENTIOMETRIC-SURFACE CONTOUR--Shows water-level altitude for simulation of 1945 hydrologic conditions. Contour interval 50 feet. Datum is sea level

— — — — APPROXIMATE BOUNDARY OF LOWLANDS

——— BOUNDARY OF STUDY AREA

Figure 17.--Simulated 1945 potentiometric surface, layer 1.



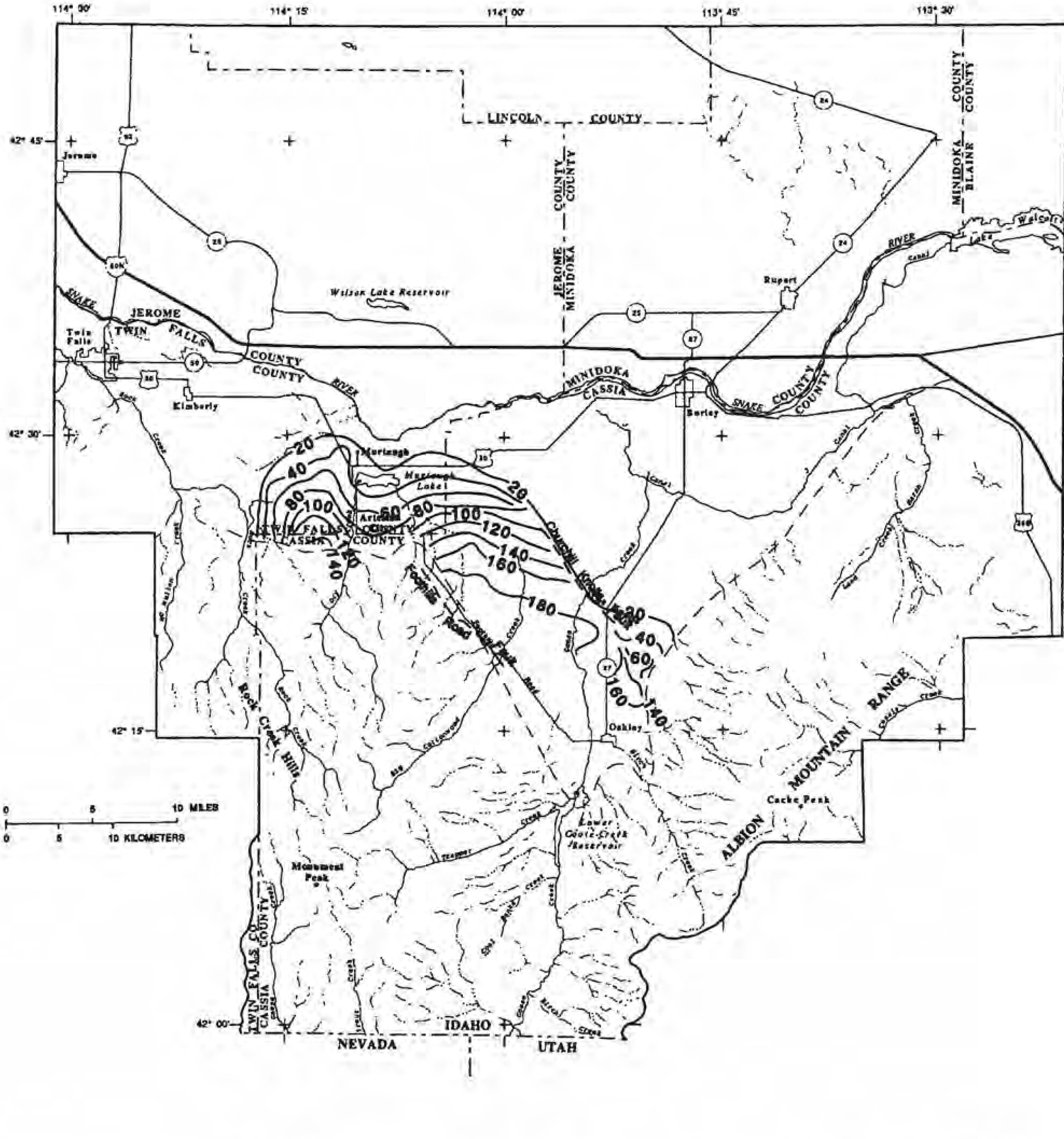
EXPLANATION

— 4000 — POTENTIOMETRIC-SURFACE CONTOUR--Shows water-level altitude for simulation of 1979 hydrologic conditions. Contour interval 50 feet. Datum is sea level

— — — — APPROXIMATE BOUNDARY OF LOWLANDS

———— BOUNDARY OF STUDY AREA

Figure 19.--Simulated 1979 potentiometric surface, layer 2.



