GROUND-WATER RESOURCES OF NORTHERN UTAH VALLEY, UTAH

U.S. GEOLOGICAL SURVEY

Open-File Report 84-455

Prepared in cooperation with the

UTAH DEPARTMENT OF NATURAL RESOURCES,

DIVISION OF WATER RIGHTS

Dept.
Seal

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By David W. Clark and Cynthia L. Appel

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UNITED STATES DEPARTMENT OF THE INTERIOR

WILLIAM P. CLARK, Secretary

GEOLOGICAL SURVEY

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CONVERSION FACTORS AND RELATED INFORMATION

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

Multiply inch-pound units	By	To obtain metric units
acre	0.4047	square hectometer
	0.004047	square kilometer
acre-foot	0.001233	cubic hectometer
acre-foot per year	0.001233	cubic hectometer per year
cubic foot per second	0.02832	cubic meter per second
cubic foot per day	0.02832	cubic meter per day
foot	0.3048	meter
foot per acre	0.7532	meter per square hectometer
foot per day	0.3048	meter per day
foot per year	0.3048	meter per year
foot per mile	0.1894	meter per kilometer
foot squared per day	0.0929	meter squared per day
gallon per minute	0.06309	liter per second
inch	25.40	millimeter
	2.540	centimeter
inch per year	2.450	millimeters per year
mile	1.609	kilometer
square mile	2.590	square kilometer

Chemical concentration and water temperature are given in metric units. Chemical concentration is given in milligrams per liter (mg/L or micrograms per liter (ug/L). Milligrams per liter is a unit expressing the concentration of chemical constituents in solution as weight (milligrams) of solute per unit volume (liter of water). One thousand micrograms per liter is equivalent to 1 milligram per liter. For concentrations less than 7,000 mg/L, the numerical value is about the same as for concentrations in parts per million.

Chemical concentration in terms of ionic interacting values is given in milliequivalents per liter (meq/L). Meq/L is numerically equal to equivalents per million.

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

$$^{\circ}F = 1.8(^{\circ}C) + 32$$

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

$$^{\circ}C = {^{\circ}F}/1.8 - 32$$

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

GROUND-WATER RESOURCES OF NORTHERN UTAH VALLEY, UTAH

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ABSTRACT

An evaluation was made of the ground-water resources of northern Utah Valley, Utah, to describe the ground-water system and to document changes in ground-water conditions since 1963. The principal ground-water reservoir is in basin-fill deposits. It consists of three major confined aquifers and an unconfined aquifer in pre-Lake Bonneville deposits along the mountains that adjoin the valley. The principal ground-water reservoir contains about 3.5 million acre-feet of recoverable water.

The surface-water inflow in major streams to the valley is a principal source of ground-water recharge. This inflow averaged approximately 390,000 acre-feet per year during water years 1963-82. The total annual ground-water recharge is estimated to average about 200,000 acre-feet. It includes about 73,000 acre-feet of seepage from waterways and 112,000 acre-feet of subsurface inflow from the consolidated rocks of the mountains.

The total annual ground-water discharge is estimated to average about 220,000 acre-feet. It includes 135,000 acre-feet discharged to waterways and springs and 68,000 acre-feet withdrawn from wells. The annual ground-water withdrawal for public supply increased from about 5,000 acre-feet during 1963 to about 20,000 acre-feet during the late 1970's. This reflected an increase in urban population from about 72,000 in 1960 to about 164,000 in 1980. Considering all factors, a reasonable estimate for both recharge and discharge to and from the principal ground-water reservoir is about 200,000 acre-feet per year.

Water levels in wells fluctuate seasonally due to changes in rates of recharge or discharge, and the greatest changes are closest to points of recharge or discharge. Since 1970, water levels have declined, despite generally greater than average precipitation, due to increased withdrawal from wells for public supply.

Ground water in the study area generally is suitable for most uses. There is little evidence of change in the chemical quality between the late 1950's and 1982.

INTRODUCTION

Purpose and Scope

An evaluation of the ground-water resources of northern Utah Valley, Utah, was made by the U.S. Geological Survey during 1980-82 in cooperation with the Utah Department of Natural Resources, Division of Water Rights. The purpose of this report, which is part of that study, is twofold: (1) To describe the ground-water system, and (2) to document changes in ground-water conditions since 1963, in the northern Utah Valley.

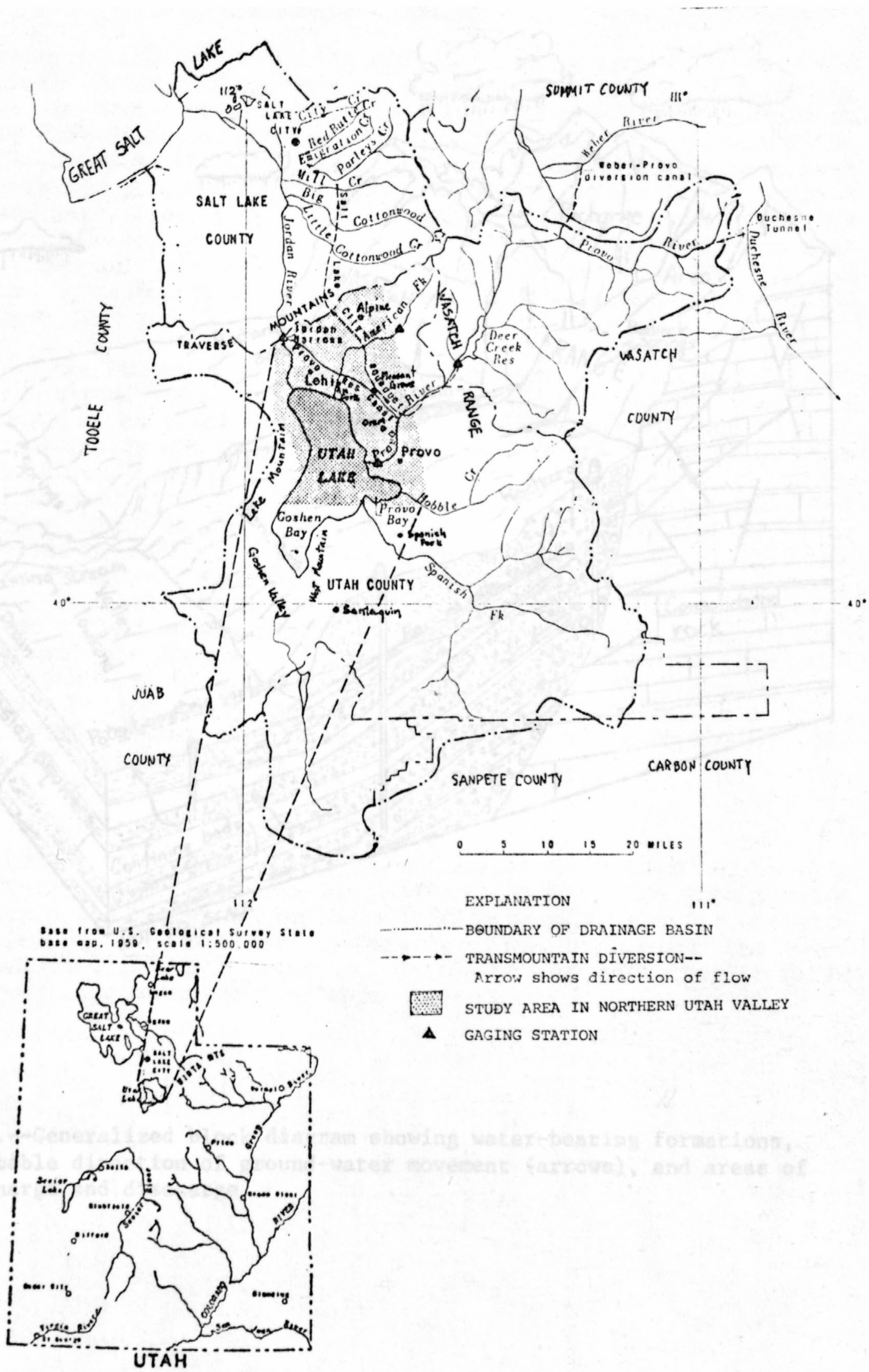
The interpretations and conclusions in this report are based primarily on data presented in a separate report by Appel and others (1982). That report includes tabulations of hydrologic records for wells, springs, drains, and surface-water sites in northern Utah Valley.

Location and Topography

Northern Utah Valley encompasses about one-half of Utah Valley, a north-trending elongate basin about 40 miles long and 10 to 20 miles wide, which is at the eastern edge of the Basin and Range physiographic province in north-central Utah. Northern Utah Valley has an area of about 270 square miles, of which about 100 square miles is occupied by Utah Lake. The valley is bounded by the Wasatch Range on the east, the Traverse Mountains on the north, and the Lake Mountains on the west. The southern boundary, as defined for this study, is an arbitrary line south of Provo Bay (fig. 1), which coincides with the boundary between Townships 7 and 8 South.

The altitude of the valley floor ranges from less than 4,500 feet near Utah Lake to 5,200 feet near the mountains. The highest point in the Wasatch Range is Mt. Timpanogos with an altitude of 11,750 feet, whereas the Lake and Traverse Mountains attain maximum altitudes of only approximately 7,600 and 6,600 feet.

The mountains that adjoin the valley lowlands are bounded by benches (terraces) formed by glacial Lake Bonneville, which extend toward the center of the valley and Utah Lake (fig. 2). The gradient on the benches and the lowlands is generally less than 50 feet per mile, whereas the sharp topographic break between the two has a gradient of approximately 300 feet per mile. Streams that drain the mountains have dissected the benches and now flow over the lowlands toward Utah Lake.



igure 1.--Location of northern Utah Valley

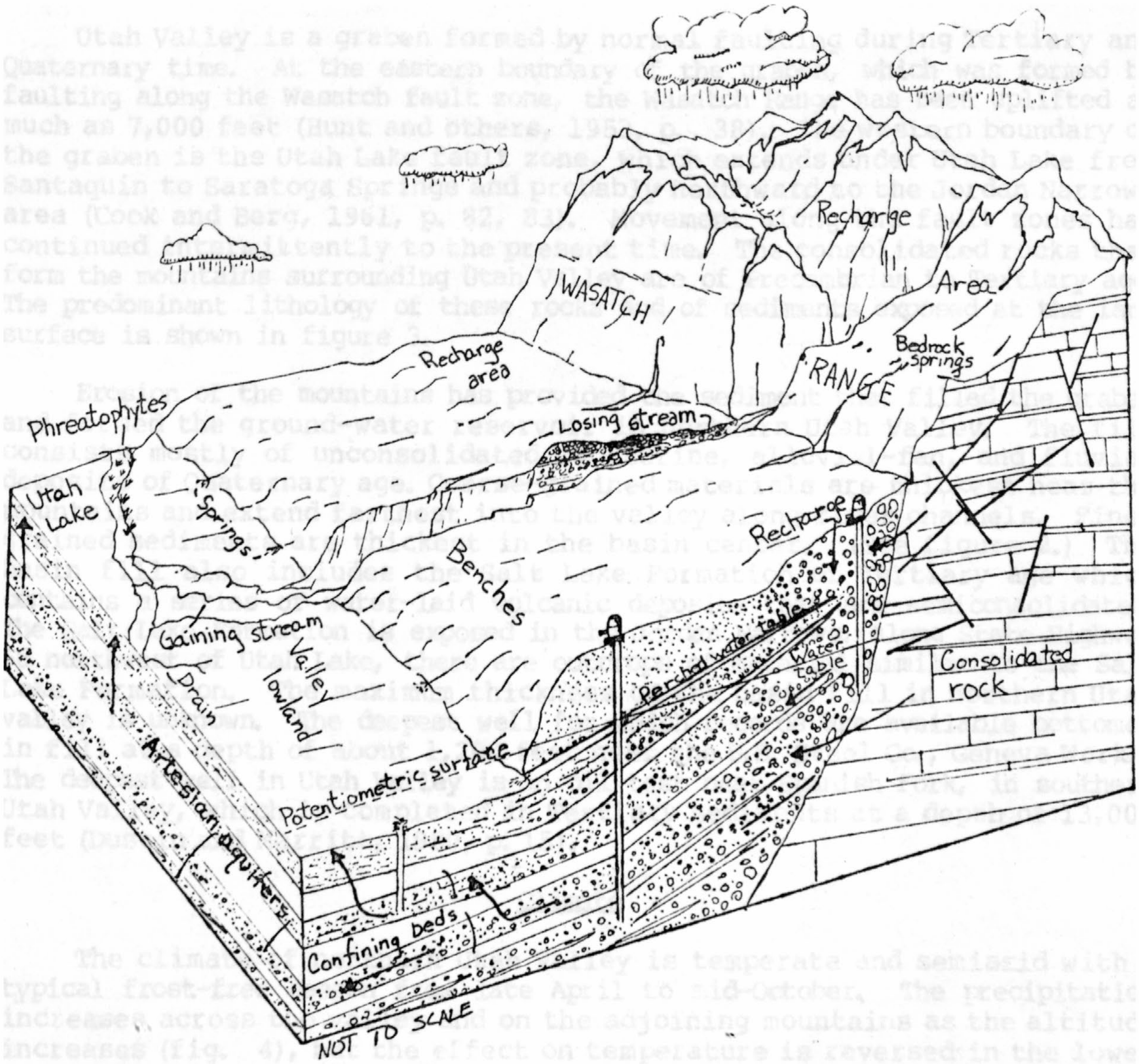


Figure 2.--Generalized block diagram showing water-bearing formations, probable direction of ground-water movement (arrows), and areas of recharge and discharge.

Hydrogeologic Setting

Utah Valley is a graben formed by normal faulting during Tertiary and Quaternary time. At the eastern boundary of the graben, which was formed by faulting along the Wasatch fault zone, the Wasatch Range has been uplifted as much as 7,000 feet (Hunt and others, 1953, p. 38). The western boundary of the graben is the Utah Lake fault zone, which extends under Utah Lake from Santaquin to Saratoga Springs and probably northward to the Jordan Narrows area (Cook and Berg, 1961, p. 82, 83). Movement along the fault zones has continued intermittently to the present time. The consolidated rocks that form the mountains surrounding Utah Valley are of Precambrian to Tertiary age. The predominant lithology of these rocks and of sediments exposed at the land surface is shown in figure 3.

Erosion of the mountains has provided the sediment that filled the graben and formed the ground-water reservoir in northern Utah Valley. The fill consists mostly of unconsolidated lacustrine, alluvial-fan, and fluvial deposits of Quaternary age. Coarse-grained materials are thickest near the mountains and extend farthest into the valley along river channels. Fine-grained sediments are thickest in the basin center. (See figure 2.) The basin fill also includes the Salt Lake Formation of Tertiary age which contains a series of water-laid volcanic deposits that are semiconsolidated. The Salt Lake Formation is exposed in the Jordan Narrows. Along State Highway 68 northwest of Utah Lake, there are outcrops of material similar to the Salt Lake Formation. The maximum thickness of the basin fill in northern Utah valley is unknown. The deepest well for which records are available bottomed in fill at a depth of about 1,200 feet near the U.S. Steel Co., Geneva Works. The deepest well in Utah Valley is an oil test near Spanish Fork, in southern Utah Valley, which is completed in Tertiary sediments at a depth of 13,000 feet (Dustin and Merritt, 1980, p. 15).

Climate

The climate of northern Utah Valley is temperate and semiarid with a typical frost-free season from late April to mid-October. The precipitation increases across the valley and on the adjoining mountains as the altitude increases (fig. 4), but the effect on temperature is reversed in the lower parts of the area (table 1). About two-thirds of the precipitation falls during the nongrowing season of mid-October through April.

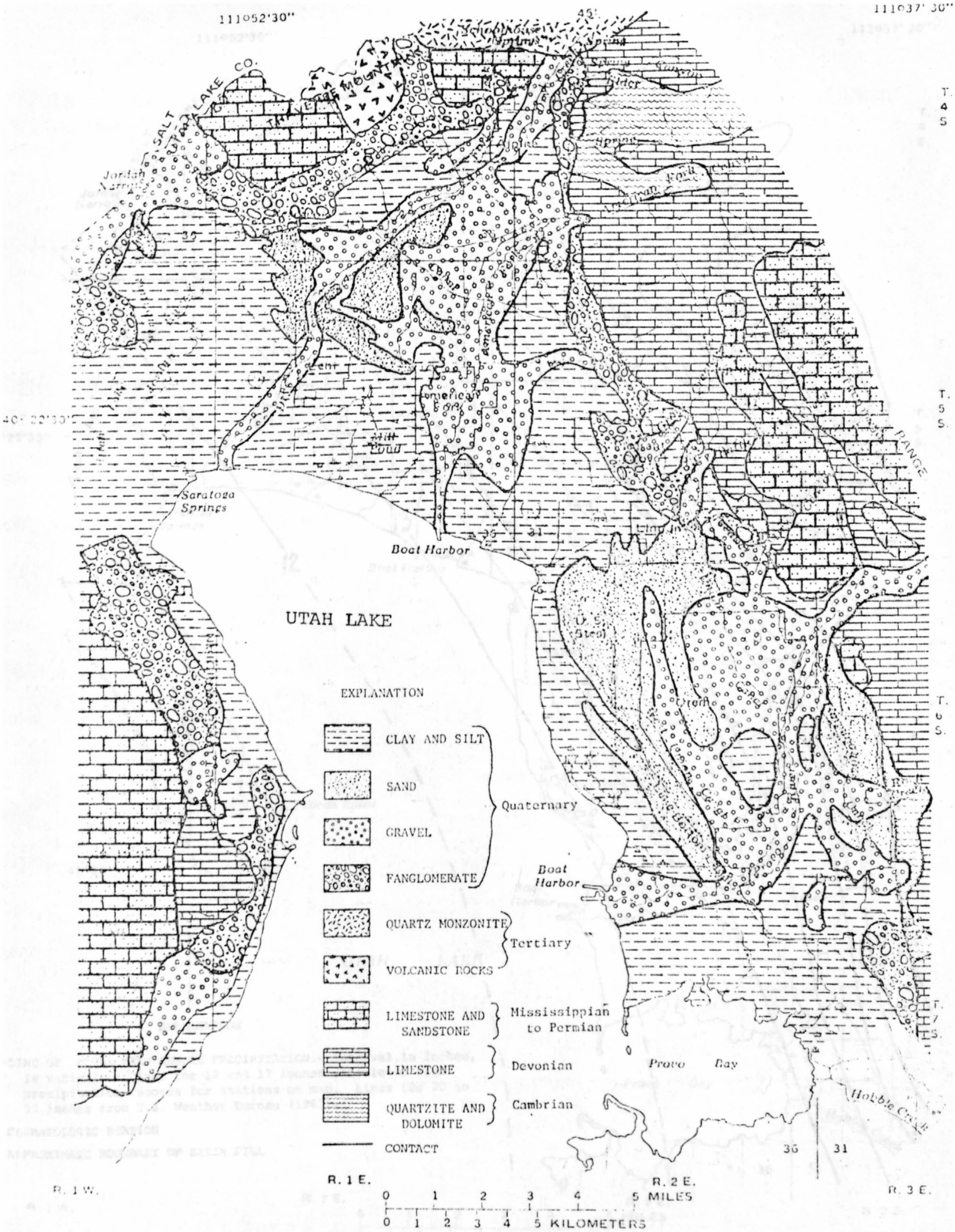


Figure 3 .--Generalized lithology of surficial geologic units

(adapted from Hunt and others, 1953, pl. 1; Baker, 1964, 1972, 1973; and Crittenden, 196]; and Hintze, 1980).

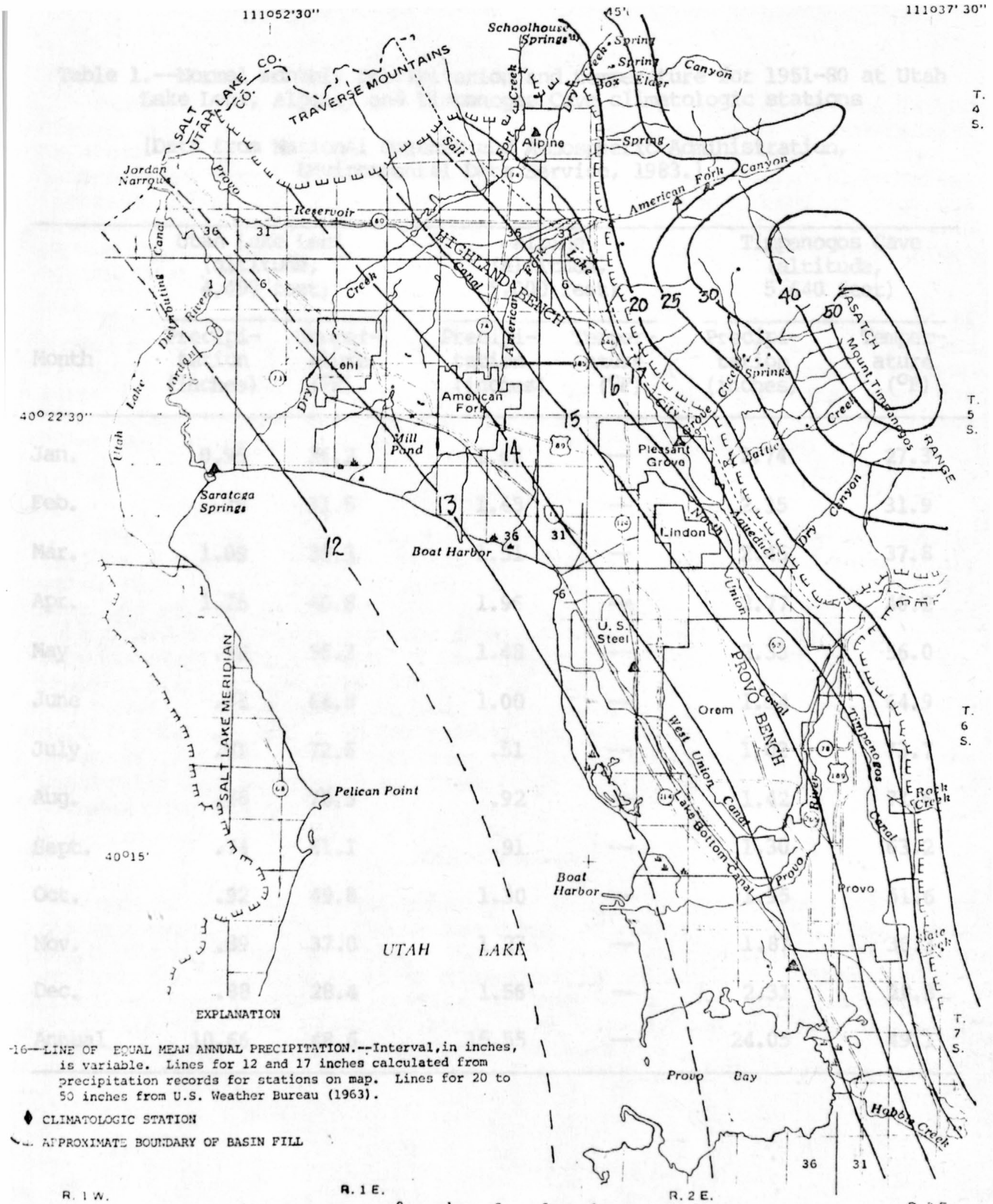


Figure 4.--Mean annual precipitation, 1963-81.

Table 1.--Normal monthly precipitation and temperature for 1951-80 at Utah Lake Lehi, Alpine, and Timpanogos Cave climatologic stations

[Data from National Oceanic and Atmospheric Administration, Environmental Data Service, 1983.]

Month	Utah Lake Lehi (altitude, 4,497 feet)		Alpine (altitude, 5,000 feet)		Timpanogos Cave (altitude, 5,640 feet)	
	Precipitation (inches)	Temperature (°F)	Precipitation (inches)	Temperature (°F)	Precipitation (inches)	Temperature (°F)
Jan.	0.95	26.2	1.68	--	2.74	27.3
Feb.	.76	31.5	1.45	--	2.35	31.9
Mar.	1.09	38.3	1.51	--	2.45	37.8
Apr.	1.25	46.8	1.96	--	2.77	46.2
May	.98	56.3	1.48	--	2.33	56.0
June	.71	64.8	1.00	--	1.54	64.9
July	.61	72.6	.51	--	1.02	73.7
Aug.	.88	70.3	.92	--	1.42	71.6
Sept.	.74	61.1	.91	--	1.30	63.2
Oct.	.92	49.8	1.30	--	1.95	51.6
Nov.	.89	37.0	1.27	--	1.87	36.3
Dec.	.88	28.4	1.56	--	2.31	28.3
Annual	10.66	48.6	15.55	--	24.05	49.1

Population and Land Use

Northern Utah Valley is one of the fastest growing areas in the United States, and in 1980 it included 78 percent of the population of Utah County, or about 170,000 people. Ninety-six percent of those people live in incorporated areas (table 2). The population in northern Utah Valley increased 59 percent from 1970 to 1980, and the population of numerous communities more than doubled from 1960 to 1980. The large increase in population has been mostly in suburban areas, which have expanded into former agricultural areas.

The major shift in land use from agriculture to urban from 1966-80 is shown by comparing figures 5 and 6. The land classified as urban increased by 10,000 acres (58 percent), and the agricultural land decreased by 6,000 acres (12 percent). Approximately 60 percent of the new urban area was formally agricultural land, and the greatest land-use changes occurred on the Provo Bench where nearly 5,700 acres were converted to urban use.

Previous Investigations

The first hydrologic study that included northern Utah Valley was made in 1904 by Richardson (1906). Taylor and Thomas (1939) reported on multiple water-level measurements in more than 50 wells near Lehi. During 1946-47, Hunt and others (1953) studied the Pleistocene geology of northern Utah Valley, and their report included detailed descriptions of four aquifers and potentiometric maps for each of the aquifers. Cordova and Subitzky (1965), based on field studies from 1956 to 1963, reported on ground-water conditions for 1948-63. Their report included a ground-water budget and potentiometric maps for March-April 1963 for each of the aquifers. Since 1961, the U.S. Bureau of Reclamation has made many studies of the potential effects of the Bonneville Unit of the Central Utah Project on the ground-water system in northern Utah Valley.

Acknowledgments

Special acknowledgments are extended to the residents, the officials of the irrigation and distribution companies, of the various cities and towns, and of the industries in northern Utah Valley who gave permission for the use of their wells for water-level measurements and aquifer testing, and who provided other useful information for this study. The cooperation of the officials from the State of Utah, Utah County, and the U.S. Bureau of Reclamation was very helpful and is appreciated.

Table 2.--Population in Utah County

[Data from U.S. Department of Commerce, Bureau of Census, 1971 and 1980.]

Location	1980 census[1]	Percent change 1970-80	1970 census	Percent change 1960-70	1960 census	Percent change 1960-80
Utah County	217,281	57.7	137,776	28.8	106,991	103.1
Northern Utah Valley	170,294	59.2	106,956	--	--	--
Alpine	2,656	153.7	1,047	35.1	775	242.7
American Fork	12,076	56.6	7,713	21.0	6,373	89.5
Highland	2,320	--	--	--	--	--
Lehi	6,847	47.0	4,659	6.4	4,377	56.4
Lindon	2,749	67.2	1,644	43.0	1,150	139.0
Orem	52,474	103.9	25,729	39.9	18,394	185.3
Pleasant Grove	10,684	100.6	5,327	11.6	4,772	123.9
Provo	74,007	39.3	53,131	47.4	36,047	105.3
Total for incorporated areas	163,813	65.1	99,250	38.1	71,888	127.9
Total for unincorporated areas	6,481	-15.9	7,706	--	--	--

[1] Preliminary data.

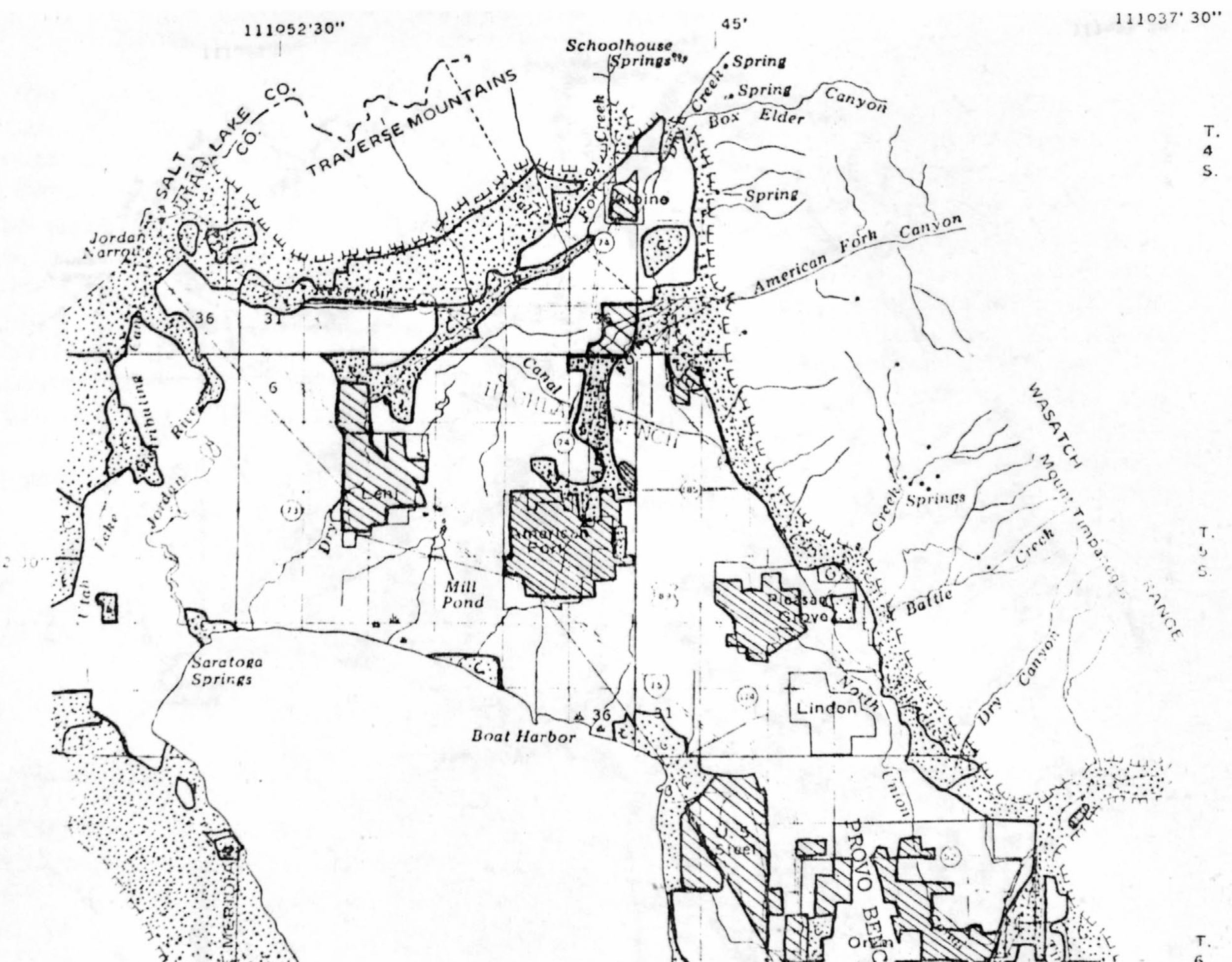


Figure 5.--Land use, 1966. (Adapted from Hyatt and others, 1968.)

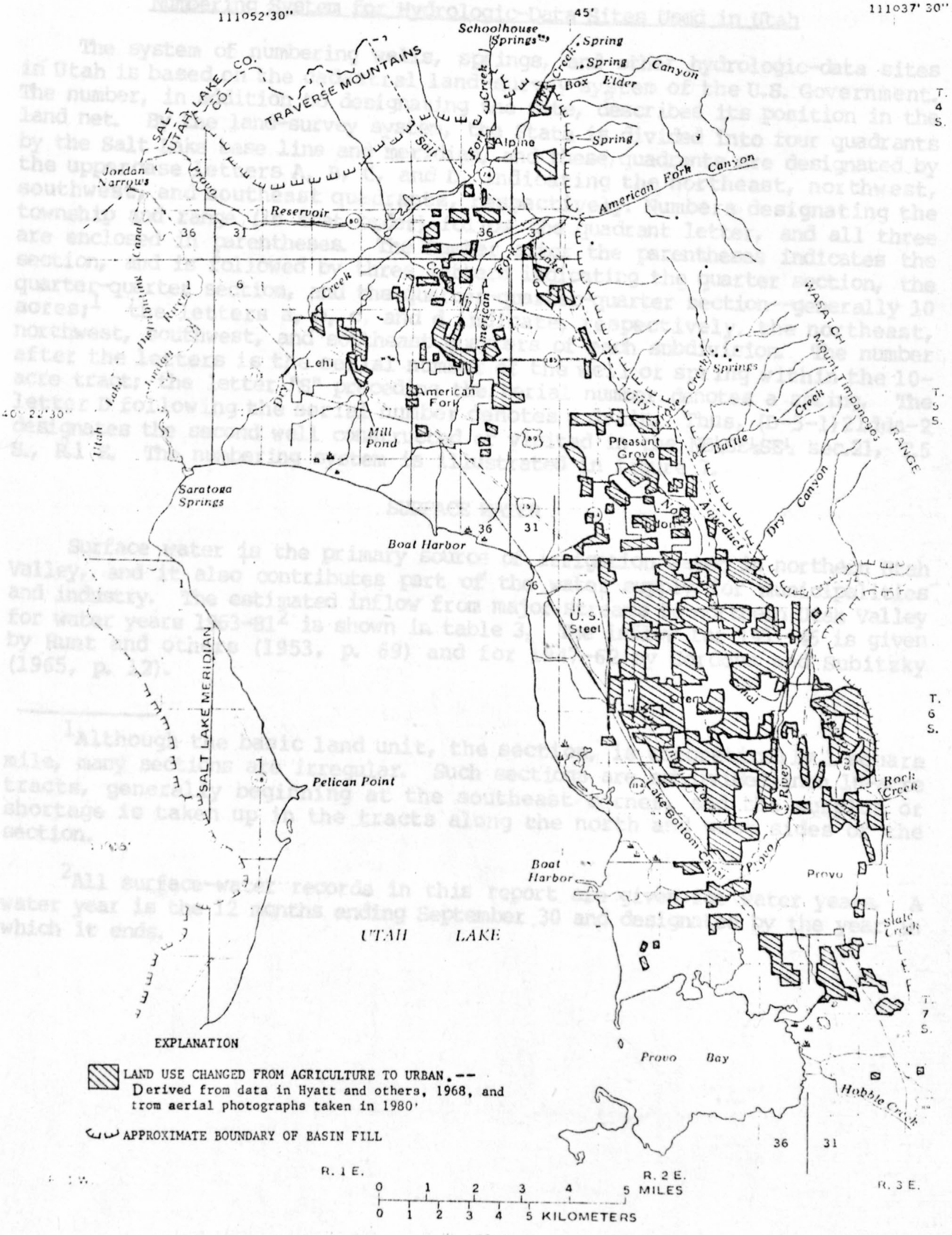


Figure 6.--Areas of land-use change, 1966-80.

Numbering System for Hydrologic-Data Sites Used in Utah

The system of numbering wells, springs, and other hydrologic-data sites in Utah is based on the cadastral land-survey system of the U.S. Government. The number, in addition to designating the site, describes its position in the land net. By the land-survey system, the State is divided into four quadrants by the Salt Lake base line and meridian, and these quadrants are designated by the uppercase letters A, B, C, and D, indicating the northeast, northwest, southwest, and southeast quadrants, respectively. Numbers designating the township and range (in that order) follow the quadrant letter, and all three are enclosed in parentheses. The number after the parentheses indicates the section, and is followed by three letters indicating the quarter section, the quarter-quarter section, and the quarter-quarter-quarter section--generally 10 acres;[1] the letters a, b, c, and d indicate, respectively, the northeast, northwest, southwest, and southeast quarters of each subdivision. The number after the letters is the serial number of the well or spring within the 10-acre tract; the letter "S" preceding the serial number denotes a spring. The letter D following the serial number denotes a drain. Thus, (D-5-1)21dda-2 designates the second well constructed or visited in the NE¼SE¼SE¼ sec.21, T.5 S., R.1 E. The numbering system is illustrated in figure 7.

