EXPLANATION

Qds
Dune sand
Surficial deposits of eolian dune sand stabilized by natural vegetation

Ql
Lakebed deposits
Compacted silt and clay with some evaporites

Qa
Valley-fill deposits, undifferentiated
Mainly of fluvial origin but include older lakebed deposits and, locally, intra-alluvial basaltic lava flows

Qb
Basalt
Lava flows and related volcanic rocks

QUATERNARY

QTu
Older alluvium, undifferentiated
Fanglomerate, older stream-terrace deposits, landslide debris, and colluvium

Tvu
Volcanic rocks, undifferentiated
Include Roger Park Basaltic Breccia, Mount Dutton and Bear Valley Formations, Bullion Canyon Volcanics, Page Ranch and Rencher Formations of Cook (1957), Quichapa Group, and Isom and Needles Range Formations

Tc
Tw
Claron and Wasatch Formations

Tqm
Quartz-monzonite porphyry

TERTIARY

Cretaceous rocks, undifferentiated
Kaiparowits and Iron Springs Formations, Wahweap and Straight Cliffs Sandstones, Tropic Shale, Dakota Formation, and Marshall Creek Breccia

CRETACEOUS and CRETACEOUS(?)

Jsr
San Rafael Group
Carmel Formation

Glen Canyon Group
Navajo Sandstone and Kayenta and Moenave Formations

JURASSIC

Tru
Triassic rocks, undifferentiated
Chinle and Moenkopi Formations (uppermost part of Kaibab Limestone of Permian age, in local exposures too small to be shown separately, is included with formations of Triassic age)

TRIASSIC

Contact
Dashed where approximately located

Normal or reverse fault
Dashed where inferred

Thrust fault
Barbs on side of thrust sheet

Surface-drainage divide

Base from U.S. Geological Survey 1:250,000 series: Richfield, 1972, and Cedar City, 1953 (revised 1961 and 1971)

5 0 5 10 MILES
5 0 5 10 KILOMETERS

CONTOUR INTERVAL 200 FEET (60 METERS)
WITH SUPPLEMENTARY CONTOURS AT 100-FOOT (30-METER) INTERVALS
DATUM IS MEAN SEA LEVEL

Geology adapted from Averitt (1962, 1967), Averitt and Threet (1973), Machin (1954), and Thomas and Taylor 1946)

Geologic map of the Parowan-Cedar City drainage basin, Iron County, Utah

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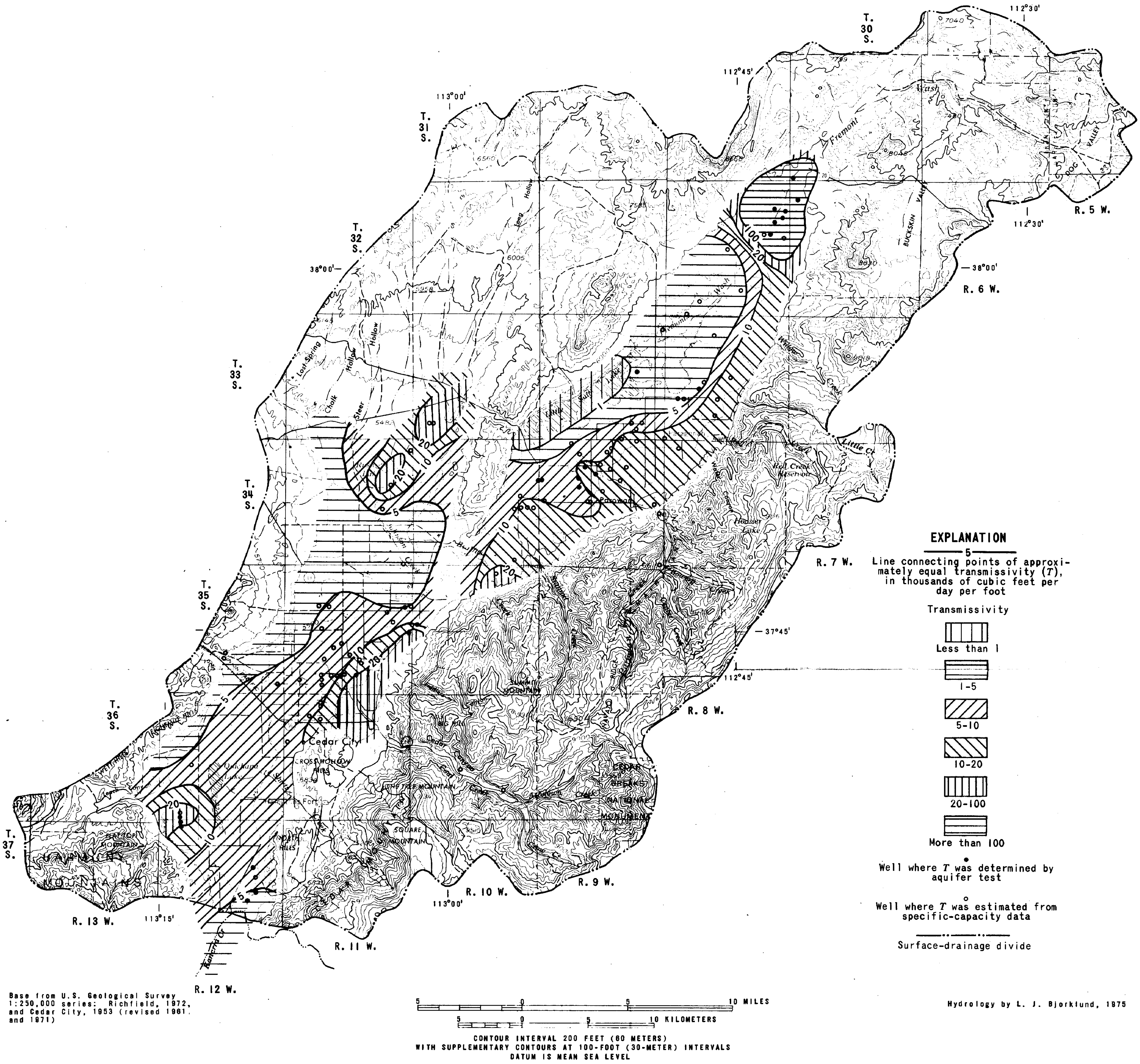
STATE OF UTAH
DEPARTMENT OF NATURAL RESOURCES

TECHNICAL PUBLICATION NO. 60
PLATE 2 1978

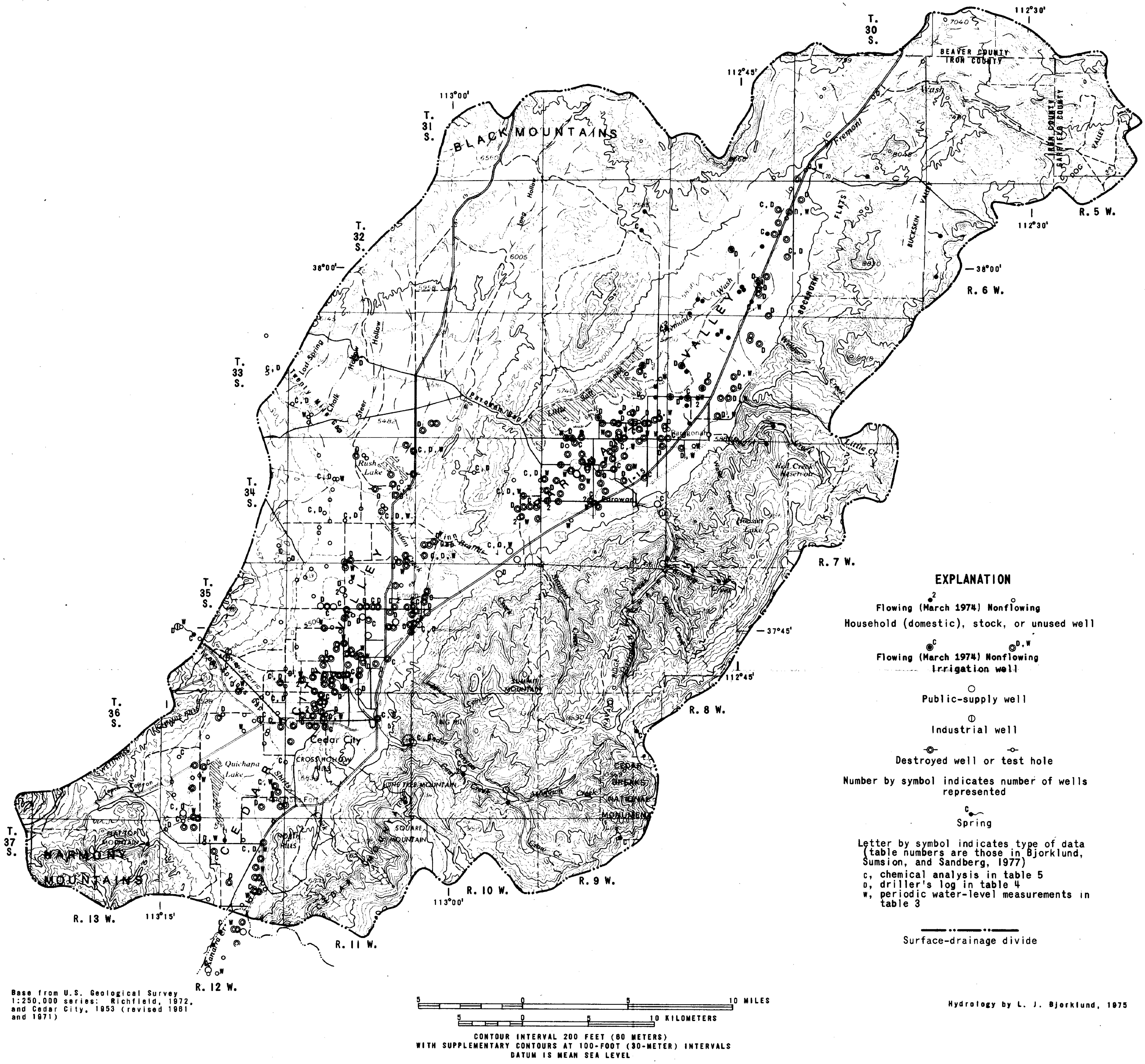


Map showing distribution of transmissivity values of the valley fill in Parowan and Cedar City Valleys, Iron County, Utah

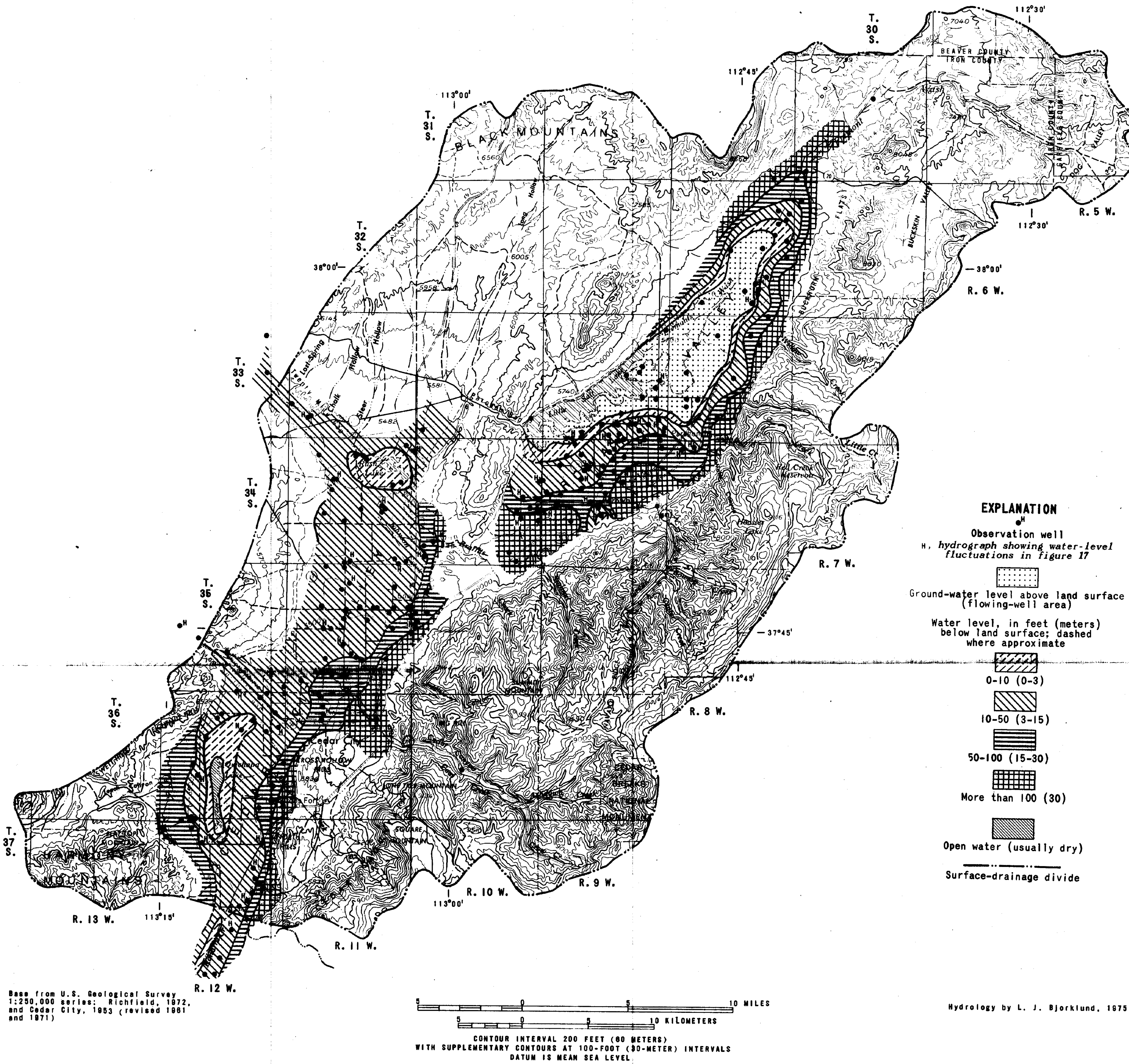
UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

STATE OF UTAH
DEPARTMENT OF NATURAL RESOURCES

TECHNICAL PUBLICATION NO. 60
PLATE 3 1978



Map showing the location of selected wells and springs in the Parowan-Cedar City drainage basin, Iron County, Utah



Base from U.S. Geological Survey 1:250,000 series: Richfield, 1972, and Cedar City, 1953 (revised 1961 and 1971)

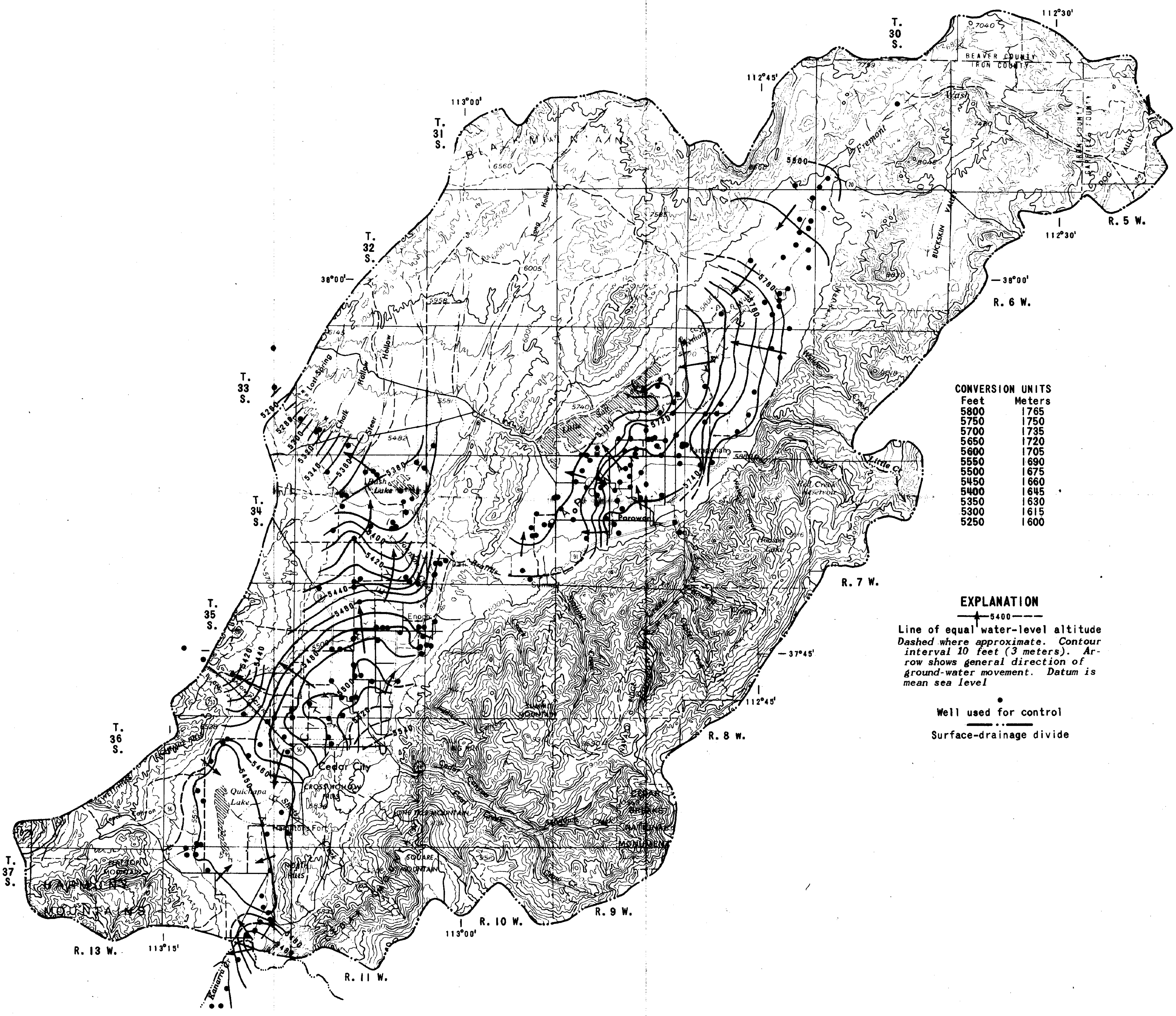
Hydrology by L. J. Bjorklund, 1975

Map showing relation of water levels to land surface during March 1974 in Parowan and Cedar City Valleys, Iron County, Utah

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

STATE OF UTAH
DEPARTMENT OF NATURAL RESOURCES

TECHNICAL PUBLICATION NO. 60
PLATE 5 1978



CONVERSION UNITS	
Feet	Meters
5800	1765
5750	1750
5700	1735
5650	1720
5600	1705
5550	1690
5500	1675
5450	1660
5400	1645
5350	1630
5300	1615
5250	1600

EXPLANATION

5400

Line of equal water-level altitude
Dashed where approximate. Contour interval 10 feet (3 meters). Arrow shows general direction of ground-water movement. Datum is mean sea level

Well used for control

Surface-drainage divide

Base from U.S. Geological Survey 1:250,000 series: Richfield, 1972, and Cedar City, 1953 (revised 1961 and 1971)