— 100 — WATER-LEVEL CHANGE CONTOUR--Shows simulated declines in water levels, 1945-79. Contour interval 20 feet

– – – – APPROXIMATE BOUNDARY OF LOWLANDS

——— BOUNDARY OF STUDY AREA

Figure 20.--Simulated declines in water levels for layer 2, 1945-79.

net subsurface outflow for 1979 was 297 ft^3/s. The difference was due to the combination of reduced outflow in some areas and increased inflow in others. Pumping also induced an increase in inflow from the Snake River and Murtaugh Lake from 1945 to 1979 (fig. 8). Losses from the Snake River increased 7 ft^3/s; losses from Murtaugh Lake increased 35 ft^3/s.

During the period 1945-79, simulated ground-water pumpage was 3,000,000 acre-ft; simulated change in storage for the same period was 250,000 acre-ft. The apparent 92-percent discrepancy is a result of diminished outflow and increased inflow induced by lowered water levels in the aquifers.

Water-level declines near Murtaugh Lake since 1945 were as large as 240 ft, although most were less than 140 ft. Declines were greatest south of Murtaugh Lake near Artesian City. The 100-ft difference between historical and simulated water levels may, in part, be due to an inferred southeast-northwest fault along the foothills, which separates basalt aquifers to the north from rhyolite aquifers to the south. Transmissivity and storage coefficients are apparently much lower in the rhyolite than in the basalt.

Figure 21 compares historical and simulated water-level changes for selected wells for the period 1979-84. Simulated water levels in wells 4, 8, 9, 12, and 17 match historical water levels closely. However, water levels in wells 16 and 18 are 40 ft lower than historical water levels and, in well 5, are 60 ft higher. Some of the differences may represent localized water-level changes, rather than average conditions.

Evaluation of Model Results

Although calculations performed by the model are precise, accuracy of the results depends on the validity of simplifying assumptions used in model formulation and the accuracy of the authors' concept of the hydrologic system. If the simplifying assumptions are valid and the hydrologic system is accurately represented, the simulated response will be a close approximation of the real system.

In the Oakley Fan area, rates of subsurface flow into and out of the model are difficult to estimate. Assumptions made for inflow and outflow introduce a large degree of uncertainty into the model results. Boundary conditions and transmissivity for areas bordering the Snake River Plain are particularly critical for model accuracy. The magnitude of