SURFACE WATER

Surface water is the primary source of irrigation water in northern Utah Valley, and it also contributes part of the water supply for municipalities and industry. The estimated inflow from major streams to northern Utah Valley for water years 1963-81[2] is shown in table 3. The inflow for 1931-46 is given by Hunt and others (1953, p. 69) and for 1947-62 by Cordova and Subitzky (1965, p. 12).

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

[2]All surface-water records in this report are given for water years. A water year is the 12 months ending September 30 and designated by the year in which it ends.

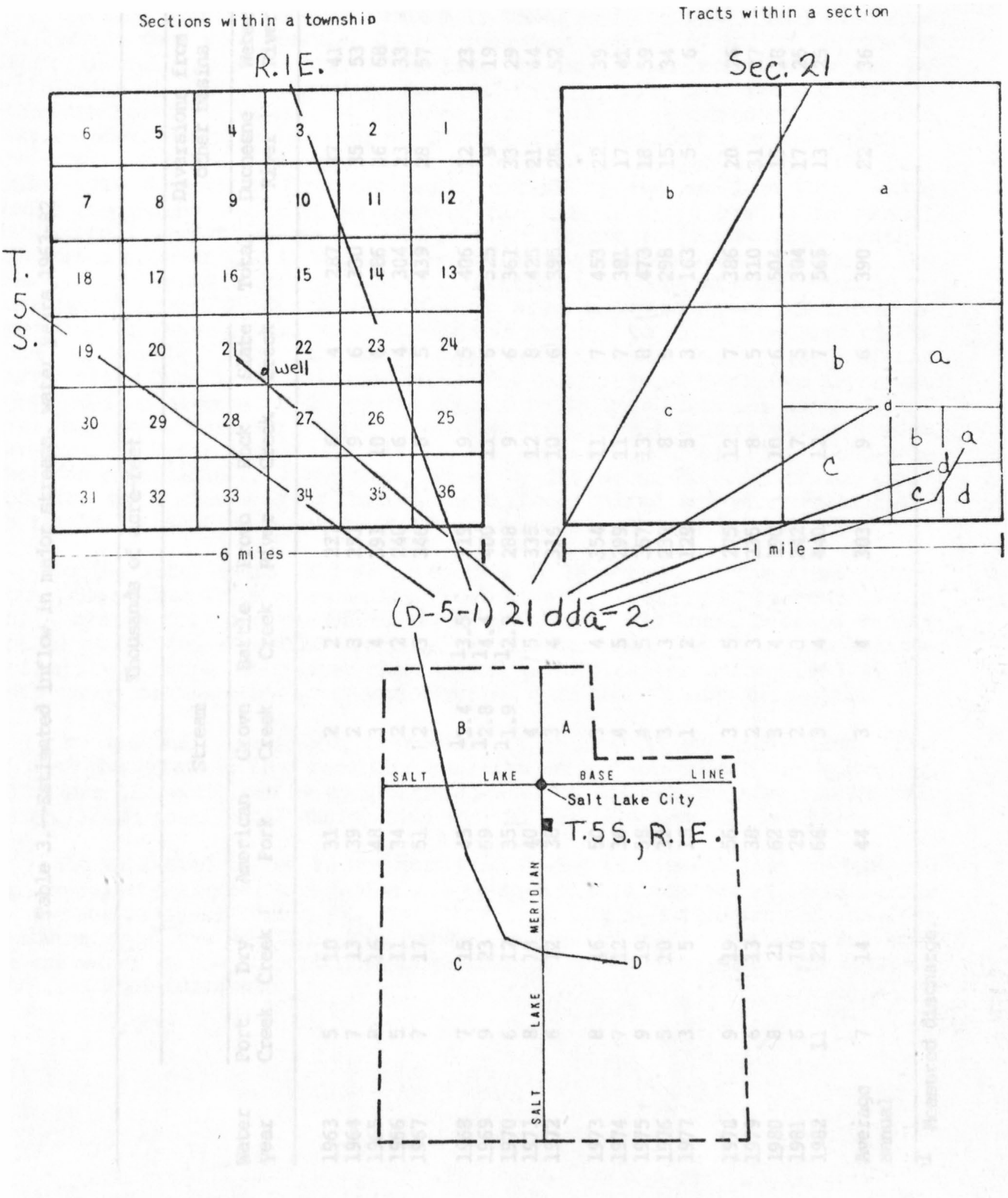


Figure 7 .--Numbering system for hydrologic-data sites used in Utah.

Table 3.--Estimated inflow in major streams, water years 1963-82

Water year	Thousands of acre-feet										
	Stream									Diversions from other basins	
	Fort Creek	Dry Creek	American Fork	Grove Creek	Battle Creek	Provo River	Rock Creek	Slate Creek	Total	Duchesne River	Weber River
1963	5	10	31	2	2	227	6	4	287	37	41
1964	7	13	39	2	3	251	9	6	330	35	53
1965	8	16	48	3	4	391	10	6	486	36	68
1966	5	11	34	2	2	240	6	4	304	23	33
1967	7	17	51	2	3	346	8	5	439	28	57
1968	7	15	45	[1]2.4	[1]3.5	319	9	5	406	12	23
1969	9	23	69	[1]2.8	[1]4.4	400	11	6	525	9	19
1970	6	12	35	[1]1.9	[1]2.9	288	9	6	361	33	29
1971	8	13	40	4	5	335	12	8	425	21	44
1972	6	12	38	3	4	316	10	6	395	28	52
1973	8	16	50	3	4	354	11	7	453	22	39
1974	7	12	36	4	5	299	11	7	381	17	41
1975	9	19	58	4	5	357	13	8	473	18	59
1976	5	10	32	3	3	232	8	5	298	15	34
1977	3	5	15	1	2	129	5	3	163	5	6
1978	9	19	56	3	5	275	12	7	386	20	26
1979	6	13	38	2	3	235	8	5	310	31	27
1980	8	21	62	3	4	390	10	6	504	15	18
1981	6	10	29	2	3	242	7	5	304	17	25
1982	11	22	66	3	4	440	12	7	565	13	25
Average annual	7	14	44	3	4	303	9	6	390	22	36

[1] Measured discharge.

The flow of Fort Creek in table 3 is based on records of annual discharge for 1947-55 that were correlated with long-term records of Little Cottonwood Creek in Salt Lake County. The flow in Dry Creek was determined by correlation of monthly discharge for 1947-55 with long-term records for the American Fork. Discharge of the American Fork is measured at the gaging station above the upper powerplant about 4 miles upstream from the mouth of the canyon (fig. 1). The records in table 3 do not include inflow from four tributaries downstream from the gaging station on the American Fork, which would contribute about 10 percent of the inflow stipulated. The annual discharge from Battle, Rock, and Slate Creeks was estimated from monthly discharge records for 12 streams in the Wasatch Range (seven in Salt Lake County, two in Davis County, two in Utah County, and one in Weber County) by correlating annual discharge with drainage areas and mean annual precipitation that fell on those areas. Grove Creek was assumed to have 70 percent of the flow of Battle Creek, based on measurements made during 1968-70 and information from local watermasters. The discharge of the Provo River was compiled from records at the gaging station below Deer Creek Dam (fig. 1) and from the commissioners' reports of the Provo River Distribution System (Wayman, 1962-67; McKellar, 1968-71; and Roberts, 1972-82). The discharge includes diversions from the Weber River by the Weber-Provo diversion canal and from the Duchesne River through the Duchesne Tunnel and water distributed to the Salt Lake City Aqueduct and Provo Reservoir Canal (fig. 1).

During water years 1963-82 an average of 78 percent of the total inflow to northern Utah Valley was in the Provo River and nearly 90 percent was in the American Fork and the Provo River combined. The total average annual inflow of 390,000 acre-feet probably was greater than the long-term average primarily because of greater than normal precipitation during 1963-82 and secondarily because more water was diverted from other basins after 1943.

The seasonal fluctuation of surface-water flow is extremely large (fig. 8) with the greatest flow resulting from the spring snowmelt. The hydrograph in figure 11, which can be considered typical of streams draining the Wasatch Range, shows peak runoff during 1969 and 1975 and a drought during 1977.

The estimated inflow to northern Utah Valley from small intermittent and ephemeral streams for which there is no record of discharge is about 10,000 acre-feet per year (table 4). The flow from Box Elder Canyon and the four tributaries of the American Fork reaches the valley on the surface, but most of the water in the other drainages percolates into the alluvial fans at which the drainages terminate.

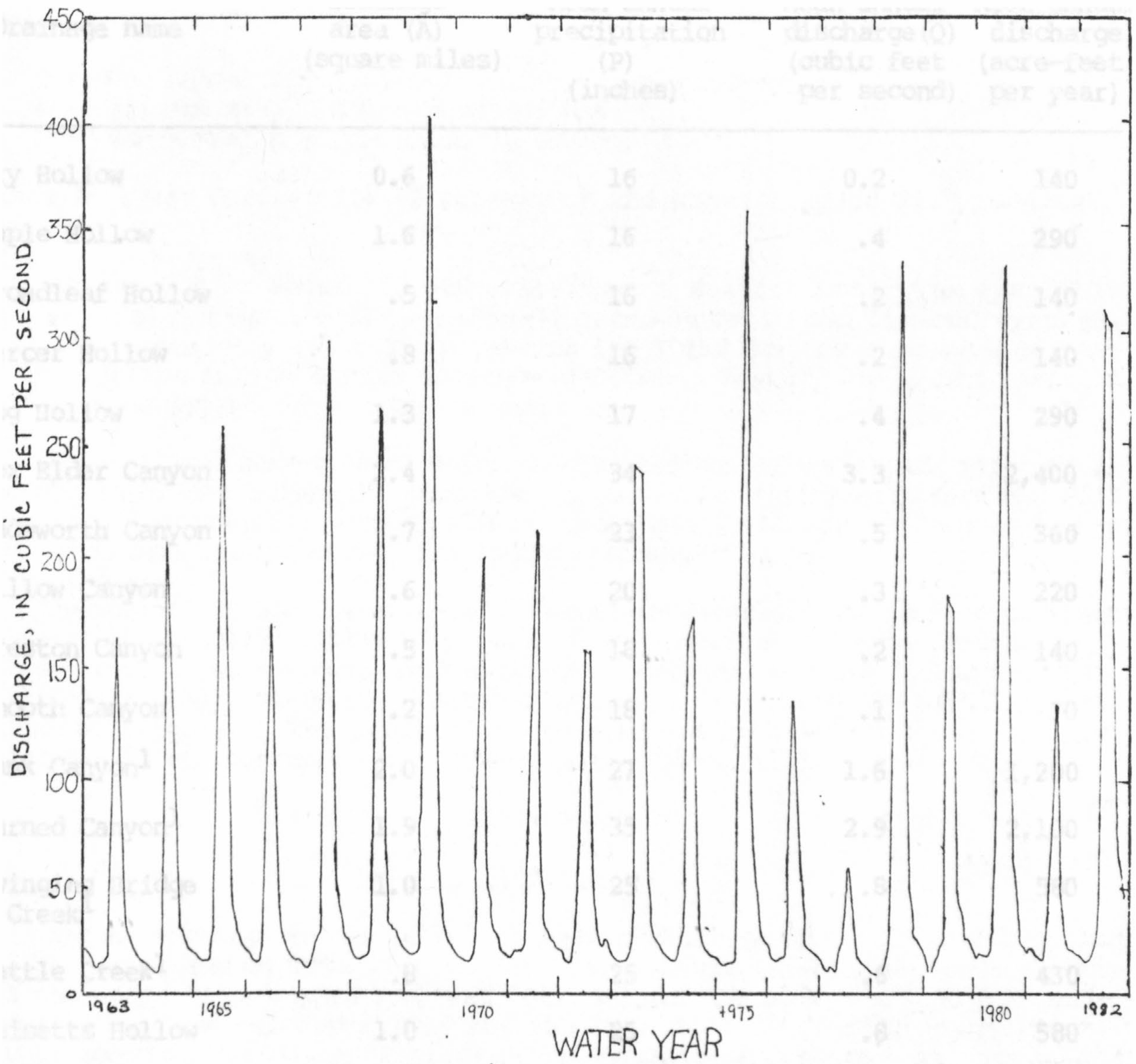


Figure 8 .--Seasonal discharge of the American Fork above the upper powerplant, 1963-82. (See figure 1 for location.)

Table 4.--Estimated inflow of intermittent and ephemeral streams

[See figure 9 for location of streams.]

Drainage name	Drainage area (A) (square miles)	Mean annual precipitation (P) (inches)	Mean annual discharge (Q) (cubic feet per second)	Mean annual discharge (acre-feet per year)
Dry Hollow	0.6	16	0.2	140
Maple Hollow	1.6	16	.4	290
Broadleaf Hollow	.5	16	.2	140
Mercer Hollow	.8	16	.2	140
Hog Hollow	1.3	17	.4	290
Box Elder Canyon	2.4	34	3.3	2,400
Wadsworth Canyon	.7	23	.5	360
Willow Canyon	.6	20	.3	220
Preston Canyon	.5	18	.2	140
Smooth Canyon	.2	18	.1	70
Tank Canyon[1]	2.0	27	1.6	1,200
Burned Canyon[1]	1.9	35	2.9	2,100
Swinging Bridge Creek[1]	1.0	25	.8	580
Cattle Creek[1]	.8	25	.6	430
Heisetts Hollow	1.0	25	.8	580
Little Rock Canyon	.7	20	.3	220
Slide Canyon	1.1	24	.8	580
			Total (rounded)	10,000

[1] Ungaged tributary to American Fork downstream from the gaging station.

The discharge in the intermittent and ephemeral streams was computed by the equation:

$$Q = 3.30 \times 10^{-4} (A)^{0.815} (P)^{2.41} \quad (1)$$

where

Q = mean annual discharge, in cubic feet per second;
A = drainage area, in square miles; and
P = mean annual precipitation, in inches.

Equation 1 was derived for 12 streams in the Wasatch Range with long-term records.

An average of about 150,000 acre-feet of surface water was available annually for irrigation during 1969-72 based on data from 14 canal systems. This represents only about 35 percent of the total surface flow because most of the surface inflow occurs during mid-October through June when there is little or no demand for irrigation water.

About 27,000 acre-feet of water is diverted annually from the Provo River for municipal and industrial purposes. About 20,000 acre-feet enters the Salt Lake City Aqueduct for municipal use, and about 7,000 acre-feet goes to the U.S. Steel Co., Geneva Works, for industrial use (fig. 9).

Approximately 350,000 acre-feet of surface water discharges from northern Utah Valley annually. About 80 percent of the outflow is in the Jordan River, through the Jordan Narrows, with additional northward outflow in the Utah Lake Distibuting Canal, the Provo Reservoir (Murdock) Canal, and the Salt Lake City Aqueduct (fig. 9). The proportions of this surface-water discharge that originate in the northern and southern parts of Utah Valley is not known.

GROUND WATER

Recharge

Annual recharge to the principal ground-water reservoir in northern Utah Valley is estimated to be 200,000 acre-feet (table 5). The source of nearly all the water is precipitation that falls within the Utah Lake drainage basin. Recharge has been calculated only for the principal ground-water reservoir, which consists of three confined (artesian) aquifers and an unconfined (water-table) aquifer in pre-Lake Bonneville deposits along the mountain fronts. A perched water table in Lake Bonneville deposits (formally designated Lake Bonneville Group by the U.S. Geological Survey) on the Highland and Provo Benches has little hydraulic connection to and is not considered a part of the principal ground-water reservoir. Recharge to the principal ground-water reservoir was calculated only for the primary recharge area, which is a relatively narrow band of permeable unconsolidated material near the adjacent mountains. (See figure 9.)

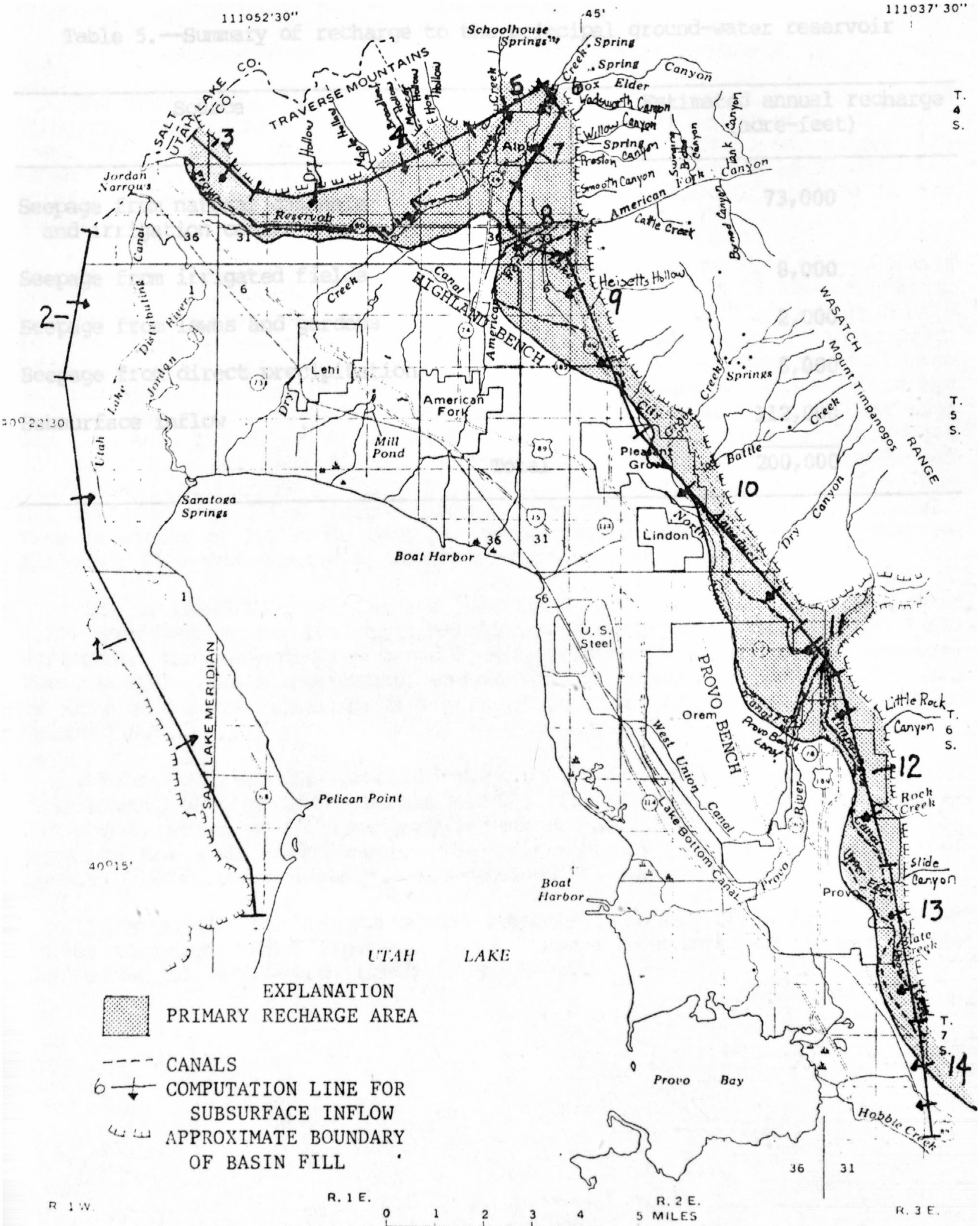


Figure 9.--Primary recharge area, canals within the recharge area, and computation lines for subsurface inflow.

Table 5.--Summary of recharge to the principal ground-water reservoir

Source	Estimated annual recharge (acre-feet)
Seepage from natural channels and irrigation canals	73,000
Seepage from irrigated fields	8,000
Seepage from lawns and gardens	2,000
Seepage from direct precipitation	5,000
Subsurface inflow	112,000
Total	200,000

Seepage From Natural Channels and Irrigation Canals

The average annual recharge during 1963-82 from natural channels and irrigation canals that cross the primary recharge area was about 73,000 acre-feet. The channels, which consist largely of gravel, cobble, and larger-size material, are extremely permeable. Water levels in wells in or near the stream channels fluctuate rapidly in response to changes in flow in the channels.

American Fork.--The average annual recharge during the 1963-82 water years from the American Fork and associated canals was 13,400 acre-feet. Seepage losses from the natural channel ranged from 4,800 acre-feet during 1977 to 13,400 acre-feet during 1969 and averaged 8,100 acre-feet per year. The losses are based on seven sets of measurements or estimates made in the natural channel during 1981-82. In the first 1.25 miles downstream from the mouth of the canyon, seepage losses ranged from 100 percent when the discharge was less than 20 cubic feet per second to 35 percent when the discharge was 200 cubic feet per second. Total annual loss from the natural channel was calculated from records of daily discharge with the assumptions that flow was not diverted out of the channel from mid-October to mid-April and that all flow in excess of 200 cubic feet per second remained in the natural channel. All other flow was assumed to be diverted to irrigation canals.

The estimated annual seepage loss from irrigation canals ranged from 1,700 acre-feet during 1977 to 7,700 acre-feet during 1982 and averaged 5,300 acre-feet. The estimates are based on daily discharge records of the American Fork, seepage-loss measurements, and records of appropriations. Measurements of seepage losses ranged from 5 percent in lined canals to 20 percent in unlined canals.

Recharge from the American Fork is indicated in figure 10 by the relationship of flow in the stream and the rise of water levels in well (D-4-2)31abd-1, which is in the streambed about 2,000 feet downstream from the mouth of American Fork Canyon. The well was drilled through 463 feet of unconsolidated, predominately coarse-grained sediments.

Provo River.--The average annual recharge from the Provo River is about 30,000 acre-feet. That figure is based largely on results of studies by the U.S. Bureau of Reclamation (1981) from 1967-77.

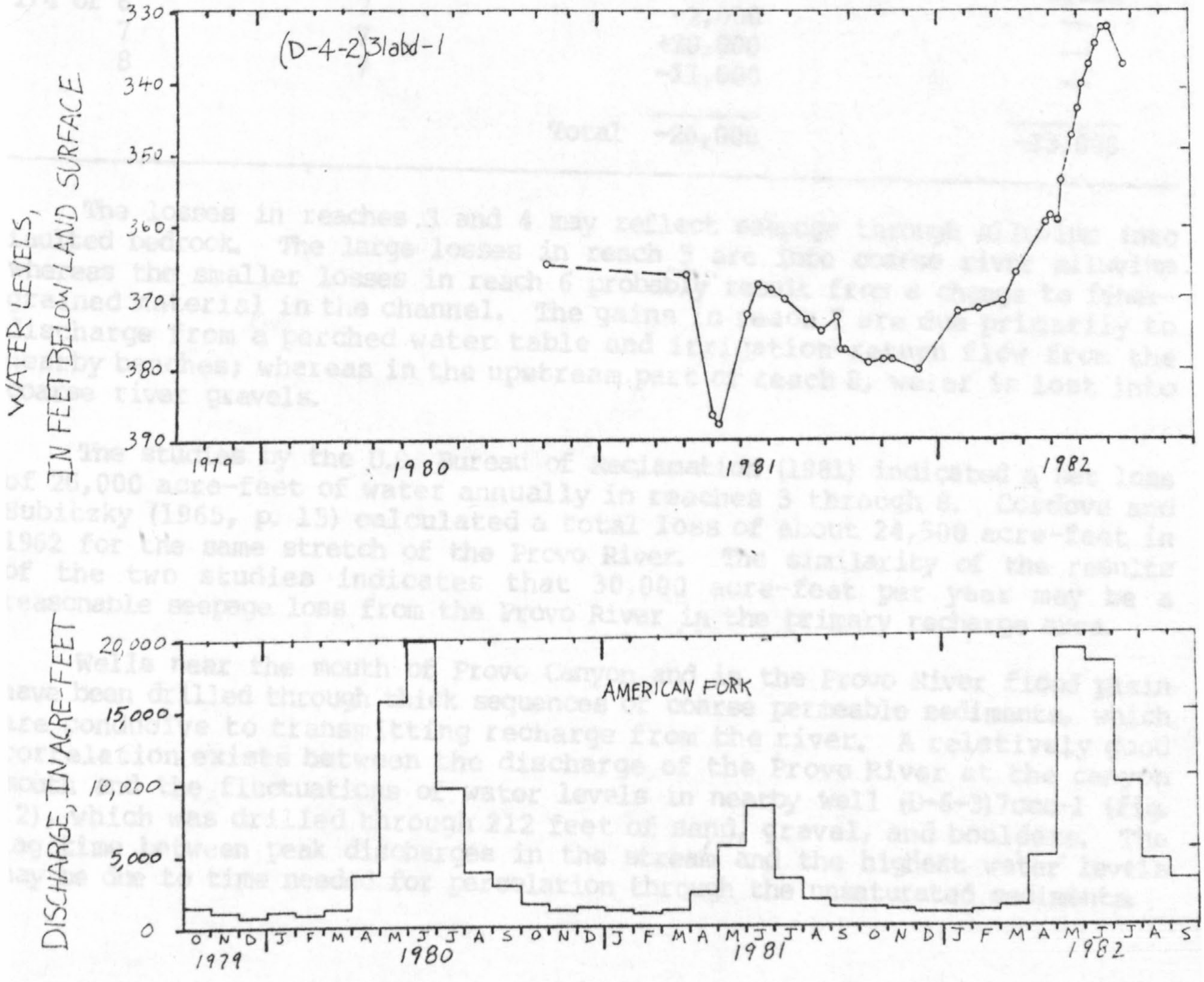


Figure 10.--Relationship between water levels in well (D-4-2)31abd-1 and monthly discharge of the American Fork above the upper powerplant, 1979-82.

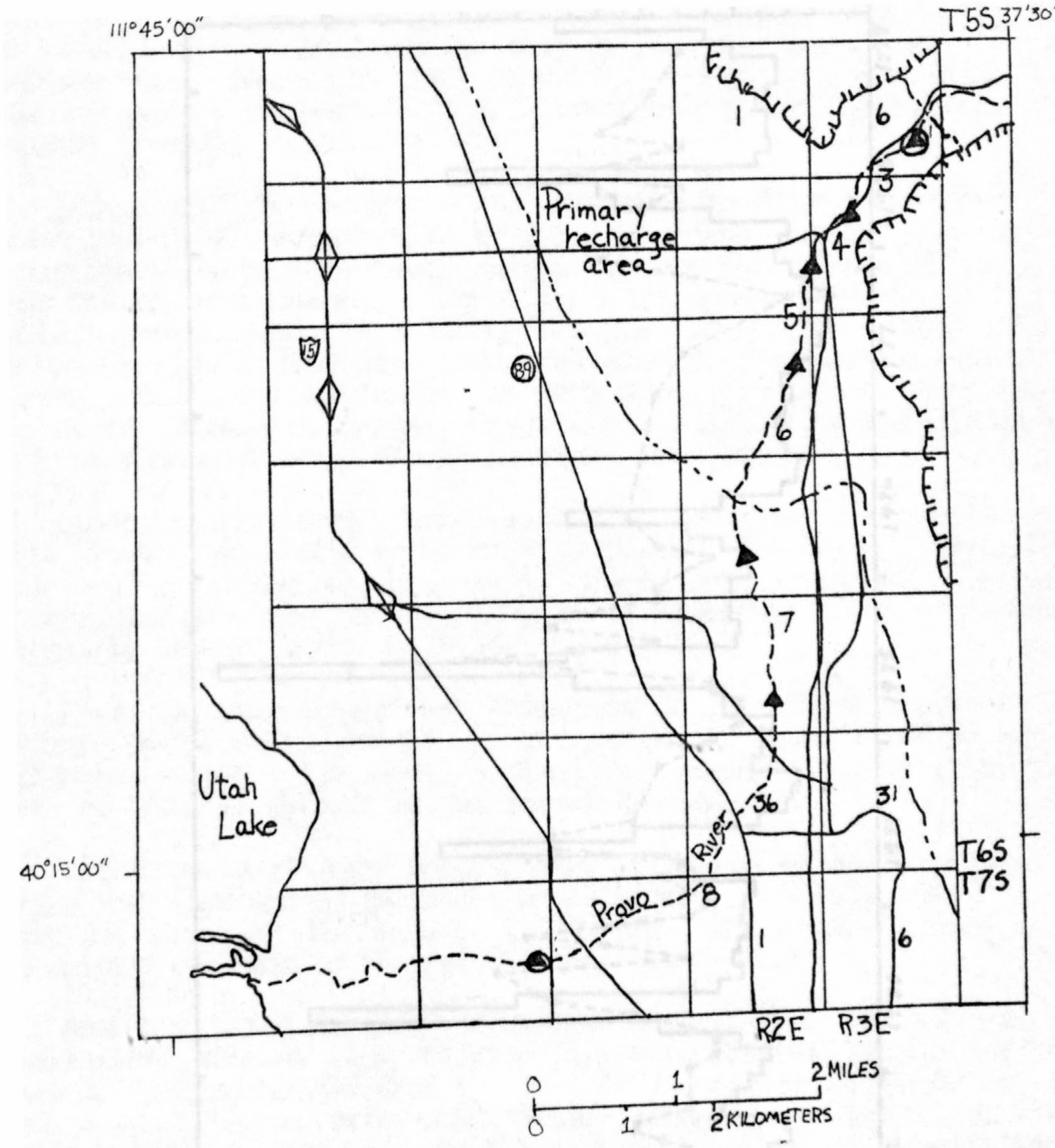
The U.S. Bureau of Reclamation (1981) divided the Provo River into eight reaches between Deer Creek Reservoir and the U.S. Geological Survey gaging station at Provo (fig. 11) in order to measure seepage losses. Reaches 1, 2, 7, and 8 and the downstream one-fourth of reach 6 are outside of the primary recharge area. The seepage losses measured in the primary recharge area in reaches 3, 4, 5, and upstream three-fourths of reach 6 averaged 33,000 acre-feet per year as listed below:

Reach	Number of years used in calculation	Gain (+) or loss (-) (acre-feet)	Loss in primary recharge area (acre-feet)
3	5	-2,500	-2,500
4	5	-12,000	-12,000
5	7	-13,000	-13,000
3/4 of 6	7	-5,500	-5,500
1/4 of 6	7	-2,000	---
7	7	+20,000	---
8	7	-11,000	---
	Total	-26,000	-33,000

The losses in reaches 3 and 4 may reflect seepage through alluvium into faulted bedrock. The large losses in reach 5 are into coarse river alluvium whereas the smaller losses in reach 6 probably result from a change to finer-grained material in the channel. The gains in reach 7 are due primarily to discharge from a perched water table and irrigation-return flow from the nearby benches; whereas in the upstream part of reach 8, water is lost into coarse river gravels.

The studies by the U.S. Bureau of Reclamation (1981) indicated a net loss of 26,000 acre-feet of water annually in reaches 3 through 8. Cordova and Subitzky (1965, p. 15) calculated a total loss of about 24,500 acre-feet in 1962 for the same stretch of the Provo River. The similarity of the results of the two studies indicates that 30,000 acre-feet per year may be a reasonable seepage loss from the Provo River in the primary recharge area.

Wells near the mouth of Provo Canyon and in the Provo River flood plain have been drilled through thick sequences of coarse permeable sediments, which are conducive to transmitting recharge from the river. A relatively good correlation exists between the discharge of the Provo River at the canyon mouth and the fluctuations of water levels in nearby well (D-6-3)7ccc-1 (fig. 12), which was drilled through 212 feet of sand, gravel, and boulders. The lag time between peak discharges in the stream and the highest water levels may be due to time needed for percolation through the unsaturated sediments.



EXPLANATION

GAGING SITE USED FOR U.S. GEOLOGICAL SURVEY CALCULATIONS

GAGING SITE USED BY U.S. BUREAU OF RECLAMATION.--Number between sites indicates reach

BOUNDARY OF PRIMARY RECHARGE AREA

APPROXIMATE BOUNDARY OF BASIN FILL

Figure 11.--Location of gaging sites and reaches on the Provo River used for seepage-loss calculations.

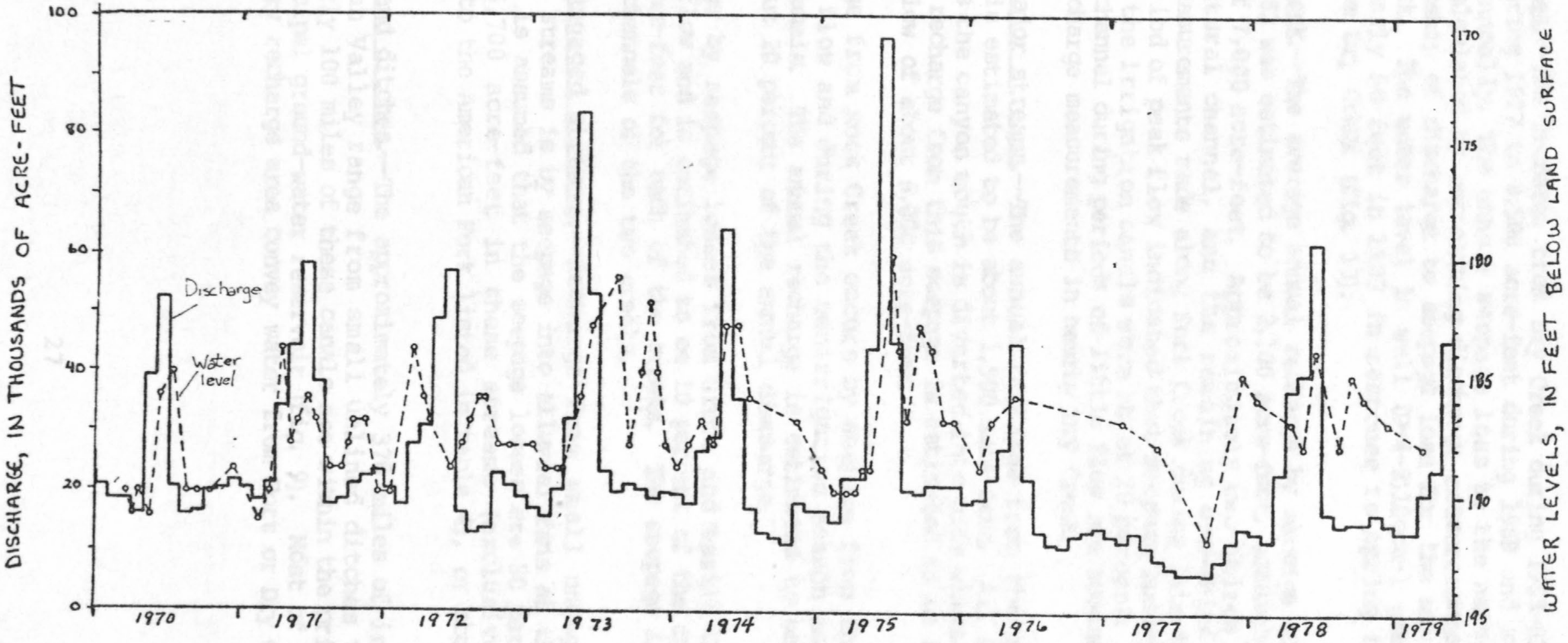


Figure 12.--Relationship between monthly discharge of the Provo River at the canyon mouth and water levels in well (D-6-3)7ccc-1, 1970-79.

Dry Creek.--The recharge from Dry Creek during 1963-82 ranged from 2,000 acre-feet during 1977 to 8,500 acre-feet during 1969 and averaged about 5,500 acre-feet annually. The annual seepage loss to the natural channel of Dry Creek was calculated by correlating discharge measurements in Dry Creek with the relationship of discharge to seepage loss for the natural channel of the American Fork. The water level in well (D-4-2)18cca-1 rose about 20 feet in 1981 and nearly 50 feet in 1982 in response to spring runoff, indicating recharge from Dry Creek (fig. 13).

Fort Creek.--The average annual recharge by seepage loss from Fort Creek during 1963-82 was estimated to be 2,100 acre-feet, assuming an average annual discharge of 7,000 acre-feet. Approximately two-thirds of the losses were from the natural channel, and the remaining one-third was from canals. Discharge measurements made along Fort Creek during late April 1982 (fig. 14) during a period of peak flow indicated that seepage losses from the natural channel and the irrigation canals were about 20 percent. Seepage losses in the natural channel during periods of little flow are assumed to be 50 percent based on discharge measurements in nearby Dry Creek.

Other major streams.--The annual recharge from the natural channel of Slate Creek is estimated to be about 1,500 acre-feet. All flow in Slate Creek that reaches the canyon mouth is diverted into pits where it seeps into the ground. The recharge from this seepage is estimated to be about one-fourth of the yearly flow of about 6,000 acre-feet.