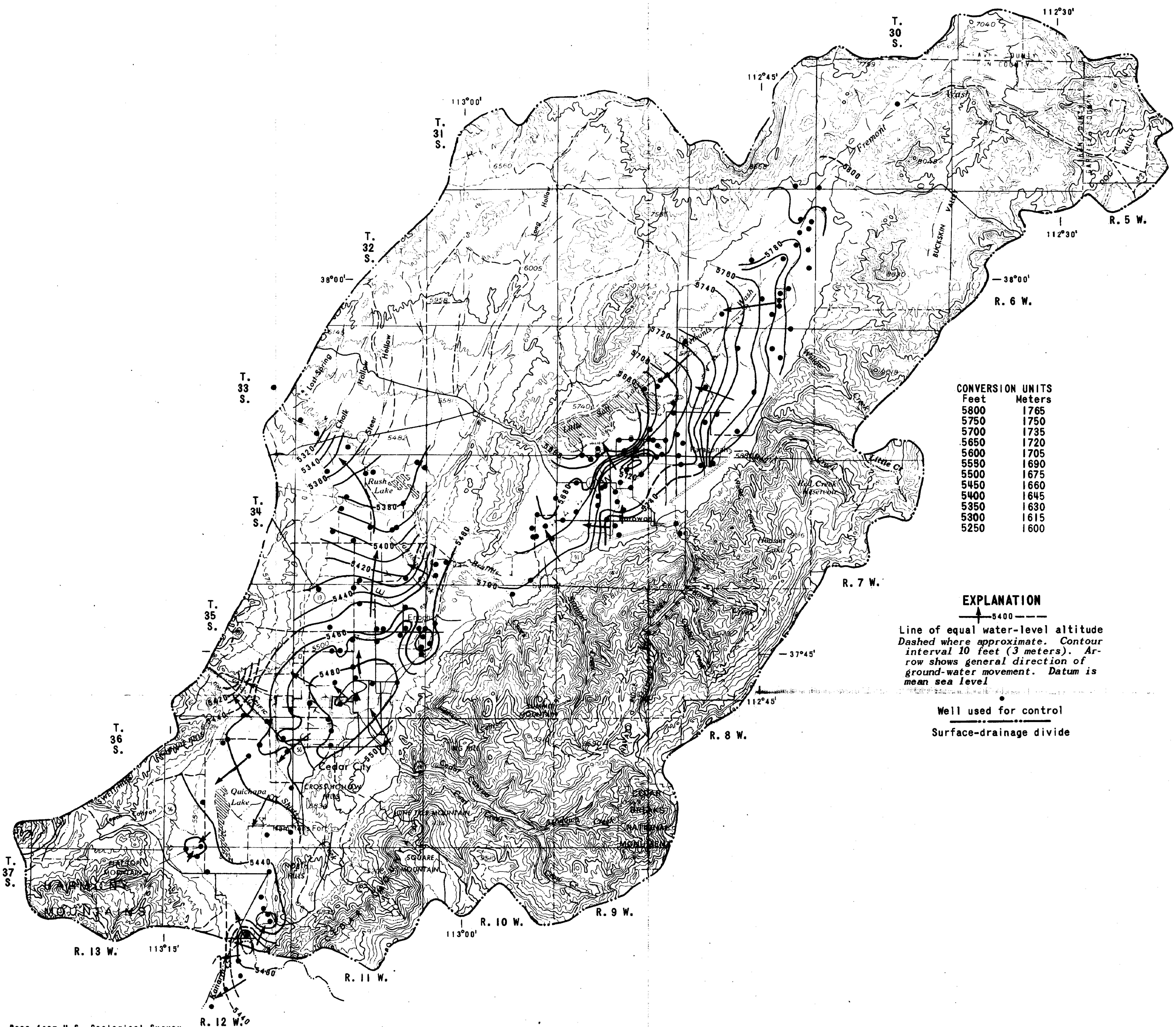
5 0 10 MILES

5 0 5 10 KILOMETERS

CONTOUR INTERVAL 200 FEET (60 METERS)
WITH SUPPLEMENTARY CONTOURS AT 100-FOOT (30-METER) INTERVALS
DATUM IS MEAN SEA LEVEL

Hydrology by L. J. Bjorklund, 1975

Map showing the configuration of the potentiometric surface and the direction of ground-water movement during March 1974 in Parowan and Cedar City Valleys, Iron County, Utah



CONVERSION UNITS

Feet	Meters
5800	1765
5750	1750
5700	1735
5650	1720
5600	1705
5550	1690
5500	1675
5450	1660
5400	1645
5350	1630
5300	1615
5250	1600

EXPLANATION

5400

Line of equal water-level altitude
Dashed where approximate. Contour interval 10 feet (3 meters). Arrow shows general direction of ground-water movement. Datum is mean sea level

Well used for control

Surface-drainage divide

Base from U.S. Geological Survey 1:250,000 series: Richfield, 1972, and Cedar City, 1953 (revised 1961 and 1971)

5 0 5 10 MILES

5 0 5 10 KILOMETERS

CONTOUR INTERVAL 200 FEET (60 METERS)
WITH SUPPLEMENTARY CONTOURS AT 100-FOOT (30-METER) INTERVALS
DATUM IS MEAN SEA LEVEL

Hydrology by L. J. Bjorklund, 1975

Map showing the configuration of the potentiometric surface and the direction of ground-water movement during October and November 1974 in Parowan and Cedar City Valleys, Iron County, Utah

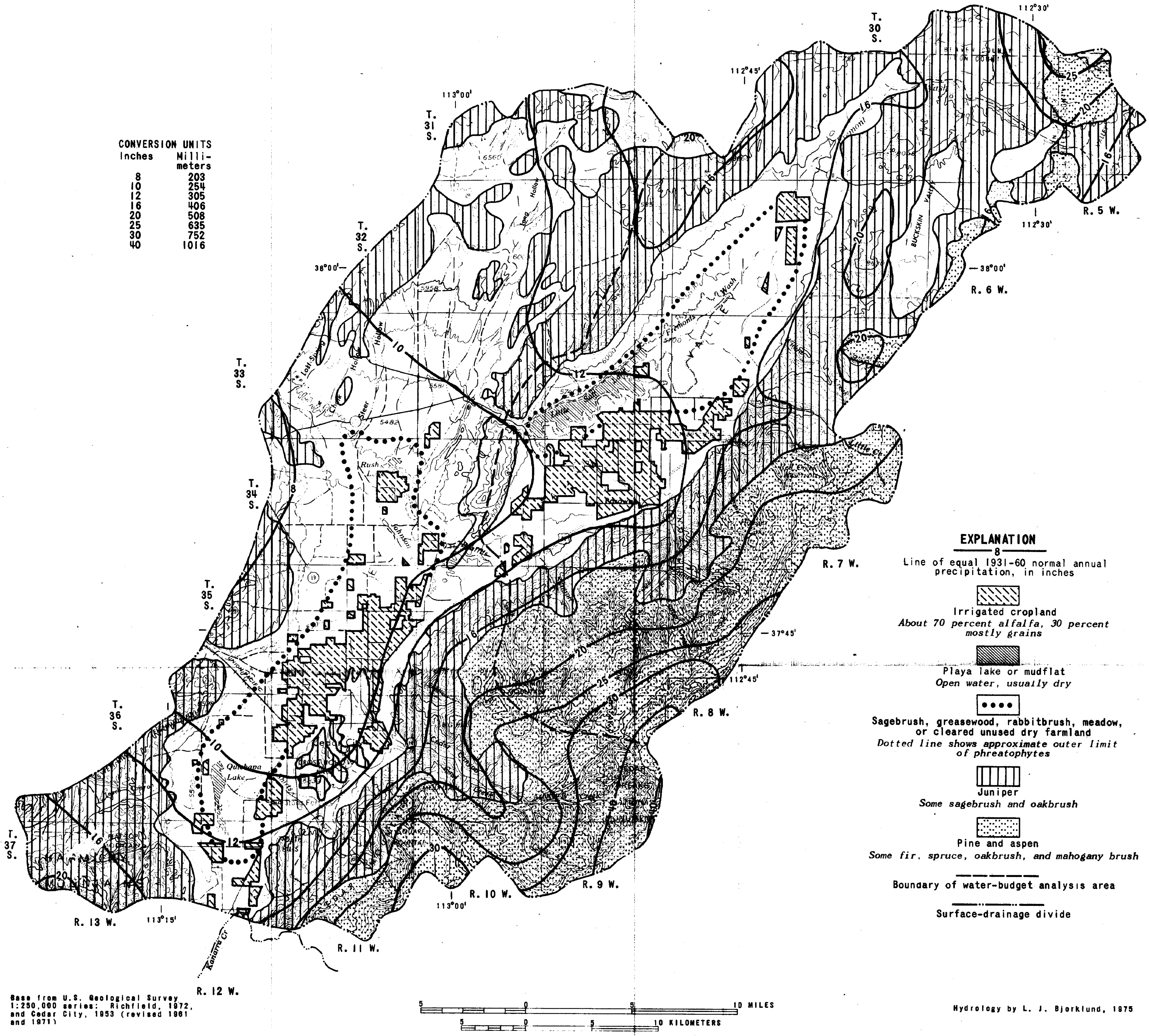
UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

STATE OF UTAH
DEPARTMENT OF NATURAL RESOURCES

TECHNICAL PUBLICATION NO. 60
PLATE 7 1978

CONVERSION UNITS

Inches	Millimeters
8	203
10	254
12	305
16	406
20	508
25	635
30	752
40	1016

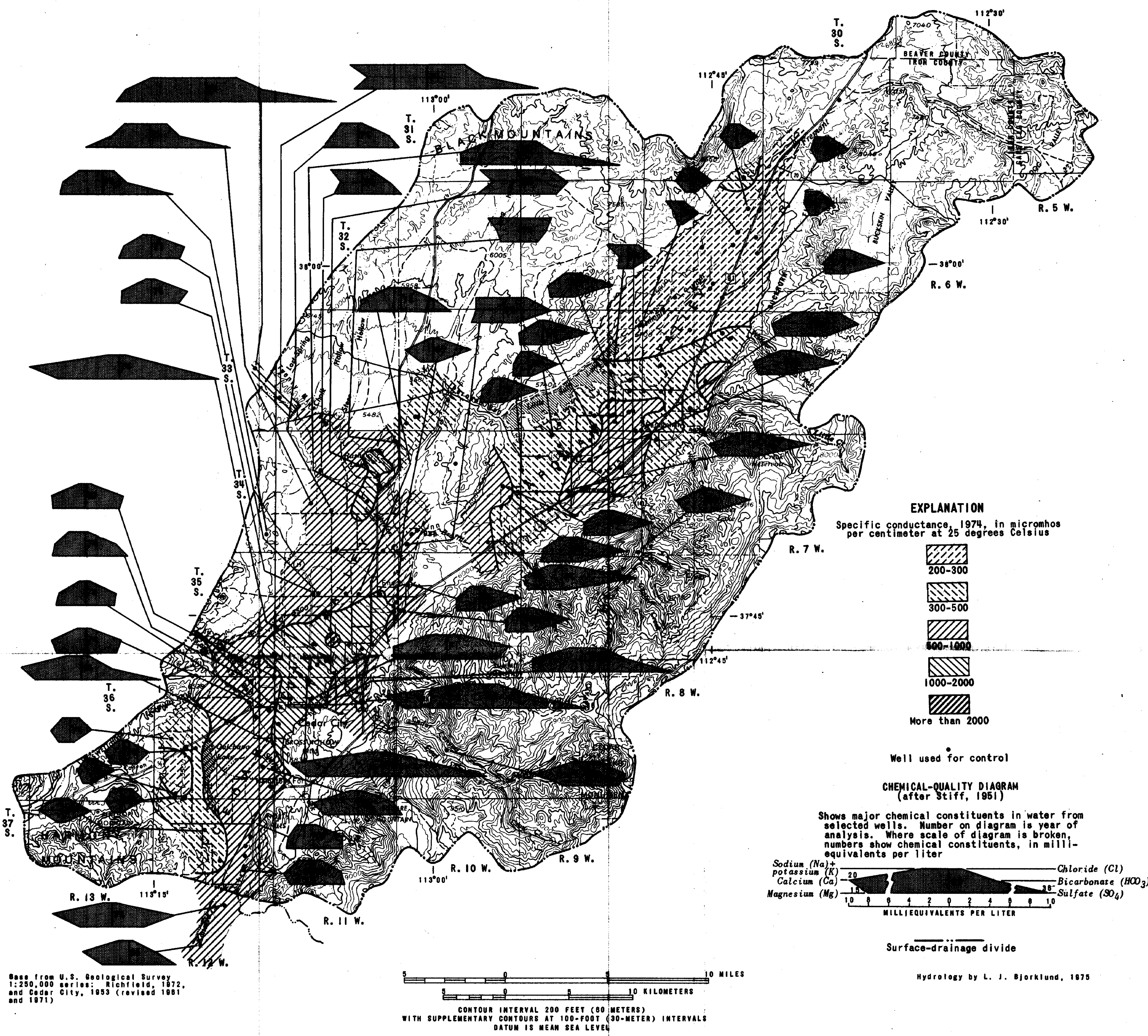


Base from U.S. Geological Survey 1:250,000 series: Richfield, 1972, and Cedar City, 1953 (revised 1961 and 1971)

CONTOUR INTERVAL 200 FEET (60 METERS)
WITH SUPPLEMENTARY CONTOURS AT 100-FOOT (30-METER) INTERVALS
DATUM IS MEAN SEA LEVEL

Hydrology by L. J. Bjorklund, 1975

Map showing land use, natural vegatation, water-budget analyses areas, and normal annual precipitation in the Parowan-Cedar City drainage basin, Iron County, Utah



Map showing specific conductance and the chemical quality of the ground water in Parowan and Cedar City drainage basins, Iron County, Utah

STATE OF UTAH
DEPARTMENT OF NATURAL RESOURCES

Technical Publication No. 60

GROUND-WATER RESOURCES OF THE PAROWAN-CEDAR CITY DRAINAGE BASIN, IRON COUNTY, UTAH

by

L. J. Bjorklund, C. T. Sumsion, and G. W. Sandberg
Hydrologists, U.S. Geological Survey

Prepared by
the United States Geological Survey
in cooperation with
the Utah Department of Natural Resources
Division of Water Rights

1978

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CONTENTS - Continued

ILLUSTRATIONS

[Plates are in pocket]

TABLES

ENGLISH-TO-METRIC CONVERSION FACTORS

Most values are given in this report in English units followed by metric units. The conversion factors used are shown to four significant figures. In the text, however, the metric equivalents are shown only to the number of significant figures consistent with the accuracy of the value in English units.

English Units (Multiply)	English Abbreviation	(by)	Metric Units (to obtain)	Metric Abbreviation
Acre		0.4047	Square hectometer	hm^2
Acre-foot	acre-ft	.001233	Cubic hectometer	hm^3
Cubic foot per second	ft^3/s	.02832	Cubic meter per second	m^3/s
Foot	ft	.3048	Meter	m
Foot per mile	ft/mi	.1894	Meter per kilometer	m/km
Gallon	gal	3.785	Liter	L
		.003785	Cubic meter	m^3
Gallon per minute	gal/min	.06309	Liter per second	L/s
Mile	mi	1.609	Kilometer	km
Square foot	ft^2	.09290	Square meter	m^2
Square mile	mi^2	2.590	Square kilometer	km^2

Chemical concentration and water temperature are given only in metric units. Chemical concentration is given in milligrams per liter (mg/L). For concentrations less than 7,000 mg/L, the numerical value is about the same as for concentrations in the English unit, 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 the English unit, equivalents per million.

Water temperature is given in degrees Celsius (°C), which can be converted to degrees Fahrenheit (°F) by the following equation: °F = 1.8 (°C) + 32.

GROUND-WATER RESOURCES OF THE PAROWAN-CEDAR CITY DRAINAGE BASIN, IRON COUNTY, UTAH

by

L. J. Bjorkland, C. T. Sumsion, and G. W. Sandberg
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ABSTRACT

The Parowan-Cedar City drainage basin, Iron County, Utah, includes about 1,100 mi^2 (square miles)(2,800 km^2 [square kilometers])--520 mi^2 (1,300 km^2) in the Parowan basin and 580 mi^2 (1,500 km^2) in the Cedar City basin. Parowan and Cedar City Valleys are structural depressions formed by northeast-trending faults. Parowan Valley is essentially a closed basin, whereas Cedar City Valley is drained by two gaps in the mountains bordering the west side of the valley, and a small part of Cedar City Valley is drained at a gap at the south end. Water flowing into the basin from the highlands to the east is used to irrigate lands near Cedar City, Parowan, Paragonah, and Summit. The surface-water outflow from the basin is negligible.

The geologic units exposed in the basin attain a maximum total thickness of more than 16,000 ft (feet) (4,900 m [meters]). The oldest formation is the Kaibab Limestone of Permian Age.

Ground water in the basin is derived almost exclusively from precipitation within the basin which normally amounts to about 936,000 acre-ft (acre-feet) (1,150 hm^3 [cubic hectometers]) annually. Most of the wells in the area derive water from the unconsolidated valley fill of Quaternary age. Annual recharge to the alluvial deposits in the basin is about 80,000 acre-ft (98 hm^3), approximately half of which is to Parowan Valley and half is to Cedar City Valley. Recharge is mostly from streams, irrigation, and subsurface inflow from the mountains to the east.

Ground water occurs in the valley fills under both confined (artesian) and unconfined (water-table) conditions. The most productive aquifers are beds of well-sorted gravel and sand. Flowing wells in 1975 existed in an area of about 36 mi^2 (93 km^2) in Parowan Valley, although they existed in an area of 46 mi^2 (120 km^2) in 1940. No flowing wells now exist in Cedar City Valley although they existed throughout an area of more than 50 mi^2 (130 km^2) in 1939. Local perched ground-water bodies are common in the valley fill. More than 40 million acre-ft (50,000 hm^3) of water is estimated to be stored in the unconsolidated fills of Parowan and Cedar City Valleys.

Transmissivity of the valley fill as determined from nine aquifer tests ranged from about 1,000 to 400,000 feet squared per day (90 to 40,000 meters squared per day). Transmissivity was also estimated from specific-capacity data at 110 wells. The highest transmissivity and potential yield were determined in the Buckhorn Flats area where the valley fill consists largely of volcanic rocks. High transmissivity is indicated also in the Coal Creek alluvial fan from Cedar City about 3 miles (5 kilometers) northward and northwestward.

Interference between pumped wells is common and prompt. The drawdown impulse in one instance traveled 3,060 ft (933 m) in 5 minutes. Mutual interference among pumped wells in parts of Parowan and Cedar City Valleys during an irrigation season is considerable. Inferred faults in the valley fill in Parowan Valley, however, had no observed damming, blocking, or restricting effects on water levels during an aquifer test.

The potentiometric surface of the ground-water reservoir slopes generally westward to northward, and the ground water moves from the mountain front of the Markagunt Plateau generally northwestward to the lower parts of the valleys where most of the natural discharge of ground water takes place. The potentiometric surface ranges from 16 ft (4.9 m) above land surface to 266 ft (81.1 m) below land surface in Parowan Valley and from 2 to 250 ft (0.7 to 76.2 m) below land surface in Cedar City Valley. Water levels generally decline during the irrigation season and recover most of the decline between irrigation seasons. Declines during 1940-74 of more than 30 ft (9 m) occurred in areas of 9 mi^2 (23 km^2) in Parowan Valley and of 8 mi^2 (20 km^2) in Cedar City Valley. The estimated average annual depletion of ground water is about 3,600 acre-ft (4.4 hm^3) in Parowan Valley and about 3,300 acre-ft (4.1 hm^3) in Cedar City Valley.

Discharge of ground water from the area occurs in several ways. Springs in the mountains bordering the basin on the east discharge more than 25,000 acre-ft (30.82 hm^3) annually. Springs in the valleys discharge less than 1,000 acre-ft (1 hm^3). The evapotranspiration of ground water amounts to about 14,000 acre-ft (17 hm^3) of which about 12,000 acre-ft (15 hm^3) is in Parowan Valley and about 2,000 acre-ft (2 hm^3) is in Cedar City Valley. The largest means of ground-water discharge are wells, amounting to approximately 73,000 acre-ft (90 hm^3) in the basin in 1974. Subsurface outflow in Parowan Valley is negligible and amounts to less than 500 acre-ft (0.6 hm^3) a year in Cedar City Valley.

Ground water in Parowan basin is classified generally as sodium, calcium, or magnesium bicarbonate type, whereas in Cedar City basin it is classified as a calcium or magnesium sulfate type. Ground water in both basins generally is very hard. Public water-supply systems in the area provide water that is below the concentration limits recommended by the U.S. Public Health Service for various chemical constituents which have been analyzed. For irrigation, ground water in the area generally has a low sodium hazard and low-to-high salinity hazard. Wells in Cedar City Valley sampled during 1938-40 and again in 1973-74 indicate an average increase in chloride of 10 milligrams per liter.

Total pumpage from wells in the basin during 1974 was 73,000 acre-ft (90 hm^3), of which 30,700 acre-ft (38 hm^3) was in Parowan Valley and 42,300 acre-ft (52 hm^3) was in Cedar City Valley. Most of the pumpage was for irrigation. In most areas, ground water alone was used for irrigation, but in some localities ground water was used to supplement surface-water supplies. Public water supplies are obtained primarily from springs in the mountains and usually supplemented by wells in the valley. Several housing-development sites use community wells for water supplies.

INTRODUCTION

Purpose and scope of the study

This report is intended to assist public officials and water users in the Cedar City-Parowan drainage basin, Iron County, Utah, to develop, conserve, and administer their water resources. The report primarily describes the ground-water resources in the alluvial fill of Cedar City and Parowan Valleys, but it also presents information about the water in the bedrock formations in the highlands surrounding the valleys. It discusses the relation of ground water to surface water in the basin and presents a general water-budget analysis. It includes information on the source, occurrence, availability, quantity, movement, chemical quality, and development of the ground water and the effects of climate, geology, and development on the resource.

Selected hydrologic data collected for the study are given in Bjorklund, Sumsion, and Sandberg (1977), which contains information regarding selected wells and springs, including water levels, chemical quality of water, and drillers' logs of wells. Both the data report and this one were prepared by the U.S. Geological Survey in cooperation with the Utah Department of Natural Resources, Division of Water Rights. Fieldwork for the investigation began in July 1973 and continued through June 1975.