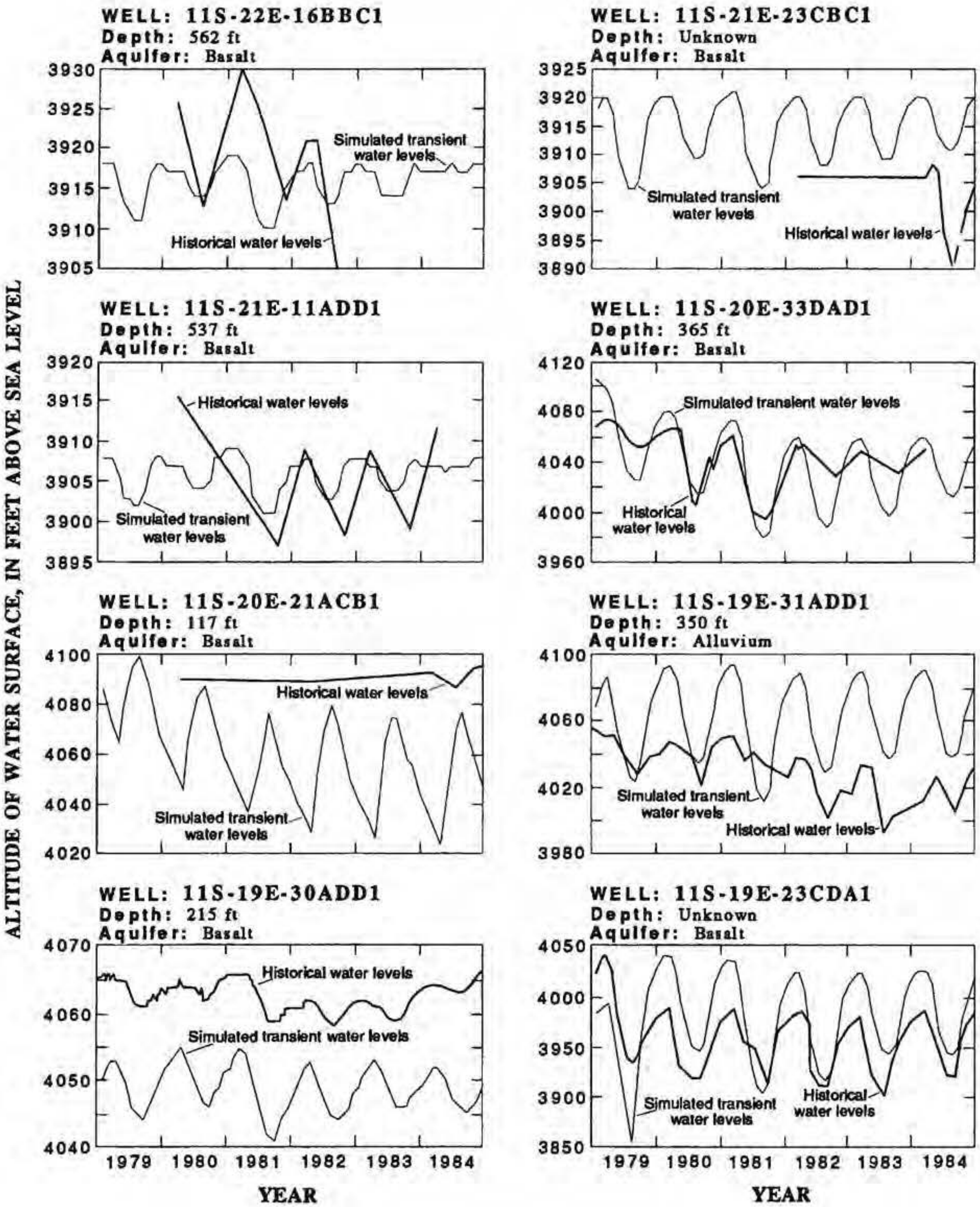


Figure 21.--Hydrographs comparing historical and simulated water-level changes for selected wells, 1979-84--Continued.
(Locations of wells are shown in figures 8 and 9)