Recharge from Rock Creek occurs by seepage from the natural channel during peak flow and during the nonirrigation season and by seepage from irrigation canals. The annual recharge is estimated to be about 2,000 acre-feet, or about 20 percent of the annual discharge.

Recharge by seepage losses from Grove and Battle Creeks occurs only during peak flow and is estimated to be 10 percent of the annual discharge, or about 500 acre-feet for each of the creeks. The seepage losses are all from the natural channels of the two creeks.

Small ungaged streams.--Recharge from small ungaged ephemeral and intermittent streams is by seepage into alluvial fans at the mouths of their canyons. It is assumed that the seepage losses are 50 percent of the annual inflow of 5,700 acre-feet in these streams (exclusive of the ungaged tributaries to the American Fork listed in table 4), or about 3,000 acre-feet per year.

Canals and ditches.--The approximately 370 miles of irrigation canals in northern Utah Valley range from small unlined ditches to large concrete canals. Nearly 100 miles of these canals are within the primary recharge area for the principal ground-water reservoir (fig. 9). Most of the unlined canals in the primary recharge area convey water from Fort or Dry Creeks.

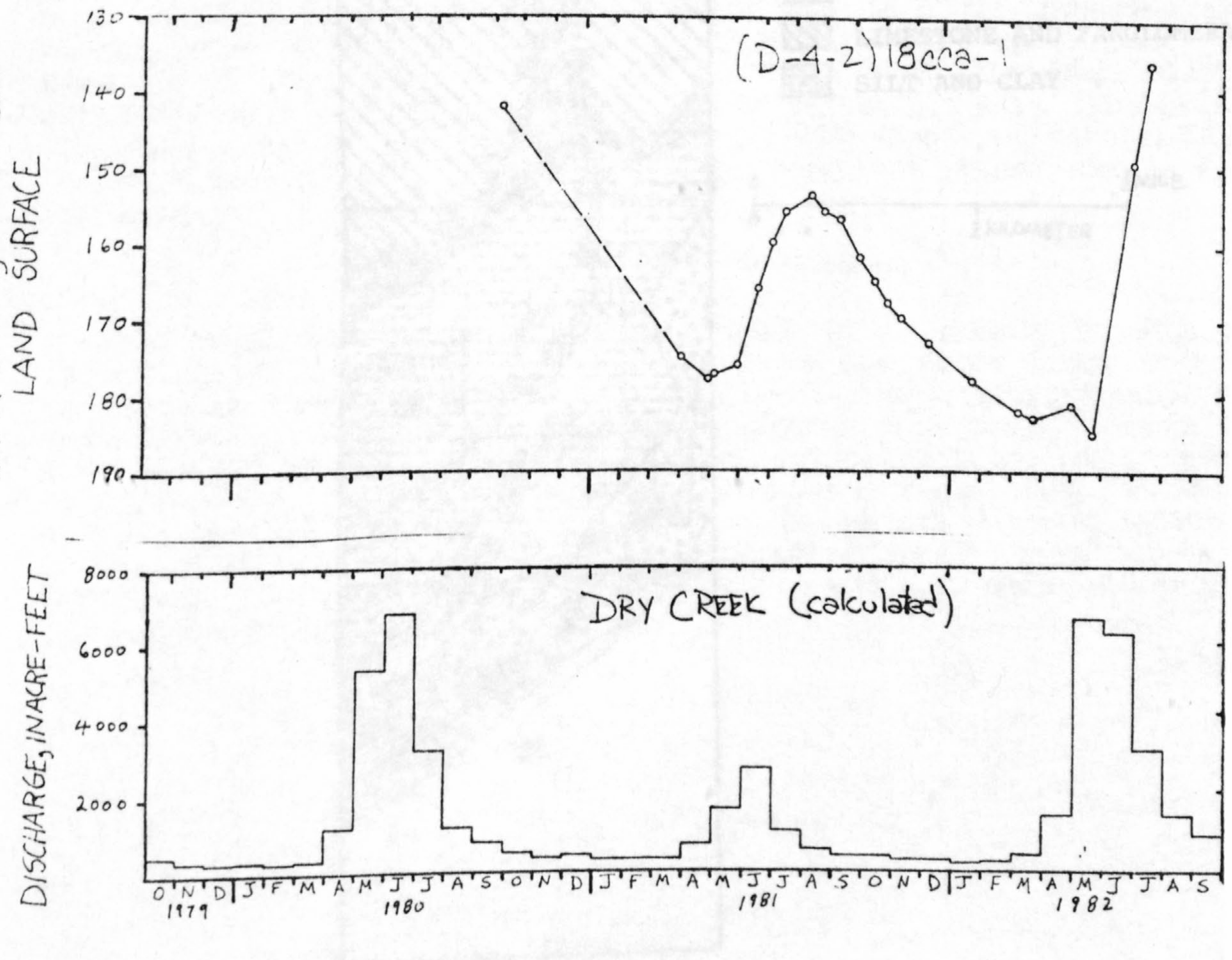


Figure 13.--Relationship between water levels in well (D-4-2)18cca-1 and calculated monthly discharge of Dry Creek, 1979-82.

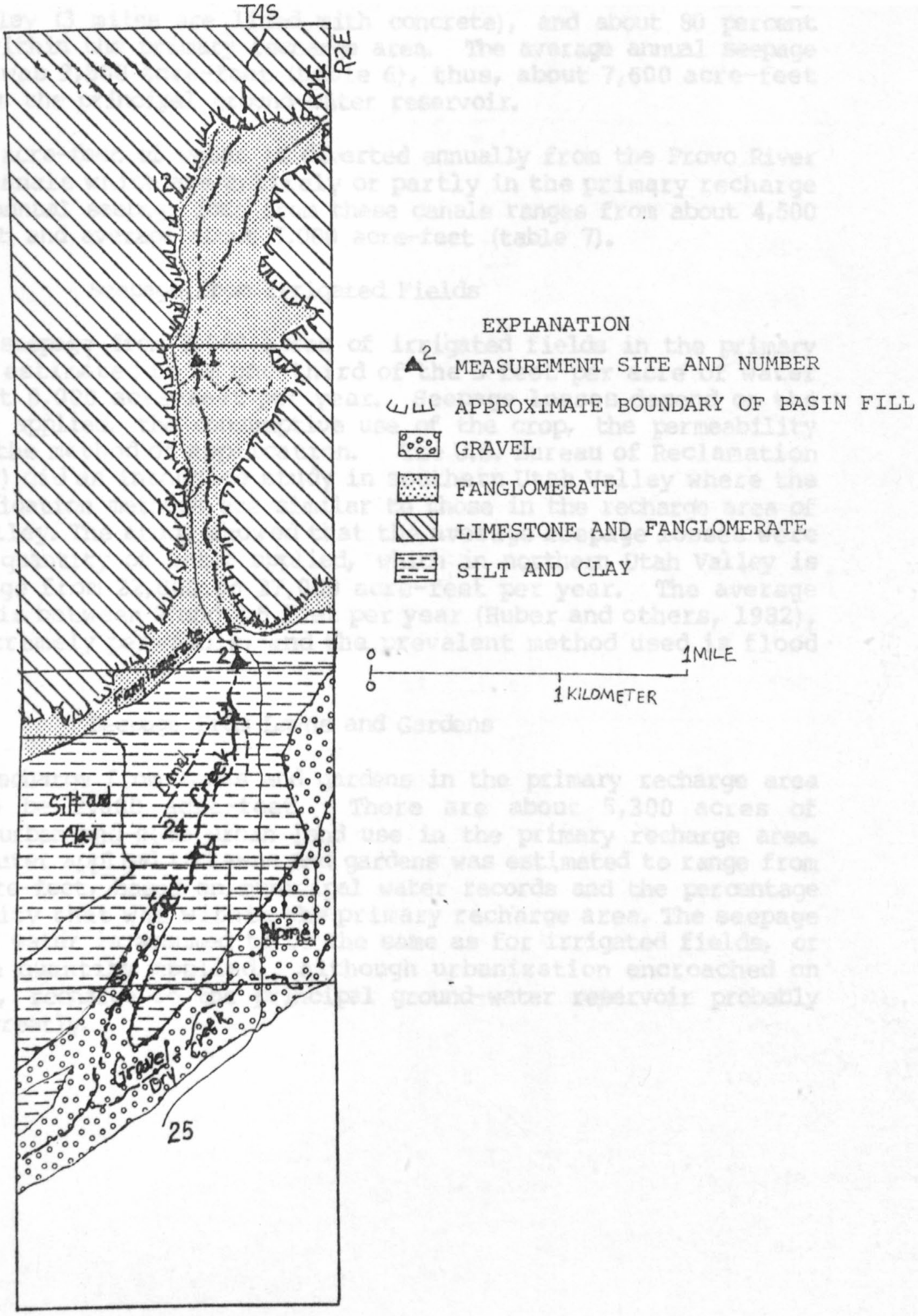


Figure 14.--Location of discharge-measurement sites for seepage-loss calculations and generalized lithology of the basin fill in the Fort Creek area.

About 150,000 acre-feet is diverted annually from the Provo River into canals during the irrigation season and about one-half of this is diverted into the Provo Reservoir (Murdock) Canal. This canal extends 22 miles through northern Utah Valley (3 miles are lined with concrete), and about 80 percent of the canal is within the primary recharge area. The average annual seepage loss for 1972-79 was 9,500 acre-feet (table 6), thus, about 7,600 acre-feet per year recharges the principal ground-water reservoir.

About 60,000 acre-feet of water is diverted annually from the Provo River into five other canals which are entirely or partly in the primary recharge area. The total annual seepage loss from these canals ranges from about 4,500 to 9,000 acre-feet and average about 7,000 acre-feet (table 7).

Seepage from Irrigated Fields

Recharge by seepage from 5,000 acres of irrigated fields in the primary recharge area is estimated to be one-third of the 5 feet per acre of water applied, or about 8,000 acre-feet per year. Seepage losses depend on the quantity of water applied, the consumptive use of the crop, the permeability of the soil, and the method of application. The U.S. Bureau of Reclamation (1967, 1968, 1969) did an intensive study in southern Utah Valley where the crops and the irrigation methods are similar to those in the recharge area of northern Utah Valley. The study showed that the average seepage losses were one-third of the quantity of water applied, which in northern Utah Valley is estimated to range from 22,000 to 27,000 acre-feet per year. The average consumptive use is between 2 and 2.5 feet per year (Huber and others, 1982), the soils are extremely permeable, and the prevalent method used is flood irrigation.

Seepage From Lawns and Gardens

The annual recharge from lawns and gardens in the primary recharge area is estimated to be 2,000 acre-feet. There are about 5,300 acres of predominately suburban and some urban land use in the primary recharge area. The quantity of water applied to lawns and gardens was estimated to range from 4,500 to 7,000 acre-feet, based on municipal water records and the percentage of the municipality that was within the primary recharge area. The seepage loss from applied water is assumed to be the same as for irrigated fields, or one-third of the quantity applied. Although urbanization encroached on agricultural land, recharge to the principal ground-water reservoir probably has not changed greatly.

Table 6.--Estimated annual seepage losses from the Provo Reservoir (Murdock) Canal in the primary recharge area, 1972-79

[Calculated from bimonthly records of the Provo Reservoir Water User's Company, Provo, Utah.]

Water year	Flow (acre-feet)	Loss of flow (percent)	Loss of flow (acre-feet)
1972	95,400	13.0	12,400
1973	92,500	10.1	9,300
1974	91,400	11.1	10,100
1975	98,700	8.1	8,000
1976	86,700	10.8	9,400
1977	29,000	20.7	6,000
1978	91,500	9.7	8,900
1979	77,700	15.6	12,100
Average (rounded)	82,900	11.5	9,500

Table 7.--Estimated annual seepage losses in the primary recharge area from five canals that divert water from Provo River

Canal system	Average annual flow, 1963-73 water years (acre-feet)	Percent of canal system within the recharge area	Estimated range of losses (acre-feet)	Estimated seepage loss (acre-feet)
Timpanogos	4,600	100	1,000-1,500	1,250
Upper East Union	5,500	50	1,000-2,000	1,500
West Union	8,000	60	1,000-2,000	1,500
North Union	40,000	10	500-1,500	1,000
Provo Bench		100	1,000-2,000	1,500
Total (rounded)	58,000	--	4,500-9,000	7,000

Recharge From Direct Precipitation

The annual recharge by infiltration of direct precipitation on the primary recharge area is estimated to be 5,000 acre-feet, but it varies considerably from year to year depending upon the length and intensity of individual storms and whether the precipitation falls as rain or snow. The precipitation on the primary recharge area was calculated from an isohyetal map for 1963-81 (fig. 4). The precipitation during 1963-81 on that part of the primary recharge area that is underlain by permeable soil averaged 16.5 inches per year, for a total of about 23,000 acre-feet. The recharge is estimated to be 20 percent of the total, or about 5,000 acre-feet per year, based on estimates by Razem and Steiger (1981, table 2) for a nearby valley with similar topography, soils, and precipitation.

Subsurface Inflow

Recharge to the principal ground-water reservoir by subsurface inflow is estimated to be a minimum of 100,000 acre-feet per year. Almost all the subsurface inflow is direct movement of water in bedrock through fractures, bedding planes, and solution channels into the basin fill. (See figure 2.) Most of the inflow is from the Wasatch Range, which contains great thicknesses of limestones that are deformed and fractured and generally dip southwestward toward Utah Valley. Caverns in limestone, such as those as in the Timpanogos Cave area, are indications of the conduit system.

From bedrock to the basin fill.--The subsurface inflow from the bedrock to the basin fill was calculated by the following variation of the Darcy equation:

$$Q = TIL \qquad (2)$$

where

Q = discharge, in cubic feet per day;
T = transmissivity, in feet squared per day;
I = hydraulic gradient (dimensionless); and
L = length, in feet.

The inflow was computed across a line that ringed the basin fill as close to the adjoining mountains as available data would permit. The line was segmented to reflect differences in hydraulic properties of the fill and differences in availability of data. The trace of the line segments is shown in figure 9, and the estimated recharge across each segment is given in table 8.

The total of 176,000 acre-feet per year includes approximately 64,000 acre-feet per year of inflow from other sources. The recharge by seepage from the American Fork, and Fort, Grove, Battle, Rock, and Slate Creeks is about 27,000 acre-feet per year, and recharge across the lines of computation by seepage from the Provo River and Dry Creek account for only a part of total recharge from these sources and is about 29,000 acre-feet. Recharge

Table 8.--Estimated annual recharge by subsurface inflow from bedrock to basin fill

Computation line (see fig. 9)	Transmissivity (T) (feet squared per day)	Hydraulic gradient (I) (dimensionless)	Length (L) (feet)	Discharge (Q) Cubic feet per day	Discharge (Q) Acre-feet per year (rounded)
1	500	0.03	60,000	900,000	[1]7,500
2	500	.01	16,000	80,000	[1]700
3	350	.01	8,000	30,000	[1]300
4	350	.02	26,000	180,000	[1]1,500
5	600	.047	11,000	310,000	2,600
6[2]					8,200
7	6,000	.013	16,000	1,200,000	10,000
8[3]					50,000
9	20,000	.0024	21,000	1,000,000	8,000
10	30,000	.0025	26,000	1,950,000	16,000
11	50,000	.01	7,500	3,750,000	[1]30,000
12	10,000	.015	21,000	3,150,000	26,000
13	20,000	.005	16,000	1,600,000	13,000
14	7,500	.003	11,000	250,000	2,000
				Total (rounded)	176,000

Less recharge within primary recharge area upgradient from computation lines (fig. 9) by seepage from streams, canals, irrigated fields, and direct precipitation 64,000

Total recharge from bedrock ... 112,000

[1] T and I are based on few of data; thus, the calculated discharge is an approximation.
[2] Computations for the Dry Creek area are on page 38.
[3] Computations for the American Fork area are on page 35-38.

contributed within the area from ephemeral and intermittent streams is estimated to be 2,500 acre-feet per year. Seepage from canals, irrigated fields, and direct precipitation may account for an additional 5,000 acre-feet per year. The adjusted total of subsurface inflow from bedrock to basin fill, therefore, is estimated to be about 112,000 acre-feet per year.

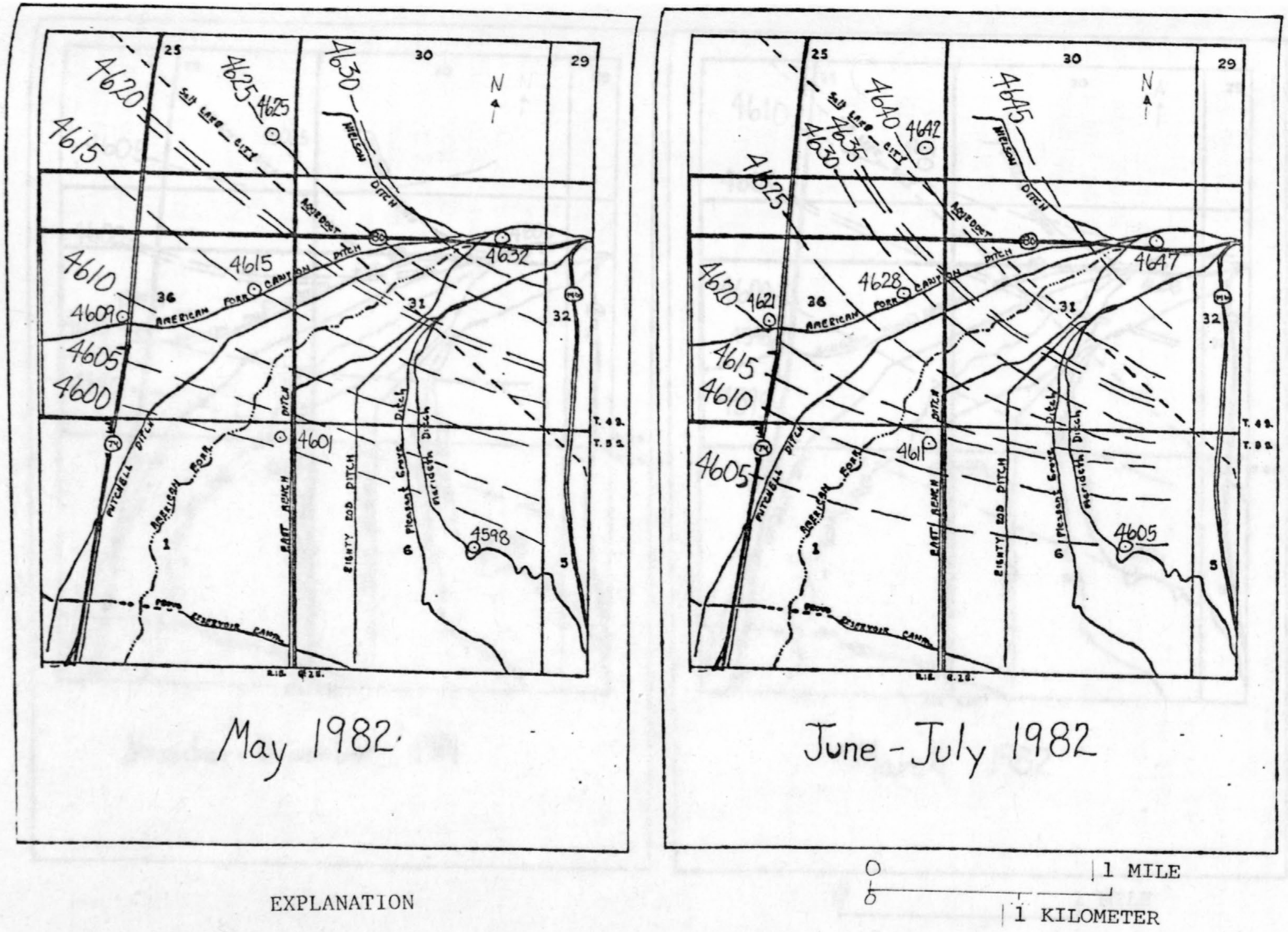
Near the mouths of canyons.--Detailed measurements were made near the mouths of American Fork and Dry Creek Canyons to provide more accurate estimates of subsurface inflow. The inflow calculated by equation (2) in the general area of line 8 near American Fork Canyon (fig. 9) was about 50,000 acre-feet during the 1982 water year. The seepage from surface water into the basin fill between the canyon mouth and the general area of line 8, based on three separate calculations, was 20,000 acre-feet in 1982. Therefore, 30,000 acre-feet of recharge was assumed to come from subsurface inflow from bedrock.

The discharge was calculated for four different periods. An average hydraulic conductivity of 500 feet per day was used for all periods, and a constant section length of 11,000 feet was used. The hydraulic gradient was calculated across water-level contours (fig. 15), and the saturated thickness was changed to reflect changes in water levels. The calculated discharges are listed below:

Time period	Contour used in calculation (feet)	Hydraulic gradient (dimensionless)	Saturated thickness (feet)	Discharge (acre-feet per day)
November-December, 1981	4,600	0.0023	295	86
March 1982	4,605	.0025	300	95
May 1982	4,620	.0044	315	175
June-July, 1982	4,635	.0053	330	220

The discharge of 86 acre-feet per day is assumed to represent the average base flow through the cross-sectional area, and 220 acre-feet per day is assumed to represent the peak discharge. The values for March and May are assumed to represent the transition period. An annual discharge was calculated by applying a discharge for each month that was based on the seasonal values for the four periods. The total inflow, therefore, was estimated to be about 50,000 acre-feet per year.

Part of the 50,000 acre-feet per year represents seepage from the American Fork and irrigation canals between the canyon mouth and the general area of line 8, and this quantity was calculated by three different methods. In the first method, the discharge of base flow, 86 acre-feet per day, was assumed for the entire the year, giving an annual total of about 31,000 acre-feet. If this is assumed to be recharge by subsurface inflow from bedrock, the remaining 19,000 acre-feet is assumed to be recharge from surface-water seepage.



EXPLANATION

⊙ OBSERVATION WELL

4600 — WATER-LEVEL CONTOUR--Shows altitude of water level. Dashed where approximately located
Datum is National Geodetic Vertical Datum of 1929.

— — WATER-LEVEL CONTOUR USED FOR CALCULATION OF DISCHARGE

Figure 15.--Water-level contours near the mouth of American Fork Canyon for four periods in 1981-82.

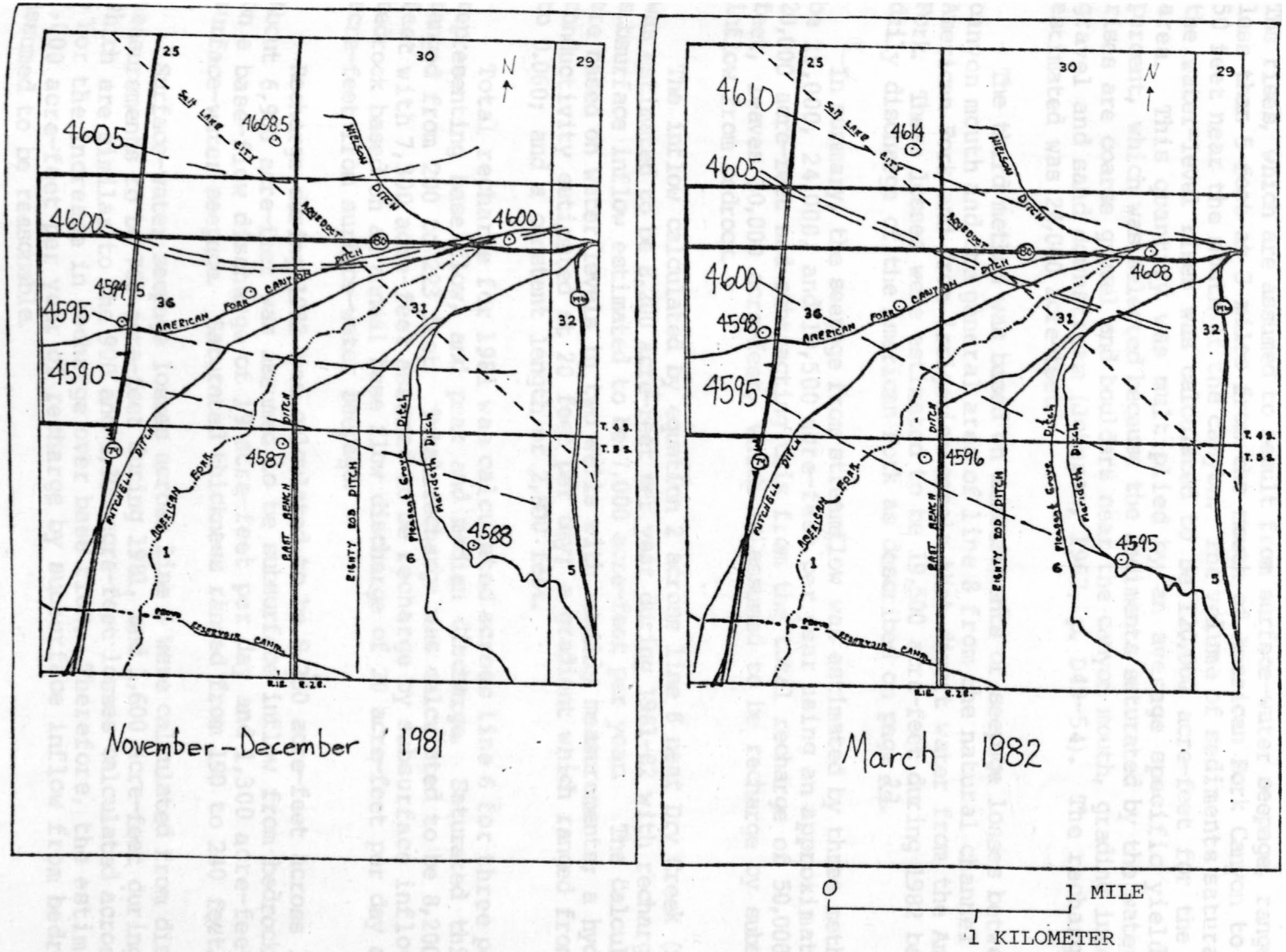


Figure 15 - continued

47

The second method involved calculation of the volume of sediments saturated by water-level rises in an area near American Fork Canyon (fig. 16). The rises, which are assumed to result from surface-water seepage, ranged from less than 5 feet at 3 miles from the mouth of American Fork Canyon to nearly 50 feet near the mouth of the canyon. The volume of sediments saturated by the water-level rises was calculated to be 120,000 acre-feet for the entire area. This quantity was multiplied by an average specific yield of 20 percent, which was selected because the sediments saturated by the water-level rises are coarse gravel and boulders near the canyon mouth, grading into finer gravel and sand downstream (Johnson, 1967, p. D49-54). The recharge thus estimated was 24,000 acre-feet.

The third method was based on measurements of seepage losses between the canyon mouth and the general area of line 8 from the natural channel of the American Fork and from irrigation canals that divert water from the American Fork. These losses were estimated to be 19,500 acre-feet during 1982 based on daily discharge of the American Fork as described on page 22.

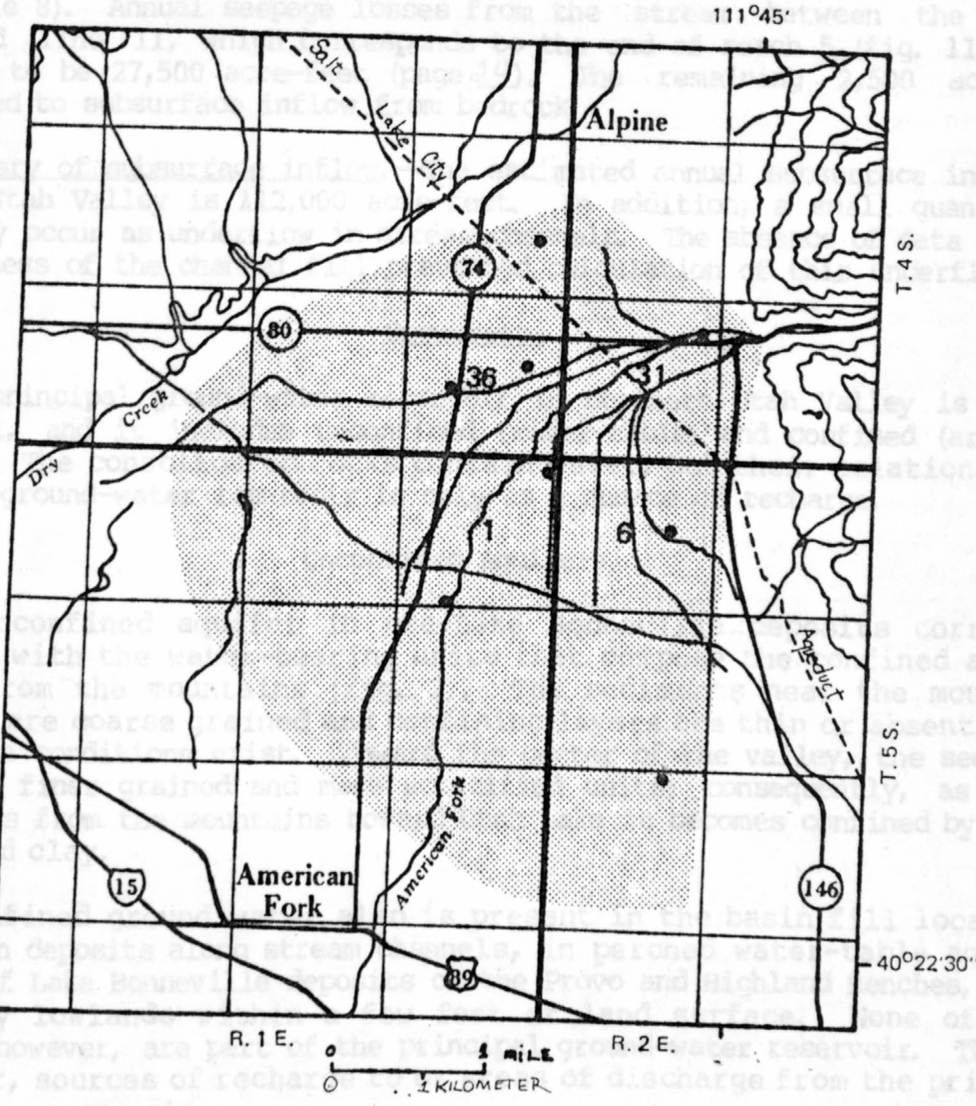
In summary, the seepage from streamflow was estimated by three methods to be 19,000, 24,000, and 19,500 acre-feet per year using an approximation of 20,000 acre-feet and subtracting this from the total recharge of 50,000 acre-feet, leaves 30,000 acre-feet, which is assumed to be recharge by subsurface inflow from bedrock.

The inflow calculated by equation 2 across line 6 near Dry Creek (fig. 9) was estimated to be 8,200 acre-feet per year during 1981-82 with recharge from subsurface inflow estimated to be 7,000 acre-feet per year. The calculations are based on water levels in two wells with monthly measurements; a hydraulic conductivity estimated at 20 feet per day; a gradient which ranged from 0.055 to 0.060; and a constant length of 2,800 feet.

Total recharge for 1981 was calculated across line 6 for three periods representing base flow, and peak and median discharge. Saturated thickness ranged from 200 to 223 feet. Total recharge was calculated to be 8,200 acre-feet with 7,300 acre-feet assumed to be recharge by subsurface inflow from bedrock based on an annual base flow discharge of 20 acre-feet per day and 900 acre-feet from surface-water seepage.

Recharge during 1982 was calculated to be 8,200 acre-feet across line 6. About 6,900 acre-feet was assumed to be subsurface inflow from bedrock based on a base-flow discharge of 19 acre-feet per day and 1,300 acre-feet from surface-water seepage. Saturated thickness ranged from 190 to 240 feet.

Surface-water seepage losses across line 6 were calculated from discharge measurements to be 760 acre-feet during 1981, and 1,600 acre-feet during 1982, which are similar to the 900 and 1,300 acre-feet losses calculated across line 6 for the increase in recharge over base flow. Therefore, the estimate of 7,000 acre-feet per year of recharge by subsurface inflow from bedrock is assumed to be reasonable.



EXPLANATION

AREA USED IN CALCULATION OF RECHARGE

● OBSERVATION WELL

Figure 16.--Generalized area used to calculate the volume of sediments saturated by water-level rises caused by seepage losses from the American Fork, 1982.

Recharge from the Provo River area was calculated across line 11 (fig. 9) an area with a wide range of transmissivity to be 30,000 acre-feet per year (table 8). Annual seepage losses from the stream between the canyon mouth and line 11, which corresponds to the end of reach 5 (fig. 11), were estimated to be 27,500 acre-feet (page 24). The remaining 2,500 acre-feet are assumed to subsurface inflow from bedrock.

Summary of subsurface inflow.--The estimated annual subsurface inflow to northern Utah Valley is 112,000 acre-feet. In addition, a small quantity of inflow may occur as underflow in stream channels. The absence of data showing the thickness of the channel fill prevented calculation of this underflow.

Occurrence

The principal ground-water reservoir in northern Utah Valley is in the basin fill, and it includes unconfined (water-table) and confined (artesian) aquifers. The consolidated rocks contain water, but their relation to the principal ground-water reservoir is only as a source of recharge.

Unconfined Aquifers

An unconfined aquifer in pre-Lake Bonneville deposits correlates laterally with the water-bearing units that compose the confined aquifer farther from the mountains (fig. 2). The sediments near the mountains typically are coarse grained and confining layers are thin or absent; thus, water-table conditions exist. Toward the center of the valley, the sediments grade into finer grained and more stratified units; consequently, as ground water moves from the mountains toward Utah Lake it becomes confined by layers of silt and clay.

Unconfined ground water also is present in the basin fill locally in flood-plain deposits along stream channels, in perched water-table aquifers composed of Lake Bonneville deposits on the Provo and Highland Benches, and in the valley lowlands within a few feet of land surface. None of these deposits, however, are part of the principal ground-water reservoir. They may be however, sources of recharge to or areas of discharge from the principal ground-water reservoir.

Confined Aquifers

The principal ground-water reservoir contains three confined aquifers: a shallow artesian aquifer in deposits of Pleistocene age, a deep artesian aquifer in deposits of Pleistocene age, and an artesian aquifer in deposits of Quaternary or Tertiary age. These aquifers are generally the same as those described by Hunt and others (1953).

The aquifers typically are separated by confining beds which are several feet thick. These confining beds usually cause a substantial difference in the hydrostatic pressure between aquifers, thus, resulting in vertical movement of water from one aquifer to another. This is evident when a well completed in one aquifer is pumped and water-level declines eventually are observed in wells completed in another aquifer. The decline of water levels in the other aquifer is a result of leakage through the confining layers that separate the aquifers. The hydrostatic pressure within the confined aquifers generally increases with depth.

Although the three confined aquifers can be separated locally, their thickness and lithology varies, making it difficult to trace them across the entire valley. This is illustrated in figures 17-19, which show the approximate stratigraphic relationship between aquifers and confining layers in several locations in northern Utah Valley (fig. 20).

The shallow artesian aquifer in deposits of Pleistocene age generally underlies the uppermost blue clay layer encountered in wells. The thickness of the aquifer ranges from 10 to 150 feet and is typically greatest near the mountains and least near Utah Lake. The aquifer apears to be thickest under the southern end of the Highland Bench and thinnest between the Highland and Provo Benches (fig. 17). The thickness of the upper confining layer ranges from about 50 to 150 feet and generally is greatest near Utah Lake (fig. 19). The confining layer between the shallow and deep artesian aquifers ranges in thickness from 20 to 200 feet and is thickest between the Highland and Provo Benches.

The deep artesian aquifer in deposits of Pleistocene age generally includes more than one water-bearing zone separated by layers of fine-grained material (figs. 17 and 18). The total thickness of the aquifer ranges from about 50 to 200 feet, and it apparently is thickest in the vicinity of the U.S. Steel Co., Geneva Works, where it includes a water-bearing zone that is about 180 feet thick (fig. 17). This aquifer has been fully penetrated by few wells, therefore, its total thickness is not known throughout the study area. The thickness of the confining layer underlying the aquifer ranges from about 20 to 90 feet east of the Jordan River and Utah Lake, and usually is described in drillers' logs as white clay, conglomerate, or hardpan. West of the Jordan River and Utah Lake, the shallow and deep artesian aquifers apparently are absent, as is the uppermost blue clay layer.