Location and general features

Topography and drainage

The Parowan-Cedar City drainage basin in southwestern Utah (fig. 1) is primarily a structural basin including approximately 1,100 mi^2 (2,800 km^2) of which 520 mi^2 (1,300 km^2) is in the Parowan Basin and 580 mi^2 (1,500 km^2) is in the Cedar City Basin. Most of this area is in the Great Basin section of the Basin and Range physiographic province (Fenneman, 1931). It is bounded on the south and east by the Markagunt Plateau, on the north by the Black Mountains, and on the west by relatively low mountains and hills. About 70 percent of the basin is mountainous or hilly and is underlain with bedrock covered in most places with a thin mantle of soil. About 30 percent of the basin is in Parowan and Cedar City Valleys; this area consists of flatlands and alluvial fans and slopes underlain by Quaternary alluvium composed of boulders, cobbles, gravel, sand, silt, and clay eroded from the surrounding highlands. Altitudes range from 11,307 ft (3,446 m) at Brian

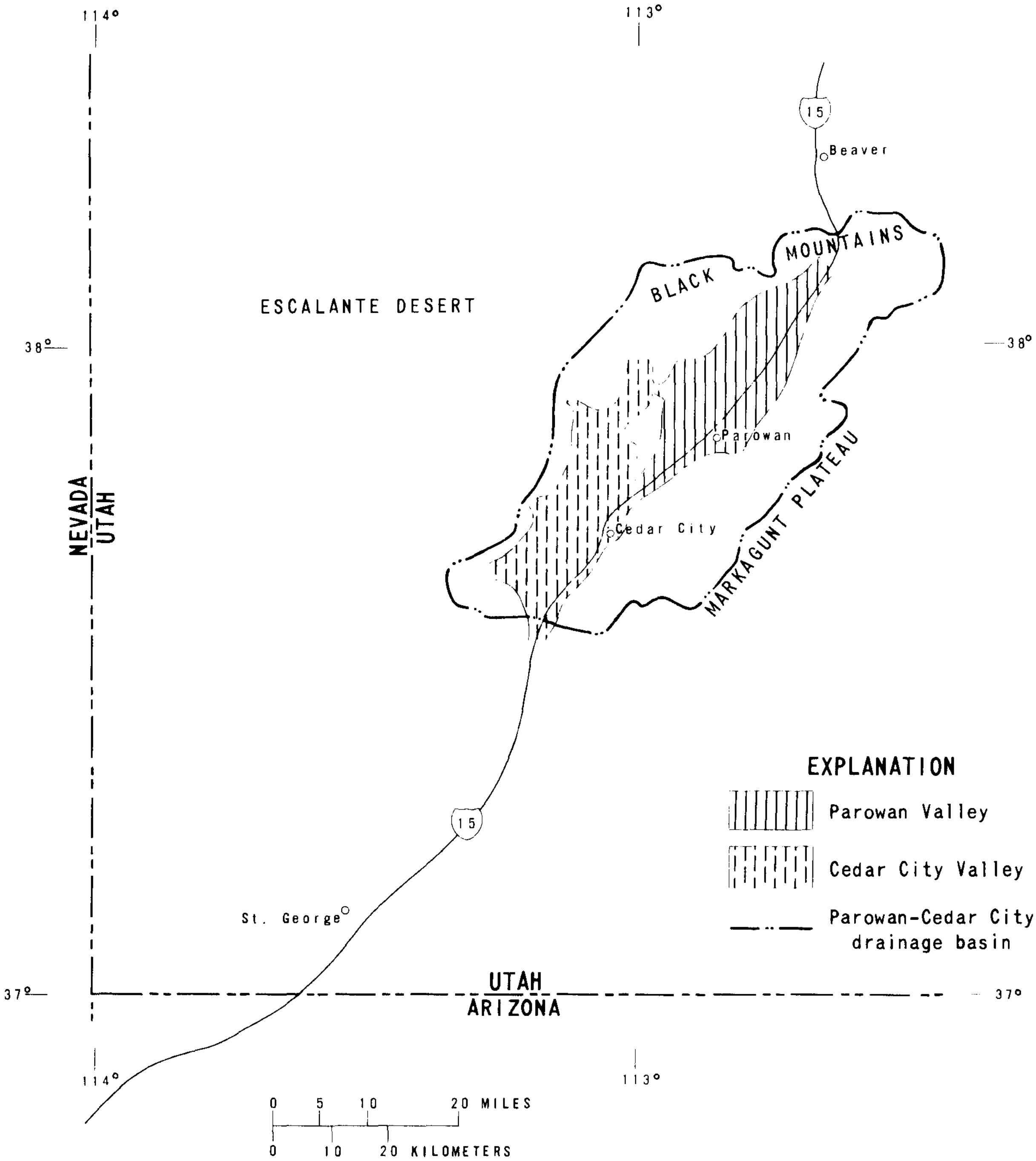

Figure 1.— Location of Parowan and Cedar City Valleys and the Parowan-Cedar City drainage basin.

Head, the highest point on the Markagunt Plateau, to 5,350 ft (1,631 m) at the edge of Cedar City Valley, at the outlet at Mud Springs Wash. The lowest altitude in Parowan Valley is about 5,690 ft (1,734 m) at the Little Salt Lake Playa.

Parowan and Cedar City Valleys are structural depressions primarily formed and bounded by faults generally trending northeast-southwestward. The highlands bordering the valleys consist of elevated fault blocks, modified by erosion, and the valleys are underlain by downthrown blocks blanketed by materials eroded from the highlands. The two valleys are separated by a southward extension of the Black Mountains, which is lower in altitude southward and ends at a low pass at the southwestern end of Parowan Valley. Each valley is about 32 mi (51 km) long and ranges from about 1 to about 8 mi (1.6 to 13 km) wide. Parowan Valley covers about 160 mi^2 (410 km^2) and Cedar City Valley covers about 170 mi^2 (440 km^2). Parowan Valley is considerably higher than Cedar City Valley, the lowest points in the valleys differing by 340 ft (104 m).

Most of the water flowing into the valleys originates as snowmelt runoff from the highlands along the eastern side of the drainage basin. The principal perennial streams are Coal Creek in Cedar City Valley and Parowan Creek in Parowan Valley. Both streams have built large alluvial fans that extend to the center of the valleys. Other important but smaller streams are Shirts Creek[1] in Cedar City Valley and Willow, Little, Red, and Summit Creeks in Parowan Valley. Excess spring runoff accumulates in three shallow playa lakes--Little Salt Lake in Parowan Valley and Quichapa and Rush Lakes in Cedar City Valley.

Parowan Valley is essentially a closed basin, although a small part of the valley at the southwestern end drains through Winn Gap into Cedar City Valley. In ages past the main part of the valley drained into Cedar City Valley through Parowan Gap. Today, however, the main outlet in Parowan Gap is blocked by alluvial fans from branch canyons and possibly by uplift of the mountain block separating the valleys. Some ground water may seep through the gap or through the mountain block into Cedar City Valley, but the quantity would be small.

Cedar City Valley is drained by three gaps in the surrounding hills. Two areas along the western side of the valley slope toward gaps or openings in the westward bordering mountains, and one area at the southern end of the valley slopes southward toward the Virgin River. Thus, Mud Springs Wash and Iron Springs Gap on the west side of the valley conduct water at times toward the Escalante Desert basin to the northwest, and Kanarra Creek drainage conducts some water from the southern parts of the valley toward the Virgin River basin to the south. These drainages conduct surface water from the valley during flash floods that occur during or following excessive local precipitation. These gaps also continually conduct a relatively small amount of ground water through the permeable alluvial fills in the gaps toward areas of lower elevation.

---

[1]Also known as Shurtz Creek.

Quichapa Lake in recent years contained water and has given the impression to some that it is the lowest part of Cedar City Valley. Rush Lake, however, is approximately 60 ft (20 m) lower in altitude, but in recent years has been dry. The general northward slope of the valley toward Rush Lake and Mud Springs Wash has been interrupted by the alluvial fan of Coal Creek isolating the Quichapa Lake basin which receives excess runoff from Coal and Shirts Creeks.

Climate

The climate of the area ranges from semiarid in Parowan and Cedar City Valleys to humid on the highlands to the east. Moderate to meager precipitation, large daily temperature changes, moderately cold winters, and warm dry summers are characteristic of the valleys. In parts of Cedar City Valley annual precipitation normally varies from 8 to 14 in. (200 to 360 mm) and in Parowan Valley, from 10 to 16 in. (250 to 410 mm). In the highlands precipitation generally varies with the altitude and ranges from about 16 in. (410 mm) near the base to about 40 in. (1,000 mm) at the crest of the Markagunt Plateau at Cedar Breaks (pl. 7). Most of the precipitation results from humid air masses that move southeastward from the north Pacific during winter and spring; much of it falls as snow in the mountains, but some precipitation in late summer and early fall results from humid air moving northwestward from the Gulf of Mexico. Snow usually covers the valley floors during winter months, but snowstorms may persist into April or May. Runoff from spring snowmelt reaches its maximum in May or June. The growing season--the number of consecutive days above -2°C (28°F)--during 1964-73 has ranged from 128 to 181 days and averaged 154 days at the Cedar City airport and has ranged from 123 to 175 days and averaged 151 days at Parowan. The normal monthly precipitation and temperature at Parowan and Cedar City are given in table 1.

Climatological data are collected by the National Weather Service (formerly U.S. Weather Bureau). Other available climatological data collected in or near the project area but not shown herein are collected at the Cedar City powerhouse in Coal Creek Canyon, at Blowhard Mountain Radar Station near the crest of Markagunt Plateau, and at New Harmony in Washington County. Graphs showing the relation of annual precipitation, cumulative departure from average precipitation at Cedar City and Parowan, discharge in Coal Creek, and ground-water levels in selected wells are shown in figures 2 and 3.

Culture and population

Approximately 12,000 people live within the project area; about 10,000 people live in Cedar City Valley and 2,000 in Parowan Valley. Cedar City (pop. 1970, 8,946) and Parowan (pop. 1970, 1,423) are the principal towns and business centers. Mining, agriculture, tourism, and diversified manufacturing are the principal industries. Iron ore is mined in the mountains west of Cedar City and shipped by rail to smelting centers. Gravel is mined and processed near Cedar City and Parowan for use in construction. The principal agricultural products are livestock products, alfalfa, grain, and timber. Nearby National Parks and other recreation areas bring many travelers to the area.

Table 1.--Normal 1941-70 monthly precipitation and temperature at Parowan and Cedar City

	Parowan Airport		Cedar City FAA-AP	
	Precipitation (in.)	Temperature (°F)	Precipitation (in.)	Temperature (°F)
January	0.84	29.6	0.65	28.7
February	1.05	34.1	.76	33.1
March	1.48	38.7	1.12	38.4
April	1.26	47.3	1.05	47.1
May	.88	56.2	.68	56.2
June	.63	64.6	.54	65.0
July	1.11	72.0	.96	73.2
August	1.39	69.8	1.22	71.3
September	.69	62.8	.72	63.2
October	.92	52.1	.89	51.5
November	1.01	40.0	.96	38.8
December	.99	32.2	.78	30.8
Annual Total	12.25		10.33	
Average		50.0		49.8

Previous investigations

The earliest descriptions of the geology and physiography of the area were published during the latter part of the 19th century as the results of reconnaissance studies that covered wide areas, including parts of Arizona and Nevada as well as southwestern Utah (Gilbert, 1875, p. 17-187; Howell, 1875, p. 227-301; Powell, 1879; and Dutton, 1880).

Detailed studies of geology in and near the Parowan-Cedar City area during the early part of the 20th century were related principally to mineral deposits, mainly coal and iron ore (Lee, 1907; Leith and Harder, 1908; and Richardson, 1909). More recent studies of geology in and near the area have been completed by Mackin (1954), Averitt (1962; 1964, p. 901-903; and 1967), Threet (1963, p. 104-117), Wright and Dickey (1963, p. E63-E67), Lawrence (1965, p. 71-91), Stewart, Poole, and Wilson (1972a, 1972b), and Averitt and Threet (1973). A geologic map of Utah was compiled and edited by Stokes (1964).

Two of the earliest studies of water resources were reconnaissance investigations intended to serve as guides in a large area of arid western and southwestern Utah by Lee (1908) and Meinzer (1911). The first comprehensive investigation of geology and ground water in the Parowan and Cedar City drainage basins was by Thomas and Taylor (1946).

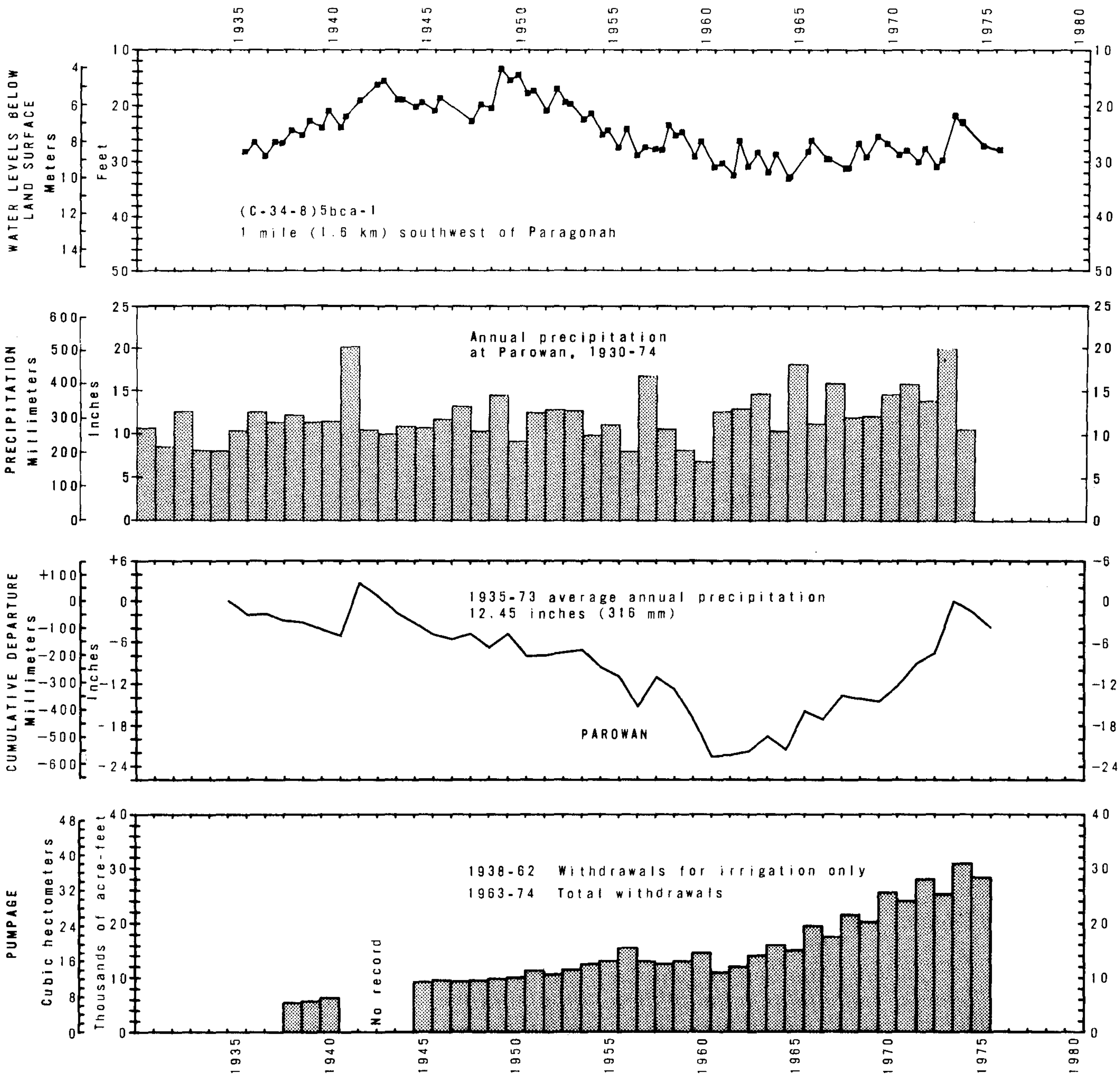

Figure 2.— Relation of water levels in well (C-34-8)5bca-1 in Parowan Valley to annual precipitation at Parowan, to cumulative departure from average annual precipitation, and to withdrawals from wells.

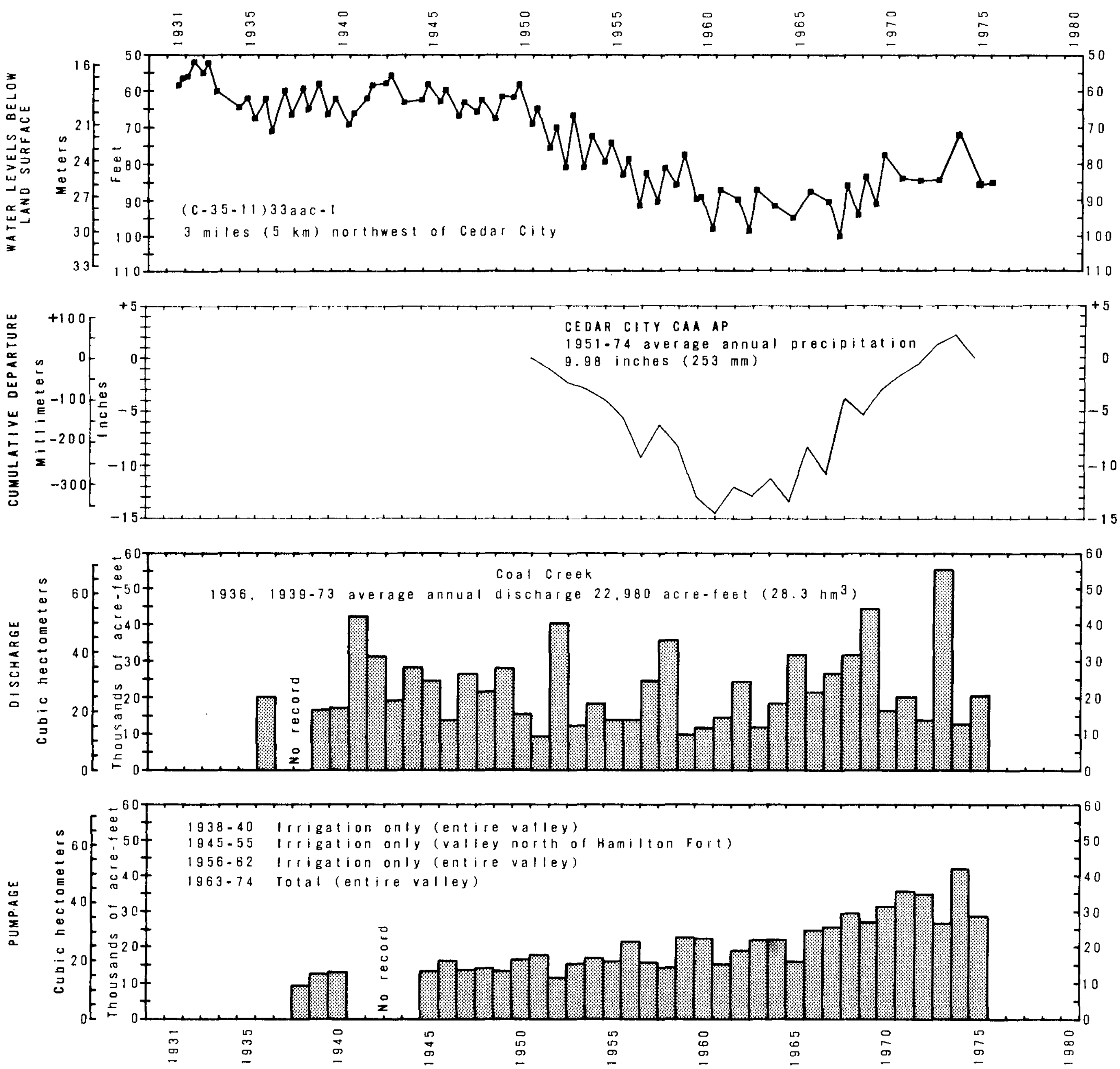

Figure 3.— Relation of water levels in well (C-35-11)33aac-1 in Cedar City Valley to cumulative departure from the average annual precipitation at the Cedar City airport, to discharge of Coal Creek near Cedar City, and to pumpage from wells.

The progress of ground-water development in Parowan Valley is discussed by Nelson, in Thomas and others (1952, p. 34-39), and in Cedar City Valley by Thomas, in Thomas and others (1952, p. 22-34). Subsequent reports on ground-water development in these same areas are given by Barnell and Nelson, in Waite and others (1954, p. 75-84), and by Butler and Barnell, in Waite and others (1954, p. 84-93). The economics of pumping ground water in southwestern Utah is discussed by Nelson, in Waite and others (1954, p. 95-104). Sandberg (1966) describes the ground-water resources of selected ground-water basins in southwestern Utah, including Parowan and Cedar City Valleys.