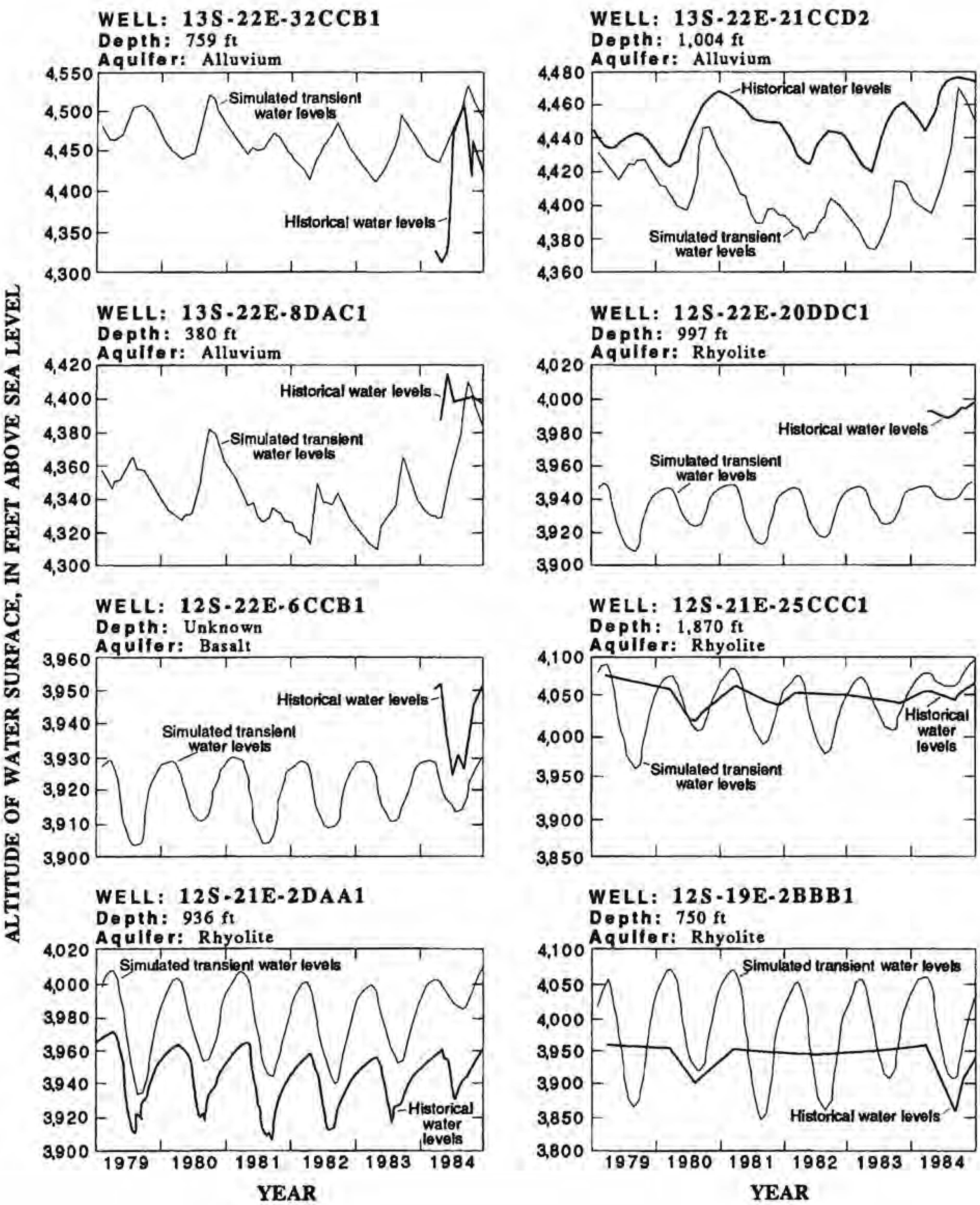


Figure 21.--Hydrographs comparing historical and simulated water-level changes for selected wells, 1979-84.
(Locations of wells are shown in figures 8 and 9)

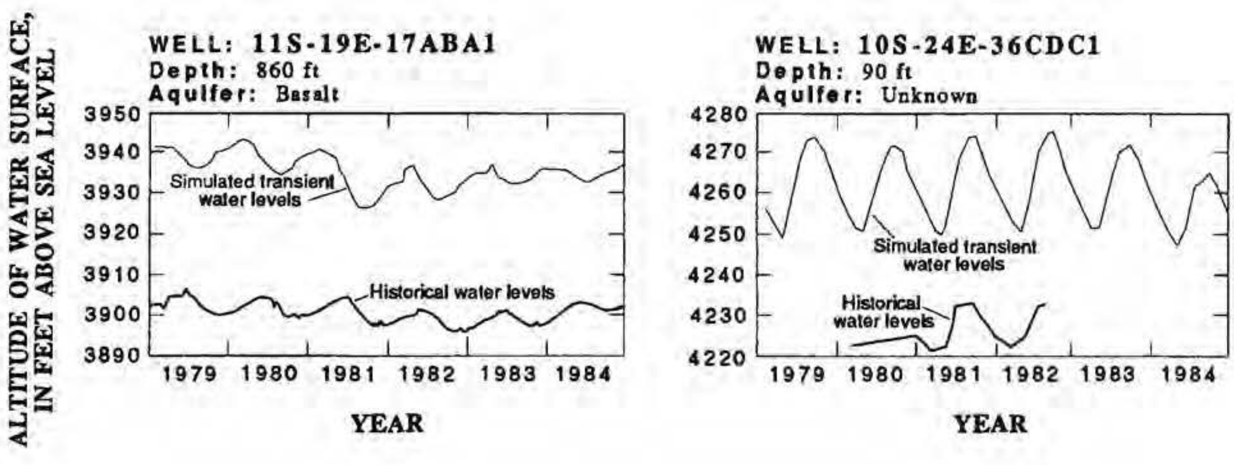


Figure 21.--Hydrographs comparing historical and simulated water-level changes for selected wells, 1979-84--Continued.
(Locations of wells are shown in figures 8 and 9)

inflow and outflow along these boundaries is large compared to other recharge components, and small changes in head or transmissivity can significantly change inflow or outflow from the modeled area. Adjustments of other parameters would be required to compensate for the change in flow. Other reasonably close matches between historical and simulated heads for steady-state conditions also may have been obtained using other values for recharge and transmissivity.