The artesian aquifer in deposits of Quaternary or Tertiary age includes several water-bearing zones and confining layers (figs. 17-18). The aquifer has been penetrated by few wells, and its thickness is generally unknown; but it is at least 600 feet thick and it yields large quantities of water which contains less than 400 milligrams per liter of dissolved solids to wells in the vicinity of the U.S. Steel Co., Geneva Works. West of the Jordan River, however, the aquifer mostly consists of layers of semiconsolidated material, and wells generally yield small quantities of water which contains qreater than 1,300 milligrams per liter of dissolved solids.

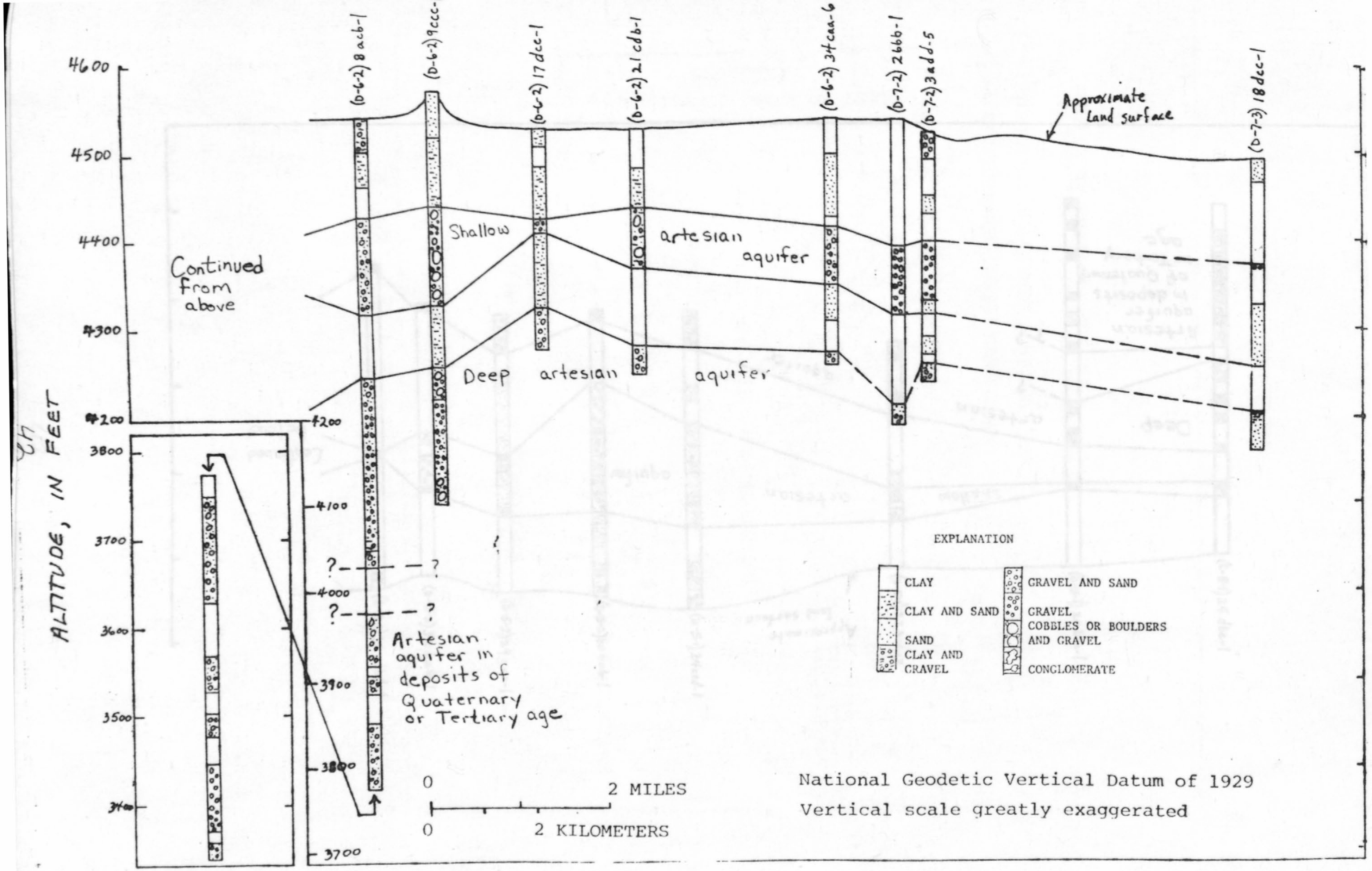
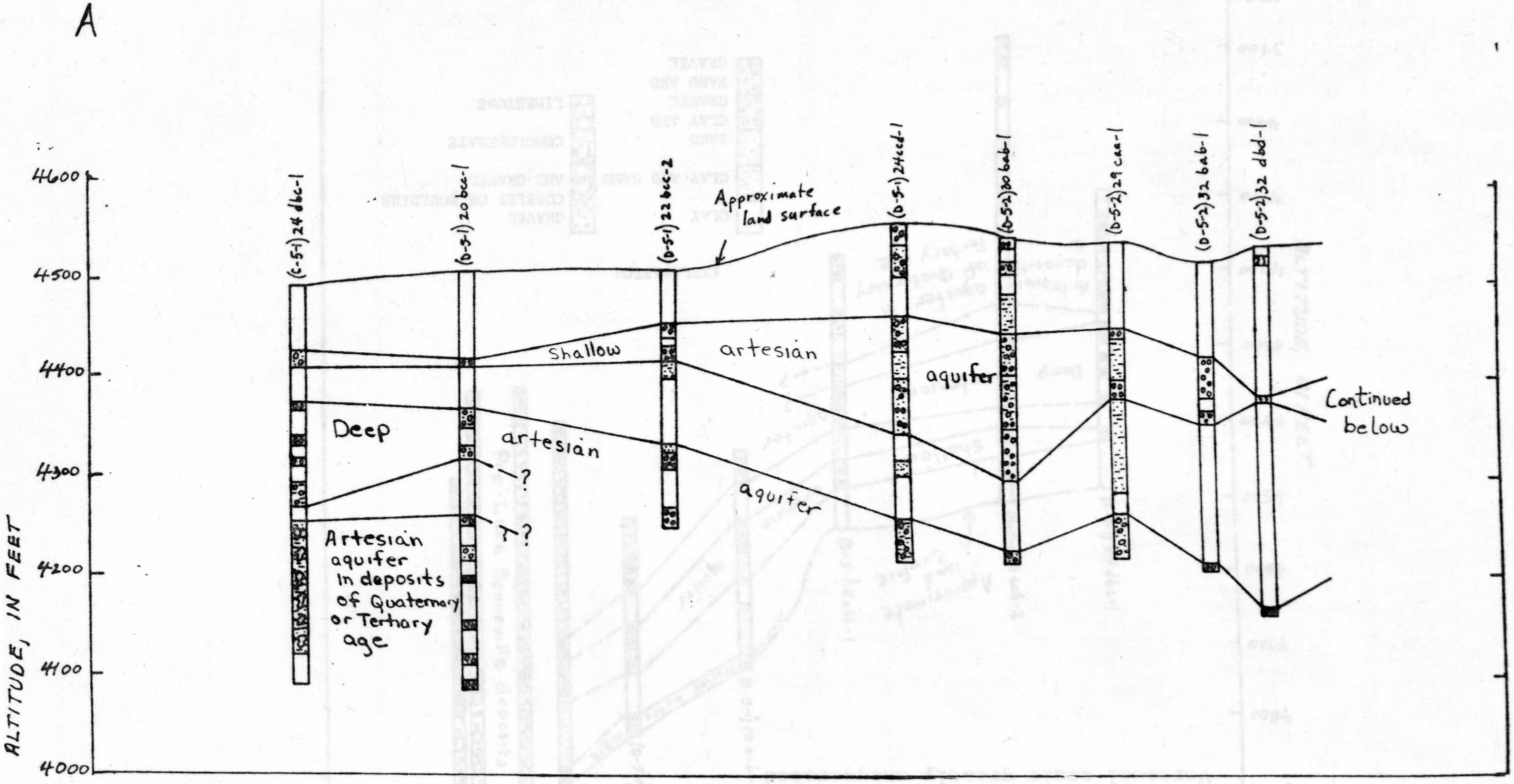


Figure 17.-- Correlation of aquifers from the Jordan River to Provo Bay. (See figure 20 for location.)


A
ALTITUDE, IN FEET
4600
4500
4400
4300
4200
4100
4000
(C-5-1)24dbc-1
(D-5-1)20bcc-1
(D-5-1)22bcc-2
(D-5-1)24ccd-1
(D-5-2)30bab-1
(D-5-2)29caa-1
(D-5-2)32bab-1
(D-5-2)32dbd-1
Approximate land surface
Shallow
artesian
aquifer
Deep
artesian
aquifer
?
?
Artesian aquifer in deposits of Quaternary or Tertiary age
Continued below

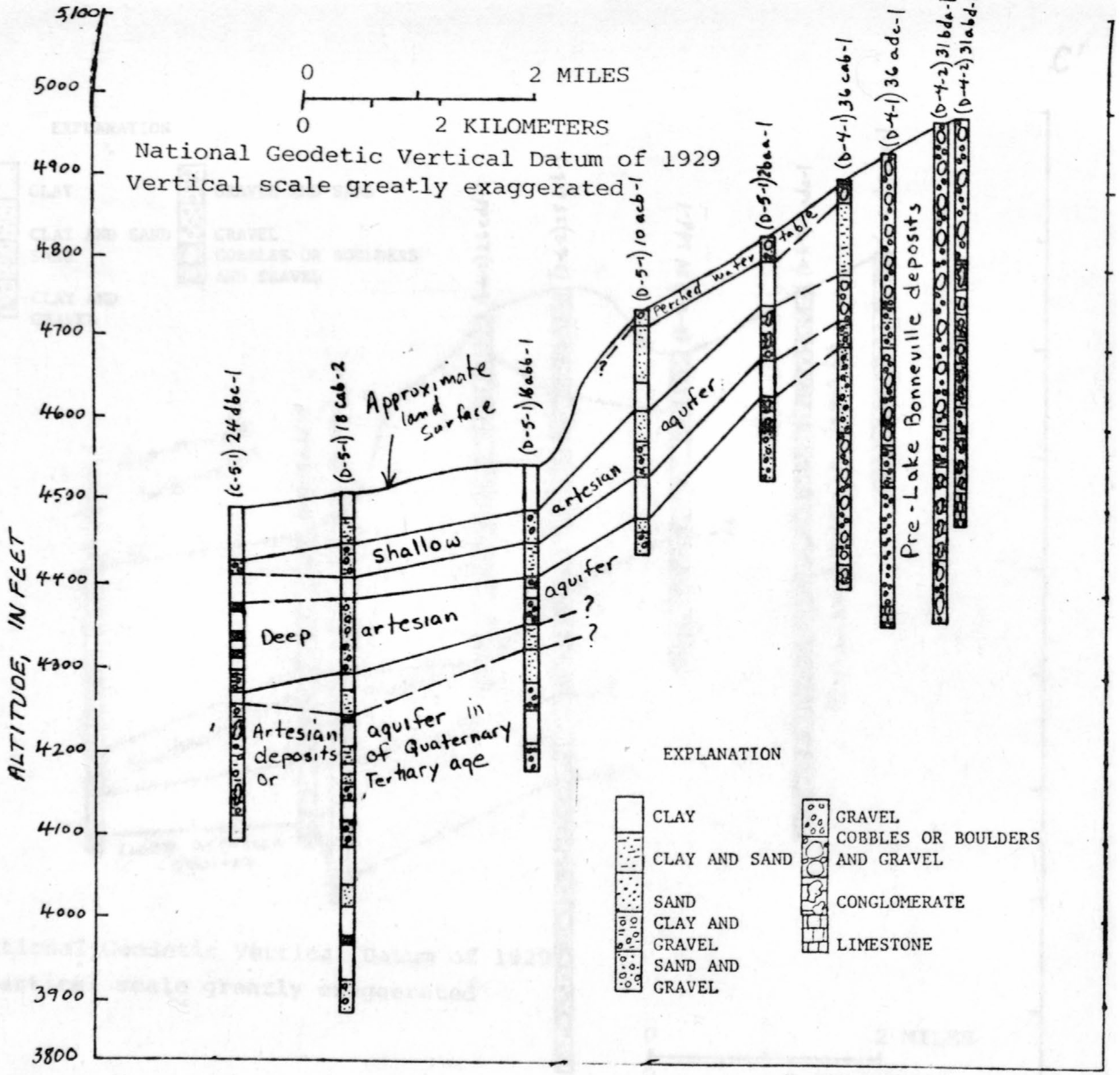


Figure 18.--Correlation of aquifers from the mouth of American Fork Canyon to the Jordan River. (See figure 20 for location.)

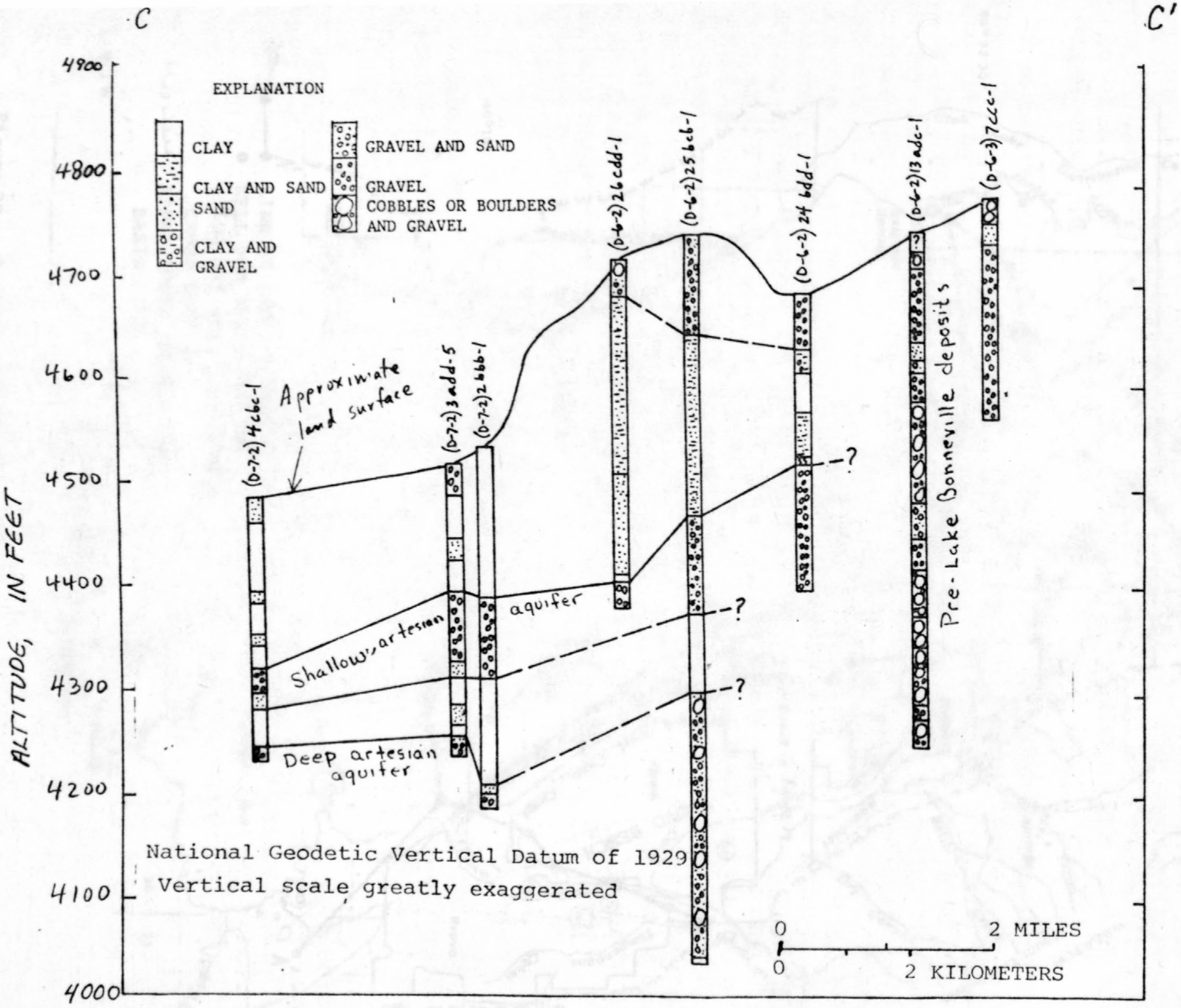


Figure 19 .--Correlation of aquifers from the mouth of Provo Canyon to Utah Lake. (See figure 20 for location.)

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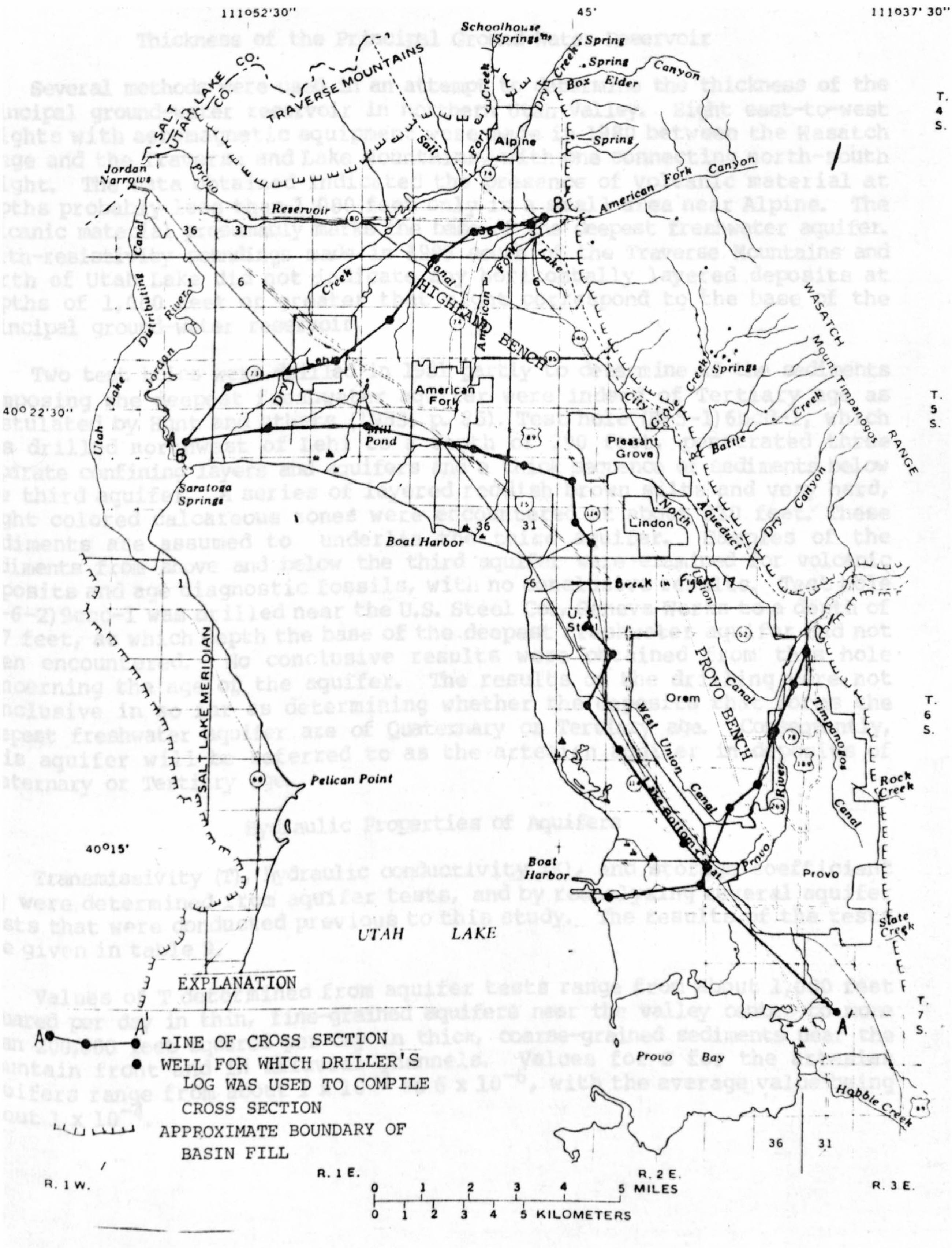


Figure 20 .--Location of cross sections shown in figures 17-19.

Thickness of the Principal Ground-Water Reservoir

Several methods were used in an attempt to determine the thickness of the principal ground-water reservoir in northern Utah Valley. Eight east-to-west flights with aeromagnetic equipment were made in 1980 between the Wasatch Range and the Traverse and Lake Mountains, with one connecting north-south flight. The data obtained indicated the presence of volcanic material at depths probably less than 1,000 feet only in a small area near Alpine. The volcanic material presumably marks the base of the deepest freshwater aquifer. Earth-resistivity soundings made in 1980 south of the Traverse Mountains and north of Utah Lake did not indicate any horizontally layered deposits at depths of 1,000 feet or greater that might correspond to the base of the principal ground-water reservoir.

Two test holes were drilled in 1981 partly to determine if the sediments composing the deepest freshwater aquifer were indeed of Tertiary age as postulated by Hunt and others (1953, p. 85). Test hole (D-5-1)6bcd-1, which was drilled northwest of Lehi to a depth of 290 feet, penetrated three separate confining layers and aquifers and a thick sequence of sediments below the third aquifer. A series of layered reddish brown silts and very hard, light colored calcareous zones were encountered at about 230 feet. These sediments are assumed to underlie the third aquifer. Samples of the sediments from above and below the third aquifer were examined for volcanic deposits and age diagnostic fossils, with no conclusive results. Test hole (D-6-2)9ccc-1 was drilled near the U.S. Steel Co., Geneva Works to a depth of 467 feet, at which depth the base of the deepest freshwater aquifer had not been encountered. No conclusive results were obtained from this hole concerning the age of the aquifer. The results of the drilling were not conclusive in so far as determining whether the deposits that forms the deepest freshwater aquifer are of Quaternary or Tertiary age. Consequently, this aquifer will be referred to as the artesian aquifer in deposits of Quaternary or Tertiary age.

Hydraulic Properties of Aquifers

Transmissivity (T), hydraulic conductivity (K), and storage coefficient (S) were determined from aquifer tests, and by reanalyzing several aquifer tests that were conducted previous to this study. The results of the tests are given in table 9.

Values of T determined from aquifer tests range from about 1,000 feet squared per day in thin, fine-grained aquifers near the valley center to more than 200,000 feet squared per day in thick, coarse-grained sediments near the mountain front and in alluvial channels. Values for S for the artesian aquifers range from about 1×10^{-3} to 6×10^{-6}, with the average value being about 1×10^{-4}.

Table 9.—Results of aquifer tests

Location: P, pumped well; F, flowing well.

Water-bearing unit: Names are adapted from Hunt and others (1953)—PLB, Pre-Lake Bonneville deposits; SP, shallow artesian aquifer in deposits of Pleistocene age; DP, deep artesian aquifer in deposits of Pleistocene age. Name specifically applied to this report—QT, artesian aquifer in deposits of Quaternary or Tertiary age [Tertiary (?) aquifers of Hunt and others (1953)]; U, unknown.

Hydraulic properties: The estimates of hydraulic conductivity represent maximum values based on thickness of water-bearing units as described in drillers' logs of wells. In some cases the entire thickness is not known.

Methods of analysis or reference: HM, Hantush modified method (Lohman, 1972, p. 32); SLM, Straight-line solution method (Lohman, 1972, p. 23); IWT, Image-well theory (Lohman, 1972, p. 59).

Location		Water-bearing unit	Date	Discharge (gallons per minute)	Hydraulic properties: Transmissivity (T) (feet squared per day)		Storage coefficient (S)		Hydraulic conductivity (K) (feet per day)	Method of analysis or reference
Well tested	Observation well				Drawdown	Recovery	Drawdown	Recovery		
(D-4-1)36cab-1 P		PLB	10-81	1,720	—	200,000	—	—	½500	SLM
(D-5-1)8acc-1 P	(D-5-1)5cbc-1	QT	4-82	2,850	2,700	—	2.9×10^{-5}	—	30	HM
	8abd-1					2,500		3.8×10^{-5}	30	
	18bab-2					—		—	120	
(D-5-1)16ccb-4 F		DP	6-82	133	—	3,500	—	—	440	SLM
(D-5-1)19acb-2 F		DP	6-82	85	—	4,850	—	—	540	SLM
(D-5-1)19ccd-1 F		SP	6-82	190	—	6,600	—	—	150	SLM
	(D-5-1)19ccb-1				1,200	1,100	2.1×10^{-5}	5.4×10^{-5}	30	
(D-5-1)19dbd-6 F		SP,DP	6-82	250	—	6,250	—	—	180	SLM
(D-5-1)20ccb-3 F		SP	6-82	133	—	3,100	—	—	240	SLM
(D-5-1)26bda-1 F		SP,DP	2-82	250	—	8,700	—	—	130	SLM
			6-82	230	—	5,000	—	—	70	SLM
(D-5-2)30cab-2 F		SP	2-82	235	—	4,400	—	—	210	SLM
	(D-5-1)30cab-1		6-82	210	—	1,200	—	6.1×10^{-6}	60	
(D-6-2)6acc-1 F		SP	2-82	210	—	25,000	—	—	—	SLM
(D-6-2)13adc-1 P		PLB	3-80	2,800	—	175,000	—	—	½500	SLM
(D-6-2)24bdd-1 P[1]	(D-6-2)24acc-1	SP	3-80	3,500	200,000	—	2.0×10^{-4}	—	—	HM
	24caa-1									
(D-7-2)4cba-2 F		SP	7-82	300	—	10,000	—	—	½500	SLM
(D-7-2)4cdb-1 F		SP	6-82	182	—	5,300	—	—	—	SLM
Aquifer tests conducted prior to 1970										
(D-5-1)19dcb-1 F		DP	10-64	60	2,400	—	—	—	300	SLM
(D-5-1)20aba-1 F	(D-5-1)20aab-4	QT	4-57	110	—	1,100	—	2.3×10^{-5}	—	HM
(D-5-1)27cca-1 P		PLB	11-68	2,720	—	61,000	—	—	500	SLM
(D-6-2)8bcd-15 F	(D-6-2)8bcd-14	DP	9-65	440	41,000	—	2.2×10^{-4}	—	400	HM
(D-6-2)8cda-1 F	(D-6-2)8cac-5	QT	9-65	3,020	71,000	—	1.0×10^{-4}	—	380	HM
(D-6-2)13cab-1 P		DP,QT	5-67	3,200	—	435,000	—	—	½500	SLM
	(D-6-2)9dab-1[1]				—	300,000	—	3.5×10^{-4}	½500	HM
(D-6-2)21cca-1 F	(D-6-2)21ccb-1	U	4-58	444	27,000	—	9.3×10^{-5}	—	—	HM
	21cbb-3									
(D-7-2)1aca-1 P	(D-7-2)1caa-4	SP	10-58	2,300	50,000	—	2.7×10^{-4}	—	—	HM
(D-7-2)12ccd-1 F		U	9-64	50	6,500	—	—	—	—	SLM
(D-7-3)7acd-1 P		DP	2-65	1,500	—	18,000	—	—	80	SLM
	(D-7-3)7dab-1				10,000	—	2.6×10^{-2}	—	280	IWT
	(D-7-3)8caa-1	PLB			18,000	—	3.0×10^{-3}	—	300	IWT

1 Data were not sufficient to analyze for leaky confined aquifers; thus, actual transmissivity may be smaller than the calculated transmissivity (Lohman, 1972, p. 32).

Vertical hydraulic conductivity (K') was calculated for the confining layers above the pumped aquifer when well (D-5-1)8acc-1 was pumped using the ratio method (Neuman and Witherspoon, 1972, p. 1284). Drawdown data from five wells finished in sediments above the aquifer pumped were used to calculate the average K' of 1 x 10^{-3} feet per day.

Values for T were estimated by using specific-capacity data (Theis and others, 1963, p. 331-340) and lithologic data from drillers' logs for wells where no aquifer-test data were available. T values so estimated are reasonably accurate, and they provide data for a digital-computer model that was constructed for the study area.

Movement

Ground water generally moves from the mountain fronts to Utah Lake and the Jordan River. A downward component of movement exists throughout the primary recharge area along the mountain fronts (fig. 2). An upward component of movement exists where the water is confined. Water moves upward through confining beds from the deeper aquifers, or zones within the aquifers, to shallower aquifers or zones. The hydraulic gradient locally may be reversed by the drawdown of water levels resulting from large-scale withdrawals of water from wells. The configurations of contours depicting the water table and the potentiometric surface of the artesian aquifers in 1981 were similar to those for 1947 (Hunt and others, 1953, pl. 3) and 1963 (Cordova and Subitzky, 1965, p. 28-30).

Unconfined Aquifers

Contours depicting the surface of the perched water table on the Highland Bench are shown in figure 21. Movement of water generally is at right angles to the contours. Insufficient data were available to show similar contours for the Provo Bench. The hydraulic gradient of the water table ranges from about 0.013 to 0.021 (70 to 110 feet per mile) and generally is similar to the slope of the land surface.

The water table is not continuous from one area to another. The Highland and Provo Benches are separate landforms, and consequently the perched water-table aquifers also are separate. Minor quantities of water move downward on these benches through an unsaturated zone to the principal ground-water reservoir, and some water moves to the edge of the benches where it discharges by evapotranspiration, springs, seeps, and into drains. Some of the water moves into Lake Bonneville deposits in the valley lowlands.

During 1981, 10 wells were augered to depths ranging from 11 to 22 feet in two areas near Utah Lake (fig. 22). The wells were completed in Lake Bonneville deposits which constituted the confining layer over the shallow artesian aquifer. The gradient of the water surface in both areas during March 1982 was toward Utah Lake at a slope of about 0.0067 (35 feet per mile), which is about the same as the slope of the land surface. The source of this water, as indicated by water levels in these wells and nearby deeper wells, is upward leakage from the shallow artesian aquifer.

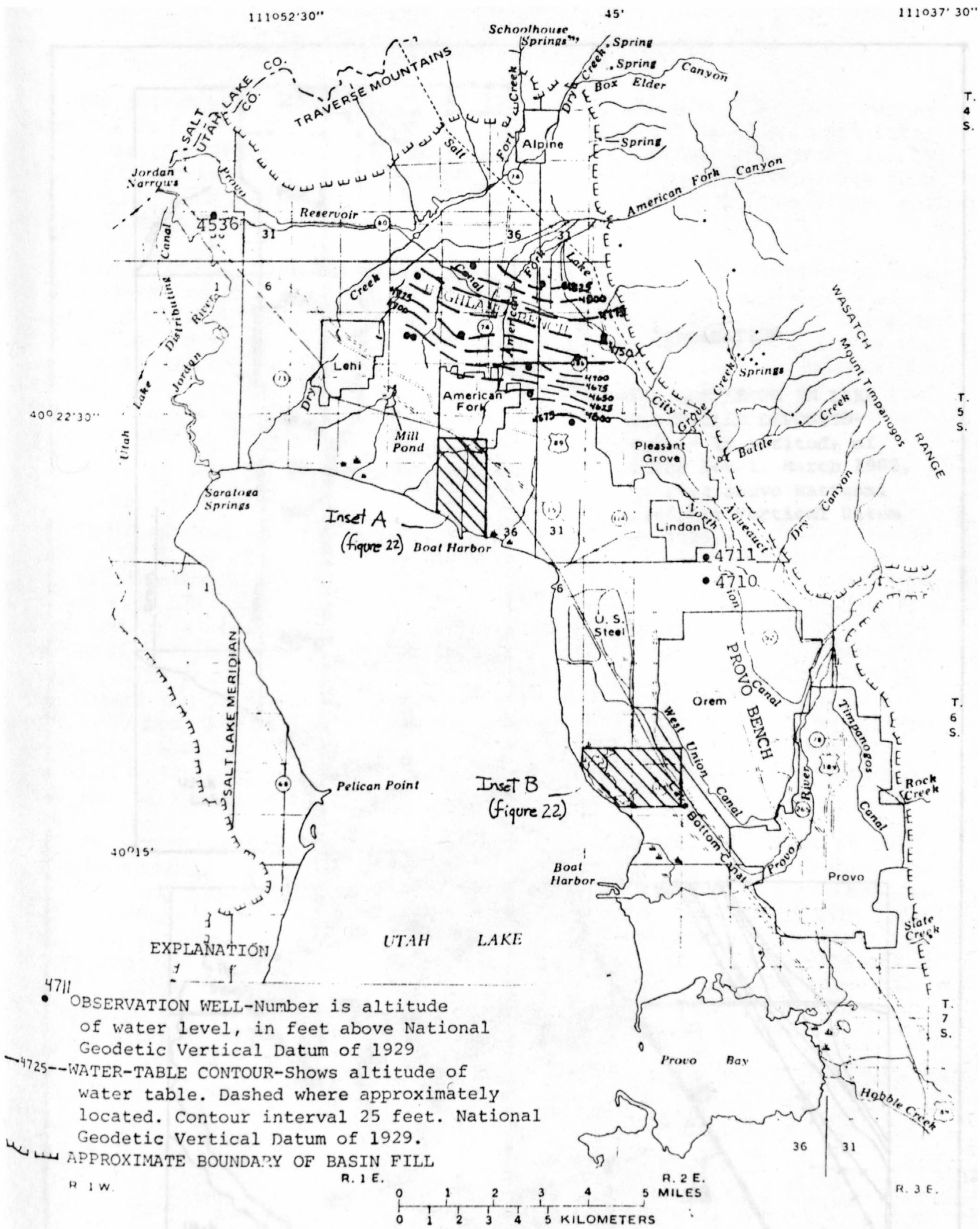


Figure 21.--Water-level contours and altitudes of water levels in selected wells completed in the perched water-table aquifer, March 1981.

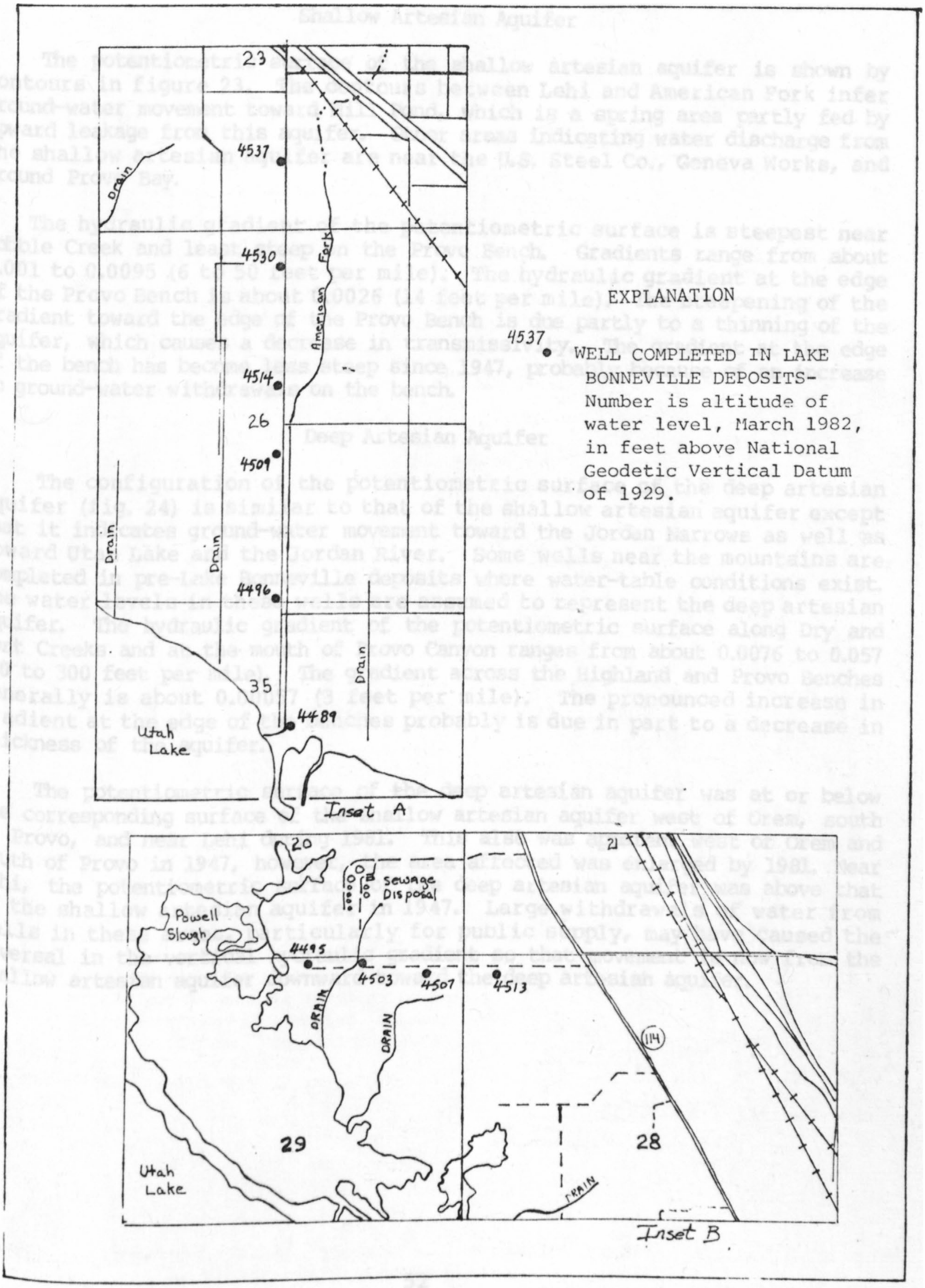


Figure 22 .-Altitudes of water levels in wells completed in Lake Bonneville deposits, March 1982. (See figure 21 for location of areas.)