Well- and spring-numbering system

The system of numbering wells and springs in Utah is based on the cadastral land-survey system of the U.S. Government. The number, in addition to designating the well or spring, describes its position in the land net. 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 (4 hm^2);[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 (4-hm^2) tract; the letter "S" preceding the serial number denotes a spring. If a well or spring cannot be located within a 10-acre (4-hm^2) tract, one or two location letters are used and the serial number is omitted. Thus (C-35-12)24ada-1 designates the first well constructed or visited in the NE¼SE¼NE¼ sec. 24, T. 36 S., R. 12 W. The numbering system is illustrated in figure 4.

SURFACE WATER

Water diverted from perennial streams flowing into the Parowan-Cedar City basin, mostly from the highlands to the east, is used to irrigate some lands near Cedar City, Parowan, Paragonah, and Summit. The measured or estimated annual discharge of the principal streams for water years 1960-74 is shown in table 2. During this period the average annual surface-water discharge into Parowan and Cedar City Valleys from the principal streams is estimated to be about 46,000 acre-ft (57 hm^3).

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[1]Although the basic land unit, the section, is theoretically 1 mi^2 (2.6 km^2), many sections are irregular. Such sections are subdivided into 10-acre (4-hm^2) tracts, generally beginning at the southeast corner, and the surplus or shortage is taken up in the tracts along the north and west sides of the section.

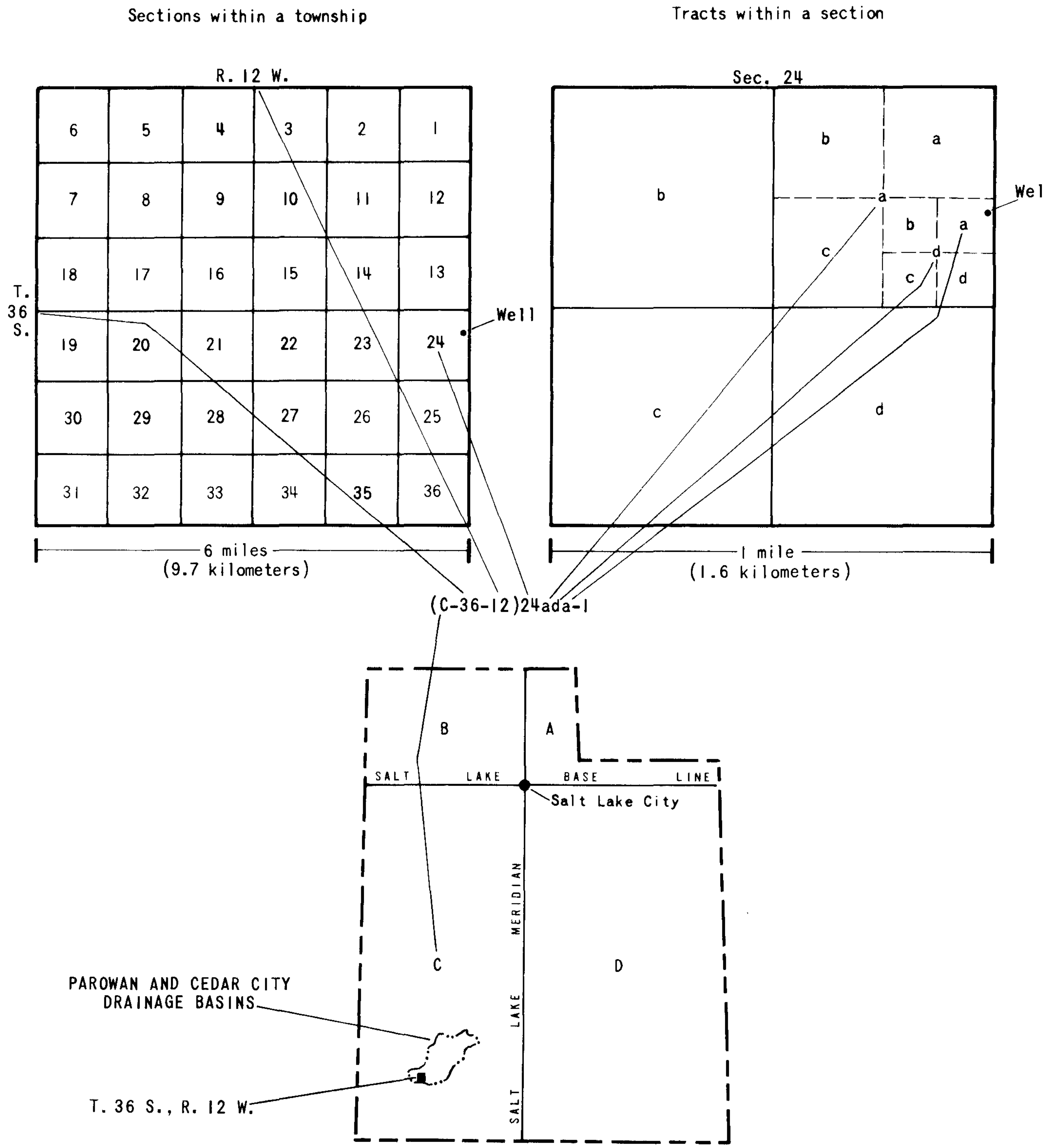


Figure 4.—Well- and spring-numbering system used in Utah.

Table 2.--Discharge of principal streams, in acre-feet, at gaging stations in the Parowan-Cedar City drainage basin, 1960-74

[E, estimated]

	Gaging stations on streams entering Cedar City and Parowan Valleys					Gaging stations on tributary streams	
Water year	Coal Creek near Cedar City	Parowan Creek near Parowan	Red Creek at Paragonah	Little Creek near Paragonah	Summit Creek near Summit	Center Creek above Parowan Creek (tributary to Parowan Creek)	Red Creek near Paragonah (6 miles upstream from Red Creek at Paragonah)
1960	11,180	6,400E	-	475	1,400E	2,700E	750E
1961	15,110	8,600	-	1,080	1,800E	3,200E	880E
1962	24,360	14,000E	-	1,350	2,900E	4,300E	1,100E
1963	11,970	6,800E	-	524	1,500E	3,000E	800E
1964	18,470	10,500E	-	649	2,200E	3,600E	920E
1965	30,870	17,000E	-	2,010	4,280	5,030	1,200E
1966	21,630	12,300E	-	1,110	2,170	4,030	1,050
1967	26,660	15,000E	-	936	2,050	4,510	1,010
1968	31,720	18,000E	-	1,540	3,900	5,790	1,070
1969	43,900	25,000E	-	1,730	4,310	5,750	1,280
1970	17,080	9,700E	-	914	2,830	4,530	1,000
1971	19,540	11,000E	3,600E	1,240	2,150	3,510	921
1972	14,240	8,000E	3,500E	688	1,480	3,160	748
1973	57,320	33,000E	8,000E	4,050	7,770	8,550	2,340
1974	13,400	7,300E	4,200E	1,280	2,190	4,270	1,440
Average	23,830	13,507	4,800	1,305	2,862	4,396	1,101

Explanation of stations and basis of estimates

Coal Creek near Cedar City - near mouth of Coal Creek Canyon - Measured and gaged by U.S. Geological Survey.
Parowan Creek near Parowan (formerly Center Creek near Parowan) - near mouth of Parowan Creek Canyon. Estimates based on correlation of Center Creek near Parowan (Parowan Creek) with Coal Creek (1943-50).
Red Creek at Paragonah - Estimates based on miscellaneous measurements by U.S. Geological Survey in 1938-39 and 1940 (Thomas and Taylor, 1946, p. 69) and hydroelectric powerplant records.
Little Creek near Paragonah - near mouth of Little Creek Canyon - Measured and gaged by U.S. Geological Survey.
Summit Creek near Summit - near mouth of Summit Creek Canyon. Estimates based on correlation with Coal Creek. Measured and gaged by U.S. Geological Survey.
Center Creek above Parowan Creek - tributary to Parowan Creek - Measured by U.S. Geological Survey.
Red Creek near Paragonah - about 5 miles above mouth of Red Creek Canyon. Only part of outflow of Red Creek at Paragonah - Measured by U.S. Geological Survey.

The surface-water discharge during the snowmelt season in the highlands is largest in parts of May and June. During years of unusually large runoff, such as 1969 and 1973 (see table 2), some water flows into Little Salt Lake and Quichapa Lake or runs onto uncultivated lands where it is used by native vegetation. After the snowmelt season the discharge in the streams decreases to base flow and the surface-water supply is supplemented with ground water pumped from wells.

Coal Creek, the largest stream in the basin, discharges almost all surface water used in Cedar City Valley and about half of the surface water used in the Parowan-Cedar City basin. Since 1960 the annual discharge in Coal Creek has ranged from 11,180 acre-ft (13.8 hm^3) in 1960 to 57,320 acre-ft (70.7 hm^3) in 1973 and has averaged 23,830 acre-ft (29.4 hm^3) (table 2). The median annual discharge for the 1960-74 period was 19,540 acre-ft (24.1 hm^3) in 1971. Discharge in Coal Creek since 1935 is shown graphically in figure 3. Other perennial, but relatively small, streams in Cedar City Valley are Shirts Creek, which enters the valley from the east near Hamilton Fort, and Quichapa Creek, which enters the valley from the Harmony Mountains on the western side of the valley. The water from Quichapa Creek is diverted into a pond and is used for irrigation.

In Parowan Valley the principal streams are Parowan, Red, Little, and Summit Creeks (see table 2), and water from each of these streams is used for irrigation. Because the base flow in Parowan and Red Creeks is quite constant these streams are also used to generate electric power in municipally owned hydroelectric plants at Parowan and Paragonah. Parowan Creek discharges more than half the surface water used in Parowan Valley. Its annual discharge since 1960 ranged from about 6,400 acre-ft (7.9 hm^3) in 1960 to 33,000 acre-ft (41 hm^3) in 1973 and averaged about 13,500 acre-ft (16.6 hm^3). Its median annual discharge was 11,000 acre-ft (14 hm^3). Some areas at and near Parowan, Paragonah, and Summit rely exclusively on water from Parowan, Red, and Summit Creeks for irrigation water; surface-water supplies for adjacent areas are supplemented with water pumped from wells. Municipal water supplies for Parowan, Paragonah, and Summit are derived from springs normally feeding Parowan, Red, and Summit Creeks.

In addition to the four principal streams in Parowan Valley, several small streams flow toward the valley but generally disappear into the underlying alluvial sediments near the edge of the valley. The largest of these minor streams is Cottonwood Creek which discharged 1.25 ft^3/s (0.035 m^3/s) on May 19, 1975. The average discharge is probably less than 1 ft^3/s (0.028 m^3/s). The water is diverted into a pond and used for irrigation and livestock.

Many intermittent and ephemeral streams enter Parowan and Cedar City Valleys from the mountains on all sides. Water from the intermittent streams, which drain minor subbasins and usually flow only during or following snowmelt or excessive rainfall, seeps into the permeable alluvial fill near the valley edge or is consumed by evaporation or transpiration. Ephemeral streams, however, may discharge large quantities of water into the valley for short periods of time during flash floods caused by excessive rainfall. Some of this water is caught in stock ponds for range cattle and sheep, but most of it evaporates, supports native vegetation, or seeps into the earth to recharge the ground-water reservoir.

The surface-water outflow from the Parowan-Cedar City basin is regarded as negligible although small flows originate near the valley edge at Iron Springs Gap and near Kanarraville. The flows form at small springs and seeps near the edge of the drainage basin and indicate ground-water discharge from the basin rather than surface-water discharge. Ephemeral discharge of surface water from the basin during flash floods caused by heavy local precipitation, however, is indicated by dry stream channels in Mud Springs Wash and Iron Springs Gap. These floods are infrequent and their duration is short. The quantity of water discharged by surface-water outflow, therefore, would be small.

GEOLOGIC SETTING

Throughout the Parowan-Cedar City drainage basins, geologic controls on all aspects of drainage-basin hydrology are readily apparent. Landforms affect the pattern and amount of precipitation. Relief and land-surface materials regulate surface drainage, infiltration, and evapotranspiration. Geologic structural and stratigraphic characteristics control the recharge and subsequent movement of ground water.

Those geologic controls most directly related to surface drainage and to ground-water occurrence are described in this report. Previous investigators have described other aspects of the geology of the area in more detail, and their publications have been extensively consulted to assemble this geologic summary. More detailed geologic information about the area may be obtained by consulting the publications cited in the section on "Previous investigations." Geologic units are listed in table 3, and areas of outcrop are shown on plate 1.

Structure and stratigraphy

Parowan and Cedar City Valleys are within the Basin and Range physiographic province (Fenneman and Johnson, 1946); the eastern margin of their drainage-basin divide is approximately the western demarcation of the Colorado Plateau province. Structurally, parts of the valleys and their adjacent eastern uplands represent a zone of transition between the physiographic provinces, with some structural features of both. A small area of thrust faults is present in the southwest, but the valleys are characterized by fault-block structure common to the Basin and Range province. The uplands east of the valleys have been elevated by displacement along the Hurricane fault zone. East of the fault zone, rock strata dip gently eastward; gently inclined strata characterize much of the Colorado Plateau province.

The geologic units exposed in the area attain a maximum total thickness of more than 16,000 ft (4,900 m). The oldest formation exposed is the Kaibab Limestone of Permian age, along the Hurricane fault zone in the southern part of the area. Formations overlying the Kaibab span geologic periods from Triassic through Tertiary. Igneous laccoliths of Tertiary age intrude formations west of Cedar City Valley. Deposits of alluvium as valley fill, with some interbedded lava flows locally, attain thicknesses of more than 1,000 ft (300 m) in Parowan and Cedar City Valleys (Bjorklund and others, 1977, table 4). A summarized description of geologic units in the area and their water-bearing characteristics is given in table 3.

Alluvium deposited as valley fill is the principal aquifer of Parowan and Cedar City Valleys. The sources of valley fill are the adjacent hills and upland areas. The principal transporting medium is runoff in streams when sufficient volume and velocity occur to carry debris that may range in size from clay to boulders. As the streams enter the valleys and lose velocity with decreasing gradient, and decrease in flow due to spreading, division, seepage, and evaporation, alluvial material is deposited. Coarser material is deposited in the higher valley areas and progressively finer material is deposited toward the valley bottoms. The stream discharge and amount of deposition are irregular and vary over a wide range. The fluvial deposits of clay, silt, sand, and coarser material thus vary in thickness and extent. The aquifers within the valley fill are discontinuous or irregularly connected, as a labyrinth of water-yielding materials.

Table 3.--Generalized section of geologic units and their characteristics

(Dashed lines separate units that may be contemporaneous in part.) [Adapted from Averitt (1962, 1967), Averitt and Threet (1973), Lawrence (1965), Mackin (1954), Rowley, Anderson, and Williams (1975), Stewart, Poole, and Wilson (1972a, 1972b), and Thomas and Taylor (1946).]

System	Series	Group	Geologic units	Approximate maximum thickness (ft)	Lithologic and water-bearing characteristics
QUATERNARY	Holocene and Pleistocene		Dune sand	30	Light-orange to tan, fine-grained eolian sand deposits in irregularly shaped dunes, mostly stablized by natural vegetation; unit does not yield water to wells or springs in this area, but may add water to ground-water reservoir through infiltration from precipitation.
			Lakebed deposits	50 (?)	Compacted beds of evaporites, clay, and silt exposed seasonally on the floors of Quichapa and Rush Lakes in Cedar City Valley and Little Salt Lake in Parowan Valley; do not yield water to wells or springs in this area.
			Valley-fill deposits, undifferentiated	1,000 +	Valley-fill and stream-channel deposits of clay, silt, sand, gravel, cobbles, and boulders mainly of fluvial origin. but include lava flows and older lakebed deposits; the lenticular deposits of sand and coaser material yield from 1 to 4,000 gal/min to wells for domestic, stock, irrigation, industrial, and public supplies; valley-fill alluvium is the principal aquifer of the area.
			Basalt and other volcanic rocks, undifferentiated	800 +	Basaltic lava flows; also includes ignimbrites, pyroclastic layers, cinder-cone debris, and related volcanic deposits; unit yields water to springs and to a few wells where basalt is within the valley-fill deposits.
QUATERNARY and TERTIARY			Older alluvium, undifferentiated	500 +	Fanglomerate, older stream-terrace deposits, landslide debris, and colluvium; material ranges in size from clay to very large boulders; not reported to yield water to wells or springs in this area.
			Unconformity		
TERTIARY	Miocene and Oligocene		Volcanic rocks, undifferentiated; include Roger Park Basaltic Breccia, Mount Dutton and Bear Valley Formations, Bullion Canyon Volcanics, Page Ranch and Rencher Formations of Cook (1957), Quichapa Group, and Isom and Needles Range Formations.	2,500	Undifferentiated basalt, rhyolite, and latite lava flows, ignimbrites, pyroclastic layers, tuffs, eolian deposits of volcanic arenite, fluvial deposits of volcanic debris, mudflow breccia, and related deposits of volcanic origin; fractures in volcanic rocks yield water to springs in a few places.
			Unconformity		
	Oligocene and Paleocene		Claron and Wasatch Formations	1,400	Varicolored lacustrine limestone, marl, subaqueous tuff, and medium to coarse basal conglomerate in red clay matrix; yields as much as 900 gal/min of water to indivdual contact springs through joints and solutions channels. Provides recharge to ground-water reservoir in upland areas by infiltration of precipitation and snowmelt.
			Unconformity		
			Quartz-monzonite porphyry	-	Laccolithic intrusive rock; fractures may be permeable, but not reported to yield water.
			Unconformity		

Table 3.--Generalized section of geologic units and their characteristics--continued

System	Series	Group	Geologic units	Approximate maximum thickness (ft)	Lithologic and water-bearing characteristics
CRETACEOUS and CRETACEOUS(?)	Upper Cretaceous and Upper Cretaceous(?)		Cretaceous rocks, undifferentiated; include Kaiparowits and Iron Springs Formations; Wahweap and Straight Cliffs Sandstones, Tropic Shale, Dakota Formation, and Marshall Creek Breccia	2,700	Brown, yellow, and white sandstone, dark-gray shale, coal beds, coquina, conglomeratic sandstone, and limestone breccia; of marine, near-shore, paludal, and fluvial origins; yield water to springs and to a few wells.
			Unconformity		
JURASSIC	Middle Jurassic	San Rafael Group	Carmel Formation; includes Winsor Member and gypsiferous, banded, and limestone members	1,000	Red-brown thin-bedded sandstone and shale, white or gray gypsum in massive beds, orange and red-brown sandstone and shale, and tan-gray thin-to-medium bedded limestone; not reported to yield water in this area.
			Unconformity		
JURASSIC	Lower Jurassic and Triassic(?)	Glen Canyon Group	Navajo Sandstone	1,700	Red-orange medium-grained sandstone in massive sets of eolian crossbeds; yields water to springs in nearby areas.
TRIASSIC	Upper Triassic(?)	Glen Canyon Group	Kayenta Formation; includes Cedar City Tongue, Shurtz Sandstone Tongue of Navajo Sandstone, and lower member	1,600	Red, brown, and orange siltstone and very fine sandstone; not reported to yield water in this area.
TRIASSIC	Upper Triassic(?)	Glen Canyon Group	Moenave Formation; includes Springdale Sandstone, Whitmore Point(?), and Dinosaur Canyon Members	500	Red-brown siltstone and sandstone, thin to medium beds; not reported to yield water in this area.
			Unconformity		
TRIASSIC	Upper Triassic		Chinle Formation; includes Petrified Forest and Shinarump Members	400	Red-brown to red-gray and lavender mudstone, siltstone, and sandstone, with a basal green-gray conglomeratic sandstone; the basal sandstone is permeable, but the formation is not reported to yield water in this area.
			Unconformity		
TRIASSIC	Middle(?) and Lower Triassic		Moenkopi Formation; includes upper red member, Shnabkaib Member, middle red members, Virgin Limestone Member, lower red member, and Timpoweap Member	1,800	Dark red-brown and dark red mudstone, siltstone, and sandstone with sparse to abundant gypsum as veinlets and layers; light gray thin bedded limestone (Virgin Limestone Member) and yellow siltstone, gray limestone, and pebble to cobble conglomerate (Timpoweap Member); not reported to yield water in this area.
			Unconformity		
PERMIAN	Lower Permian		Kaibab Limestone (uppermost part of beta member)	125 (incomplete exposure)	Gray dense limestone with abundant gray and white chert nodules; not reported to yield water in this area.

Geologic units and their hydrologic characteristics

Geologic units that are exposed in the Parowan-Cedar City basin are listed and described and their water-bearing properties are summarized in table 3. Most of the wells in the area derive water from the unconsolidated valley fill of Quaternary age. Most of the larger springs discharge from Tertiary rocks but many springs issue from Mesozoic rocks, and some small springs and seeps issue from the Quaternary valley fill.