In this study, the range of uncertainty of the final steady-state solution was evaluated by multiplying transmissivity values by a constant. The constant was selected so that changes in parameters were large enough to demonstrate a noticeable change in head, yet would allow the parameters to maintain a reasonable physical value. When model values were changed 20 percent, the agreement between historical and simulated heads changed as indicated in figure 22. The fit in both cases was not as close as in the assumed best case. When the parameters were multiplied by 1.2, 27 percent of the observation points had an error greater than 20 ft, compared to 12 percent for the assumed best case. When the parameters were multiplied by 0.80, 30 percent of the observation points had an error greater than 20 ft.

Comparison of historical and simulated head values is not the only available check on model accuracy. Simulated inflow and outflow from rivers and lakes can be compared to measured values.

The gain or loss to the Snake River is difficult to measure accurately because of backwater effects of Milner Dam, but measurements indicate that the net gain or loss in this reach approximates simulated values shown in figure 8.

Diversion records show that 1979-84 diversions into Murtaugh Lake averaged 1,174,000 acre-ft. Simulated losses were about 52,000 acre-ft, or about 5 percent of average annual diversions. In contrast, measured losses during 1984 and 1985 ranged from 21.4 to 49.4 ft^3/s, or about 15,400 to 35,700 acre-ft/yr.

The simulated seepage loss from Murtaugh Lake was 1.5 to 3 times greater than the 1979-84 average measured values. One reason may be that the measured seepage values are inaccurate, owing to variations in ground-water levels on different dates. Another reason may be that the actual seepage is only about 4 percent of the inflow and is less than the expected range of error for discharge measurements, and that during 1984-85 when seepage was measured, diversions were about one-third of the 1979 diversions. Another reason may be that ground-water levels used to check the

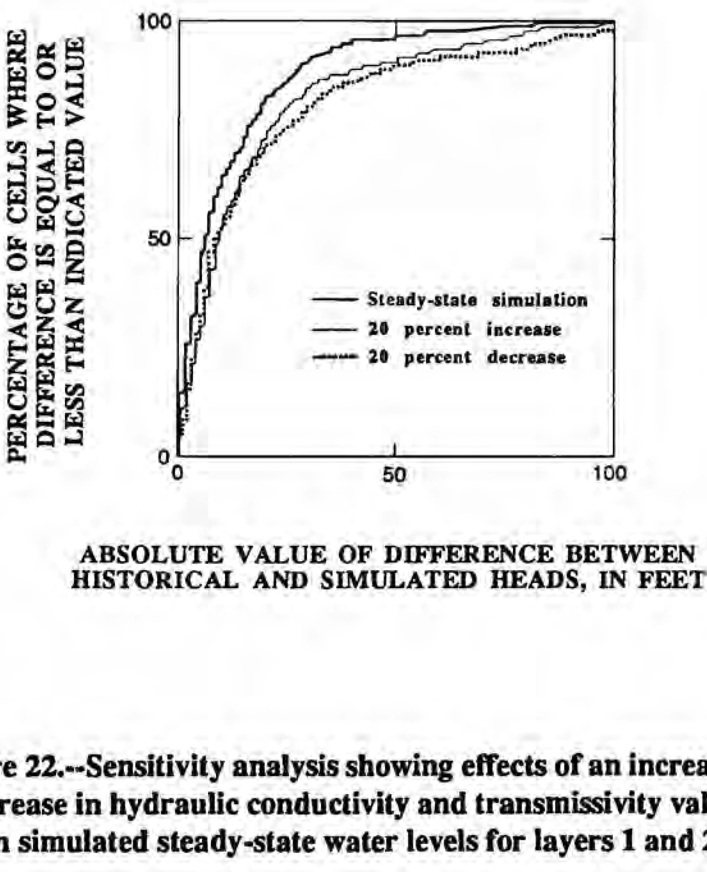


Figure 22.--Sensitivity analysis showing effects of an increase or decrease in hydraulic conductivity and transmissivity values on simulated steady-state water levels for layers 1 and 2.

steady-state simulation were measured during March when water levels were at their highest during the year. More seepage from the lake is required to maintain these higher March water levels than if lower average water levels from some other month were used during simulation. However, it seems that even if lower water levels were used, simulated seepage still would be higher than measured.