Shallow Artesian Aquifer

The potentiometric surface of the shallow artesian aquifer is shown by contours in figure 23. The contours between Lehi and American Fork infer ground-water movement toward Mill Pond, which is a spring area partly fed by upward leakage from this aquifer. Other areas indicating water discharge from the shallow artesian aquifer are near the U.S. Steel Co., Geneva Works, and around Provo Bay.

The hydraulic gradient of the potentiometric surface is steepest near Hobble Creek and least steep on the Provo Bench. Gradients range from about 0.001 to 0.0095 (6 to 50 feet per mile). The hydraulic gradient at the edge of the Provo Bench is about 0.0026 (14 feet per mile). The steepening of the gradient toward the edge of the Provo Bench is due partly to a thinning of the aquifer, which causes a decrease in transmissivity. The gradient at the edge of the bench has become less steep since 1947, probably because of an increase in ground-water withdrawals on the bench.

Deep Artesian Aquifer

The configuration of the potentiometric surface of the deep artesian aquifer (fig. 24) is similar to that of the shallow artesian aquifer except that it indicates ground-water movement toward the Jordan Narrows as well as toward Utah Lake and the Jordan River. Some wells near the mountains are completed in pre-Lake Bonneville deposits where water-table conditions exist. The water levels in these wells are assumed to represent the deep artesian aquifer. The hydraulic gradient of the potentiometric surface along Dry and Fort Creeks and at the mouth of Provo Canyon ranges from about 0.0076 to 0.057 (40 to 300 feet per mile). The gradient across the Highland and Provo Benches generally is about 0.00057 (3 feet per mile). The pronounced increase in gradient at the edge of the benches probably is due in part to a decrease in thickness of the aquifer.

The potentiometric surface of the deep artesian aquifer was at or below the corresponding surface of the shallow artesian aquifer west of Orem, south of Provo, and near Lehi during 1981. This also was apparent west of Orem and south of Provo in 1947, however, the area affected was enlarged by 1981. Near Lehi, the potentiometric surface of the deep artesian aquifer was above that of the shallow artesian aquifer in 1947. Large withdrawals of water from wells in these areas, particularly for public supply, may have caused the reversal in the vertical hydraulic gradient so that movement is now from the shallow artesian aquifer downward toward the deep artesian aquifer.

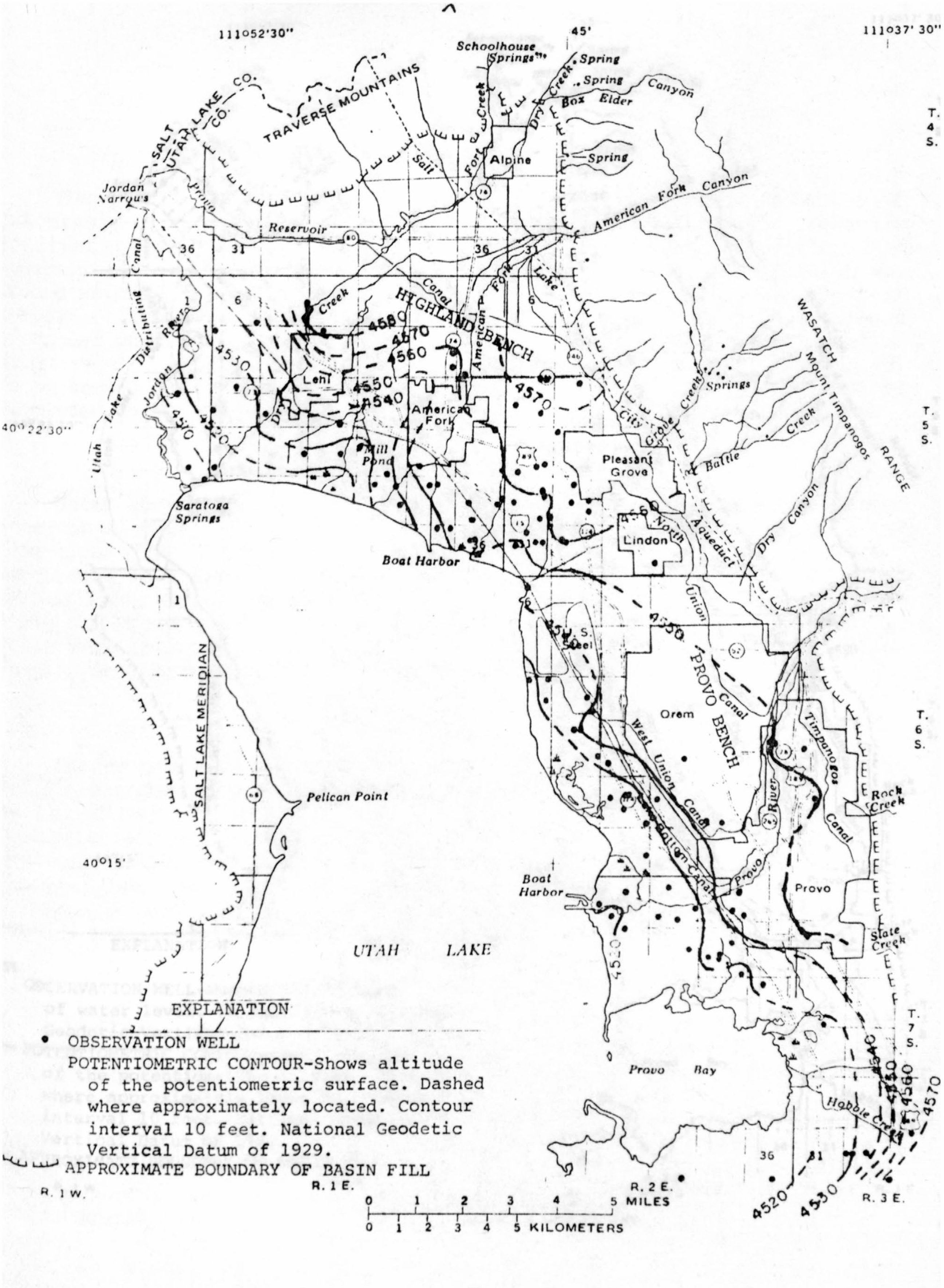


Figure 23.--Potentiometric surface of the shallow artesian aquifer in deposits of Pleistocene age, March 1981.

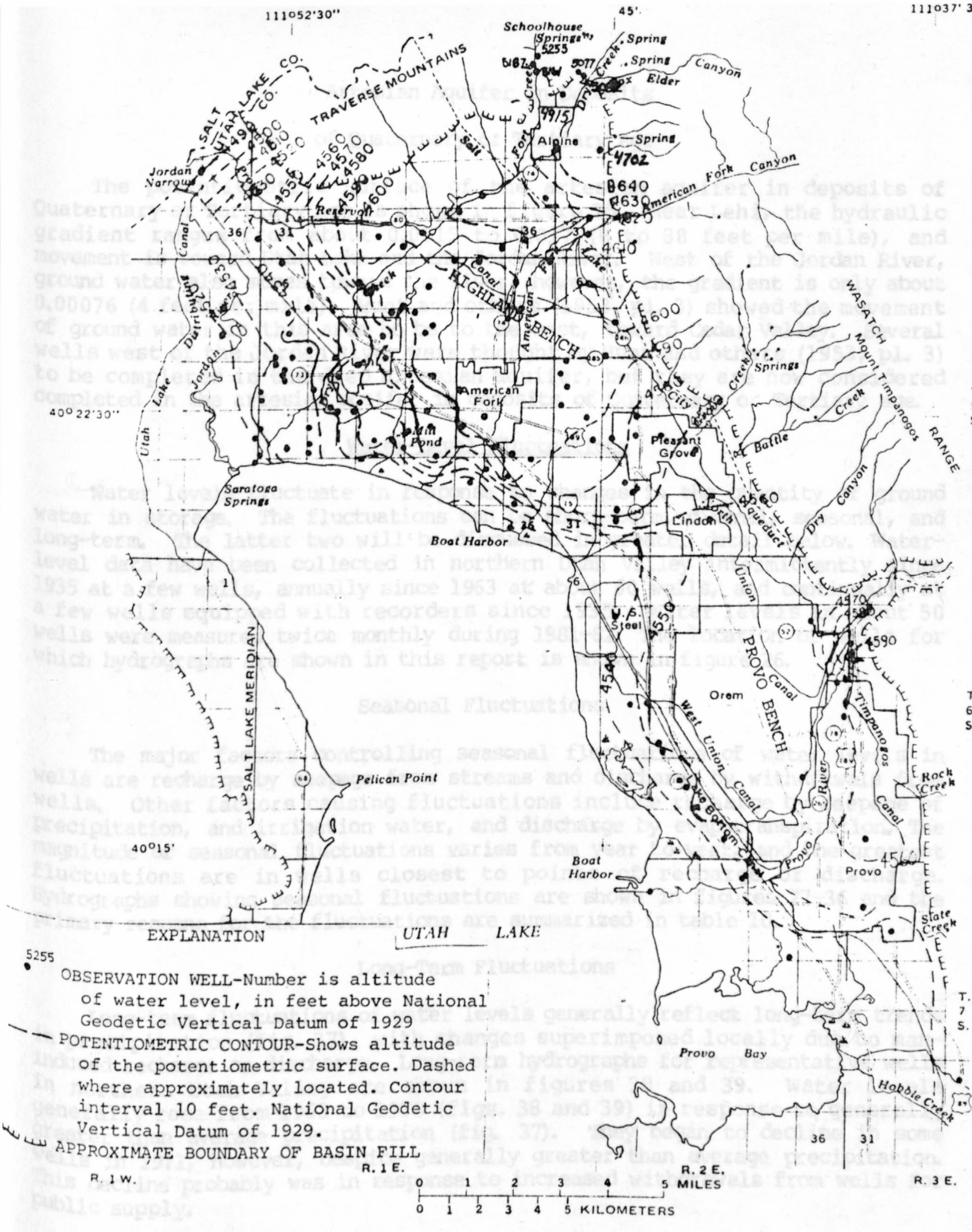


Figure 24.--Potentiometric surface of the deep artesian aquifer in deposits of Pleistocene age, March 1981.

Artesian Aquifer in Deposits of Quaternary or Tertiary Age

The potentiometric surface of the artesian aquifer in deposits of Quaternary or Tertiary age is shown in figure 25. Near Lehi, the hydraulic gradient ranges from about 0.0015 to 0.017 (8 to 88 feet per mile), and movement is toward Utah Lake and the Jordan River. West of the Jordan River, ground water also moves toward the river, however, the gradient is only about 0.00076 (4 feet per mile). Hunt and others (1953, pl. 3) showed the movement of ground water in this area to be to the west, toward Cedar Valley. Several wells west of the Jordan River were thought by Hunt and others (1953, pl. 3) to be completed in the deep artesian aquifer, but they are now considered completed in the artesian aquifer in deposits of Quaternary or Tertiary age.

Water-Level Fluctuations

Water levels fluctuate in response to changes in the quantity of ground water in storage. The fluctuations can be short-term, diurnal, seasonal, and long-term. The latter two will be discussed in greater detail below. Water-level data have been collected in northern Utah Valley intermittently since 1935 at a few wells, annually since 1963 at about 60 wells, and continually at a few wells equipped with recorders since 1935. Water levels in about 50 wells were measured twice monthly during 1981-82. The location of wells for which hydrographs are shown in this report is shown in figure 26.

Seasonal Fluctuations

The major factors controlling seasonal fluctuations of water levels in wells are recharge by seepage from streams and discharge by withdrawals from wells. Other factors causing fluctuations include recharge by seepage of precipitation, and irrigation water, and discharge by evapotranspiration. The magnitude of seasonal fluctuations varies from year to year, and the greatest fluctuations are in wells closest to points of recharge or discharge. Hydrographs showing seasonal fluctuations are shown in figures 27-36 and the primary reasons for the fluctuations are summarized in table 10.

Long-Term Fluctuations

Long-term fluctuations of water levels generally reflect long-term trends in precipitation (fig. 37), with changes superimposed locally due to man-induced recharge or discharge. Long-term hydrographs for representative wells in northern Utah Valley are shown in figures 38 and 39. Water levels generally rose from 1963 to 1970 (figs. 38 and 39) in response to generally greater than average precipitation (fig. 37). They began to decline in some wells in 1971, however, despite generally greater than average precipitation. This decline probably was in response to increased withdrawals from wells for public supply.

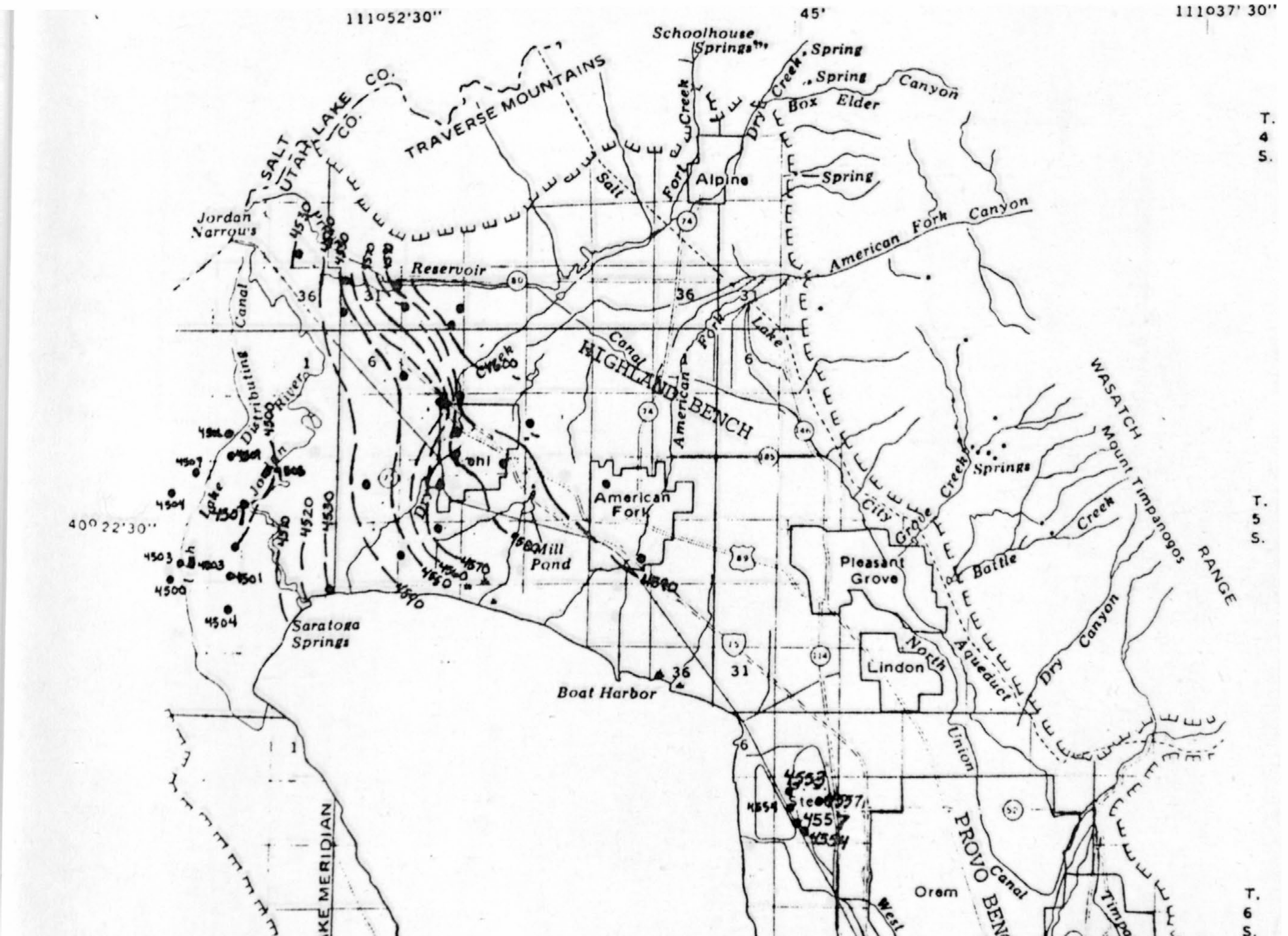


Figure 25.--Potentiometric surface of the artesian aquifer in deposits of Quaternary or Tertiary age, March 1981.

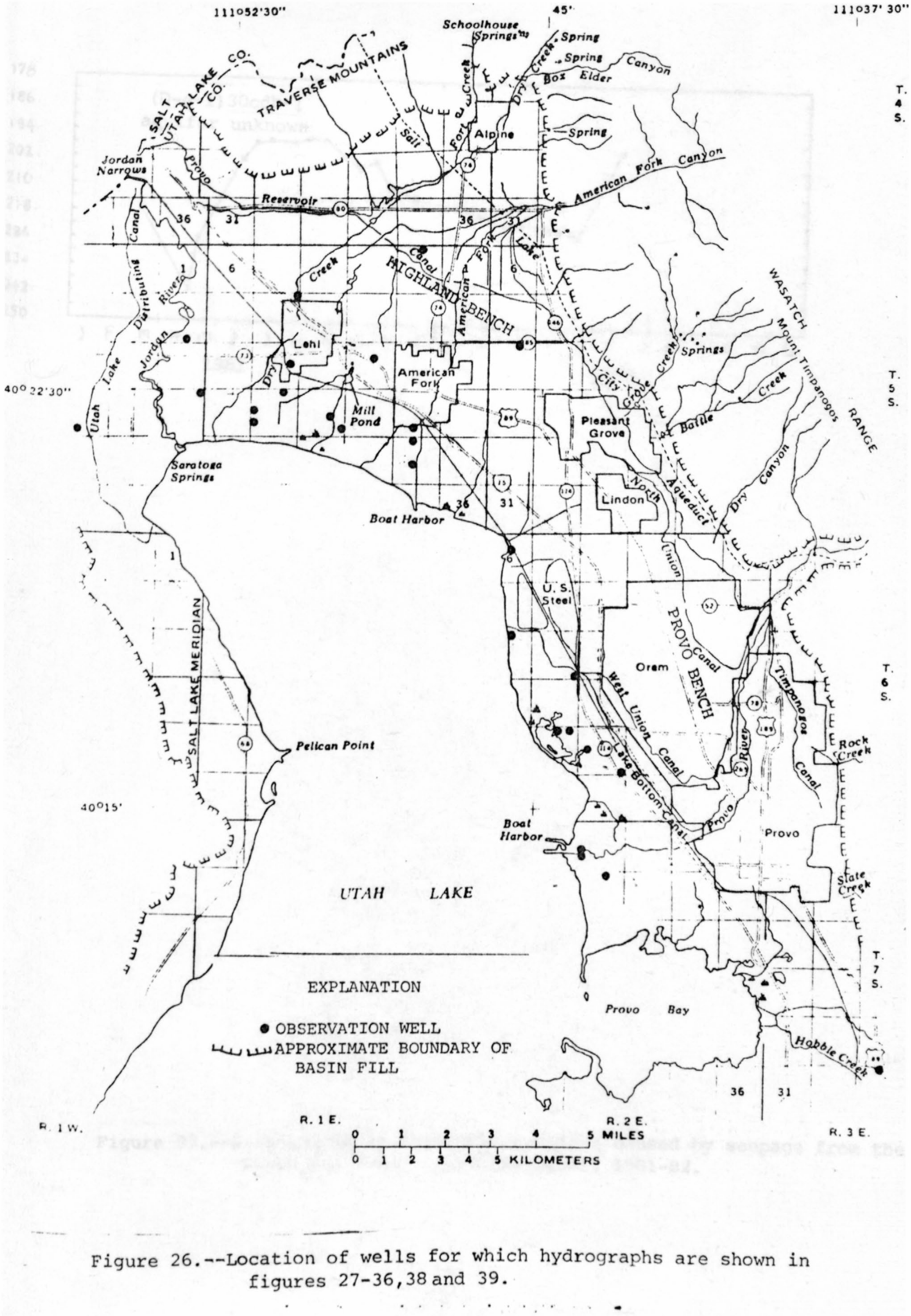


Figure 26.--Location of wells for which hydrographs are shown in figures 27-36, 38 and 39.

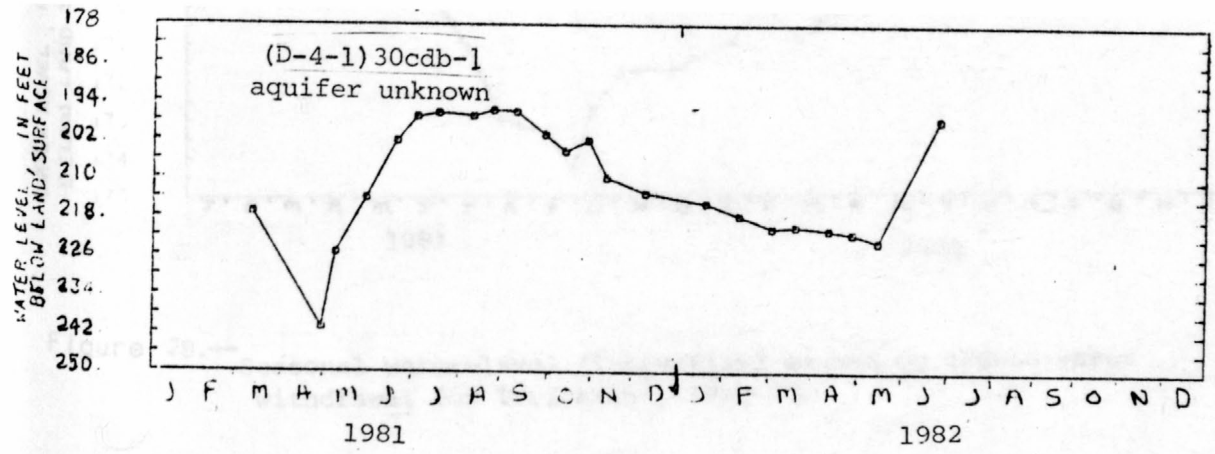


Figure 27.--Seasonal water-level fluctuations caused by seepage from the Provo Reservoir (Murdock) Canal, 1981-82.

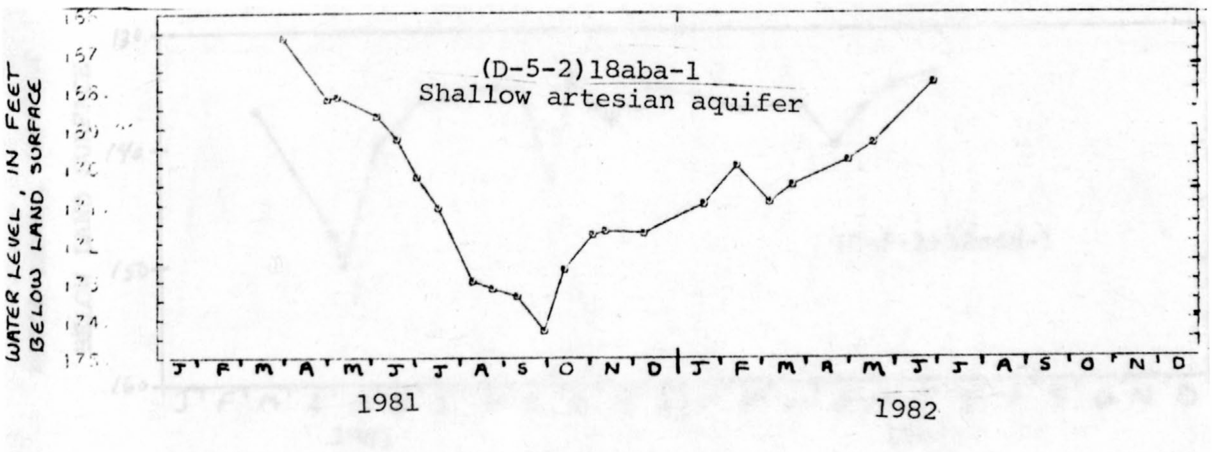


Figure 28.--Seasonal water-level fluctuations caused by ground-water withdrawal for irrigation, 1981-82.

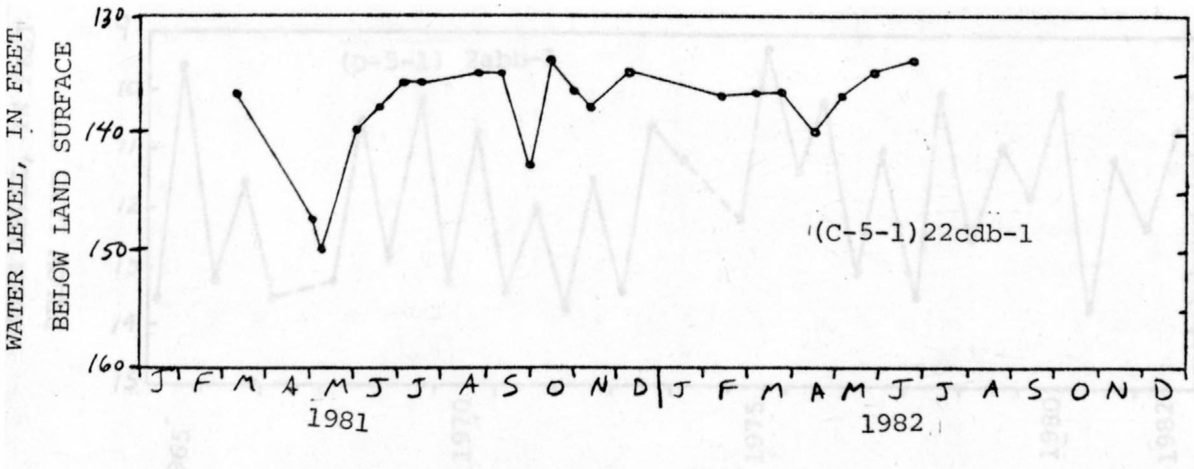


Figure 29.--Seasonal water-level fluctuations in a well completed in bedrock, 1981-82.

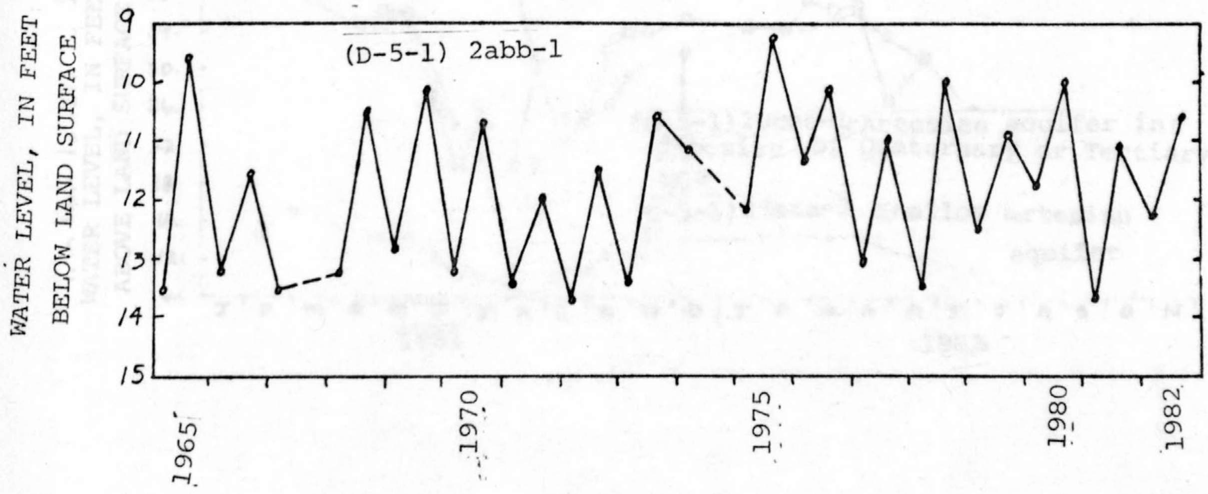


Figure 30.--Seasonal water-level fluctuations in a well completed in the perched water-table aquifer, 1965-82.

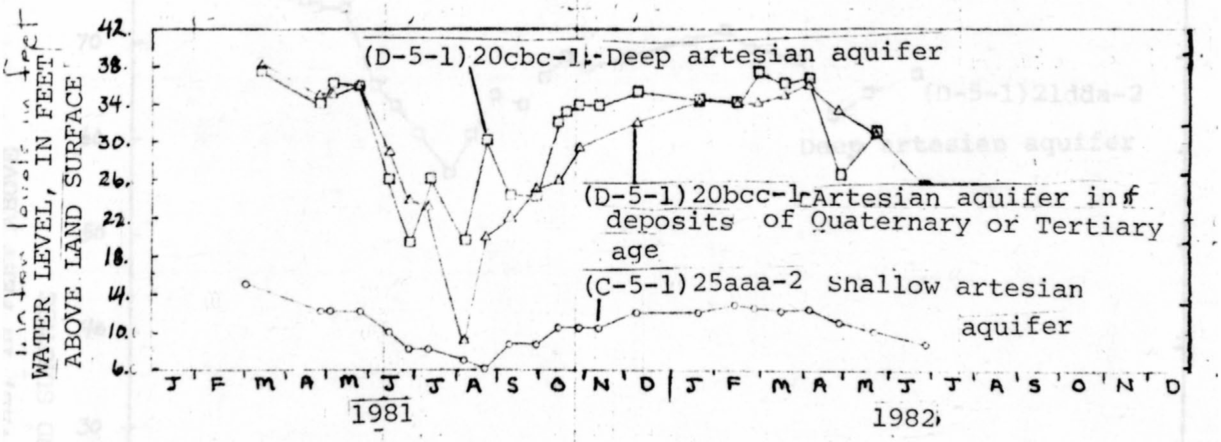


Figure 31.--Seasonal water-level fluctuations in wells southwest of Lehi, 1981-82.

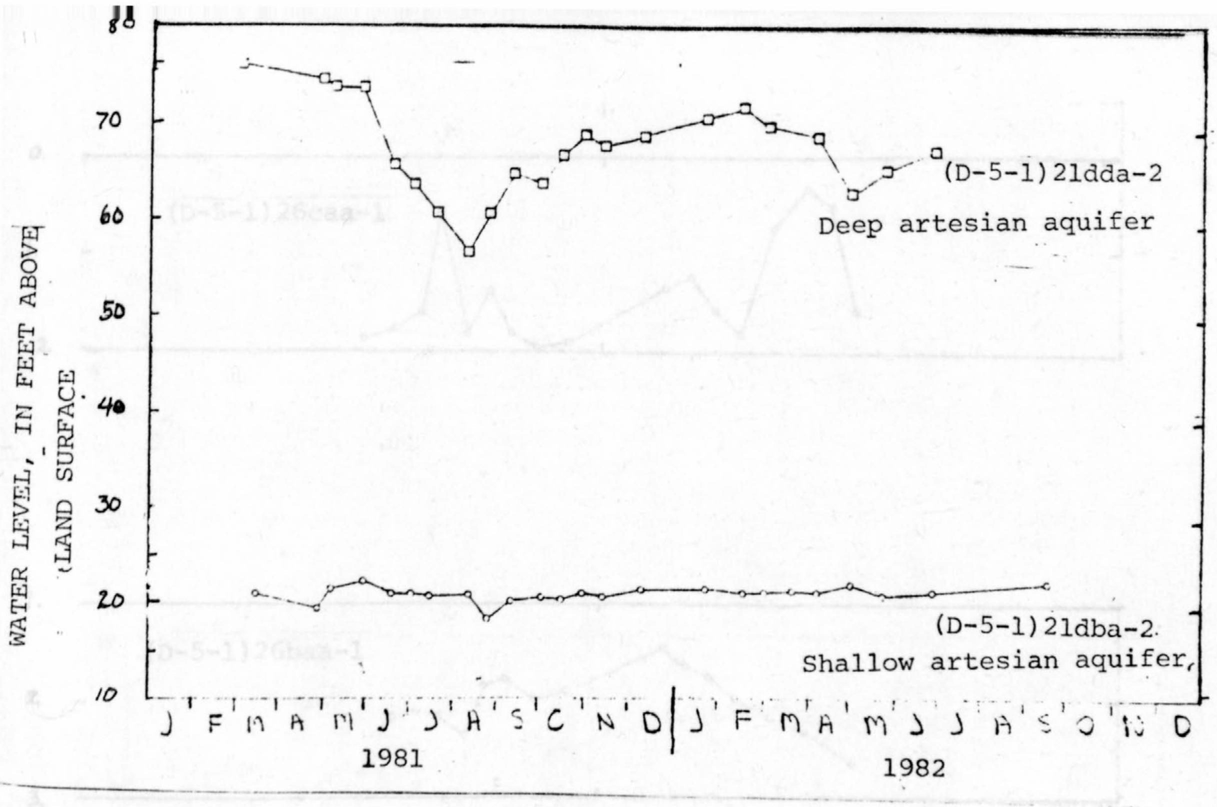


Figure 32.--Seasonal water-level fluctuations in wells near Mill Pond, 1981-82.

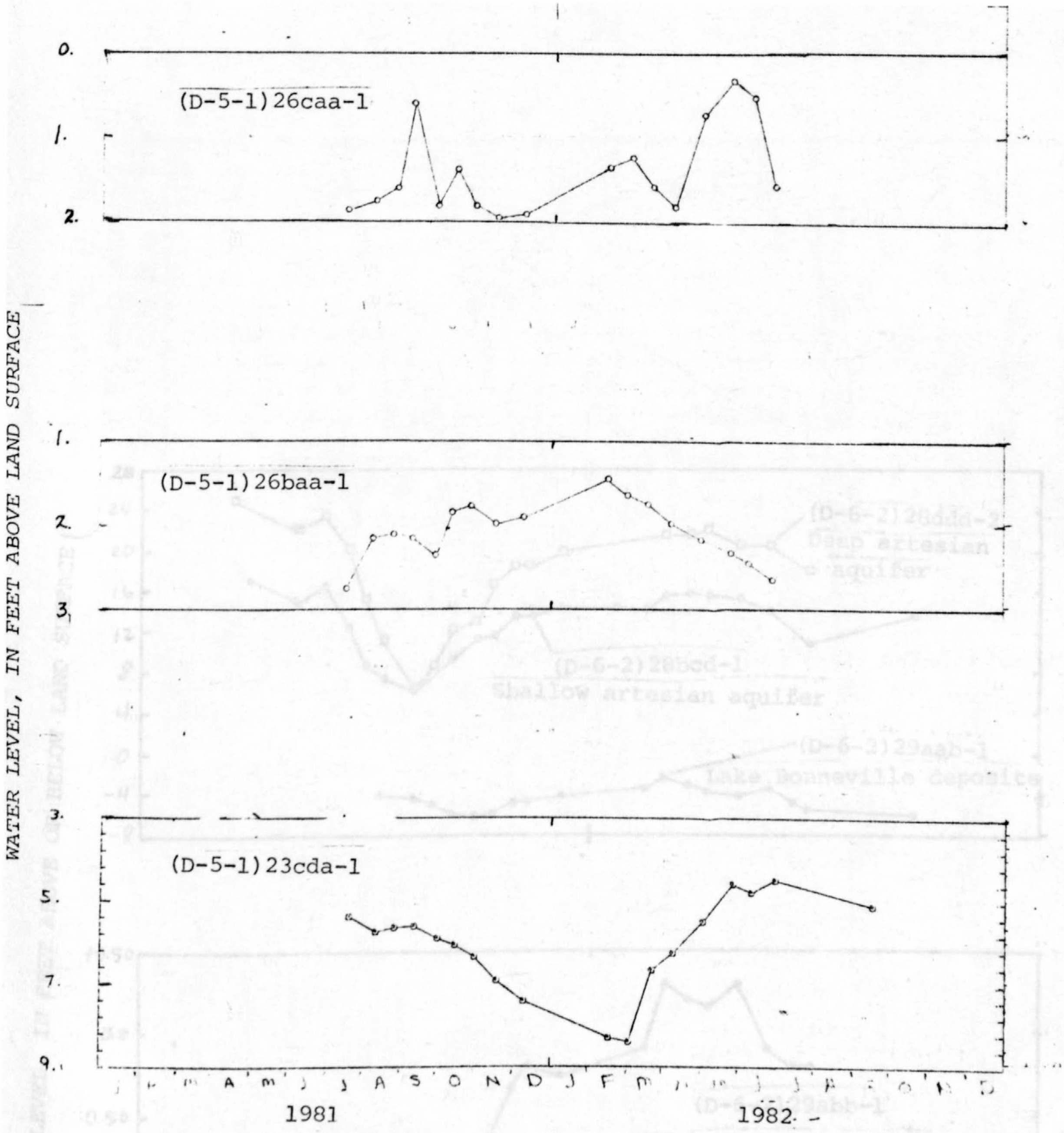


Figure 33.--Seasonal water-level fluctuations in wells completed in Lake Bonneville deposits south of American Fork, 1981-82.