The ability of rocks to transmit water depends on their permeability which in turn depends on the size, number, and interconnection of the open spaces in the rock. The most productive water-bearing materials in an aquifer are generally well-sorted gravel and sand or consolidated rocks where permeability has been increased by fracturing or solution. Clay and silt or consolidated rocks with little or no interconnected open space have low permeability and do not readily yield water to wells or springs.

GROUND WATER

Source and recharge

Precipitation

Ground water in the Parowan-Cedar City drainage basin is derived almost exclusively from the precipitation within the basin. Normal annual precipitation within the basin, calculated from data on a map of Utah published by the U.S. Weather Bureau (no date), amounts to about 936,000 acre-ft (1,150 hm^3) of water of which about 484,000 acre-ft (597 hm^3) falls in the Parowan basin and about 452,000 acre-ft (557 hm^3) falls in the Cedar City basin. The amount of water falling in the basin during a particular year could be much greater or much less than the calculated normal. Most of the precipitation is consumed by evaporation and transpiration by vegetation in the basin, but some of it reaches the ground-water reservoirs. A greater percentage of the precipitation would go to recharge during a wet year than it would during a dry year.

The total annual recharge to the alluvial deposits in the basin, assuming it is equal to discharge plus or minus change in storage (see section on discharge), is about 80,000 acre-ft (98 hm^3). About half of the recharge is in Parowan Valley and half is in Cedar City Valley.

Recharge directly from precipitation occurs mostly in and near the mountains at places where rain or snowmelt enter permeable earth materials. Springs discharging from bedrock on mountain slopes indicate recharge from precipitation on the rocks at higher altitudes. Thus many springs discharging from or near the base of the Tertiary Wasatch Formation, at or near its contact with the underlying Cretaceous Kaiparowits Formation, indicates recharge to the Wasatch Formation higher on the mountain slope. Springs of this type are Warm Spring, (C-33-8)36b-S1, and Five-Mile Spring, (C-35-8)5c-S1; other springs are listed in Bjorklund, Sumsion, and Sandberg (1977, table 2).

Streams

Most of the recharge to the unconsolidated deposits in the valleys is by infiltration from perennial streams flowing from mountain canyons into permeable gravelly alluvial fans extending into the valleys from the mouths of canyons. Such streams are Parowan, Summit, Red, and Little Creeks in Parowan Valley and Coal Creek in Cedar City Valley. Intermittent and ephemeral streams also flow for brief periods onto the permeable gravelly soils along the valley edges during and following rainstorms and periods of snowmelt, and some of this water infiltrates to the ground-water reservoir. Ground-water mounds underlying alluvial fans, indicated by water-table slopes radiating away from the axis of the fans (pls. 2 and 3), are evidence of recharge on the fans.

Irrigation

Recharge to the valley fills in Parowan and Cedar City Valleys has been increased substantially by diverting water from streams for irrigation. An average of about 24,000 acre-ft (30 hm^3) of water flows in Coal Creek into Cedar City Valley annually and about 22,000 acre-ft (27 hm^3) flows into Parowan Valley in Parowan, Summit, Red, and Little Creeks (see table 2). Most of this water is diverted from the creeks for irrigation. Because the land surface on the alluvial fans where irrigation takes place is gravelly and quite permeable, between one-fourth and one-half of the water applied is believed to infiltrate to the ground-water reservoirs in the valley fill.

Subsurface inflow

Some recharge to the alluvial valley fills occurs by inflow from adjacent mountain blocks, especially those of the Markagunt Plateau southeast of Parowan Valley and east of the southern half of Cedar City Valley. Elevated ground-water levels, high above the valleys, are indicated by many springs and seeps in the mountains; and they probably result in ground-water movement toward the valleys. Some water presumably discharges from the mountain block directly into the alluvium. The greatest amount of water probably would be discharged into the valley fill in places where the limestone and conglomerate of the Tertiary Wasatch Formation, Tertiary and Quaternary volcanic rocks, and the Mesozoic Navajo Sandstone are in contact with the Quaternary valley fill.

Some water may enter the topographic basin from adjoining basins by subsurface inflow, but the amount probably is not significant. The ground-water divide between basins generally coincides with or is near the topographic divide, but under some conditions it may be offset from the topographic divide, thus indicating ground-water movement beneath the topographic divide. The principal area where some ground water could move from an adjoining topographic basin into the Parowan-Cedar City basin would be along the western edge of the Markagunt Plateau in the general Cedar Breaks area where the western slope of the plateau is much steeper than the eastern slope. This condition would tend to offset the ground-water divide eastward from the topographic divide, resulting in some ground-water movement westward in the intervening area.

The offset distance would not be large because the water-bearing formations on the plateau dip gently toward the east, and major ground-water movement is eastward toward the Sevier River.

Occurrence

Ground water in the unconsolidated valley fill in Parowan and Cedar City valleys occurs under both confined (artesian) and unconfined (water-table) conditions. The most productive aquifers are beds of coarse, clean, well-sorted gravel and sand that absorb water readily, store it in large quantities, and yield it readily to wells. Beds of silt and clay store much water but will not yield it readily to wells. Saturated silt and clay, however, will yield some water slowly to beds of gravel and sand. A diagram of the general occurrence of ground water in the project area is shown in figure 5. Conditions shown in the diagram most nearly resemble those near the Hurricane fault, but the principles and relations apply to the entire valley.

Confined conditions

Confined ground water occurs in the unconsolidated valley fill of both Parowan and Cedar City Valleys in localities where water-bearing beds of permeable gravel and sand are confined by capping or intervening beds of relatively impermeable clay or silt. The confining beds extend from the middle of the valley toward the sides of the valley (see fig. 5). As the water moves from recharge areas near the sides of the valleys through the permeable beds of gravel and sand toward lower areas near the center of the valley, the confining beds retard the upward movement of water toward the land surface, resulting in hydrostatic pressure in the aquifer. Confined ground-water conditions are believed to exist in all the valley except near the edges of the valley floor. However, the water-bearing beds are not completely confined as water under pressure will seep slowly through the confining beds of clay or silt, and the ground water is regarded as being under leaky confined, or leaky artesian, conditions.

Area of flowing wells

In about 36 mi^2 (93 km^2) of Parowan Valley during March 1974, the artesian pressure in the valley fill was great enough to cause water to flow from wells (see pl. 4). Measured hydrostatic heads ranged from less than 1 to 16 ft (0.3 to 4.9 m) above land surface. In October of the same year the flowing-well area had been reduced by about one-third by irrigation pumpage during the summer, but by March 1975 the artesian pressure had recovered and the flowing-well area was again about the same as it was in March 1974. The size of the flowing-well area has been declining since 1940. In 1940 Thomas and Taylor (1946, pl. 25) mapped flowing wells in Parowan Valley in a maximum area of 46 mi^2 (120 km^2).

In Cedar City Valley no flowing wells exist today (1975), although Thomas and Taylor (1946, pl. 18) indicated a maximum flowing-well area of more than 50 mi^2 (130 km^2) in 1939. Confined conditions in

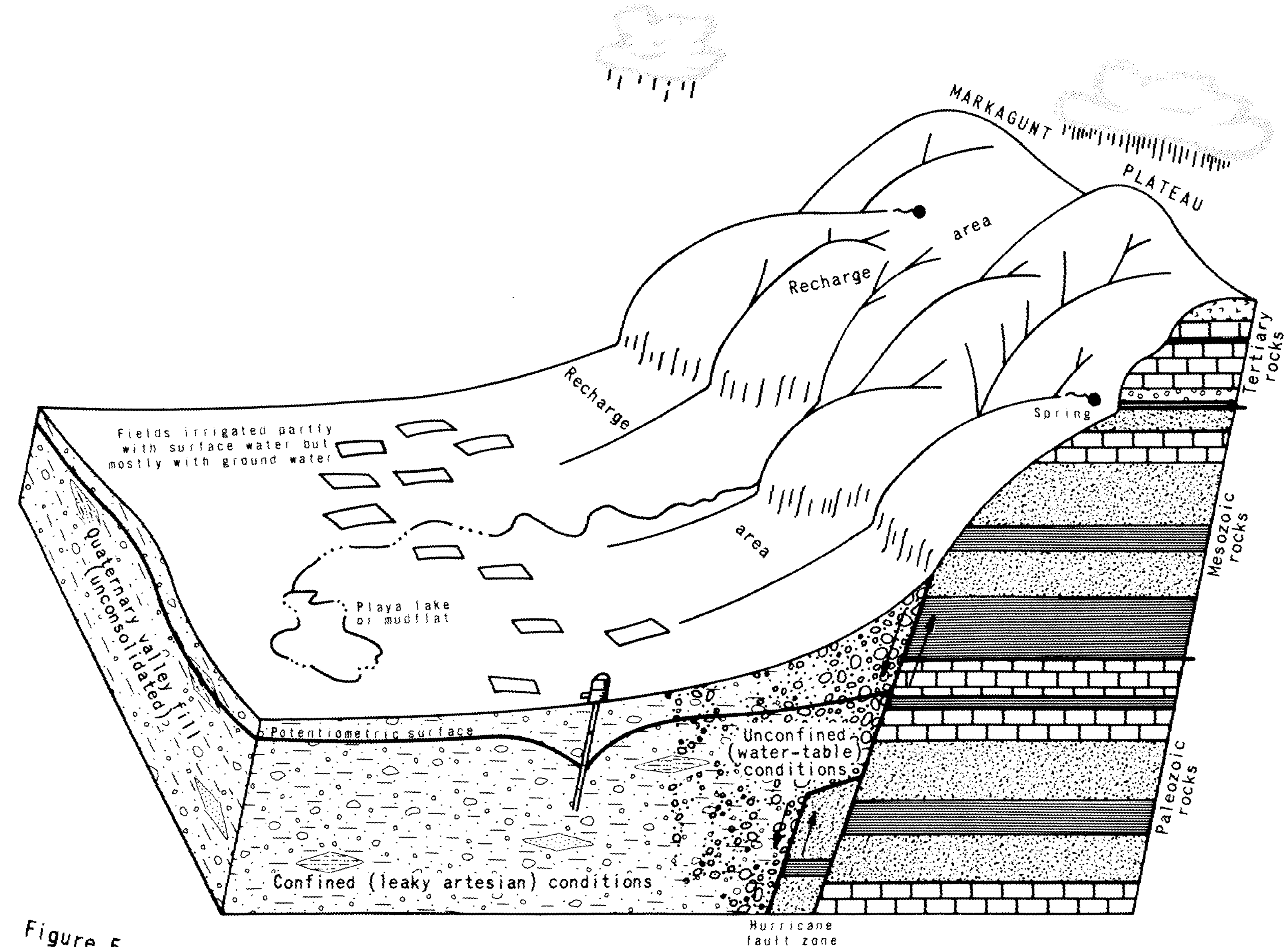


Figure 5.—General occurrence of ground water in the Parowan-Cedar City basin.

the aquifer continue to exist in the area, but artesian pressures are not great enough to cause flow at the land surface.

Unconfined conditions

Unconfined, or water-table, ground-water conditions exist in the unconsolidated valley fill in many places near the edge of the valley where the fill consists largely of coarse, granular, permeable material and the confining beds of clay and silt are absent or discontinuous (see fig. 5). The boundary between confined and unconfined ground water is indefinite and generally gradational rather than abrupt, and it changes in position as the potentiometric surface of the ground-water reservoir rises or declines. Unconfined conditions were indicated in the vicinity of the site of a test made at well (C-35-10)18cca-1 located 4 mi (6.4 km) north of Cedar City and about 0.5 mi (0.8 km) from the mountain front. This and other tests are discussed more fully in the section on aquifer characteristics and tests to determine hydrologic coefficients.

Perched conditions

Local perched ground-water bodies are common in the valley fill. They develop above the main ground-water reservoir in localities where beds of clay or other materials of low permeability intercept water percolating downward, or where water levels in lower aquifers are lowered by the withdrawal of water and the upper aquifers are less affected. Thus in two wells in Parowan Valley, (C-36-9)36daa-1 and (C-34-9) 16cdd-2, water was observed to cascade continually from an upper level in the well to the standing water in the well. At other wells, (C-34-9) 9bbd-1 and (C- 34-9)9bcc-1, water cascaded within the wells only during the irrigation season when many wells in the general vicinity were being pumped. Water would probably cascade into many wells in the area if it were not for the general practice of local drillers to seal off shallow or perched water-bearing zones and perforate well casings only in the more productive lower zones. No attempt was made to map perched ground-water bodies because they are usually poorly defined, some are seasonal, and they are not generally tapped by wells. Water in perched reservoirs eventually moves into the main and more productive reservoir.

Estimate of water in storage

More than 40 million acre-ft (50,000 hm^3) of water is estimated to be stored in the unconsolidated valley fills in Parowan and Cedar City Valleys with about half of the water in each valley, and additional water is stored in the consolidated rocks in the mountains adjoining the valleys. This estimate is based on the assumptions that the saturated fill in each valley is more than 1,000 ft (300 m) thick and that the average total porosity of the unconsolidated fill material is about 20 percent. Only a small percentage of the total water, however, is economically available for development. Bodies of gravel or sand yield water readily to wells; whereas, clay or silt bodies retain most of their stored water because of capillarity and low permeability. Changes in storage due to declining water levels will be discussed in the section on fluctuations of water levels and long-term trends.

Aquifer characteristics and tests

The capacity of an aquifer to transmit and store water is described by the transmissivity of the aquifer, the hydraulic conductivity of the water-bearing material, and the storage coefficient of the aquifer. These terms are defined below.

Transmissivity (*T*) is the rate at which water is transmitted through a unit width of the aquifer under a unit hydraulic gradient. The units for *T* are cubic feet per day per foot ($ft^3/d/ft$), which reduces to ft^2/d. The term transmissivity replaces the term coefficient of transmissibility, which was formerly used by the U.S. Geological Survey and which was reported in units of gallons per day per foot. To convert a value for coefficient of transmissibility to the equivalent value of transmissivity, divide by 7.48; to convert from transmissivity to coefficient of transmissibility, multiply by 7.48.

The hydraulic conductivity (*K*) of a water-bearing material is the volume of water that will move through a unit cross section of the material in unit time under a unit hydraulic gradient. The units for *K* are cubic feet per day per square foot ($ft^3/d/ft^2$), which reduces to ft/d. The term hydraulic conductivity replaces the term field coefficient of permeability, which was formerly used by the U.S. Geological Survey and which was reported in units of gallons per day per square foot. To convert a value for field coefficient of permeability to the equivalent value of hydraulic conductivity, divide by 7.48; to convert from hydraulic conductivity to coefficient of permeability, multiply by 7.48.

The storage coefficient (*S*) of an aquifer is the volume of water it releases from or takes into storage per unit surface area of the aquifer per unit change in head. *S* is a dimensionless number. Under confined conditions, *S* is typically small, generally between 0.00001 and 0.001. Under unconfined conditions, *S* is much larger, typically from 0.05 to 0.30.

The transmissivity, hydraulic conductivity, and storage coefficient of aquifers in the unconsolidated fill of Parowan and Cedar City Valleys were determined by aquifer tests. The tests consisted of observing the drawdown effects of pumping a well on other wells in the same vicinity and analyzing the data using methods described by Ferris and others (1962, p. 91-103), Cooper (1963, p. C43-C55), and Lohman (1972, p. 11-21, 30-34). The results of four aquifer tests in Parowan Valley and five in Cedar City Valley are given in table 4. The transmissivity was also estimated for pumped wells from specific capacity (rate of discharge per foot of drawdown) data for 55 wells in Parowan Valley and 55 wells in Cedar City Valley using a method described by Theis, Brown, and Meyer (1963, p. 331-340).

Table 4.--Results of aquifer tests

Storage coefficient: E, estimated.

Pumped well	Observation well	Date and length of test	Distance to pumped well (ft)	Discharge of well (gal/min)	Trans-missivity (T) (ft^2/d)	Average hydraulic conductivity (K) (ft/d)	Storage coeffi-cient (S)	Water-bearing material	Saturated section open to well (ft)	Type of test	Rating of test
				PAROWAN VALLEY							
(C-32-8)12bac-1		May 13-31, 1974 430 hrs		2,651				Volcanic debris			
	(C-31-7)31acc-1		12,000			-	-	Gravel	24		
	31cca-1		8,976		406,000	-	0.0056	Volcanic debris		Drawdown	Good
	(C-32-7)6cda-1		6,706		677,000	-	.0028	do	153	do	Do.
	(C-32-8)12adb-1		3,060		193,000	476	.0011	do	405	do	Do.
	12cdb-1		3,040		202,000	700	.0007	do	288	do	Do.
	12dba-1		3,010		102,000	-	.014	-		do	Fair
	13bca-1		5,550		330,000	-	.018	Volcanic debris	154	do	Good
(C-33-9)14dbd-1	(C-33-9)14dbd-1	Oct. 18-21, 1974 76 hrs		1,000	1,400			Gravel, sand, and		Recovery	Do.
	14adc-1		3,700		11,000	37	.02	silt	298	do	Poor
(C-34-9)7ccc 2		July 31-Aug. 2,		575				Gravel			
	(C-34-9)7ccc-1	1974 17 hrs	95		6,300	26	.00007	do	245	do	Good
(C-34-9)9bca-1		Mar. 25-27, 1975 50 hrs		1,310				do	560		
	(C-34-9)8aaa-1		2,200		17,900	35	.003	do	607	Drawdown	Do.
	8acc-1		3,900		-		-	do		do	Poor
	8dda-1		2,600		9,100	37	.0006	do	246	do	Good
	9bba-1		2,050		13,400	20	.0005	do	664	do	Do.
	9bbd-1		600		6,030	26	.0003	do	232	do	Do.
	9bcc-1		1,050		8,920	32	.0004	do	278	do	Do.
	9dba-1		2,600		11,300	21	.0005	do	540	do	Fair
				CEDAR CITY VALLEY							
(C-35-10)18cca-1		Apr. 16-17, 1975 24 hrs		863				Gravel	188		
	(C-35-10)18cbd-1		850		-	-	0.2E	do	-	Drawdown	Fair
	18ccb-1		1,000		-		.2E	do	116	do	Do.
	(C-35-11)13ada-1		2,650		-	-	.2E	do	201	do	Do.
	13ddb-1		2,300		-	-	.2E	do	716	do	Do.
	24aab-1		2,900		-	-	.2E	do	-	do	Do.
(C-35-10)18cca-1	(C-35-10)18cca-1	Apr. 17-21, 1975 95 hrs	0	863	5,200	28	.2E	do	188	Recovery	Good
(C-36-12)32ccb-1		Jan. 22-23, 1975 30 hrs		1,345				do	507		
	(C-36-12)32ccc-1		652		42,000	169	.0013	do	249	Drawdown	Very good
	32dcc-1		2,700		-		-	do	218	do	Poor
	32dcd-1		3,900		-		-	do	254	do	Do.
	(C-37-12)5bbb-1		1,372		52,000	251	.01	do	207	do	Fair
	5bcb-1		3,100		15,000	82	.0015	do	182	do	Good
(C-36-12)32ccc-1	(C-36-12)32ccc-1	Jan. 23-25, 1975 44 hrs	652		46,000	185	.0015	do	249	Recovery	Do.
(C-37-12)14abc-1	(C-37-12)14abc-1	July 23-24, 1974 14 hrs	0	600	10,000	44	-	do	226	do	Do.
(C-37-12)23acb-1		Apr. 20-22, 1959 86 hrs	0	845				do	254		
	(C-37-12)23aca-1		1,000		2,540	13	.0005	do	193	Drawdown	Do.
	23cbd-1		2,650		2,700	14	.013	do	197	do	Do.

Transmissivity pattern of valley fills

A map showing lines connecting points of approximately equal transmissivity in Parowan and Cedar City Valleys is shown on plate 2. The map was constructed from transmissivity data collected during aquifer tests (table 4) and from adjusted transmissivities estimated from the specific capacity at 110 wells. At several wells where transmissivity was determined by both aquifer tests and specific-capacity data, the more dependable aquifer tests indicated transmissivities 40 to 60 percent greater than the specific-capacity data. This was probably due to excessive drawdown in the pumped wells caused by insufficient perforation, or partially clogged perforation, in the well casings. The transmissivities estimated from specific capacities were therefore increased to adjust for that difference.

In Parowan Valley the area of greatest transmissivity and greatest potential yield is in the northern part of the valley. The aquifer in the unconsolidated valley fill in this area consists largely of volcanic detritus. High transmissivity in this area was also indicated by a very flat potentiometric surface of the ground-water reservoir (pl. 5). Static water-level altitudes at wells in the area show local hydraulic gradients to be less than 1 ft/mi (0.2 m/km). Moderately high transmissivity is indicated northwest of Parowan on the middle and lower parts of the Parowan Creek alluvial fan. Comparatively low transmissivity is indicated in the lowest part of the valley in the vicinity of Little Salt Lake where most of the unconsolidated valley fill is silt and clay.