Given the assumptions and limitations stated in this report, the model is a useful tool for evaluating aquifer response to changes in hydrologic conditions. The model incorporates a large body of knowledge about the Oakley Fan area into an integrated package. Simulations done with the model show that it approximately duplicates historical conditions. The accuracy demonstrates that the model probably can be used to evaluate future effects of changes in the hydrologic system.

SUMMARY

Principal aquifers in the Oakley Fan area are limestone, rhyolite, basalt, and alluvium. Ground water is confined in the limestone and rhyolite aquifers, is unconfined in the basalt aquifer, and is unconfined in perched zones in the alluvium. The general direction of ground-water movement is downgradient from areas of recharge to areas of discharge, except where the Foothills Road and Churchill Knolls faults impede movement. Water-level fluctuations in aquifers in the Oakley Fan area respond to seasonal and long-term effects. Seasonally, water levels rise in response to the application of surface water for irrigation and decline in response to ground-water pumping for irrigation. Long-term fluctuations indicate an imbalance between recharge and pumpage. Annual declines range from about 3 ft in the basalt aquifer to about 5 ft in the limestone and rhyolite aquifers. Most of the recharge to aquifers is from infiltration of surface water, precipitation on the surrounding mountains, infiltration of local runoff, and upward movement of thermal water. Ground-water pumpage for irrigation during the period 1979-84 ranged from 218,000 acre-ft in 1979 to 127,000 acre-ft in 1984.

Estimated mean annual runoff in seven streams ranged from 520 acre-ft in Big Cedar Creek to 7,200 acre-ft in Dry and Big Cottonwood Creeks. Highest mean monthly runoff is in May.

Chemically, surface water is a calcium bicarbonate type. Dissolved-solids concentrations ranged from 55 mg/L in Willow Creek to 240 mg/L in Birch Creek. Ground water is predominantly a calcium bicarbonate type with varying concentrations of dissolved solids. To aid in determining the areal extent of each aquifer, concentrations of specific constituents, particularly silica and chloride, and isotopic compositions were compared.

A three-dimensional mathematical model of the Oakley Fan area was developed. The study area was expanded north of the Snake River so that subsurface inflow and outflow to the Snake River Plain could be computed. Average annual ground-water recharge during 1979-84 was about 390,000 acre-ft. Most of the recharge is within the boundaries of the Burley and Milner Low-Lift Irrigation Districts.

The aquifer system was simulated in three phases: (1) Average 1979-84 hydrologic conditions, (2) 1910 hydrologic conditions, and (3) 1910-84 hydrologic conditions.

Hydraulic conductivity and transmissivity were adjusted during the steady-state and transient simulations. Hydraulic conductivity in layer 1 ranged from 4 ft/d for cells representing alluvium to about 4,200 ft/d for cells representing basalt. Vertical hydraulic conductivities between layers ranged from 0.4 to 56 ft/d. Transmissivity values in layer 2 ranged from about 1,700 ft^2/d for cells representing alluvium to about 3,110,000 ft^2/d for cells representing basalt.

Model simulation indicates that the Snake River gains about 41 ft^3/s above Burley and 127 ft^3/s below Murtaugh and loses 129 ft^3/s between Burley and Murtaugh. Simulated seepage from Murtaugh Lake was estimated to be 72 ft^3/s. Seepage from Murtaugh Lake is controlled by hydraulic conductivity of the underlying material and ground-water levels surrounding the lake.

The mean absolute difference between historical and simulated heads was used to evaluate accuracy of the steady-state simulation. The difference was 20 ft in layer 1 and 13 ft in layer 2.

Simulated water levels during the period 1910-45 rose as much as 400 ft and, during the period 1945-79, declined as much as 180 ft.

Model simulation indicated that, for the period 1945-79, subsurface outflow declined from 327,000 to 215,000 acre-ft/yr in response to ground-water pumping. Simulated ground-water pumpage during the period 1945-79 was 3,000,000 acre-ft; simulated change in storage for the same period was only 250,000 acre-ft. The apparent 92-percent discrepancy is a result of diminished outflow and increased inflow caused by higher hydraulic gradients induced by lowered water levels in the aquifers.

The specific yield assigned to layer 1 ranged from 0.01 for basalt to 0.07 for alluvium. The storage coefficient assigned to layer 2 ranged from 0.001 for basalt to 0.006 for alluvium.

Simulations performed with the model show that the model approximately duplicates natural conditions and probably can be used to evaluate future effects of changes in the hydrologic system.

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