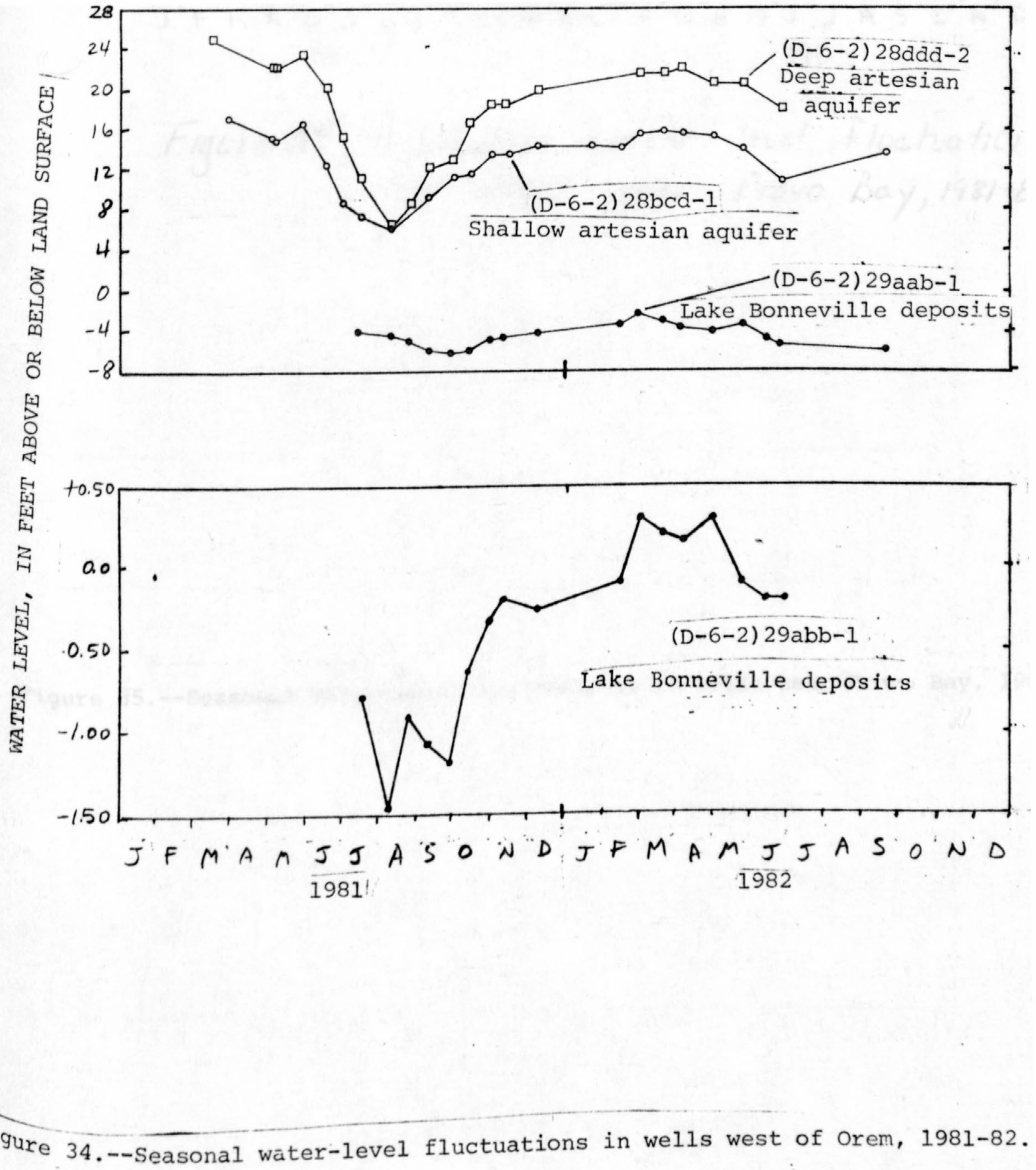


Figure 34.--Seasonal water-level fluctuations in wells west of Orem, 1981-82.

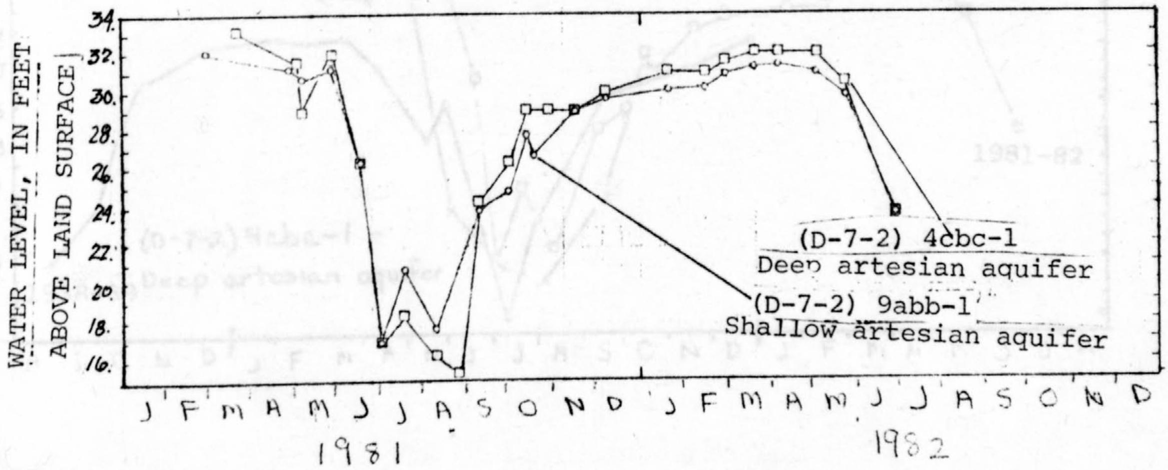


Figure 45.—Seasonal water-level fluctuations in wells near Provo Bay, 1981-82.

Figure 35.--Seasonal water-level fluctuations in wells near Provo Bay, 1981-82.

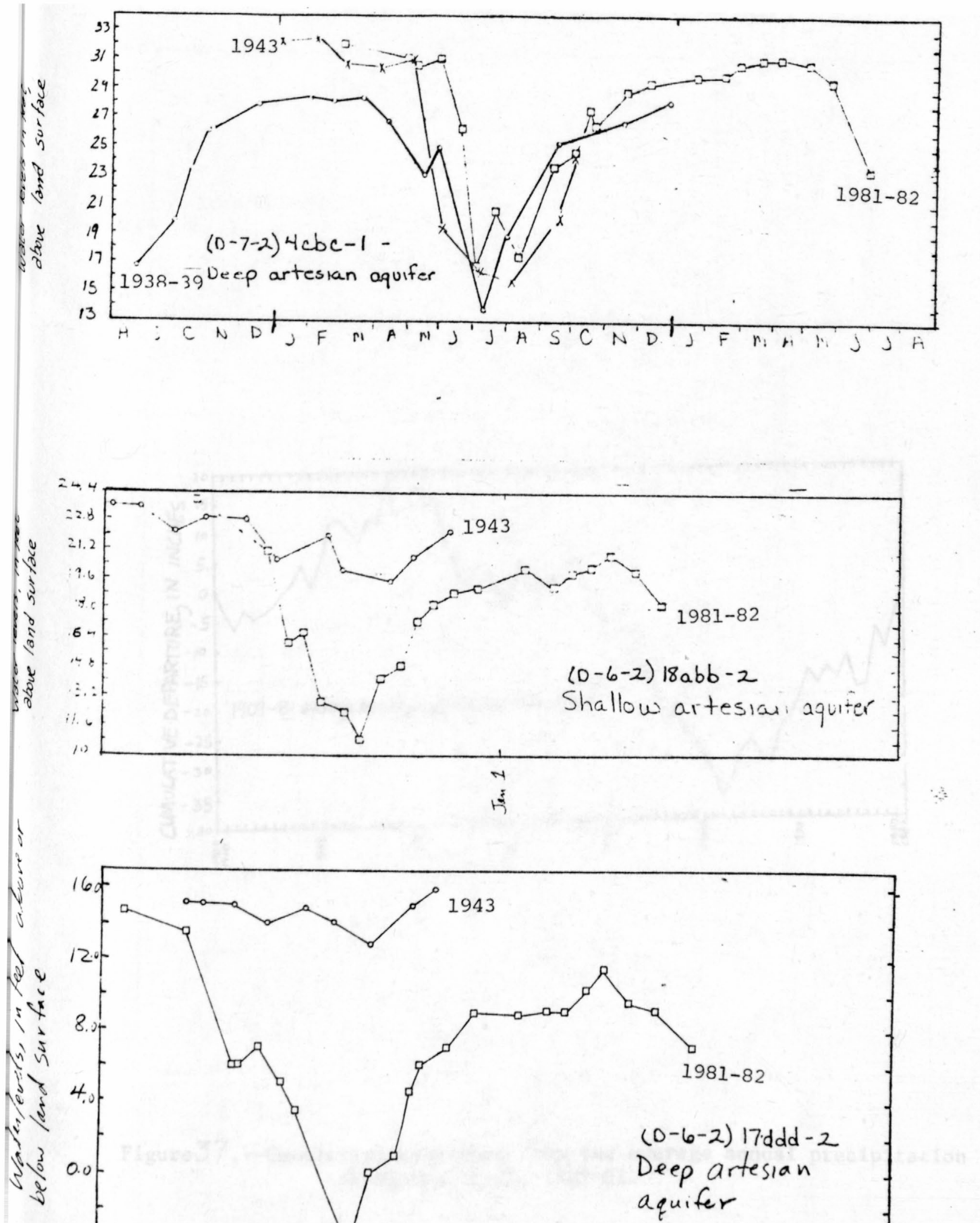


Figure 36.--Seasonal water-level fluctuations in wells, 1938-39, 1943, and 1981-82.

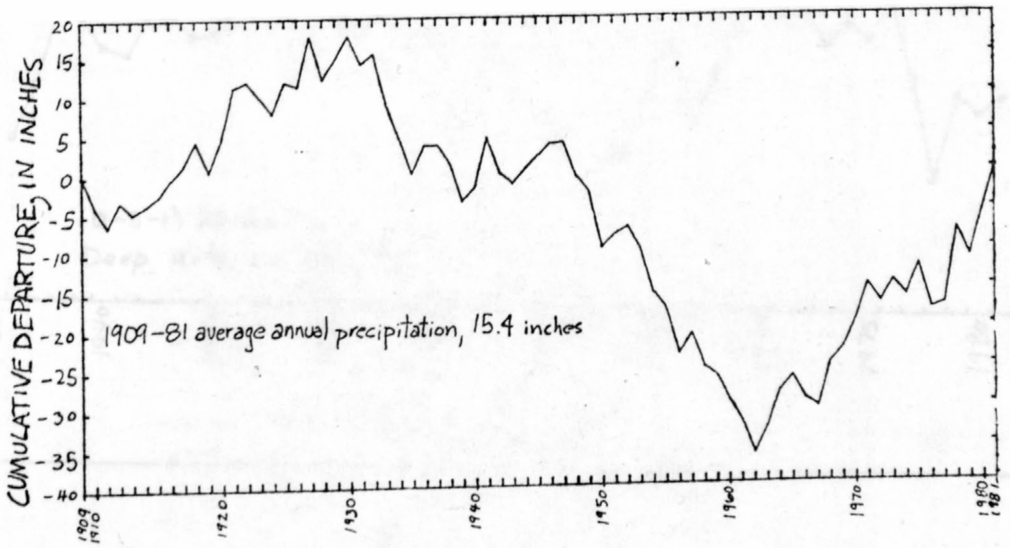


Figure 37.--Cumulative departure from the average annual precipitation at Alpine, Utah, 1909-81.

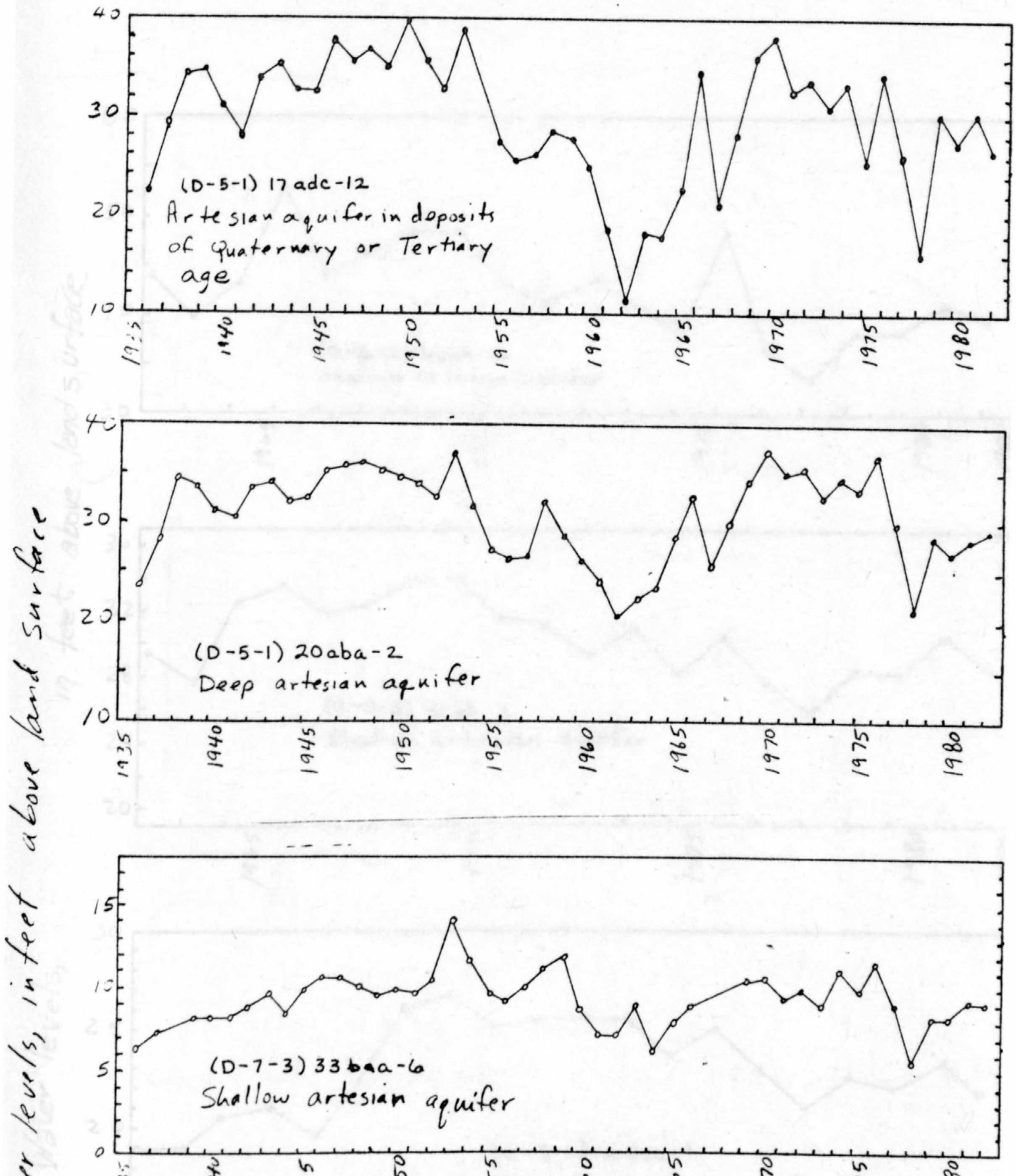


Figure 38.--Long-term water-level trends, 1936-82.

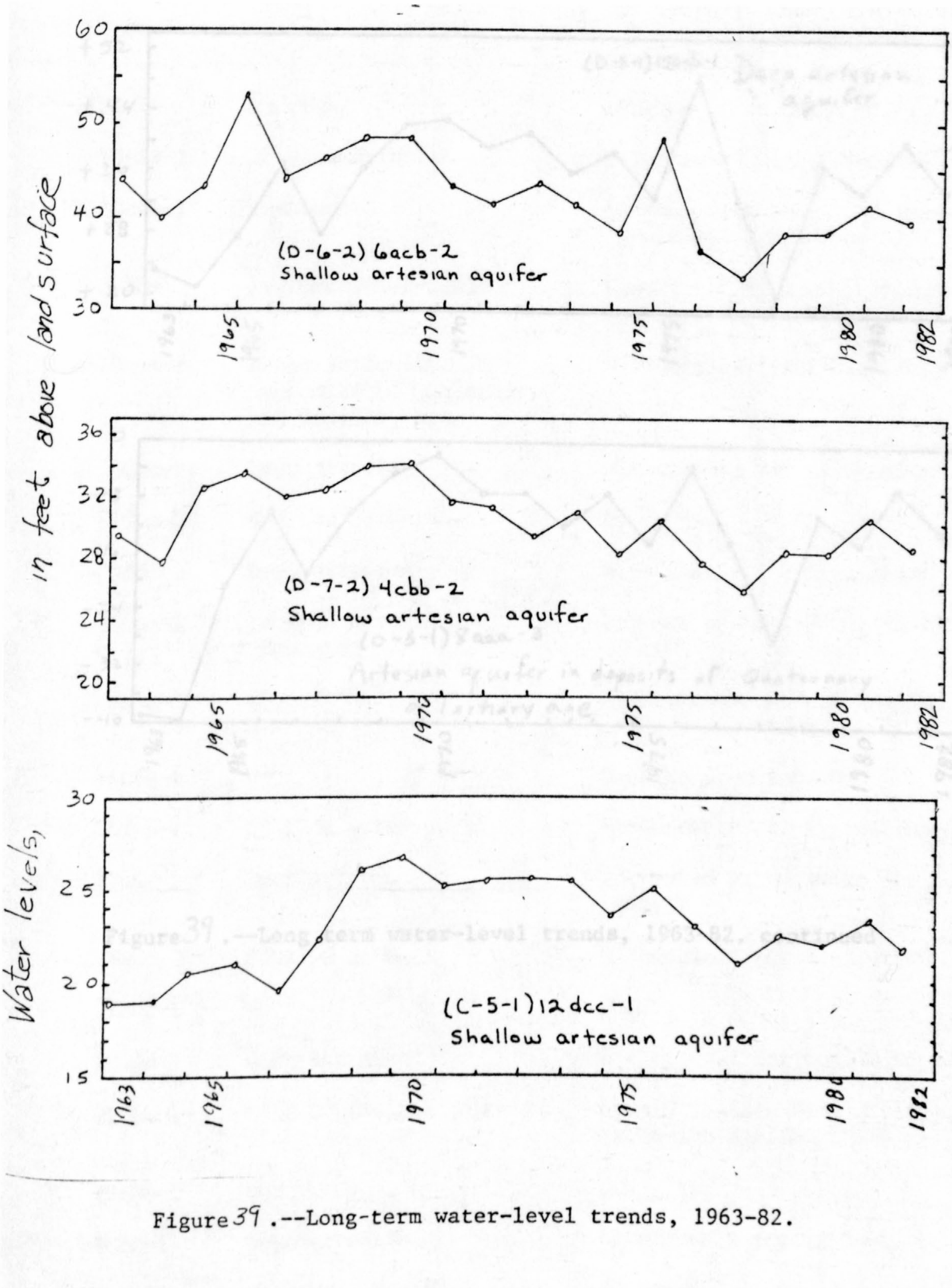


Figure 39.--Long-term water-level trends, 1963-82.

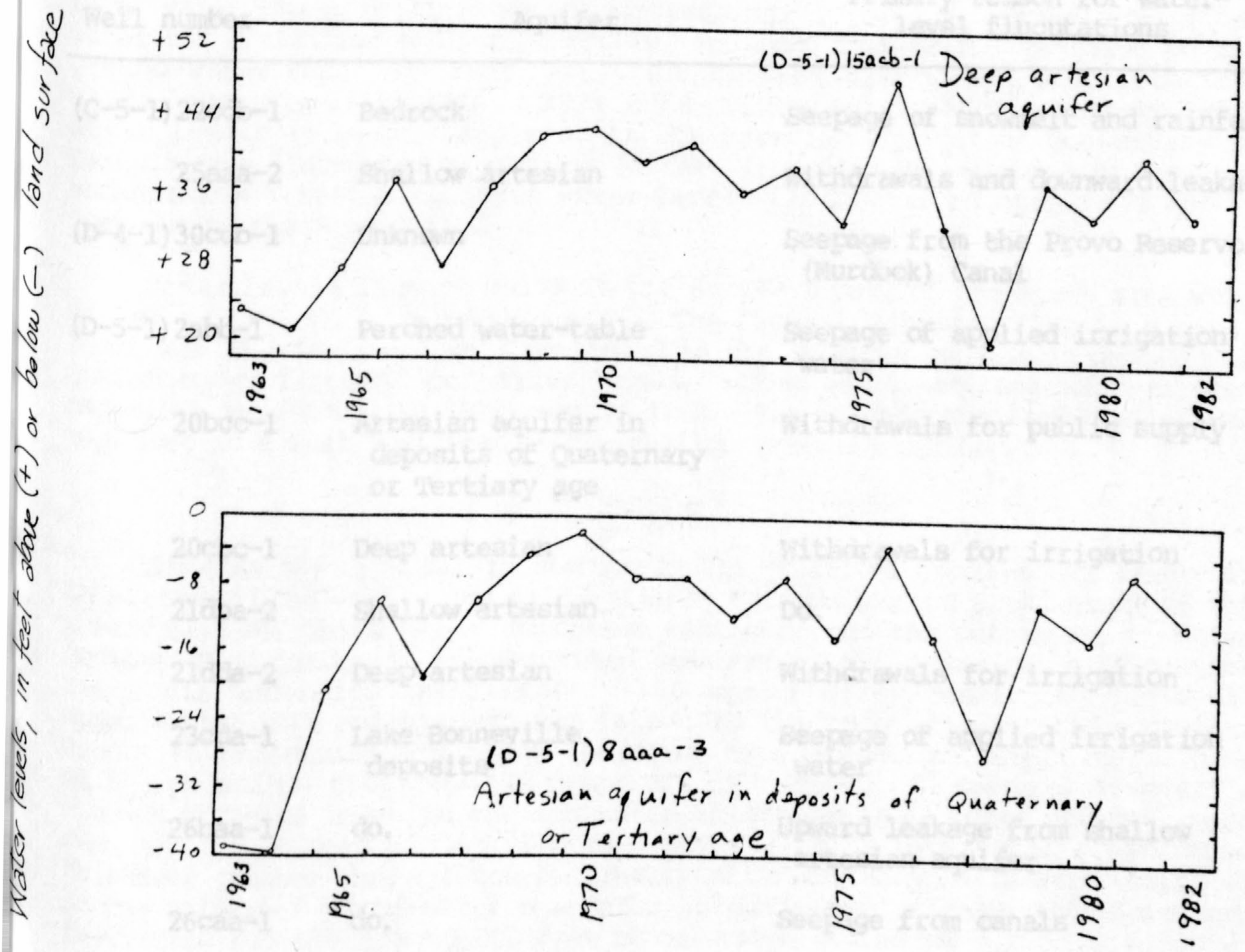


Figure 39 .--Long term water-level trends, 1963-82. continued

Table 10.--Primary reason for water-level fluctuations in observation wells (Hydrographs for the wells are shown in figures 27-36.)

Well number	Aquifer	Primary reason for water-level flucutations
(C-5-1)22cdb-1	Bedrock	Seepage of snowmelt and rainfall
25aaa-2	Shallow artesian	Withdrawals and downward leakage
(D-4-1)30cdb-1	Unknown	Seepage from the Provo Reservoir (Murdock) Canal
(D-5-1)2abb-1	Perched water-table	Seepage of applied irrigation water
20bcc-1	Artesian aquifer in deposits of Quaternary or Tertiary age	Withdrawals for public supply
20cbc-1	Deep artesian	Withdrawals for irrigation
21dba-2	Shallow artesian	Do.
21dda-2	Deep artesian	Withdrawals for irrigation
23cda-1	Lake Bonneville deposits	Seepage of applied irrigation water
26baa-1	do.	Upward leakage from shallow artesian aquifer
26caa-1	do.	Seepage from canals
(D-5-2)18aba-1	Shallow artesian	Withdrawals for irrigation
(D-6-2)17ddd-2	Deep artesian	Increased withdrawals for public supply
18abb-2	Shallow artesian	Withdrawals for irrigation
28bcd-1	do.	Do.
28ddd-2	Deep artesian	Withdrawals for public supply
29aab-1	Lake Bonneville deposits	Upward leakage from shallow artesian aquifer
29abb-1	do.	Do.
(D-7-2)4cbc-1	Deep artesian	Withdrawals for irrigation
9abb-1	Shallow artesian	Do.

Evidence of this is that seasonal fluctuations of water levels completed in the deep artesian aquifer in wells west of Orem have increased from about 2 to 18 feet (fig. 36). This caused some flowing wells that had previously flowed all year to cease flowing during the summer of the 1981. During 1977 and 1978, water levels declined sharply in response to large withdrawals of ground water for irrigation and public supply, and less than normal recharge to the ground-water reservoir that resulted from less than normal precipitation. Water levels in wells rose in 1979 and remained fairly stable through 1982. Water levels in wells completed in the artesian aquifer of Quaternary or Tertiary age fluctuated as much as 38 feet from 1963-82, whereas in the deep and shallow artesian aquifers water levels fluctuated as much as 28 and 19 feet during the same period.

Water levels in most wells in the northern part of the study area were higher in 1981 than in 1963 (fig. 40). The largest measured rise in a water level was 33.5 feet in a well completed in the artesian aquifer in deposits of Quaternary or Tertiary age. Water levels in most wells west and south of Orem and Provo were lower in 1981 than in 1963. The largest measured decline was 10.5 feet in a well completed in the shallow artesian aquifer.

Storage

The quantity of water in storage in the principal ground-water reservoir in northern Utah Valley was calculated by estimating the areal exent of the reservoir, the thickness of saturated sediment, and the percentage of water content or porosity of the saturated sediments. The principal ground-water reservoir underlies approximately 130 square miles, excluding the areas beneath Utah Lake and west of Utah Lake. The thickness of saturated sediments cannot be determined throughout the study area because the depth to the base of the principal ground-water reservoir is unknown. There are, however, a number of wells in which the saturated thickness is at least 600 feet, and near the U.S. Steel Co., Geneva Works, several wells penetrated a saturated thickness greater than 1,000 feet. Nearly all these deep wells were completed in the principal ground-water reservoir. Ground-water storage, therefore, was calculated for the upper 1,000 feet of saturated sediments.

The quantity of water contained in the saturated sediments is a small part of the total volume of the sediments, and the quantity of water that can be withdrawn through wells is even smaller. For example, the porosity of clay may be 50 percent whereas the porosity of gravel may be only 25 percent. Clay, however, may yield only about 5 percent of the contained water when pumped whereas gravel may yield about 25 percent when pumped.

The average water content (porosity) and specific yield for the principal ground-water reservoir in northern Utah Valley was estimated from drillers' logs of wells that had the greatest thickness of saturated sediments. The

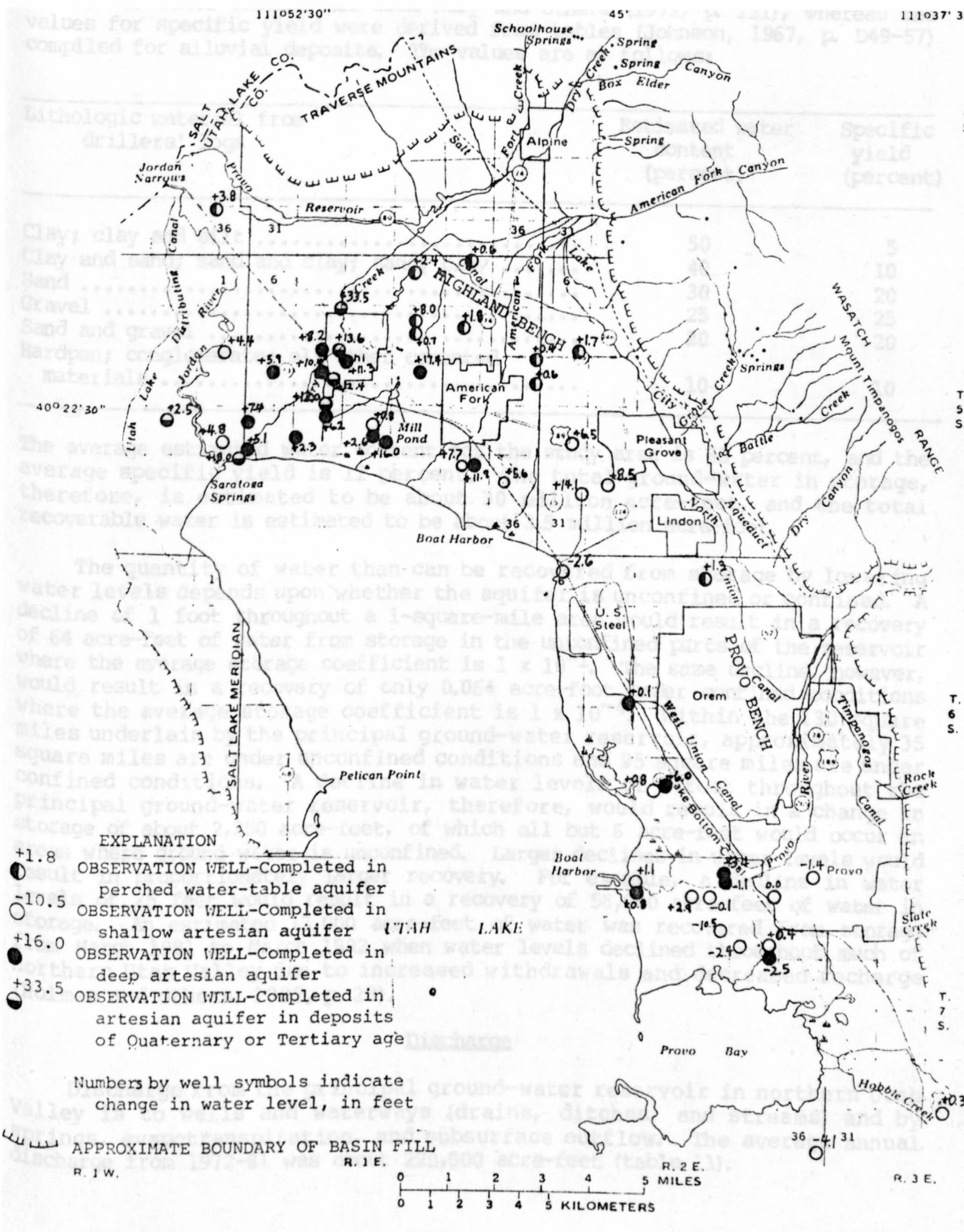


Figure 40.--Change in water levels, 1963-81.

values for water content are from Hely and others (1971, p. 131), whereas the values for specific yield were derived from tables (Johnson, 1967, p. D49-57) compiled for alluvial deposits. The values are as follows:

Lithologic material from drillers' logs	Estimated water content (percent)	Specific yield (percent)
Clay; clay and silt	50	5
Clay and sand; sand and clay; sandy clay	40	10
Sand	30	20
Gravel	25	25
Sand and gravel	20	20
Hardpan; conglomerate; all other cemented materials	10	10

The average estimated water content for the study area is 35 percent, and the average specific yield is 12 percent. The total ground-water in storage, therefore, is estimated to be about 30 million acre-feet, and the total recoverable water is estimated to be about 3.5 million acre-feet.

The quantity of water than can be recovered from storage by lowering water levels depends upon whether the aquifer is unconfined or confined. A decline of 1 foot throughout a 1-square-mile area would result in a recovery of 64 acre-feet of water from storage in the unconfined parts of the reservoir where the average storage coefficient is 1×10^{-1}. The same decline, however, would result in a recovery of only 0.064 acre-foot under confined conditions where the average storage coefficient is 1×10^{-4}. Within the 130 square miles underlain by the principal ground-water reservoir, approximately 35 square miles are under unconfined conditions and 95 square miles are under confined conditions. A decline in water levels of 1 foot throughout the principal ground-water reservoir, therefore, would result in a change in storage of about 2,250 acre-feet, of which all but 6 acre-feet would occur in areas where ground water is unconfined. Larger declines in water levels would result in proportionately larger recovery. For example, a decline in water levels of 25 feet would result in a recovery of 56,000 acre-feet of water in storage. An estimated 13,000 acre-feet of water was recovered from storage from March 1981 to March 1982 when water levels declined throughout much of northern Utah Valley due to increased withdrawals and decreased recharge (Holmes and others, 1982, p. 28).

Discharge

Discharge from the principal ground-water reservoir in northern Utah Valley is to wells and waterways (drains, ditches, and streams) and by springs, evapotranspiration, and subsurface outflow. The average annual discharge from 1972-81 was about 220,000 acre-feet (table 11).

Table 11.--Estimated average annual discharge from the principal ground-water reservoir, 1972-81

Source	Discharge (acre-feet)
Wells	68,000
Waterways and springs	135,000
Evapotranspiration	8,000
Subsurface outflow	2,000
Diffuse seepage to Utah Lake	7,000
Total (rounded)	220,000

Wells

Of the approximately 4,000 wells in northern Utah Valley for which records are available (table 12), 701 have been constructed since 1962. The average annual discharge from all wells during 1963-81 was 63,000 acre-feet, but for the last 10 years of that period it had increased to 68,000 acre-feet. Discharge from wells during 1963-81 is shown in table 13 and for some uses in figure 41. The withdrawals from wells for public supply shown in table 13 represent only part of the use of ground water by municipalities. The remainder is from springs that discharge from consolidated rocks in the Wasatch Range. (See table 14.)

The discharge from pumped irrigation wells was estimated by measuring the discharge of the well and calculating the power used to pump that quantity of water. The annual power consumption for each well was then used to estimate the annual withdrawal of ground water for that well. During this investigation only 56 of the 112 wells (table 12) were found to discharge significant quantities of water for irrigation.

The discharge from flowing irrigation wells was estimated by means of a field study of the flowing wells in four representative sections within the flowing-well area (fig. 42). The discharge from nearly all flowing irrigation wells within those sections was measured at least once, and selected wells within those and other sections were measured three or four times between October 1981 and July 1982 (Appel and others, 1982, table 3). Previous measurements of discharge also were available for some of the wells. The discharge did not vary significantly either seasonally or annually at most of the wells that were measured more than once. It was considered reasonable to compute an average discharge for all flowing irrigation wells with the same diameter in the flowing-well area. Total discharge from flowing irrigation wells was estimated from the average discharge for each casing size determined from the field measurements as shown below:

Diameter of well casing (inches)	Number of wells measured	Average discharge (gallons per minute)	Standard deviation (gallons per minute)
2	23	24	19
3	15	85	50
4	48	144	77
5	16	261	102
6	5	325	99
8	1	230	---

The average discharge was multiplied by the total number of wells for each diameter within the flowing-well area assuming that the casing was the same diameter as the discharge pipe at all wells.