In Cedar City Valley the greatest transmissivity probably is that of the Coal Creek alluvial fan about 3 mi (5 km) northward and north-westward from Cedar City where the valley fill is coarse and graded. Moderately high transmissivity exists northward, southward, and westward for several miles and then decreases northward with distance from the Coal Creek fan. High transmissivity occurs also in the vicinity of and northeast of Rush Lake in the northern part of the valley where volcanic rocks in the valley fill are permeable. High transmissivity occurs also southwest of Quichapa Lake where the alluvial fill is derived from Tertiary volcanic mountains on the western side of the valley. Little is known of the extreme northern part of Cedar City Valley between Rush Lake and the Black Mountains, but the few wells that have been drilled in the area had low yields, which suggests that it is generally an area of low transmissivity.

Artesian and water-table areas

Of the nine aquifer tests listed in table 4, six resulted in storage coefficients ranging from 0.01 to 0.00007 which indicated confined conditions in the aquifer; one test indicated unconfined conditions. Leaky artesian conditions are inferred, from the results of the aquifer tests and other considerations, to underlie most of the valley floor in both Parowan and Cedar City Valleys.

Water-table conditions were indicated by results of a pumping test at well (C-35-10)18cca-1 near the edge of the valley fill about 4 mi (6.4 km) northeast of Cedar City. Water levels in observation wells located 850 to 2,900 ft (260 to 880 km) from the pumped well were not affected by pumping at a rate of 863 gal/min (54.4 L/s) for 24 hours; all the wells penetrated coarse gravel in the same aquifer.[1] These data

[1]Seasonal drawdown does reach well (C-35-10)18cbd-1, a non-pumped observation well, 850 ft (260 m) from the pumped well. A hydrograph of the well (see fig. 17) indicated seasonal fluctuation of more than 20 ft (6 m) because of pumping from other wells in the vicinity. In recent years the October-November water-level measurements at the well have been discontinued because the well is dry for a period following the irrigation season, but the well contains water when measurements are made in March.

showed that the cone of depression around the pumped well expanded at a rate of less than 850 ft (259 m) in 24 hours, or less than 35.4 ft (10.8 m) per hour. This relatively slow spreading rate indicated water-table conditions, although the test was not long enough to yield data from which the storage coefficient could be computed. An estimated storage coefficient of 0.2 was used for this well, which is about the average for an unconfined aquifer (Lohman, 1972, p. 8).

Interference between wells

Well interference occurs when a pumped well induces drawdown of water level in other wells in the vicinity. In artesian areas, such as most of Parowan and Cedar City Valleys, drawdown by interference and recovery when pumping stops is relatively rapid and far-reaching because the interference is caused mostly by a reduction of hydrostatic pressure in the confined aquifer and does not necessarily require the withdrawal of a large amount of water from the aquifer. In water-table areas, drawdown and recovery of water levels are relatively slow and localized. They are related mostly to the removal of water from the cone of depression surrounding the pumped well. Mutual interference between wells occurs when two or more pumped wells induce additional drawdown in each other. Mutual interference among pumped wells is common in both Parowan and Cedar City Valleys during the summer when many wells are pumped for irrigation.

Interference between wells in Parowan Valley was observed in several aquifer tests. At Buckhorn Flats, pumping from well (C-32-8) 12bac-1 at an average rate of 2,651 gal/min (167.3 L/s) caused measurable drawdown in well (C-32-8)12adb-1, at a distance of 3,060 ft (933 m) 5 minutes after pumping began; the drawdown was 1.27 ft (0.387 m) after 18 days of pumping. The velocity of the drawdown impulse, therefore, was greater than 600 ft (200 m) per minute. In the same test, drawdown started in well (C-31-7)31cca-1, at a distance of 8,976 ft (2,736 m) in less than 160 minutes and developed to 0.41 ft (0.12 m) at 16 days of pumping. In the southern part of the valley, pumping of well (C-34-9) 9bca-1 at 1,310 gal/min (82.7 L/s) caused drawdown in well (C-34-9) 9bbd-1 at a distance of 600 ft (200 m) to start in less than 3 minutes and increase to 19.30 ft (5.88 m) in 46 hours. At the same test, the water level in well (C-34-9)9bcc-1, 1,050 ft (320 m) from the pumped well, started to decline in 5 minutes and declined to 10.64 ft (3.24 m) in 48 hours. The average drawdown impulse velocity in these instances was greater than 200 ft (60 m) per minute. Drawdowns were observed at distances from the pumped well ranging to 2,600 ft (790 m).

In Cedar City Valley, pumping of well (C-36-12)32ccb-1 at 1,345 gal/min (84.86 L/s) caused drawdown to start at well (C-36-12)32ccc-1, 652 ft (199 m) away in 3 minutes and increase to 2.76 ft (0.84 m) in 30 hours. Also, well (C-37-12)23acb-1, when pumped at 845 gal/min (53.3 L/s), induced drawdown in well (C-37-12)23aca-1, 1,000 ft (300 m) away within 2 minutes, and the drawdown increased to 15.16 ft (4.62 m) in 46.1 hours. It took 3 hours, however, for the drawdown impulse to reach an automatic recording gage at well (C-37-12)23cbd-1, 2,650 ft (808 m) from the pumped well, but the drawdown then increased to 5.50 ft (1.7 m) in 86 hours.

From the facts presented in the two preceding paragraphs, it is evident that the effects of mutual interference among pumped wells in parts of Parowan and Cedar City Valleys during an irrigation season is substantial. Heavy and continuous pumping from a well withdrawing water from a confined aquifer can induce additional drawdown in another pumped well a mile or more away during a pumping season. As additional wells within the effective radius are pumped, the drawdown in an affected well will increase.

Possible effects of faulting in the valley fill on an aquifer test

An aquifer test was conducted at the site of pumped well (C-34-9) 9bca-1 and seven other wells to be observed in its general vicinity, about 2.5 mi (4.0 km) west-northwest of Parowan, partly to determine the effects of inferred fault in the saturated valley fill (table 4). Two faults--the Summit Creek fault and the Culver fault--were mapped as inferred by Thomas and Taylor (1946, pl. 3) and were shown to pass through the prospective aquifer-test area. Thomas and Taylor (1946, p. 51-64, p. 88, p. 155) discussed faults in Parowan and Cedar City Valleys and suggested that some faults in the valley fill probably have a subsurface damming effect, thus restricting the movement of ground water from one part of the alluvial basin to another part. The effect of pumping a well on one side of a fault on water levels in wells on the other side was considered.

During the test pumping of well (C-34-9)9bca-1, drawdown was observed at two wells on the opposite side of the inferred Culver fault and at one well on the opposite side of the inferred Summit Creek fault. At well (C-34-9)9dba-1, 2,600 ft (790 m) east-southeast of the pumped well and about 2,000 ft (600 m) east-southeast of the Culver fault, 0.19 ft (0.068 m) of drawdown was measured 19 minutes after the start of pumping; drawdown was 5.45 ft (1.66 m) after 50 hours. The average velocity of the drawdown impulse in the aquifer, therefore, was greater than 130 ft (40 m) per minute. Likewise, at well (C-34-9)8dda-1, 2,600 ft (790 m) south-southwest of the pumped well and about 1,500 ft (460 m) south-southwest of the intervening Culver fault, 0.31 ft (0.09 m) of drawdown was measured after 35 minutes of pumping; the drawdown increased to 4.35 ft (1.33 m) after 49.5 hours of pumping.

At well (C-34-9)8acc-1, 3,900 ft (1,200 m) west of the pumped well and about 500 ft (150 m) west of the inferred Summit Creek fault, drawdown was 0.06 ft (0.02 m) after 70 minutes of pumping, and increased to 0.64 ft (0.20 m) in 24.7 hours. The average velocity of the initial drawdown impulse, therefore, was about 56 ft (17 m) per minute.

The inferred faults involved in the aquifer test apparently did not have any noteworthy damming, blocking, or restricting effect on water in the unconsolidated valley fill. The drawdown impulse in the aquifer, induced by pumping the well, crossed the faults. Thus the inferred faults would have little bearing on well interference in the vicinity. The average velocity of the drawdown impulse was less in the instances where the fault lines were crossed, mostly because the total distances were greater and the velocity apparently decreases with distance from the pumped well.

Movement

Ground water is seldom stationary, but moves by force of gravity in the direction of a hydraulic gradient. The direction it moves in almost any part of Parowan and Cedar City Valleys can be inferred from plate 5 which shows the configuration of the potentiometric surface of the ground-water reservoir during March 1974.

The arrows on the map, which are perpendicular to the water-level contours, indicate the general direction the ground water moves. A map showing the configuration and direction of ground-water movement during October-November 1974 is presented on plate 6.

The pattern of water-level contours and ground-water movement directions for March and October-November 1974, shown on plates 5 and 6, are generally similar, but differ locally. A general decline of water levels due to pumping for irrigation during the summer of 1974 caused most of the contours to move toward the margins of the valleys for distances ranging from a few hundred feet to more than a mile. These contours moved back toward the March position when water levels recover between pumping seasons. Locally the direction of movement is altered or even reversed by pumping from wells. Water-level fluctuations are discussed in a later section.

In comparison to movement of surface water, the rate of ground-water movement through the unconsolidated valley fill is slow, generally ranging from less than 1 ft (0.3 m) to a few feet per day. The quantity of water moving through a section of the fill, however, may be large or small, depending on several factors, and it may be expressed by a form of Darcy's law:

$$Q = T\ I\ L$$

in which Q is the discharge in cubic feet per day, T is the coefficient of transmissivity, I is the hydraulic gradient in feet per foot, and L is the width of the cross section in feet through which the discharge moves.

Configuration of the potentiometric surface

The potentiometric surface of the ground-water reservoir includes (1) the surface of the saturated zone, or water table, in areas where the ground water is not confined and (2) the imaginary surface defined by the hydrostatic head of the ground water in areas where it is confined. In Parowan and Cedar City Valleys the potentiometric surface is irregular and sloping (pls. 5 and 6); it generally slopes from the mountain front of the Markagunt Plateau east of the valleys, where most of the recharge to the ground-water reservoir takes place, toward the lower parts of the valleys, where most of the discharge of ground water occurs. Hence, the slope of the potentiometric surface indicates the movement of ground water from the areas of recharge to the areas of discharge.

Relation of the potentiometric surface to land surface

The relation of ground-water levels to land surface during March 1974 is shown on plate 4. Water-level data given in Bjorklund, Sumsion, and Sandberg (1977, table 3) show a range from 16 ft (5 m) above land surface to 266 ft (81 m) below land surface in Parowan Valley and from 2 to 250 ft (0.6 to 76 m) below land surface in Cedar City Valley. Some deeper water levels are reported in the mountainous areas within the drainage basin. However, the static water level in most wells in both valleys is less than 100 ft (30 m) below land surface. In the area where the potentiometric surface is above the land surface, about 36 mi^2 (93 km^2), in Parowan Valley, the wells flow and some water moves upward through the confining silts and clays toward the land surface where it is consumed by evaporation and by the transpiration of phreatophytes, mainly greasewood.

Movement of ground water in the mountain areas

In the consolidated rocks of the mountains bordering Parowan and Cedar City Valleys, ground water presumably moves mainly through fractures, joints, solution channels, and along bedding planes where permeable rocks overlie relatively impermeable rocks. Much of the water moves in perched zones. For example, many contact springs discharge near the base of the Wasatch Formation which is mostly limestone and is known to contain many solutional openings. Also some volcanic beds contain many joints which were formed by shrinkage when the hot lava cooled, and these provide channels through which the water can move. Likewise, the Mesozoic sandstones, particularly the Navajo Sandstone, have enough porosity and permeability to permit the movement of water.

Little is known regarding the configuration of the main (lowermost) zone of saturation in the mountains, but its potentiometric surface is generally higher in altitude than the valley floors, and thus the hydraulic gradients in the mountains slope toward the valleys and the ground water moves toward the valleys. Some of the water discharges at springs and seeps along the way, but the remainder eventually discharges directly into the valley fill.

Fluctuation of water levels

Ground-water levels in Parowan and Cedar City Valleys are caused to rise mainly by recharge from streams and surface-water irrigation; they decline during periods of drought and by pumping from wells for irrigation. In areas where water levels are not affected greatly by development, they usually rise in years when annual precipitation is greater than average and decline when precipitation is less than average. This is illustrated in both Parowan and Cedar City Valleys in figures 2 and 3. Also note the same general form in the hydrographs of wells (C-34-8)5bca-1, (C-34-9)16cdd-1, (C-35-11)17dcd-1, (C-35-11)27bbc-1, (C-35-12)18ddd-2, and (C-36-11)8aab-1 in figure 17.

Water-level data have been collected at selected wells in Parowan Valley since 1931 and in Cedar City Valley since 1935. Water-level fluctuations for selected wells are shown in figure 17. During the current investigation, water levels were measured at approximately 240 wells in March 1974, October and November 1974, and March 1975 to determine the relation of water level to land surface (pl. 4) and the general annual and seasonal changes in water levels (fig. 17). Monthly water levels were measured at 12 selected wells and 2 wells were equipped with automatic water-level recording gages. Basic water-level data for this report are given in Bjorklund, Sumsion, and Sandberg (1977). Changes in water level in wells from March 1974 to October-November 1974 are shown in figure 6. The declines are generally the result of residual drawdowns from pumping for irrigation, most of which recovered by the following March. Compare figure 6 with figures 9 and 10 which show general changes in water levels from March 1974 to March 1975 and contain some additional recovery from residual drawdown and some recovery due to recharge during the winter and early spring of 1974-75.

Seasonal fluctuations

Seasonal changes of ground-water level are caused by seasonal changes of recharge and discharge. In Parowan and Cedar City Valleys the hydrographs of water level in wells follow a similar pattern but differ greatly in magnitude. The pattern is drawdown (or decline) of water levels during the irrigation season which occurs mostly during May through September when many irrigation wells are pumped, and recovery (or rise) of water levels occurs mostly during October-May. All the hydrographs in both valleys show rising water levels throughout the recovery season, which indicate that recovery from the preceding pumping season is not complete when pumping starts late in the spring.

Parowan Valley.--Figure 7 illustrates seasonal fluctuations in Parowan Valley. The hydrographs of wells (C-31-7)31cca-1 and (C-32-8) 13bca-1 are typical of seasonal fluctuations in the Buckhorn Flats area in the northern part of the valley. Here, water is pumped from highly transmissive valley fill composed largely of volcanic debris. Although the fluctuations are relatively small, the interference effects of pumping are far reaching (see sections on aquifer tests and interference). Water levels throughout this area, which includes more than 20 mi^2 (50 km^2), apparently fluctuate according to the same pattern.

The hydrograph of well (C-33-9)24cdd-1 in figure 7 shows relatively large seasonal fluctuation due to interference from pumped irrigation wells more than a mile to the south. After the pumping season of 1974, the water level rose steadily from more than 15 ft (5 m) below land surface and reached land surface late in the winter when the well started to flow. The flow then increased steadily until pumping started in the other wells late in the spring; then it stopped flowing abruptly a few hours after pumping started. Other flowing wells 0.5 to 2 mi (0.8 to 3 km) to the east do not seem to be affected by interference from pumped wells to the south.

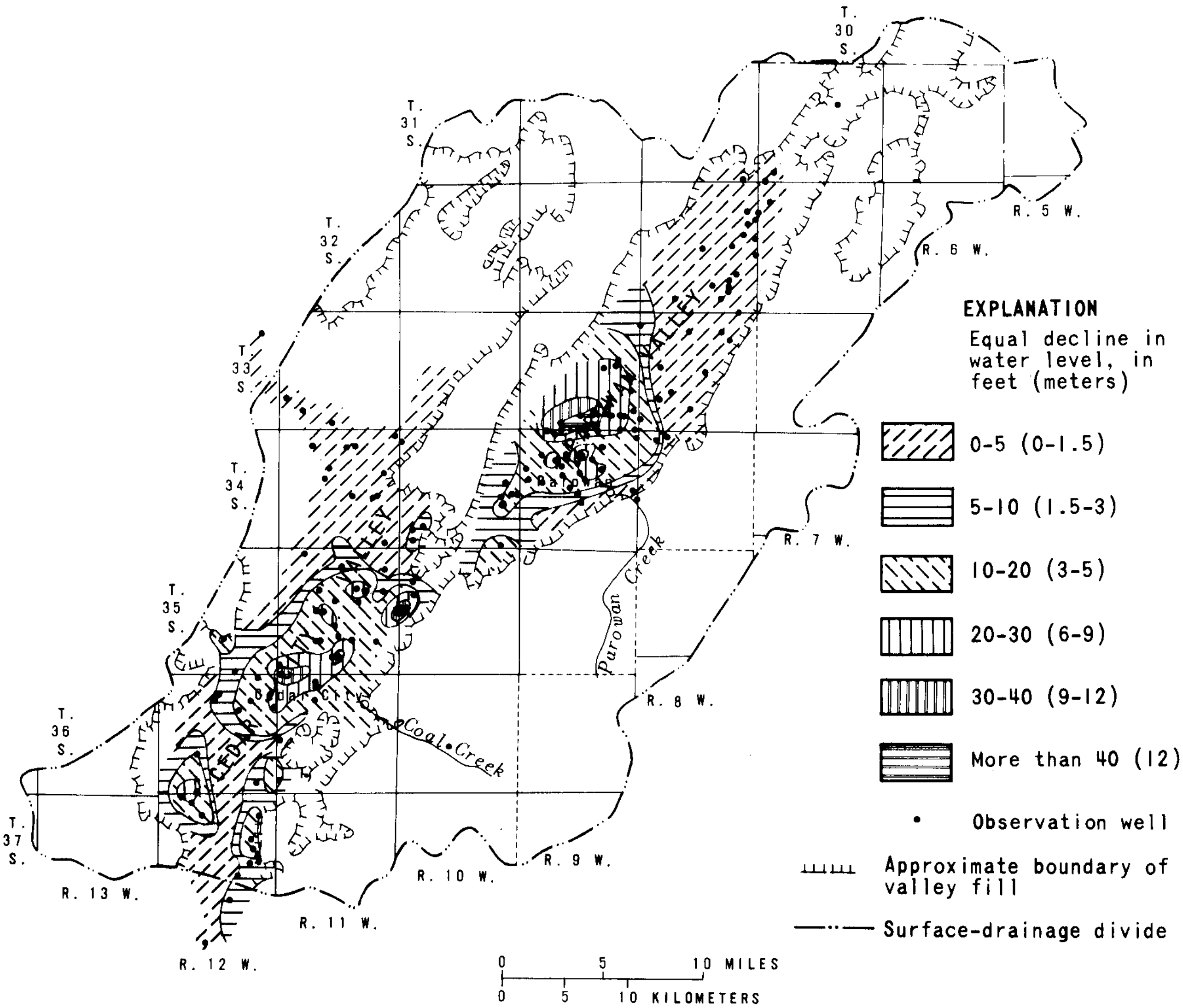


Figure 6.—Water-level declines in Parowan and Cedar City Valleys from March 1974 to October-November 1974.