Table 12.--Estimated number and classification of wells, 1981

[Based on drillers' logs and field-inventory records on file with the U.S. Geological Survey.]

Use of well	Estimated number of wells 1962	Constructed from 1963-81	Total
Irrigation[1]			
Flowing	[2] 594	47	641
Nonflowing	[2] 85	27	112
Public supply	41	23	64
Industrial	67	8	75
Stock	[2] 163	13	176
Domestic[3]			
Flowing	[2] 1,380	320	1,700
Nonflowing	[2] 336	236	572
Unused (includes test holes)	610	27	637
		Total	3,977

1 Includes some stock.
2 Differs from Cordova and Subitzky (1965, table 9) because boundary of study area is different.
3 Includes some stock and irrigation.

Table 13.--Discharge from wells, in acre-feet, 1963-81

Stock: Includes some watering of pastures.
Domestic: Includes some water for stock and irrigation.

Year	Irrigation		Public supply	Industrial	Stock	Domestic		Total
	Pumped	Flowing				Pumped	Flowing	
1963	7,900	28,000	5,100	9,000	5,000	300	2,000	57,000
1964	6,200	28,000	5,200	9,000	5,000	300	2,000	56,000
1965	3,000	28,000	4,100	7,000	5,000	400	2,000	50,000
1966	12,300	28,000	8,400	7,000	5,000	400	2,000	63,000
1967	6,500	28,000	8,700	7,000	5,000	400	2,000	58,000
1968	5,800	28,000	6,400	6,000	5,000	400	2,000	54,000
1969	4,800	28,000	7,700	7,000	5,000	400	2,000	55,000
1970	6,300	28,000	10,400	6,000	6,000	400	2,000	59,000
1971	6,400	28,000	11,500	6,000	6,000	400	2,000	60,000
1972	8,000	28,000	12,400	6,000	6,000	400	2,000	63,000
1973	5,100	28,000	13,300	8,000	6,000	400	2,000	63,000
1974	5,300	28,000	18,300	13,000	6,000	500	2,000	73,000
1975	1,600	28,000	14,300	9,000	6,000	500	2,000	61,000
1976	7,200	28,000	17,100	13,000	6,000	500	2,000	74,000
1977	10,000	28,000	24,200	7,000	6,000	500	2,000	78,000
1978	3,000	28,000	19,200	10,000	6,000	500	2,000	69,000
1979	5,300	28,000	20,900	11,000	6,000	600	2,000	74,000
1980	2,300	28,000	12,500	11,000	6,000	600	2,000	62,000
1981	4,800	28,000	18,400	11,900	6,000	600	3,000	72,000
1963-81 average (rounded)	6,000	28,000	12,000	9,000	6,000	400	2,000	63,000
1972-81 average (rounded)	5,300	28,000	17,100	9,000	6,000	500	2,000	68,000

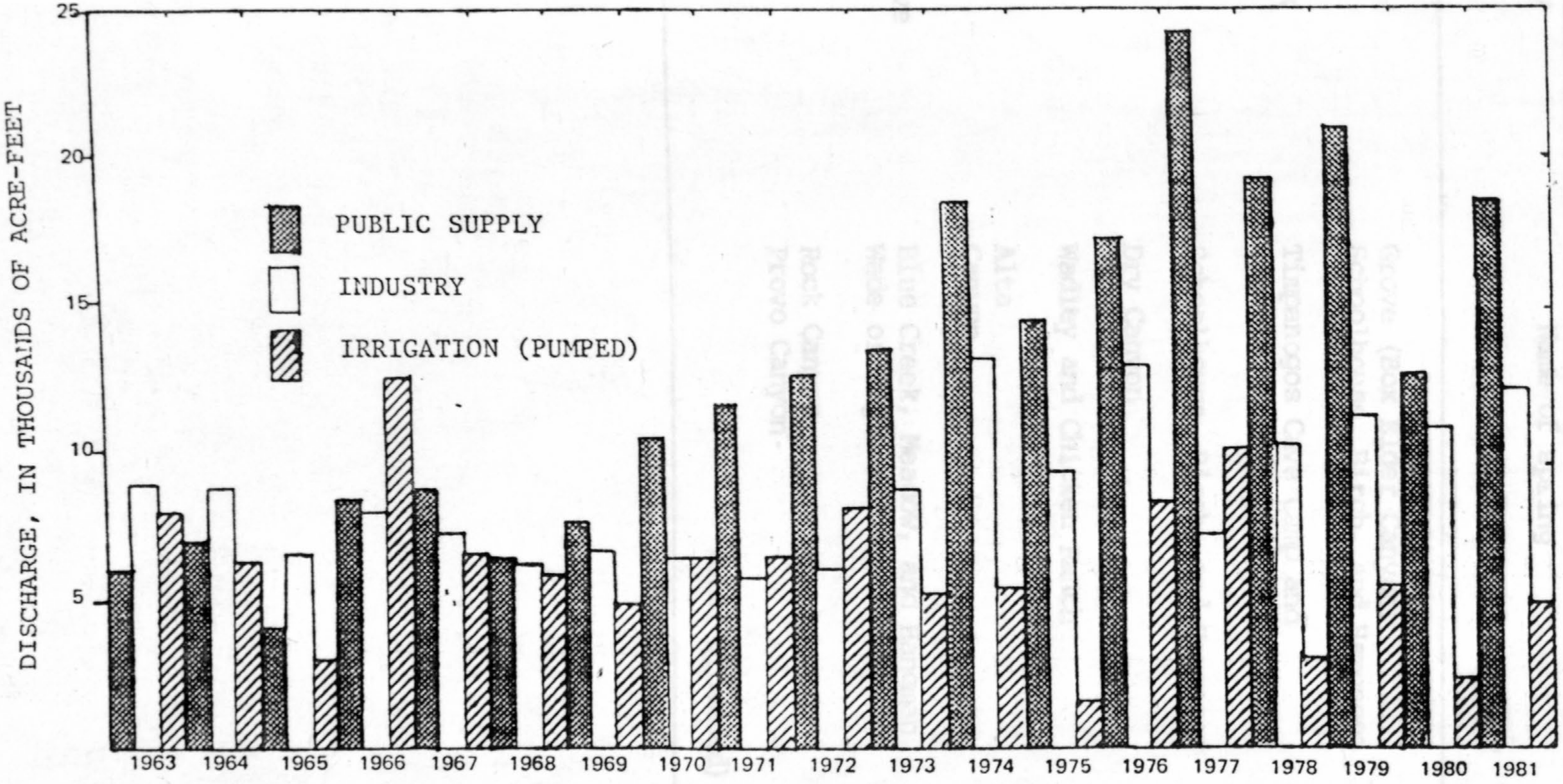
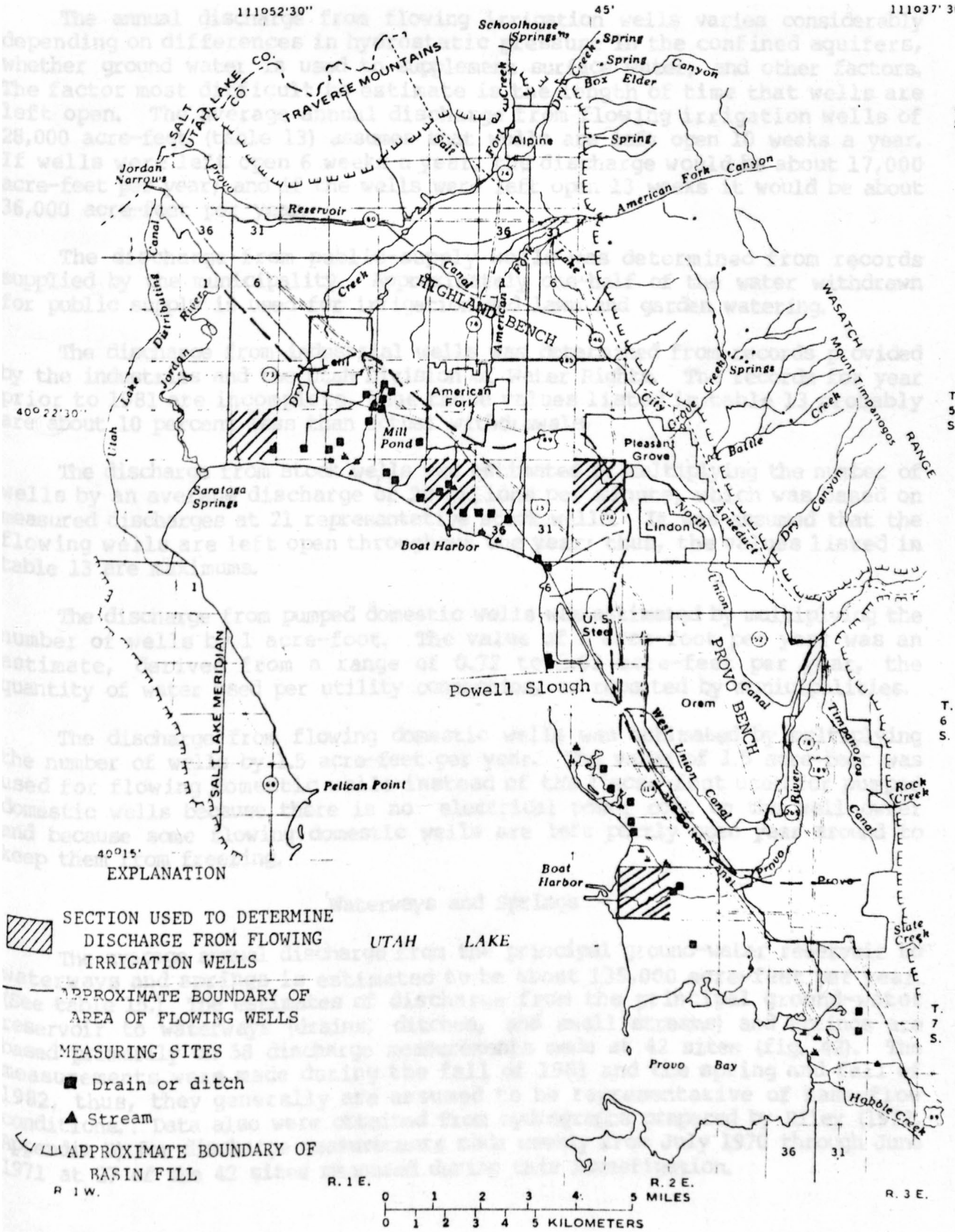


Figure 41.--Discharge from wells for public supply, industry, and irrigation (pumped), 1963-81.

Table 14.--Estimated use by municipalities of water discharged by springs from consolidated rocks in the Wasatch Range, 1979-81

Municipality	Name of spring	Discharge (acre-feet per year)
Alpine	Grove (Box Elder Canyon)	350
	Schoolhouse, Birch, and Hamongog	100
American Fork	Timpanogos Cave Camp and Gaging Station	2,600
Lehi	Schoolhouse, Birch, and Hamongog	550
Lindon	Dry Canyon	150
Manila	Wadley and Chicken Ranch	250
Orem	Alta	3,750
	Canyon	900
Pleasant Grove	Blue Creek, Meadow, and Hangman	2,100
	Wade or Big	700
Provo	Rock Canyon	1,300
	Provo Canyon	17,500
	Total (rounded)	30,000



re 42.--Location of sections used to determine discharge from flowing irrigation wells, approximate boundary of area of flowing wells, and measuring sites for drains, ditches, streams, and springs.

The annual discharge from flowing irrigation wells varies considerably depending on differences in hydrostatic pressure in the confined aquifers, whether ground water is used to supplement surface water, and other factors. The factor most difficult to estimate is the length of time that wells are left open. The average annual discharge from flowing irrigation wells of 28,000 acre-feet (table 13) assumes that wells are left open 10 weeks a year. If wells were left open 6 weeks a year, the discharge would be about 17,000 acre-feet per year; and if the wells were left open 13 weeks it would be about 36,000 acre-feet per year.

The discharge from public-supply wells was determined from records supplied by the municipality. Approximately one-half of the water withdrawn for public supply is used for irrigation and lawn and garden watering.

The discharge from industrial wells was determined from records provided by the industries and the Utah Division of Water Rights. The records for year prior to 1981 are incomplete, thus those values listed in table 13 probably are about 10 percent less than actual withdrawals.

The discharge from stock wells was estimated by multiplying the number of wells by an average discharge of 20 gallons per minute, which was based on measured discharges at 21 representative stock wells. It was assumed that the flowing wells are left open throughout the year; thus, the values listed in table 13 are maximums.

The discharge from pumped domestic wells was estimated by multiplying the number of wells by 1 acre-foot. The value of 1 acre-foot per year was an estimate, derived from a range of 0.72 to 2.03 acre-feet per year, the quantity of water used per utility connection, as reported by municipalities.

The discharge from flowing domestic wells was estimated by multiplying the number of wells by 1.5 acre-feet per year. The value of 1.5 acre-feet was used for flowing domestic wells instead of the 1 acre-foot used for pumped domestic wells because there is no electrical power cost to the well owner and because some flowing domestic wells are left partly open year around to keep them from freezing.

Waterways and Springs

The average annual discharge from the principal ground-water reservoir to waterways and springs is estimated to be about 135,000 acre-feet per year. (See table 15.) The estimates of discharge from the principal ground-water reservoir to waterways (drains, ditches, and small streams) and springs are based primarily on 58 discharge measurements made at 42 sites (fig. 42). The measurements were made during the fall of 1981 and the spring and fall of 1982, thus, they generally are assumed to be representative of base-flow conditions. Data also were obtained from hydrographs prepared by Riley (1972, Appendix B) for discharge measurements made weekly from July 1970 through June 1971 at 27 of the 42 sites measured during this investigation.

Table 15.--Discharge to waterways and by springs, in acre-feet per year, from the principal ground-water reservoir

Discharge from principal ground-water reservoir to:	Minimum	Maximum	Average (rounded)
Drains, ditches, springs, and small streams	96,700	103,000	100,000
Springs in Utah Lake	25,000	36,000	30,000
Jordan River	3,500	5,600	4,600
Total (rounded)	125,000	145,000	135,000

All known points of discharge were measured or otherwise accounted for. The source of water in the drains, ditches, and small streams was determined by field investigation, by examination of hydrographs, and by comparison of the chemical quality of the water with that from nearby wells and surface sources.

The discharge from the principal ground-water reservoir to waterways and by springs primarily is by upward leakage, and it varies seasonally and annually depending on changes in the hydrostatic pressure in the aquifers. The discharge is largest in the spring, when water levels in wells are highest, and smallest after the irrigation season, when water levels are lowest.

Drains, ditches, springs, and small streams.--The discharge from the principal ground-water reservoir to drains, ditches, springs, and small streams is estimated to range from 96,700 to 103,000 acre-feet per year, with an average annual discharge of about 100,000 acre-feet (table 15). The discharge, which was measured before and after the irrigation season at several of the sites, ranged from less than 1 to nearly 29 cubic feet per second. The greatest measured discharge at individual sites was near Mill Pond, Provo Bay, and the U.S. Steel Co., Geneva Works. Two of the areas of greatest discharge were near Mill Pond and Powell Slough.

Water from 10 sites was collected in April 1982 for chemical analysis. At all sites, the water type (calcium bicarbonate) and the range of dissolved-solids concentrations (300 to 500 milligrams per liter) were similar to those of water from the shallow artesian aquifer.

Mill Pond, which is a spring area between Lehi and American Fork, also is used as a storage reservoir for irrigation water. The discharge into and out of the pond was measured before and after the irrigation season. Based on these measurements, the average annual discharge to Mill Pond by upward leakage from the principal ground-water reservoir is estimated to be 9,100 acre-feet. The discharge to Mill Pond from the principal ground-water reservoir is indicated by the configuration of the potentiometric surface of the shallow artesian aquifer (fig. 23).

Powell Slough is a spring area in sec. 29, T.6 S., R.2 E. for which Riley (1972, p. 9) shows an average monthly discharge that totals about 16,800 acre-feet per year. The water from Powell Slough is of the calcium bicarbonate type (Mundorff, 1974, p. 52) and has similar dissolved-solids concentrations to water in the principal ground-water reservoir. There is no apparent surface inflow to Powell Slough, therefore, the water in the slough is assumed to be water that discharges upward from the principal ground-water reservoir.

Springs in Utah Lake.--The discharge by springs in the part of Utah Lake that is in northern Utah Valley was estimated to be between 25,000 and 36,000 acre-feet per year and to average about 30,000 acre-feet per year (Cordova and Subitzky, 1965, p. 19). The discharge by springs varies with hydrostatic pressure in the aquifers, and as the estimates were made during 1937-40 when water levels were low, the estimate of discharge by springs in Utah Lake probably is small.

Jordan River.--The ground-water discharge to the Jordan River between Utah Lake and the Jordan Narrows was estimated to be 7,000 acre-feet per year (Cordova and Subitzky, 1965, p. 22). About one-half of the river miles between Utah Lake and Jordan Narrows are in an area where the hydrostatic pressure in the confined aquifers is sufficient to cause wells to flow and upward leakage to occur. It is estimated, therefore, that between 50 and 80 percent, or 3,500 to 5,600 acre-feet per year, of the ground-water inflow to the Jordan River is from the principal ground-water reservoir and the remainder is assumed to be discharge from Lake Bonneville deposits.

Diffuse Seepage to Utah Lake

In addition to approximately 30,000 acre-feet per year of discharge by springs in Utah Lake, there is some diffuse seepage through lake-bottom sediments from the artesian aquifers under the lake. The total annual ground-water discharge (Q) to the lake was estimated with equation 2 as the flow through the cross-sectional area of the principal ground-water reservoir along the edge of the lake. (See table 16.) Transmissivity (T) was estimated for the three artesian aquifers for the areas with small T on the north side and relatively larger T on the east side of the lake. The hydraulic gradient (I) for the three artesian aquifers, using 1981 water levels, ranged from 0.001 to 0.004 (5 to 21 feet per mile) and averaged 0.0025 (13 feet per mile). These values are approximate because of the lack of water-level data close to the lake. The length (L) of the shoreline used was 20 miles.

The total discharge of 37,000 acre-feet includes the 30,000 acre-feet of discharge by springs in Utah Lake. The discharge by diffuse seepage, therefore, is estimated to average about 7,000 acre-feet.

Evapotranspiration

The total discharge of water by evapotranspiration from approximately 16,000 acres of land surrounding the northern part of Utah Lake (fig. 43) is estimated to be about 24,000 acre-feet per year (table 17). Only 8,000 acre-feet per year, however, is estimated to come from the principal ground-water reservoir.

The Blaney-Criddle method (Huber and others, 1982, p. 3-5) was used to estimate the consumptive use (evapotranspiration) of water by plant type. It was assumed that evapotranspiration occurs only during an average frost-free period from late-April to mid-October. The average precipitation during the frost-free period was subtracted from the value for consumptive use on the assumption that all precipitation is consumed by plants. Vegetation type and plant density were determined at 10 transects shown in figure 43. This was then supplemented by aerial photographs taken in 1980 and data in Hyatt and others (1968) to determine the total number of acres of each plant type (table 17).

Table 16.--Estimated annual ground-water discharge to Utah Lake

[Transmissivity: a, north of lake; b, east of lake.]

Aquifer	Transmissivity (T) (feet squared per day)	Hydraulic gradient (I) (dimensionless)	Length (L) (miles)	Discharge (Q) (acre-feet, rounded)
Shallow artesian	1,500(a)	0.0025	7	1,000
	5,000(b)		13	7,000
Deep artesian	2,500(a)	.0025	7	2,000
	7,500(b)		13	11,000
Artesian, in deposits of Quaternary or Tertiary age	2,500(a)	.0025	7	2,000
	10,000(b)		13	14,000
			Total	37,000

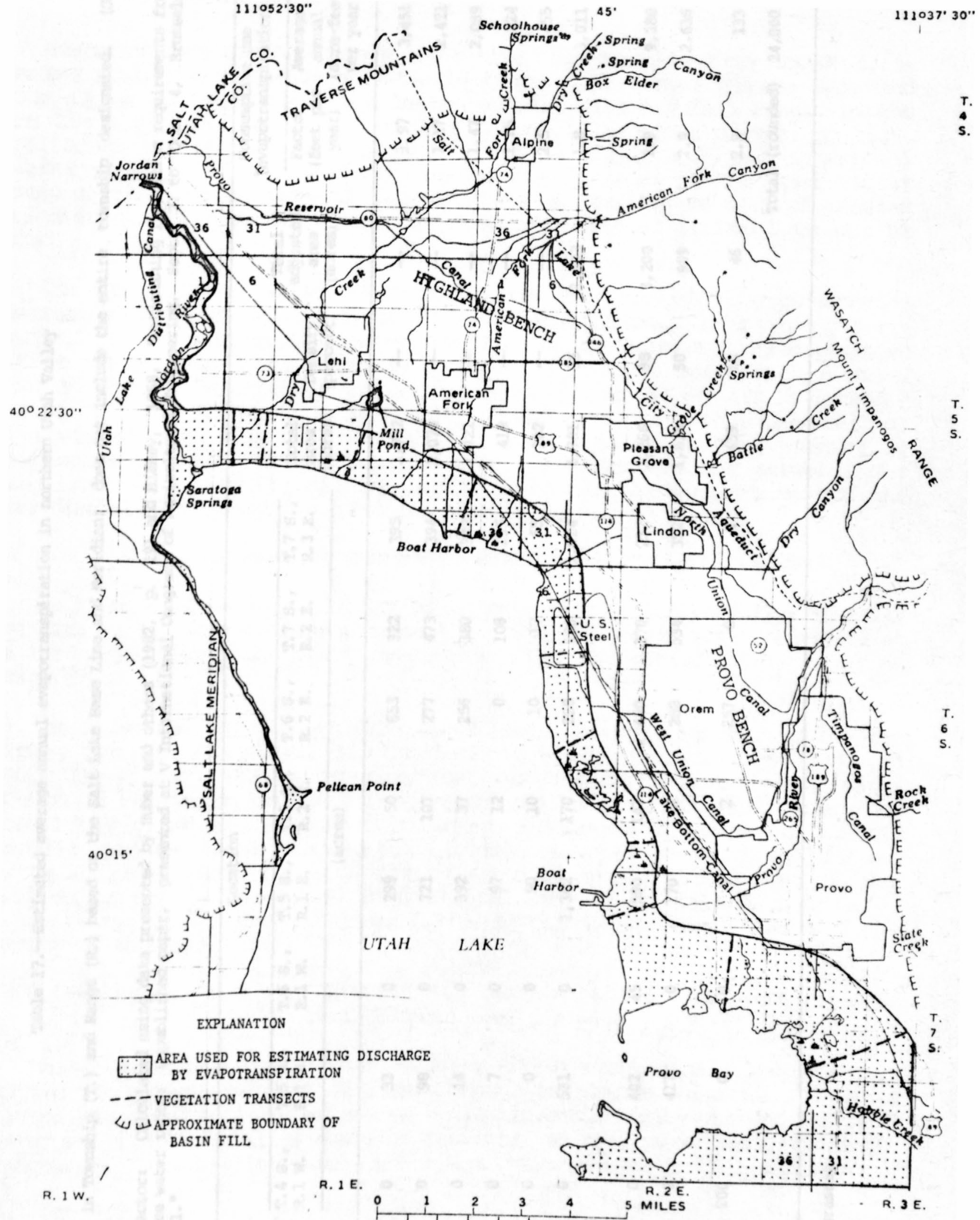


Figure 43.--Area for which discharge by evapotranspiration was estimated and location of vegetation transects.

Table 17.--Estimated average annual evapotranspiration in northern Utah Valley

Location: Given in Township (T.) and Range (R.) based on the Salt Lake Base Line and Meridian; does not include the entire township designated. (See figure 43.)

Consumptive-use factor: Calculated using data presented by Huber and others (1982, p. 19) and Blaney, 1958, "Determining irrigation requirements from consumptive use water rates: Unpublished paper, presented at V International Congress of Agriucltural Engineering, Sept. 27 to Oct. 4, Brussels, Belgium, p. 11."

Plant type	Location (acres)								Total area (acres)	Density (percent)	Total adjusted area (acres)	Consumptive use (evapotranspiration)	
	T.4 S., R.1 W.	T.5 S., R.1 W.	T.6 S., R.1 W.	T.5 S., R.1 E.	T.5 S., R.2 E.	T.6 S., R.2 E.	T.7 S., R.2 E.	T.7 S., R.3 E.				Factor (feet per year)	Average annual (acre-feet per year)
Alfalfa	0	33	0	299	50	653	322	395	1,752	—	—	1.97	3,451
Grain	0	98	0	721	107	277	473	394	2,070	—	—	1.17	2,421
Corn	0	14	0	392	37	256	380	342	1,421	—	—	1.47	2,089
Other crops	0	7	0	97	12	0	108	195	419	—	—	1.25	524
Bare ground	0	0	0	90	10	10	17	55	182	—	—	2.5	455
Grasses	0	531	0	1,342	170	228	586	1,924	4,781	35	1,673	1.8	3,011
Native vegetation[1]													
Dense	0	402	45	590	147	1,480	370	232	3,266	98	3,200	2.9	9,280
Moderately dense	0	417	0	170	57	288	534	352	1,818	50	909	2.9	2,636
Slightly dense	200	0	0	0	2	257	0	0	459	10	46	2.9	133
												Total (rounded)	24,000

[1] Excluding grasses.

Evapotranspiration by grasses and native vegetation is about 15,000 acre-feet per year. Dense stands of cattails (Typha sp.), rushes (Juncus sp.), and sedge (Carex sp.) grow along the shores of Utah Lake and Mill Pond. Inland from the shore of the lake, russian olive (Elaeagnus angustifolia), rabbitbrush (Chrysothamnus nauseosus), willow (Salix sp.), and occasional tamarix (Tamarix sp.) grow along with several grasses as the predominant ground cover. Grasses grow throughout the area, and the density of grasses varied substantially, primarily dependent on whether it had been cut or grazed.

The quantity of water discharged from the principal ground-water reservoir by evapotranspiration is unknown. For the purpose of this report, however, it is estimated that about one-third of the total evapotranspiration is from the principal ground-water reservoir, or 8,000 acre-feet per year. Water levels in the Lake Bonneville deposits near Utah Lake are less than 7 feet below land surface (fig. 34); thus, ground water is within the reach of the roots of many plants. Much of the ground water in Lake Bonneville deposits has discharged upward from the principal ground-water reservoir. The water is then consumed by plants. Most of the remaining two-thirds of the water discharged by evapotranspiration is applied for irrigation.

Subsurface Outflow to Salt Lake Valley

At least 2,000 acre-feet of ground water enters Salt Lake Valley annually from Utah Valley as underflow through the principal ground-water reservoir at the Jordan Narrows. The quantity of underflow was estimated by means of equation 2.

The measuring section was about 6,600 feet wide (fig. 44) with an eastern boundary that was determined from an electrical-sounding profile by Zohdy and Jackson (1969) and a western boundary that was an outcrop of semiconsolidated material in the Jordan Narrows. A saturated thickness of 300 feet determined at well 3 (fig. 44) was used to calculate the cross-sectional area, and the hydraulic gradient was determined to be 0.006 from water levels in wells 2 and 3. The average hydraulic conductivity was estimated to be 20 feet per day based on materials described in drillers' logs of wells and hydraulic-conductivity values used by Mower (1978, p. 16). Thus, from equation 2 the quantity of underflow is:

6,000 feet squared per day (0.006) (6,600 feet) = 240,000 cubic feet per day or about 2,000 acre-feet per year.

This agrees reasonably with Mower's (1970) estimate of 2,500 acre-feet per year for ground-water underflow through the Jordan Narrows. Mower's estimate was based on large values of hydraulic conductivity whereas drillers' logs of wells in Utah Valley describe materials of relatively small hydraulic conductivity. The smaller value, therefore, will be used in this report.

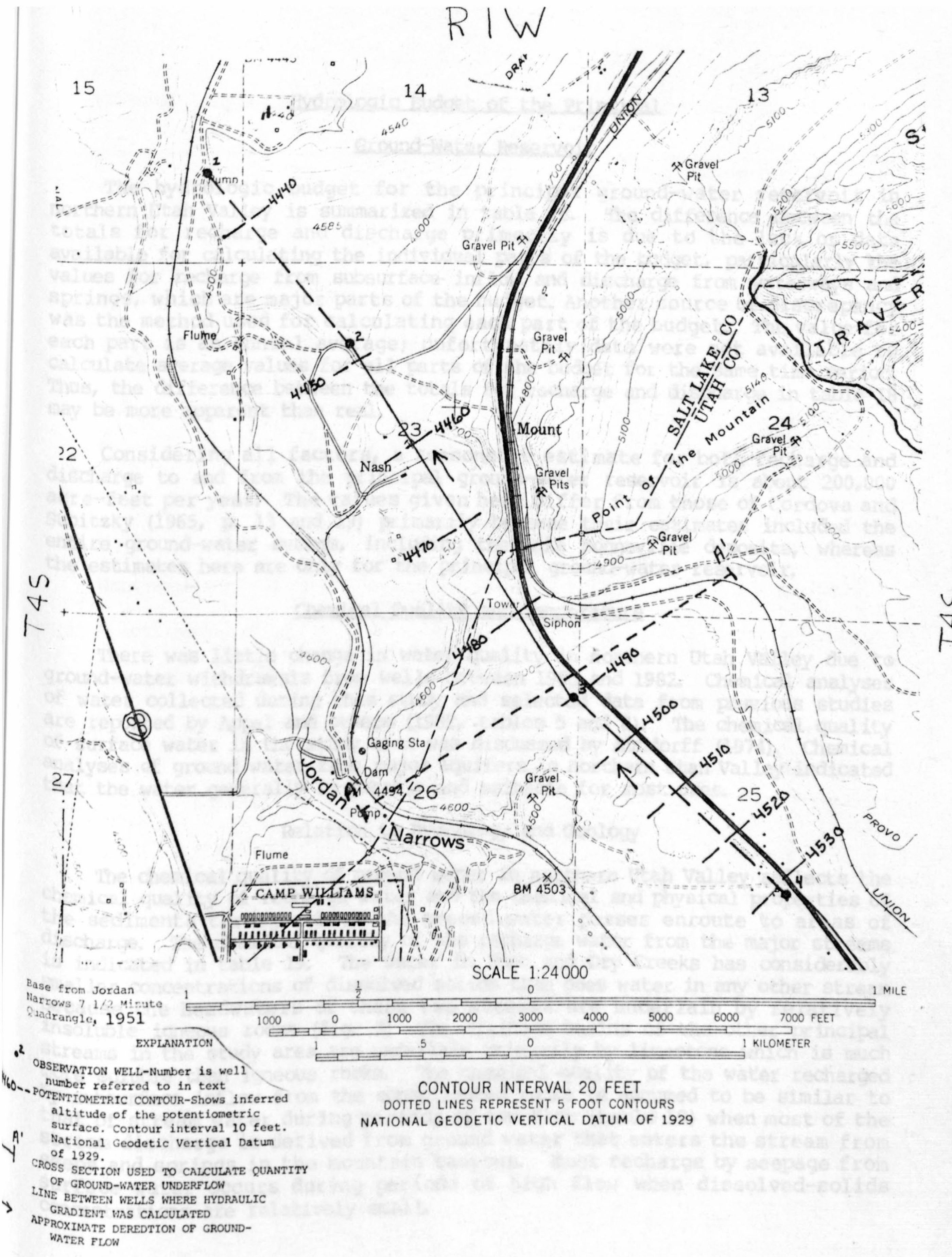


Figure 44.--Jordan Narrows and vicinity, where underflow from northern Utah Valley to Salt Lake Valley was computed.

Hydrologic Budget of the Principal Ground-Water Reservoir

The hydrologic budget for the principal ground-water reservoir in northern Utah Valley is summarized in table 18. The difference between the totals for recharge and discharge primarily is due to the lack of data available for calculating the individual parts of the budget, particularly the values for recharge from subsurface inflow and discharge from waterways and springs, which are major parts of the budget. Another source of discrepancy was the method used for calculating each part of the budget. The value for each part is an annual average; unfortunately data were not available to calculate average values for all parts of the budget for the same time period. Thus, the difference between the totals for recharge and discharge in table 18 may be more apparent than real.

Considering all factors, a reasonable estimate for both recharge and discharge to and from the principal ground-water reservoir is about 200,000 acre-feet per year. The values given here differ from those of Cordova and Subitzky (1965, p. 13 and 19) primarily because their estimates included the entire ground-water system, including the Lake Bonneville deposits, whereas the estimates here are only for the principal ground-water reservoir.

Chemical Quality and Temperature

There was little change in water quality in northern Utah Valley due to ground-water withdrawals from wells between 1963 and 1982. Chemical analyses of water collected during this study and selected data from previous studies are reported by Appel and others (1982, tables 5 and 8). The chemical quality of surface water in the study area was discussed by Mundorff (1974). Chemical analyses of ground water from major aquifers in northern Utah Valley indicated that the water generally is potable and suitable for most uses.

Relation to Hydrology and Geology

The chemical quality of ground water in northern Utah Valley reflects the chemical quality of recharge water and the chemical and physical properties of the sediments through which the ground water passes enroute to areas of discharge. The chemical quality of the recharge water from the major streams is indicated in table 19. The water in Fort and Dry Creeks has considerably smaller concentrations of dissolved solids than does water in any other stream because the headwaters of these two streams are underlain by relatively insoluble igneous rocks (fig. 3) The drainage basins of the other principal streams in the study area are underlain primarily by limestone which is much more soluble than igneous rocks. The chemical quality of the water recharged by subsurface inflow from the consolidated rocks is assumed to be similar to that of stream water during periods of low flow (table 19) when most of the stream discharge is derived from ground water that enters the stream from seeps and springs in the mountain canyons. Most recharge by seepage from surface water occurs during periods of high flow when dissolved-solids concentrations are relatively small.

Table 18.--Hydrologic budget for the principal ground-water reservoir

Budget component	Acre-feet per year (rounded)
Recharge	
Seepage from natural channels and irrigation canals	73,000
Seepage from irrigated fields, lawns, gardens, and direct precipitation	15,000
Subsurface inflow	112,000
Total...............	200,000
Discharge	
Wells	68,000
Waterways and springs	135,000
Evapotranspiration	8,000
Subsurface outflow	2,000
Diffuse seepage to Utah Lake	7,000
Total...............	220,000

Table 19.--Dissolved-solids concentrations of streams at various flow regimes

[Representative dissolved-solids concentration: Number in parentheses indicates average discharge when sampled, in cubic feet per second.]

Name	Average dissolved-solids concentration (milligrams per liter)	
	High flow	Low flow
Fort Creek	40 (35)	70 (8)
Dry Creek	50 (120)	150 (5)[1]
American Fork	170 (210)	260 (27)
Grove Creek	230 (5)	--
Battle Creek	180 (3)	--
Provo River	200 (410)	210 (25)
Rock Creek	180 (7)	220 (1)[1]
Slate Creek	170 (0.1)	--

[1] Discharge estimated.

Information about the chemical and physical properties of the basin fill was obtained from samples collected during the drilling of test holes (D-5-1)6bcd-1 and (D-6-2)9ccc-1 and by examination of samples obtained from well drillers' for well (D-5-1)1cdc-1 drilled north of the city of American Fork. The results were reported by Fairbanks (1982) and shown in table 20.

There are significant quantities of quartz, calcite, and dolomite virtually throughout the principal ground-water reservoir, particularly in the confining layers. The clay minerals illite, kaolinite, and montmorillonite are dominant in the upper confining layers, and significant quantities of montmorillonite and chlorite are in the lower confining layers.

As water moves upward from the lower aquifers, the dissolved-solids concentration is increased by the solution of minerals from the fine-grained sediments that form the confining layers. The increase of calcite and dolomite, which are readily soluble and are found throughout the ground-water reservoir is demonstrated in table 21. The data in table 21 indicate that ground water in the recharge area is undersaturated with calcite and dolomite (negative values), whereas in the shallow artesian aquifer in the discharge area, the ground water tends to be supersaturated (positive values greater than 1.0).

Although the concentration of dissolved solids in the ground water generally increases from recharge area to discharge area, the percentage of the total concentration attributed to a specific ion may decrease. The predominant ions in the recharge area are calcium and bicarbonate. As water passes through the principal ground-water reservoir, the percentage of these ions decreases while the percentage of other major ions increases. (See table 22.)