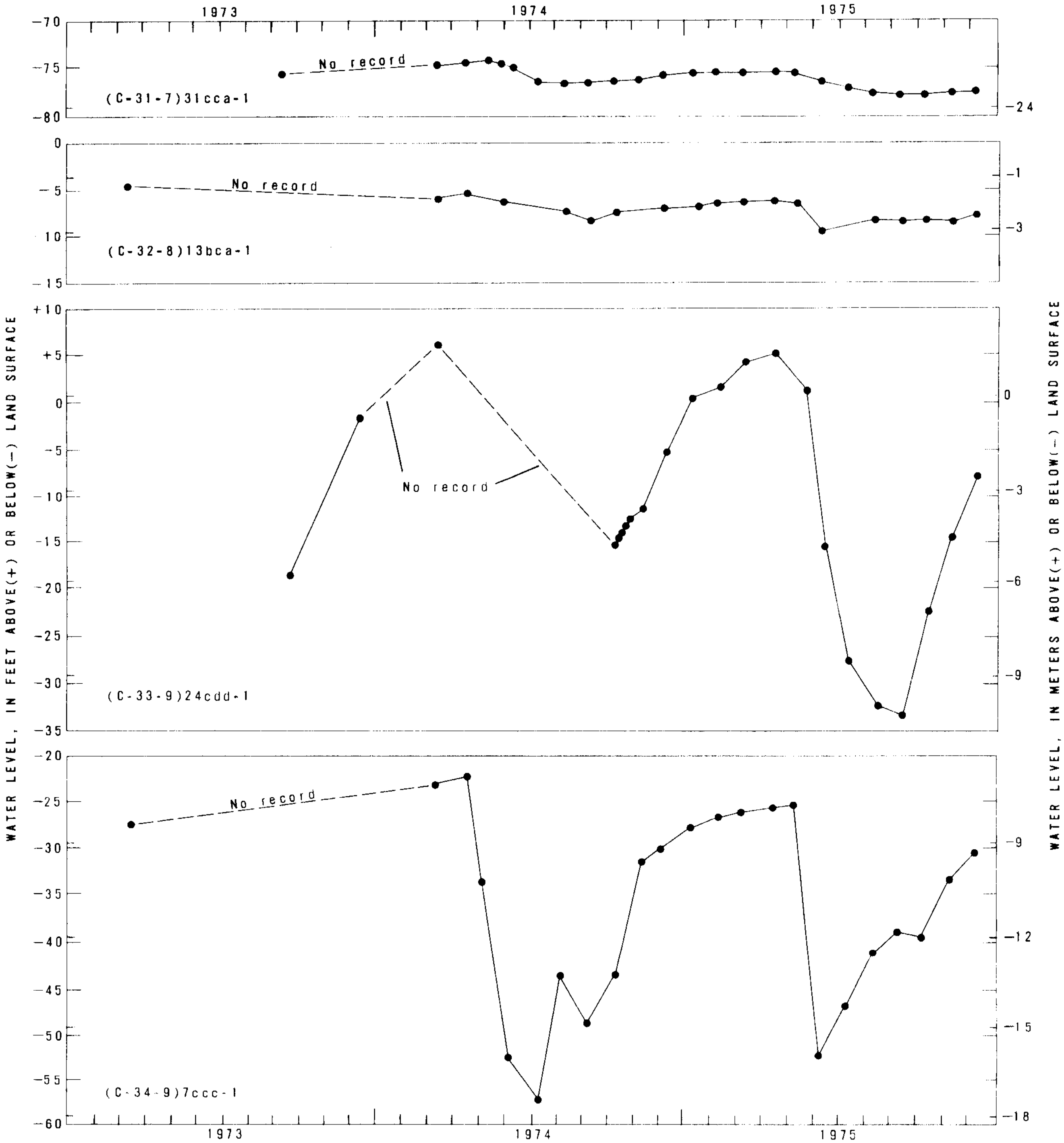


Figure 7.—Seasonal fluctuation of water levels in selected wells in Parowan Valley, 1973-75.

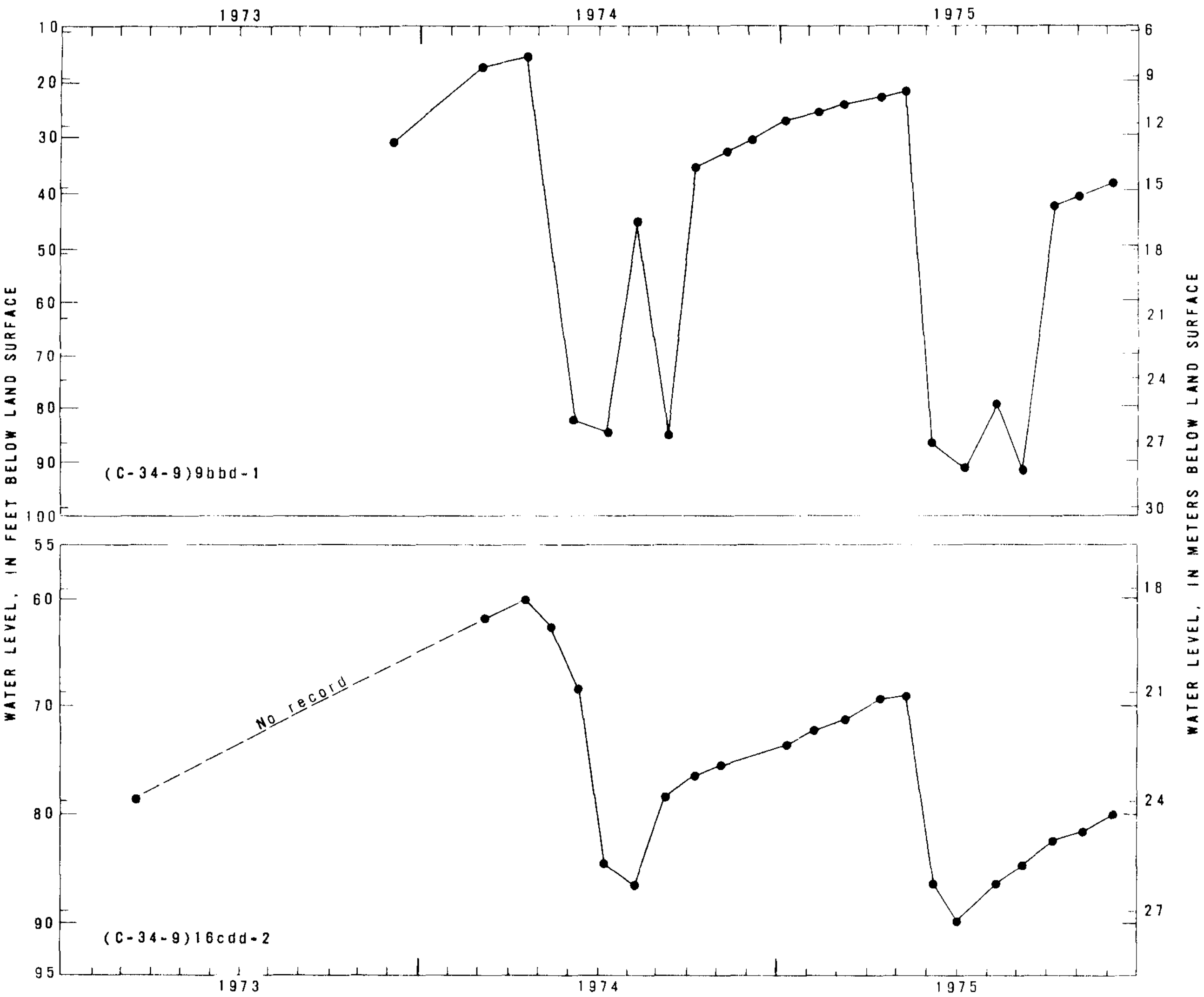


Figure 7.— Continued.

Seasonal water-level fluctuations in the heavily pumped parts of Parowan Valley north and west of Parowan are illustrated in figure 7 by the hydrographs of wells (C-34-9)16cdd-1, (C-34-9)9bbd-1, and (C-34-9) 7ccc-1. All these hydrographs show interference effects caused by pumped wells less than 0.25 mi (0.4 km) away, and all show steadily rising water levels just before they start to decline because of pumping of other wells.

Cedar City Valley.--Seasonal water-level fluctuations in wells in Cedar City Valley are shown by hydrographs in figure 8. Well (C-35-11) 4dda-1 is remote from areas of concentrated pumping and is affected only slightly by interference. Most of the general decline shown in the 3-year period, 1973-75, is probably adjustment from recharge in the vicinity which occurred during the winter and spring of 1972-73 and brought water levels almost to the land surface in the vicinity in March 1973.

Fluctuations at the margins of pumped areas in Cedar City Valley, but quite remote from the center of heaviest pumping, are shown by the hydrographs of wells (C-36-12)10dda-1, (C-36-12)20ddc-1, and (C-37-12) 9bbb-1. Although these wells are more than 2 mi (3 km) apart, the hydrographs have the same general shape. They all show interference (drawdown) from pumped wells 0.25 to 2 mi (0.4 to 3 km) away, and they all show recovery taking place immediately prior to the following pumping season.

Long-term trends

During most of the years since 1940, the amount of water discharged from the ground-water reservoir by wells, springs, and evapotranspiration has been greater than the amount of water added to the reservoir by recharge. Consequently, the overall trend of ground-water levels (see section on recharge) has been downward. The principal cause of the downward trend has been the withdrawal of water by wells. The decline has been greatest during and following dry years as a consequence of lessened recharge plus additional pumping. It has been least during and following wet years as a consequence of greater recharge and reduced pumping. In March 1974, following a period of excessive precipitation, most water levels were several feet higher than they were a year earlier, but they declined to new lows in March 1975 because of less-than-average precipitation and record pumping during 1974 (figs. 9 and 10).

The approximate decline of ground-water levels for the 35-year period, 1940-74, in Parowan and Cedar City Valleys is shown as areas on a map in figure 11. This illustration was constructed by comparing 1974 potentiometric water-level contour maps (pls. 5 and 6) with maps showing similar data for 1940 (Thomas and Taylor, 1946, pls. 13 and 23). Declines in Parowan Valley are based on data collected during September and October in 1940 and 1974, whereas declines in Cedar City Valley are based on data collected in March and April for the same years. Estimates of declines were made also from the hydrographs in figure 17. As some of the hydrographs show little decline between 1940 and 1950, some estimates of decline were based on 1950-74 hydrographs.

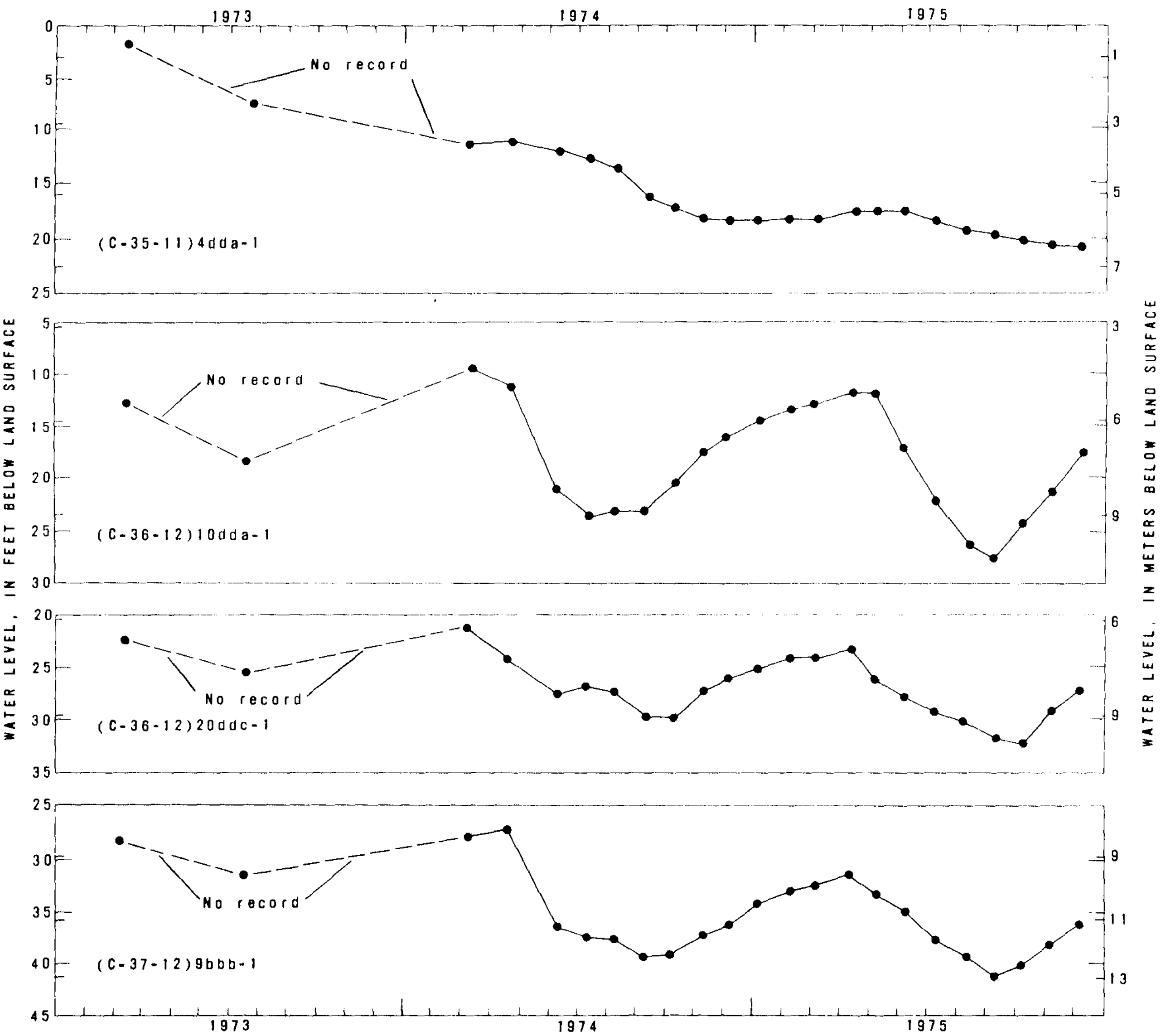


Figure 8.— Seasonal fluctuation of water levels in selected wells in Cedar City Valley, 1973-75.

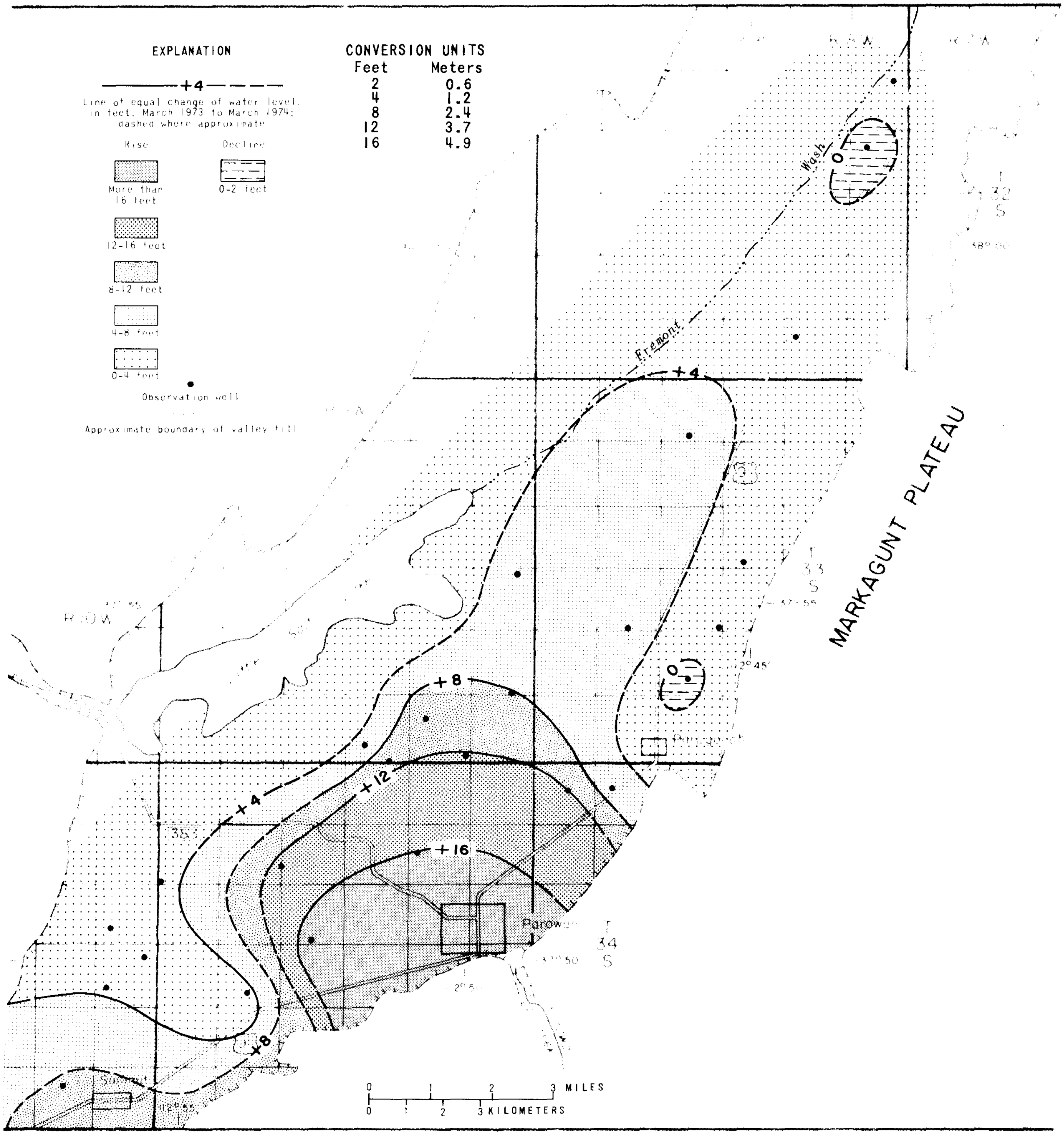


Figure 9.—Maps of Parowan Valley showing changes in ground-water levels, March 1973 to March 1974 and March 1974 to March 1975.

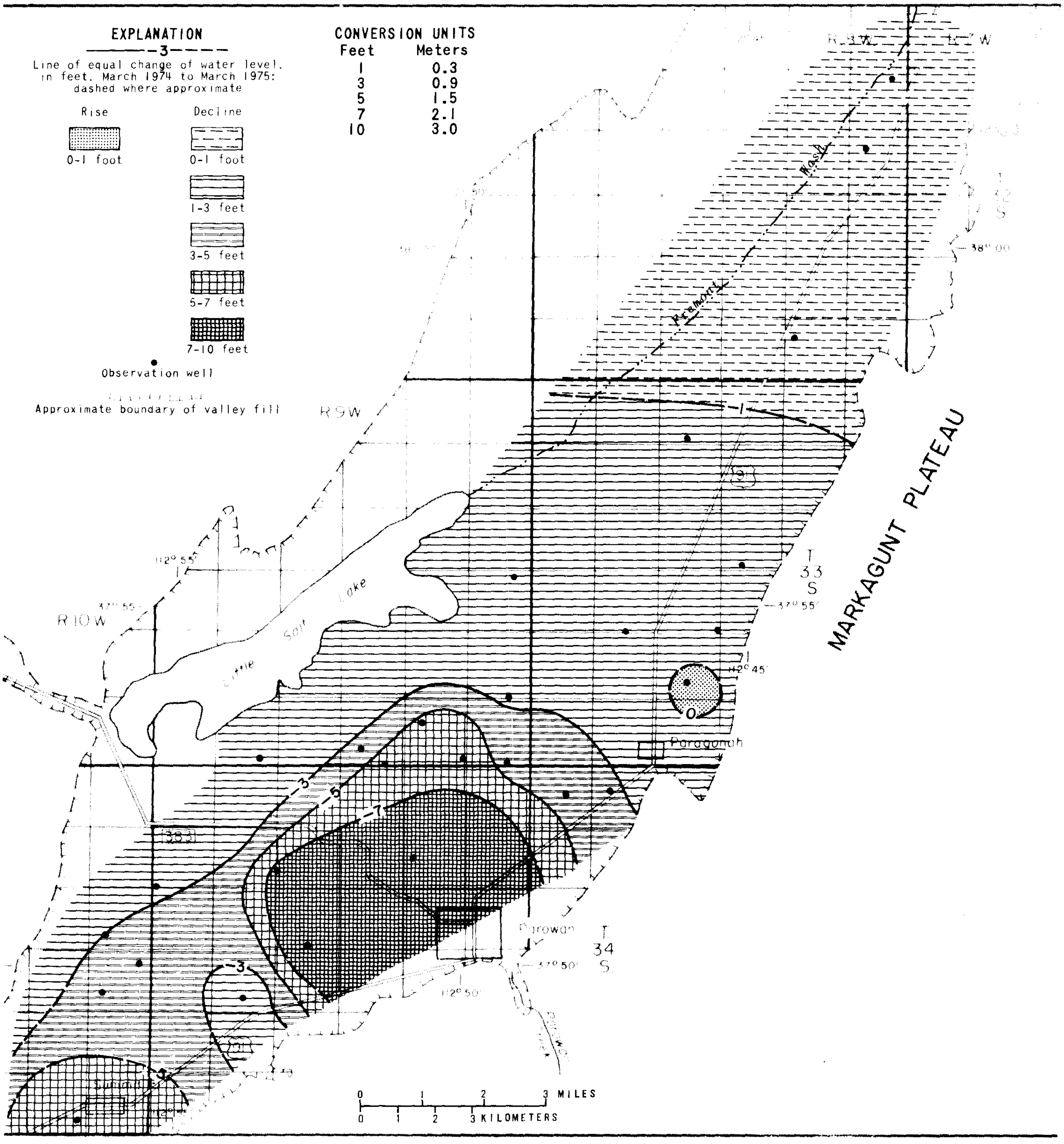


Figure 9.— Continued.