Dissolved-Solids Concentration

The dissolved-solids concentrations of water from the principal ground-water reservoir in northern Utah Valley range from less than 100 to more than 1,000 milligrams per liter. Water from most wells, however, contains between 150 and 500 milligrams per liter. The smallest dissolved-solids concentrations in water from wells are near Alpine and Lehi, and the largest are near Saratoga Springs, west of the Jordan River, and north of Lehi. The dissolved-solids concentrations vary within and between aquifers, with concentrations generally increasing toward the land surface. The dissolved-solids concentrations at selected sampling sites are shown in figure 45 and the change in concentration at three cross sections through the study area is shown in figures 46-48.

Table 20.--Mineralogy of aquifers and confining layers (from Fairbanks, 1982, p. 57-58)

[Mineralogy: C, calcite; Cl, chlorite; D, dolomite; I, illite; K, kaolinite; M, montomorillonite; P, plagioclase; Q, quartz.]

Aquifer or confining layer	Particle size for indicated mineralogy	
	Less than 2 millimeters	Less than 0.002 millimeter
Upper confining layer	C D Q	I K M
Shallow artesian aquifer	C P Q	I
Middle confining layer	C D Q	I K M
Deep artesian aquifer	C D	--
Lower confining layer	C D Q	Cl M
Artesian aquifer of Quaternary or Tertiary age	D Q	M

Table 21.--Saturation indices for calcium and dolomite for ground water in the American Fork area (from Fairbanks, 1982, p. 33-38)

Aquifer	Number of samples	Saturation indices	
		Calcite ($CaCO_3$)	Dolomite ($CaMgCO_3$)
Water table in recharge area	9	-0.03	-0.36
Artesian of Quaternary or Tertiary age	7	.22	.22
Deep artesian	11	.52	.81
Shallow artesian in discharge area	6	1.07	2.01

Table 22.--Average percentages of specific ions in water

[Cations and anions: Ca, calcium; Mg, magnesium; K, potassium; Na, sodium; HCO_3, bicarbonate; Cl, chloride; SO_4, sulfate.]

Source	Percent based on milliequivalents per liter						
	Cations				Anions		
	Ca	Mg	K	Na	HCO_3	Cl	SO_4
Surface water and springs in recharge area	65	26	1	8	82	4	14
Wells, with dissolved-solids concentration similar to recharge water	58	29	1	12	81	8	11
Wells, with dissolved-solids concentrations greater than recharge water	53	34	1	12	69	8	23
Surface water and springs in discharge area	54	34	1	12	63	9	28

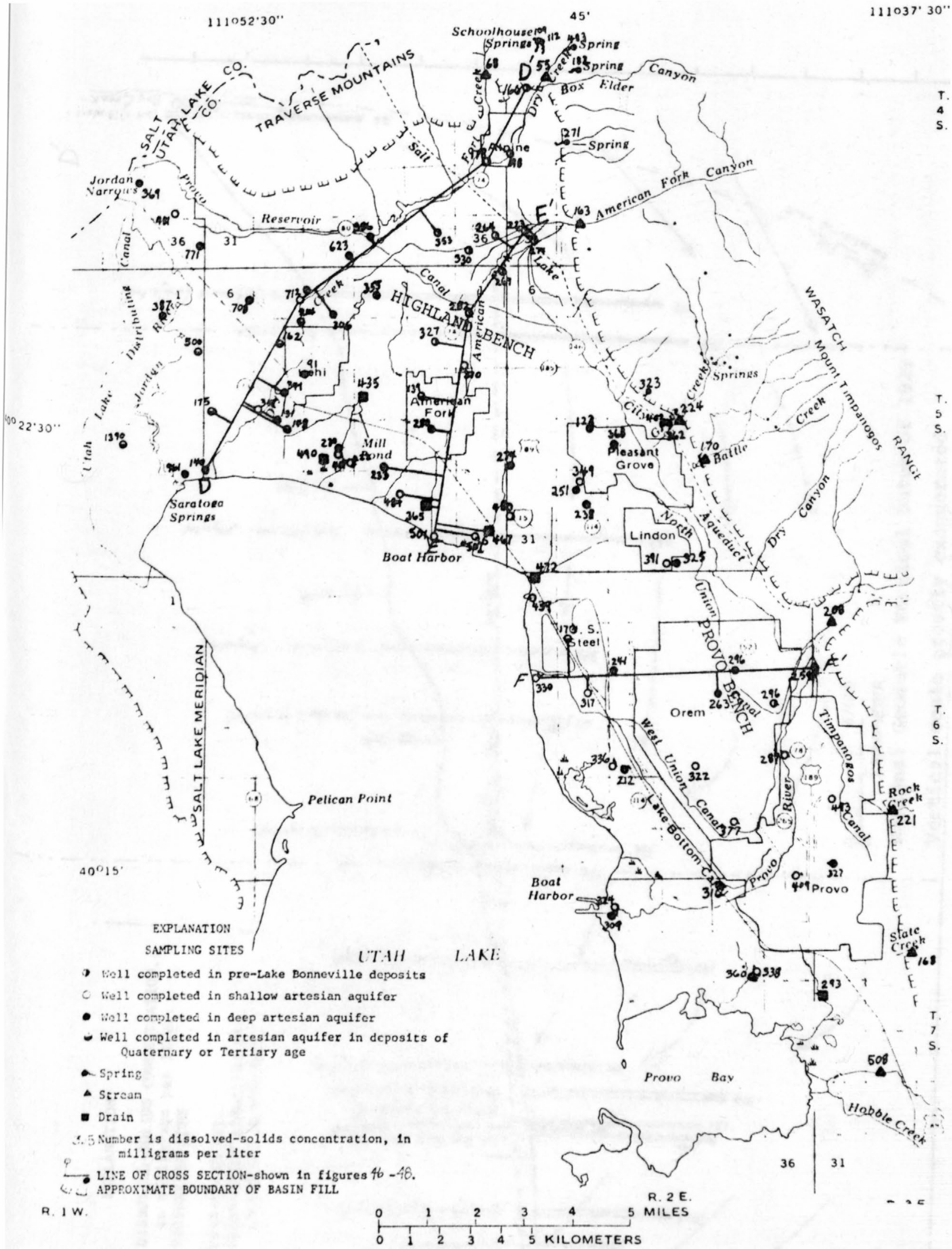


Figure 45.--Location of selected water-quality sampling sites, dissolved-solids concentrations, and location of cross sections.

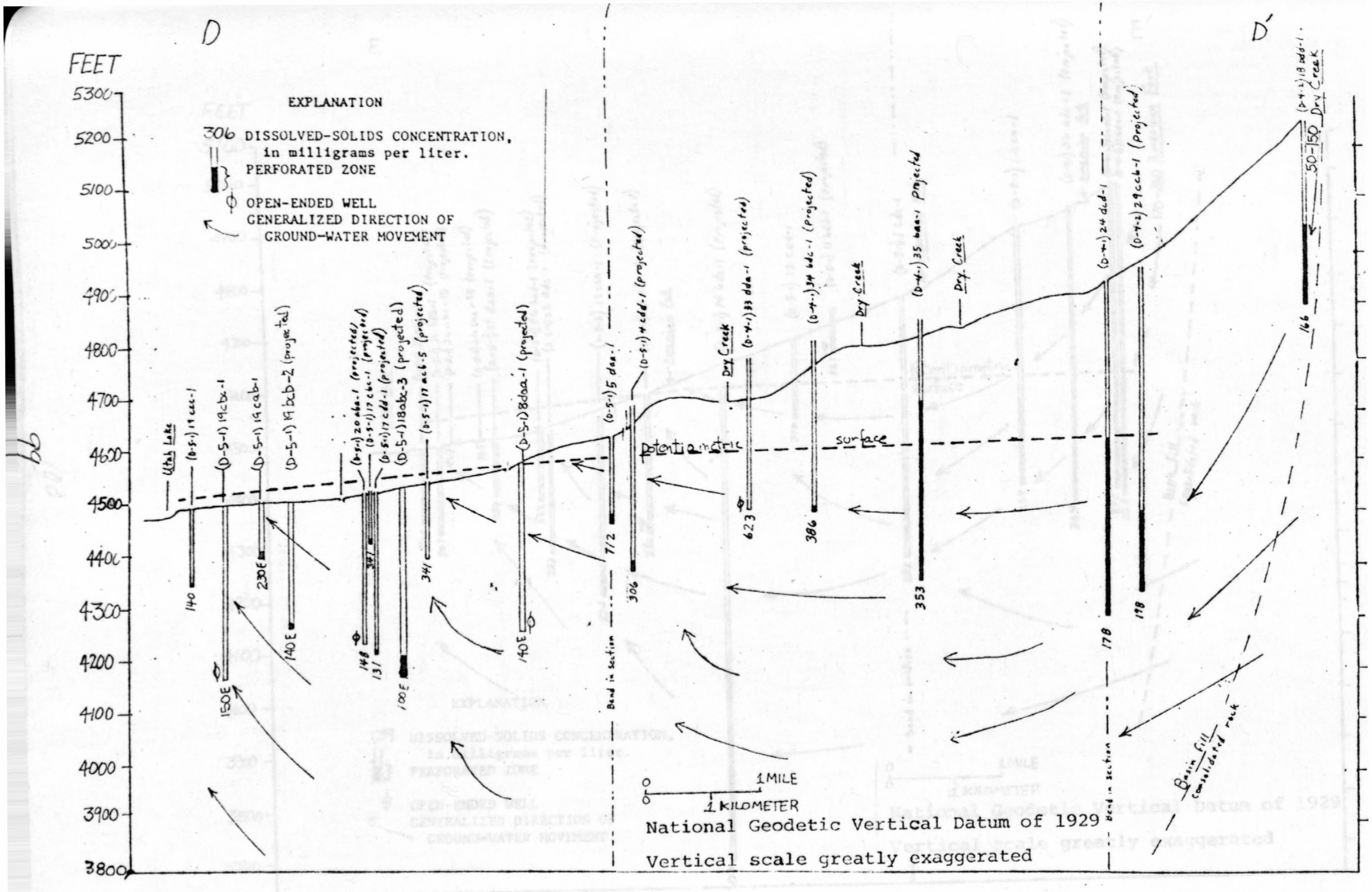


Figure 46.--Cross section from Dry Creek near Alpine to Utah Lake, showing flow path of ground water and dissolved-solids concentrations. (The location of the section is shown in figure 45.)

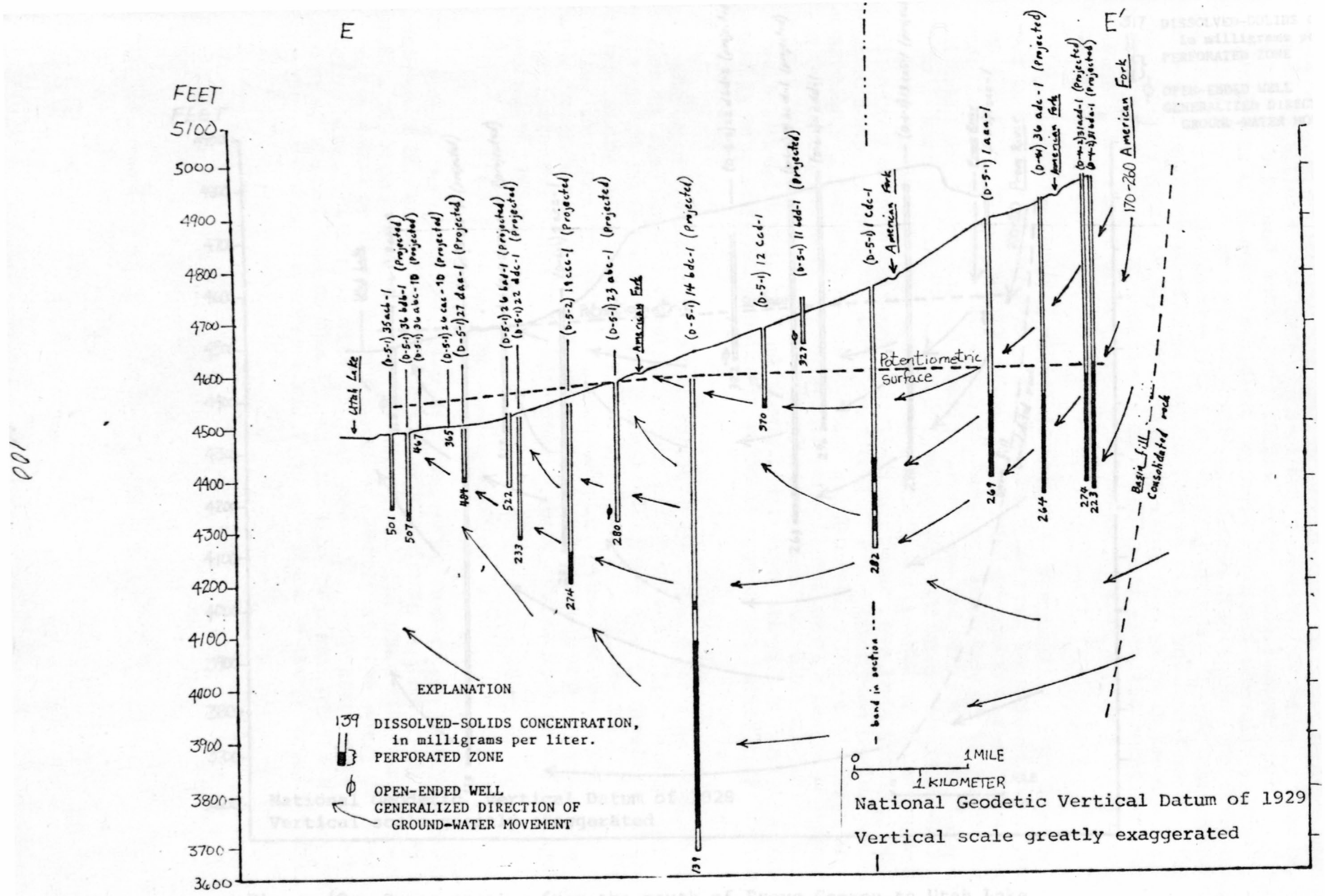


Figure 47.--Cross section from near American Fork Canyon to Utah Lake, showing flow path of ground water and dissolved-solids concentrations. (The location of the section is shown in figure 45.)

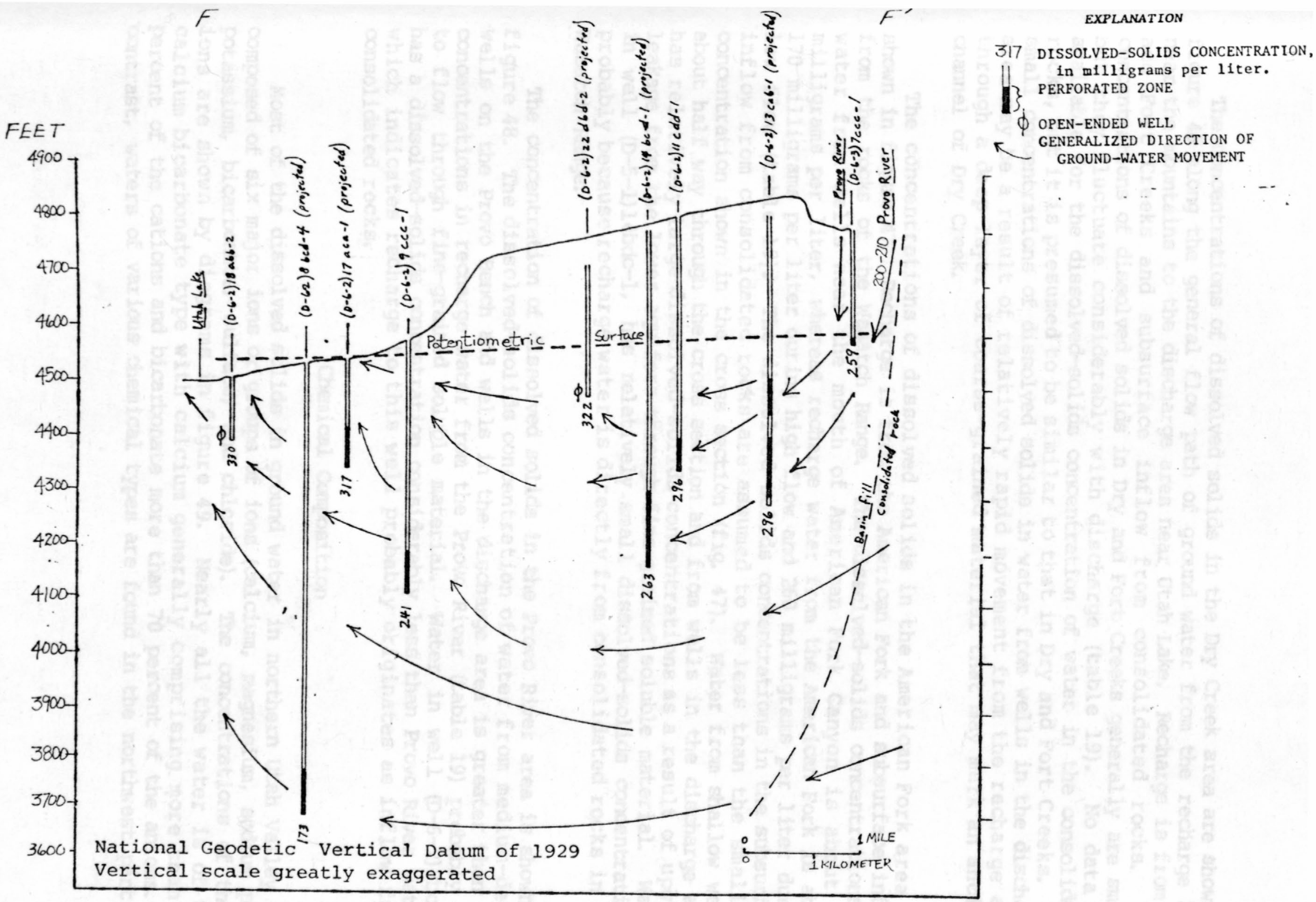


Figure 48.--Cross section from the mouth of Provo Canyon to Utah Lake, showing flow path of ground water and dissolved-solids concentrations. (The location of the section is shown in figure 45.)

The concentrations of dissolved solids in the Dry Creek area are shown in figure 46 along the general flow path of ground water from the recharge area near the mountains to the discharge area near Utah Lake. Recharge is from Dry and Fort Creeks and subsurface inflow from consolidated rocks. The concentrations of dissolved solids in Dry and Fort Creeks generally are small, but they fluctuate considerably with discharge (table 19). No data are available for the dissolved-solids concentration of water in the consolidated rocks, but it is presumed to be similar to that in Dry and Fort Creeks. The small concentrations of dissolved solids in water from wells in the discharge area may be a result of relatively rapid movement from the recharge area through a deep layer of coarse-grained material that may mark an ancient channel of Dry Creek.

The concentrations of dissolved solids in the American Fork area are shown in figure 47. Recharge is from the American Fork and subsurface inflow from the rocks of the Wasatch Range. The dissolved-solids concentrations in water from wells near the mouth of American Fork Canyon is about 250 milligrams per liter, whereas recharge water from the American Fork is about 170 milligrams per liter during high flow and 260 milligrams per liter during low flow (table 19). The dissolved-solids concentrations in the subsurface inflow from consolidated rocks are assumed to be less than the smallest concentration shown in the cross section (fig. 47). Water from shallow wells about half way through the cross section and from wells in the discharge area has relatively large dissolved-solids concentrations as a result of upward leakage from the lower aquifers through fine-grained soluble material. Water in well (D-5-1)14bdc-1, has relatively small dissolved-solids concentrations probably because recharge water is directly from consolidated rocks in the Wasatch Range.

The concentration of dissolved solids in the Provo River area is shown in figure 48. The dissolved-solids concentration of water from medium-depth wells on the Provo Bench and wells in the discharge area is greater than the concentrations in recharge water from the Provo River (table 19) probably due to flow through fine-grained soluble material. Water in well (D-6-2)8bcd-4 has a dissolved-solids concentration considerably less than Provo River water, which indicates recharge to this well probably originates as inflow from consolidated rocks.

Chemical Composition

Most of the dissolved solids in ground water in northern Utah Valley are composed of six major ions or groups of ions (calcium, magnesium, sodium plus potassium, bicarbonate, sulfate, and chloride). The concentrations of these ions are shown by diagrams in figure 49. Nearly all the water is of the calcium bicarbonate type with calcium generally comprising more than 50 percent of the cations and bicarbonate more than 70 percent of the anions. By contrast, waters of various chemical types are found in the northwest part of

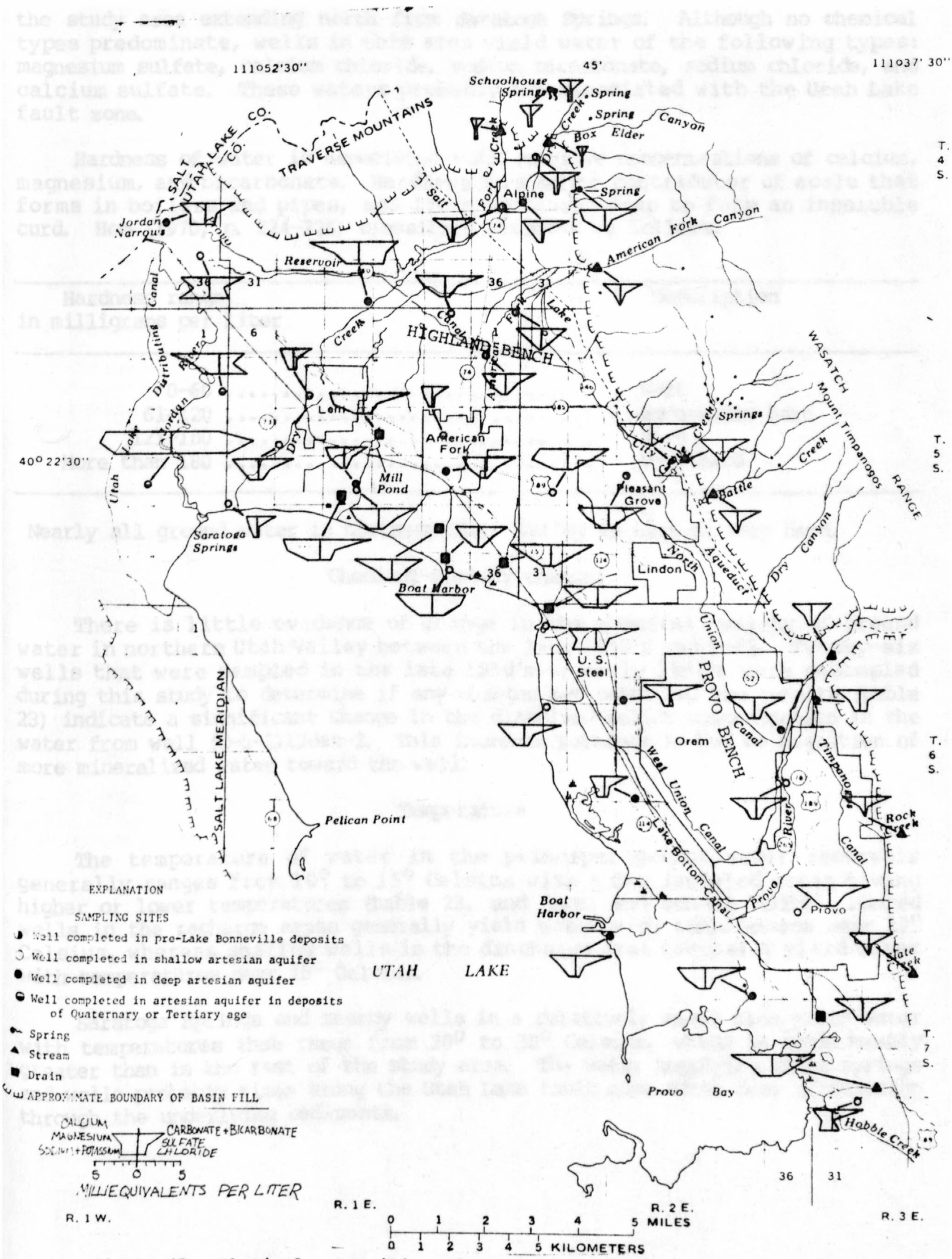


Figure 49.--Chemical composition of water from selected wells, springs, streams, and drains.

the study area extending north from Saratoga Springs. Although no chemical types predominate, wells in this area yield water of the following types: magnesium sulfate, calcium chloride, sodium bicarbonate, sodium chloride, and calcium sulfate. These waters probably are associated with the Utah Lake fault zone.

Hardness of water is associated with relative concentrations of calcium, magnesium, and bicarbonate. Hardness is a major contributor of scale that forms in boilers and pipes, and its also causes soap to form an insoluble curd. Hem (1970, p. 224-226) classifies hardness as follows:

Hardness range, in milligrams per liter	Description
0-60	Soft
61-120	Moderately hard
121-180	Hard
More than 180	Very hard

Nearly all ground water in northern Utah Valley is hard or very hard.

Chemical-Quality Changes

There is little evidence of change in the chemical quality of ground water in northern Utah Valley between the late 1950's and 1982. Twenty-six wells that were sampled in the late 1950's or early 1960's were resampled during this study to determine if any changes had occurred. The results (table 23) indicate a significant change in the dissolved-solids concentration in the water from well (C-5-1)12daa-2. This increase possibly is due to migration of more mineralized water toward the well.

Temperature

The temperature of water in the principal ground-water reservoir generally ranges from 10° to 15° Celsius with a few isolated areas having higher or lower temperatures (table 23, and Appel and others, 1982). Pumped wells in the recharge areas generally yield water with temperatures near 10° Celsius, whereas shallow wells in the discharge area generally yield water with temperatures near 15° Celsius.

Saratoga Springs and nearby wells in a relatively small area yield water with temperatures that range from 20° to 30° Celsius, which is considerably greater than in the rest of the study area. The water supplying these springs and wells probably rises along the Utah Lake fault zone after deep circulation through the underlying sediments.

Table 23.--Chemical analysis of water from selected wells with samples previous to 1962 and after 1978

[Location: See text for explanation of numbering system for hydrologic-data sites. Units: DEG C, degrees Celsius; UMHOS, micromhos per centimeter at 25° Celsius; MG/L, milligrams per liter.]

LOCATION	DATE OF SAMPLE	TEMPER-ATURE (DEG C)	SPE-CIFIC CON-DUCT-ANCE (UMHOS)	PH (UNITS)	SILICA, DIS-SOLVED (MG/L AS SIO2)	CALCIUM DIS-SOLVED (MG/L AS CA)	MAGNE-SIUM, DIS-SOLVED (MG/L AS MG)	ALKA-LINITY (MG/L AS CACO3)	SULFATE DIS-SOLVED (MG/L AS SO4)	CHLO-RIDE, DIS-SOLVED (MG/L AS CL)	SOLIDS, SUM OF CONSTI-TUENTS, DIS-SOLVED (MG/L)	HARD-NESS (MG/L AS CACO3)
(C- 4- 1)25DBC- 1	59-05-21	14.5	910	7.6	27	73	24	--	72	102	529	280
	80-08-21	--	890	7.3	20	66	22	210	82	78	481	260
(C- 5- 1)12DAA- 2	57-11-27	14.0	475	7.1	11	40	20	--	24	54	262	183
	82-04-05	13.0	780	--	23	106	34	160	83	120	500	400
23BDA -1	58-05-05	21.0	2300	6.9	26	182	55	--	438	352	1380	682
	80-08-21	--	2200	--	42	160	100	290	470	250	1390	810
(D- 4- 1)36CAB -1	58-06-11	10.0	620	7.5	13	68	29	239	72	10	367	290
	81-09-01	10.5	600	7.5	13	65	29	190	74	11	330	280
(D- 4- 2)31ACD- 1	58-08-13	9.5	495	7.6	8.4	66	21	--	79	7.5	299	250
	81-08-25	9.5	480	7.3	8.7	58	21	160	75	7.1	274	230
31BDA- 1	58-11-24	9.0	445	7.5	9.9	59	21	170	64	4.0	267	231
	81-07-13	11.0	360	8.0	9.4	52	17	140	51	3.4	223	200
(D- 5- 1) 6DAA- 1	58-05-28	14.5	1130	7.6	30	110	45	--	70	207	635	458
	80-08-22	15.0	1250	7.0	27	120	51	210	140	180	708	510
8AAA- 3	58-06-30	--	395	7.6	22	39	16	141	10	37	231	162
	78-08-22	15.0	360	6.8	19	37	16	120	12	36	214	160
16BBB- 6	57-11-26	11.0	510	7.2	11	54	24	216	47	10	306	234
	80-08-22	--	210	7.5	2.0	8.8	4.9	26	18	25	91	42
18CAB- 2	57-11-27	13.5	360	7.3	10	26	14	134	8.0	29	196	122
	60-04-20	11.5	405	7.4	19	33	15	148	10	35	230	145
	68-10-15	14.0	310	8.0	15	24	15	125	7.2	22	179	120
	80-08-02	18.0	325	7.9	16	24	13	120	8.9	21	175	110
19CCC- 1	57-12-05	13.0	255	7.5	9.2	29	11	116	5.0	5.5	138	116
	60-04-20	13.0	260	7.8	14	30	10	116	10	5.9	148	117
	68-10-15	13.0	260	8.0	14	28	15	120	12	8.0	156	132
	80-08-21	14.5	260	7.4	12	25	11	110	11	6.9	140	110
21DBA- 2	58-01-09	10.5	720	8.0	14	77	33	221	110	31	433	325
	81-07-21	12.0	680	7.7	16	69	33	220	99	17	401	310
21DBA- 3	58-01-09	11.0	390	7.7	11	43	18	141	39	11	221	180
	80-08-22	13.5	420	7.4	12	44	20	140	44	11	230	190
21DDA- 2	57-12-18	11.0	355	7.2	11	41	17	143	30	9.5	206	173
	80-08-22	12.0	400	7.1	11	43	18	140	43	11	222	180
35ACB- 1	57-12-10	10.5	900	7.1	9.1	88	44	189	184	70	548	402
	80-08-22	12.0	860	7.2	15	85	37	200	160	46	501	360
(D- 5- 2)21CBA- 1	58-08-28	11.5	620	7.2	10	73	31	--	84	17	380	308
	81-07-30	13.0	650	8.3	11	72	31	220	91	11	368	310
29BAD- 4	58-05-08	11.0	455	7.8	8.9	58	21	--	47	10	271	229
	80-08-27	13.0	620	7.5	9.6	69	26	210	79	15	349	280
30CCB- 2	61-05-26	11.5	780	8.1	12	--	32	221	151	33	492	352
	73-07-30	13.5	720	7.7	14	73	34	215	130	24	435	320
	80-08-27	12.0	820	7.5	14	77	36	220	150	25	480	340
(D- 6- 2) 6ACC- 1	57-12-10	14.0	790	7.2	12	65	27	--	62	64	460	272
	62-06-26	14.5	780	7.9	19	71	26	267	62	57	461	284
	81-07-25	16.0	780	7.7	21	65	28	250	70	37	439	280
18ABB- 2	58-04-16	14.0	560	7.5	15	67	23	227	52	14	331	260
	80-08-27	16.5	580	7.3	18	63	24	220	51	15	330	260
21CCA- 4	58-04-16	11.5	560	7.5	16	71	21	--	60	10	338	262
	80-08-27	15.0	610	7.1	18	67	21	230	57	11	336	250
21CDC- 2	58-04-16	14.5	360	7.8	18	36	14	144	21	12	206	146
	80-08-27	--	365	7.4	20	35	14	140	25	12	212	150
(D- 6- 3)31CAB- 2	56-08-20	--	630	8.2	4.8	34	34	--	73	94	392	224
	81-08-31	16.5	610	7.2	13	55	23	160	30	76	327	230
(D- 7- 2) 1ACA- 1	58-10-18	13.5	620	7.6	12	79	27	243	71	22	376	310
	60-04-20	14.0	560	7.9	15	63	22	197	59	29	329	349
	60-09-21	14.0	620	7.8	11	79	26	227	87	22	383	306
	81-08-31	15.0	720	6.8	13	86	30	240	85	23	409	340
4CBB- 2	58-05-05	13.0	530	7.5	19	63	23	222	47	16	321	251
	80-08-27	13.5	580	7.3	19	62	23	220	52	15	324	250
5DAA- 1	58-05-01	11.5	510	7.8	18	57	20	--	23	18	297	226
	80-08-27	13.0	580	7.4	18	61	22	210	47	15	309	240

CENTRAL UTAH PROJECT

Plans for the Bonneville unit of the Central Utah Project include the importation of 20,000 acre-feet of surface water for municipal and industrial users within the study area by means of the Alpine Aqueduct. At present (1984), plans call for full utilization of the 20,000 acre-feet of water by the year 2015 (U.S. Bureau of Reclamation, oral commun., 1984), contingent upon other aspects of the project being completed as planned. The 20,000 acre-feet represents about one-third of the total water presently being obtained by municipalities and industries from wells in the principal ground-water reservoir and springs discharging from consolidated rocks. (See tables 13 and 14.) The effect of importing this water might be to slightly decrease the rate of increase of ground-water withdrawals for these users during the next 30 years.

SUMMARY

The basin-fill deposits in northern Utah Valley include three major confined aquifers which are a lateral extension of an unconfined aquifer in pre-Lake Bonneville deposits along the mountain fronts. These aquifers form the principal ground-water reservoir. The reservoir underlies about 95 square miles in which ground water is under confined conditions and about 35 square miles in which ground water is under unconfined conditions. The principal ground-water reservoir has approximately 30 million acre-feet of water in storage of which about 3.5 million acre-feet is recoverable. During 1981, about 13,000 acre-feet of ground water was recovered from storage.

Seepage from waterways and subsurface inflow from consolidated rocks are the primary sources of ground-water recharge. Recharge also results from seepage from irrigated fields, lawns, and gardens, and from direct precipitation. During water years 1963-82, the average annual inflow in major streams to northern Utah Valley was approximately 390,000 acre-feet. The average annual recharge to the principal ground-water reservoir is about 200,000 acre-feet, of which about 73,000 acre-feet is by seepage from waterways and about 112,000 acre-feet is by subsurface inflow.

The hydraulic properties of the principal ground-water reservoir vary greatly throughout the study area with transmissivities ranging from about 1,000 to more than 200,000 feet squared per day. Storage coefficients in the artesian aquifers range from about 6×10^{-6} to 1×10^{-3} and hydraulic conductivity varies from less than 50 to more than 500 feet per day.

Ground water in northern Utah Valley generally moves from recharge areas near the mountain fronts to discharge areas near Utah Lake and the Jordan River. A downward component of movement exists near the mountains. As water moves laterally toward the valley center it becomes confined by layers of fine-grained material and moves upward through these layers to more shallow aquifers. The hydraulic gradients may show large seasonal fluctuations, as indicated by water-level rises in some wells of about 50 feet during 1981-82.

Long-term trends indicate that in some wells, water levels have declined since about 1970 despite generally greater than average precipitation. Seasonal fluctuation of water levels in wells west of Orem have increased from about 2 to 18 feet, and this caused some flowing wells to cease flowing during the summer of 1981. These changes probably are due to increased withdrawals from wells for public supply since about 1970. Hydrostatic pressure within the confined aquifers generally increases with depth. Vertical movement of water from one aquifer to another is evident when a well completed in one aquifer is pumped and water-level declines eventually are observed in wells completed in another aquifer. A decrease or reversal in the vertical hydraulic gradient in some areas may have been caused by large withdrawals of ground water particularly for public supply.

The average annual discharge from the principal ground-water reservoir during 1972-81 was about 220,000 acre-feet. That included 135,000 acre-feet discharged to waterways and springs and 68,000 acre-feet discharged to wells. The withdrawal of ground water from wells for public supply has increased from about 5,000 acre-feet during 1963 to about 20,000 acre-feet during the late 1970's. This reflected an increase in the urban population from about 72,000 in 1960 to about 164,000 in 1980.

Discharge also occurs by diffuse seepage to Utah Lake, evapotranspiration, and subsurface outflow through the Jordan Narrows to Salt Lake Valley. Considering all factors, a reasonable estimate for both recharge and discharge to and from the principal ground-water reservoir is 200,000 acre-feet per year.

The water in the principal ground-water reservoir generally is potable and suitable for most uses. There is little evidence of change in the chemical quality of the water between the late 1950's and 1982.

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