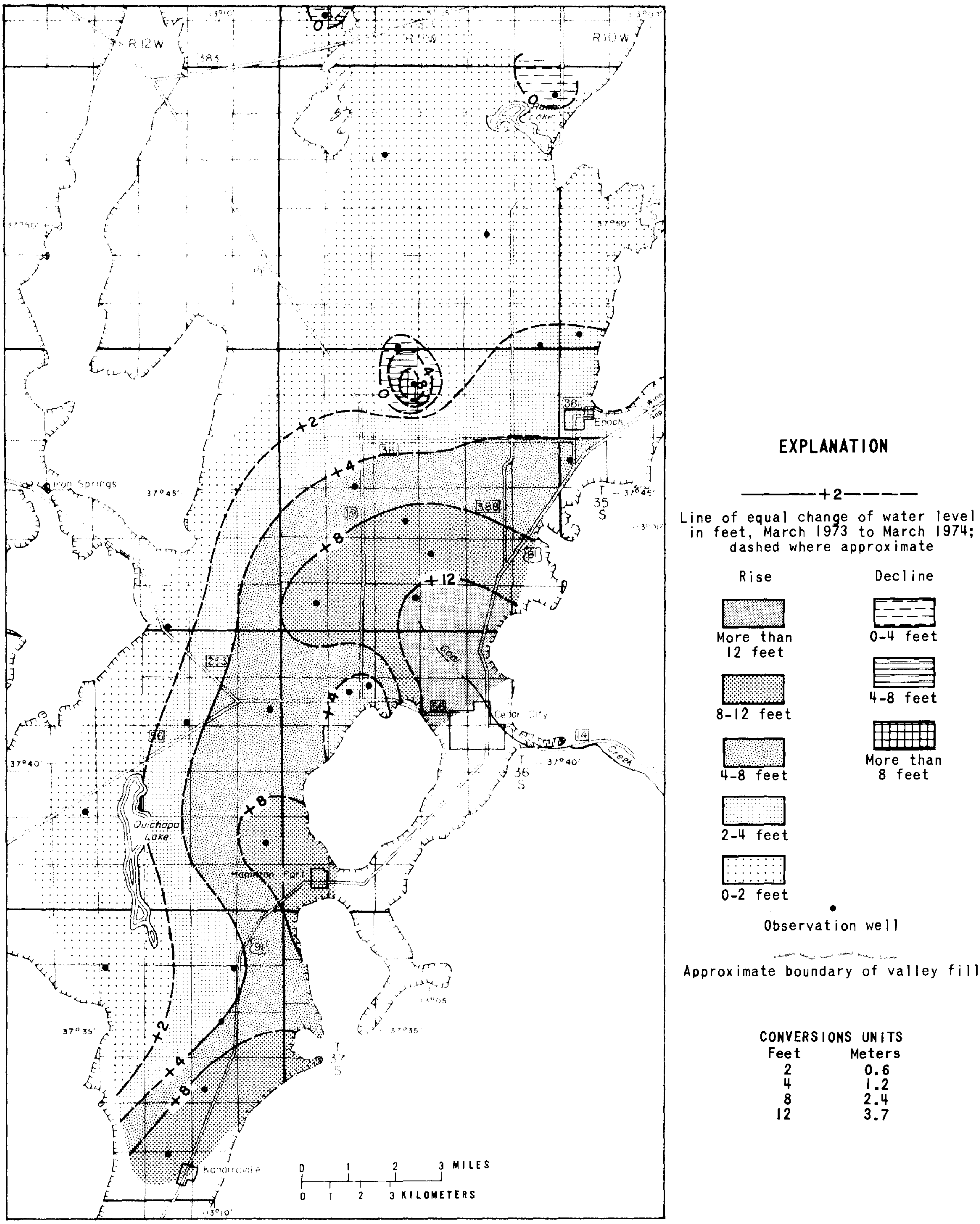
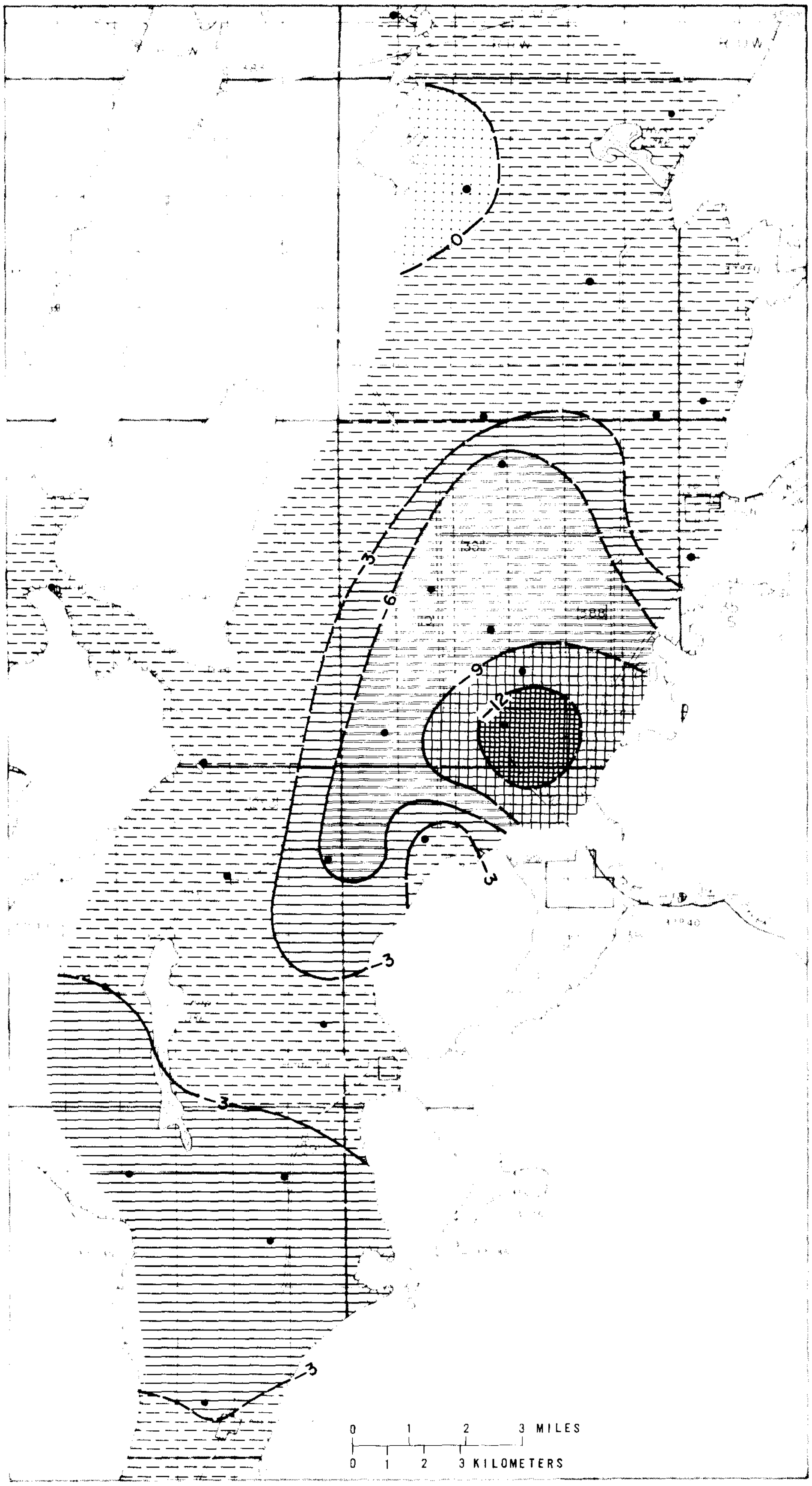


Figure 10.—Maps of Cedar City Valley showing changes in ground-water levels, March 1973 to March 1974 and March 1974 to March 1975.



EXPLANATION

—3—

Line of equal change of water level, in feet, March 1974 to March 1975; dashed where approximate

Rise

0-1 foot

Decline

0-3 feet

3-6 feet

6-9 feet

9-12 feet

More than 12 feet

●

Observation well

Approximate boundary of valley fill

CONVERSION UNITS

Feet	Meters
1	0.3
3	0.9
6	1.8
9	2.7
12	3.7

Figure 10.— Continued.

In both Parowan and Cedar City Valleys major water-level declines (fig. 11) exist in areas where large amounts of water are pumped from wells to irrigate crops. The principal pumpage areas are north and west of Parowan and north and west of Cedar City (pl. 3). Recharge in Parowan Valley from Parowan Creek and from diversions for irrigation and in Cedar City Valley from Coal Creek and diversions has prevented long-term declines of water level in these areas from being greater than they are.

Major long-term declines are indicated in figure 11 in three areas marginal to Cedar City Valley. These areas are: (1) near the edge of the valley about 7 mi (11 km) northeast of Cedar City, (2) near the edge of the valley about 6 mi (10 km) southwest of Cedar City, and (3) west of Quichapa Lake. The decline of water levels in these areas is attributed partly to moderately heavy pumpage and partly to an apparent lack of recharge, as no large perennial streams flow in these areas. The drawdown effects of pumping reflected from the nearby bedrock at the edge of the valley fill may account for part of the decline. Also water-table conditions along the edge of the valley fill may tend to localize the decline.

The approximate areal extent of the water-level declines during 1940-74, as shown in figure 11, is given in the following table:

Decline of ground-water level 1940-74	Size of area affected	
	Parowan Valley	Cedar City Valley
More than 30 ft (9 m)	9 mi^2 (23 km^2)	8 mi^2 (20 km^2)
20 to 30 ft (6 to 9 m)	20 mi^2 (50 km^2)	18 mi^2 (47 km^2)
10 to 20 ft (3 to 6 m)	63 mi^2 (160 km^2)	49 mi^2 (130 km^2)
0 to 10 ft (0 to 3 m)	33 mi^2 (85 km^2)	75 mi^2 (190 km^2)

The approximate volume of water represented by the declines listed above is 1,220,000 acre-ft (1,500 hm^3) in Parowan Valley and about 1,110,000 acre-ft (1,370 hm^3) in Cedar City Valley. If the volume of decline represents a dewatered volume with an average specific yield of 0.1, the ground-water loss from storage in 35 years would be about 122,000 acre-ft (150 hm^3) in Parowan Valley and 111,000 acre-ft (137 hm^3) in Cedar City Valley. This would amount to an average annual loss from storage of about 3,600 acre-ft (4.4 hm^3) of ground water in Parowan Valley and about 3,300 acre-ft (4.1 hm^3) in Cedar City Valley.

The estimates of average annual depletion given in the preceding paragraphs, although apparently reasonable, should be regarded as only approximate. The largest error in the calculations could be in the estimated average specific yield of the dewatered rocks, regarded to be 0.1. As leaky artesian conditions exist in most of the valleys, much of the long-term declines could be only a decline in hydrostatic pressure and the storage coefficient may be smaller.

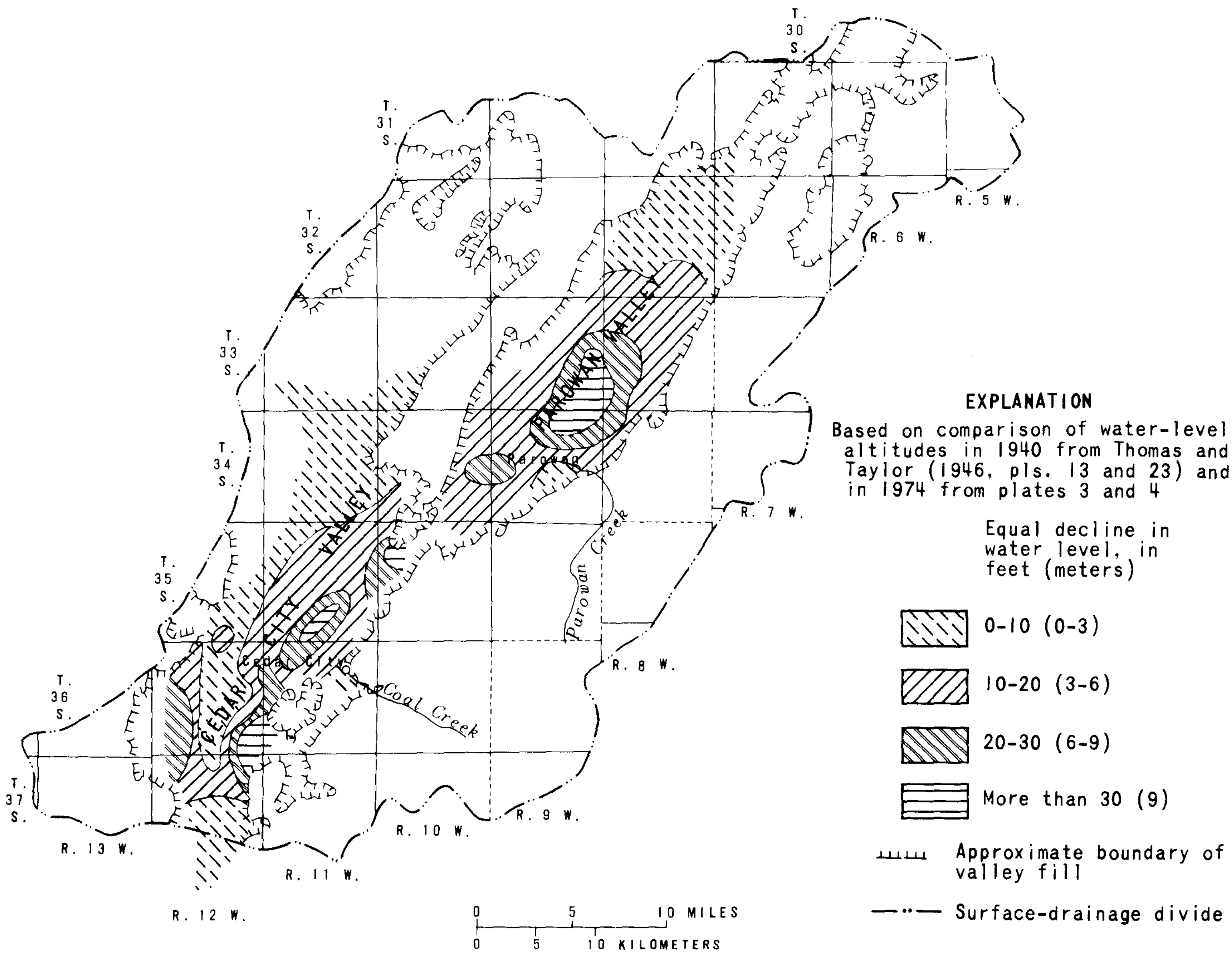


Figure 11.—Approximate decline of ground-water levels in Parowan and Cedar City Valleys, 1940-74 (based on September-October data in Parowan Valley and March-April data in Cedar City Valley).

Discharge

Ground water is discharged in the Parowan-Cedar City drainage basin by springs, seeps, evapotranspiration, wells, and subsurface outflow. The average annual discharge from the valleys is estimated to be about 87,000 acre-ft (110 hm^3). About half of this amount is discharged from each valley.

Springs in the mountains

Most of the discharge of water by springs and seeps takes place in the highlands bordering the valleys, especially on the western slope of the Markagunt Plateau. Here the discharge from springs is estimated to amount to more than 25,000 acre-ft (30 hm^3) annually; it forms the base flow of Coal Creek, Parowan Creek, and all the perennial streams in the basin (see table 2), and provides most of the water for the municipal water systems in the basin. Many contact springs issue from the bedrock of Tertiary and Mesozoic age. Most of the large springs discharge from joints and solution channels in limestone and conglomerate near the base of the Tertiary Wasatch Formation; these include Warm Spring, (C-33-8)36b-S1, South Fork Spring, (C-34-8)2a-S1, and Box Elder Spring, (C-35-8)9b-S1, each of which discharge about 2 ft^3/s (0.5 m^3/s) in the mountains east of Parowan Valley. Some large springs also issue from rocks of Cretaceous age; these include Right Hand Spring, (C-36-10) 21cda-S1, which discharges about 2 ft^3/s (0.5 m^3/s) from sandstone beds in the mountains east of Cedar City Valley.

Springs and seeps in the valleys

Only a relatively small amount of water, probably less than 1,000 acre-ft (1 hm^3) per year, is discharged from springs and seeps on the floors of Parowan and Cedar City Valleys. Many springs and seeps existed in both valleys prior to 1940 (Thomas and Taylor, 1946, p. 102-106, 168-172) but few of these remain due to the decline of ground-water levels. (See section on the fluctuation of water levels.)

Scattered marshy meadow areas and a few small springs and seeps exist in the artesian lowlands of Parowan Valley northwest of Paragonah (see area where the potentiometric surface of the ground-water reservoir is above land surface on plate 4). The largest spring on the valley floor is Willow Spring, (C-33-8)32bbc-S1, estimated to discharge about 40 gal/min (2 L/s). Also some ground-water discharge by seeps is indicated by patches of damp earth and saltgrass along the western margins of Little Salt Lake. The artesian area of Parowan Valley is an area of ground-water discharge with most of the discharge taking place by evapotranspiration and by flowing and pumped wells rather than springs.

Very little water discharges by springs in Cedar City Valley today, although in 1940 Thomas and Taylor (1946, p. 106) estimated an average annual discharge of about 4,700 acre-ft (5.8 hm^3). Many springs and seeps that discharged near Rush Lake and near Enoch in 1940 are dry today. Some ground water continues to discharge from seeps at the northeast edge of Quichapa Lake where several acres of land are wet and muddy. About 1 gal/min (0.06 L/s) was estimated to seep to the surface at Mud Springs, (C-37-12)3ccc-S1, and about 10 gal/min (0.6 L/s) was estimated to discharge from each of two springs near Kanarraville, (C-37-12)33aad-S1 and (C-37-12)33dcb-S1. The largest spring discharge, 225 gal/min (14.2 L/s), was estimated at Iron Springs, (C-35-12)20abc-S1, which is outside of the valley floor at one of the topographic outlets from the valley. The total discharge by springs and seeps in Cedar City Valley is estimated to be less than 500 acre-ft (0.6 hm^3) per year and most of this is consumed by evapotranspiration near the points of discharge.

Evapotranspiration

Evapotranspiration values for various land classifications were developed with the assistance of the Utah Water Research Laboratory, Utah State University, on the basis of a modified Blaney-Criddle formula (Hill and others, 1970, p. 17-19). These values were used in estimating evapotranspiration.

The discharge of ground water by evapotranspiration in the Parowan-Cedar City Valleys amounts to about 14,000 acre-ft (17 hm^3) annually. Evapotranspiration occurs where the water table is shallow enough to cause evaporation from a moist land surface or where roots of plants extend into the wet zone at or near the water table and get water from the ground-water reservoir. Plants that habitually obtain their water supply from the zone of saturation, either directly or through the capillary fringe, are called phreatophytes (Meinzer, 1923, p. 55). The principal native phreatophytes that consume ground water in the Parowan and Cedar City Valleys are greasewood (*Sarcobatus vermiculatus*), rabbitbrush (*Chrysothamnus* sp.) and desert saltgrass (*Distichlis stricta*). Communities of these plants may be segregated, mixed with other phreatophytes, or mixed with big sagebrush (*Artemesia tridentata*). The approximate outer limit of phreatophytes, shown on plate 7, encompasses about 45 mi^2 (120 km^2) in Parowan Valley and about 55 mi^2 (140 km^2) in Cedar City Valley; these areas include tracts of phreatophytes, phreatophytes mixed with sagebrush, dry-farm land, and cleared uncultivated land.

Parowan Valley.--About 12,000 acre-ft (15 hm^3) of ground water is estimated to be discharged annually by evapotranspiration from phreatophytes in the Parowan Valley and by evaporation from the Little Salt Lake.

Saltgrass grows in several wet meadow areas in Parowan Valley and is estimated to cover an area of about 3.5 mi^2 (9.1 km^2). The annual evapotranspiration of ground water is estimated to be about 2 ft (0.6 m), which would amount to about 4,500 acre-ft (5.5 hm^3). The estimate is based on White's experiments with saltgrass grown in tanks in Escalante Valley (Robinson, 1958, p. 58).

The area of phreatophyte growth in Parowan Valley coincides generally with the area of flowing wells but is slightly larger (pls. 4 and

7). Although the position of the potentiometric surface of the ground-water reservoir is known to be above the land surface in most of this area, little is known regarding the position of the shallow water table. The flowing wells in the area generally are more than 200 ft (60 m) deep and upward movement of ground water from this depth through many layers of clay, silt, sand, and gravel to near the land surface would be slow. As the land surface is generally dry, it is assumed that greasewood would have to extend their roots 5 to 10 ft (2 to 3 m) below land surface to obtain water in most of the area. The seasonal use of ground water under these conditions in Escalante Valley was estimated by White to range from 0.08 to 0.38 ft (0.02 to 0.12 m) (Robinson, 1958, p. 69). An inferred average seasonal use of 0.2 ft (0.07 m) applied to the approximate area of phreatophytes (including rabbitbrush and sagebrush but excluding the area already calculated for saltgrass) would amount to about 5,300 acre-ft (6.5 hm^3).

Little Salt Lake, covering an area of 6 mi^2 (16 km^2), is a natural ground-water discharge area for Parowan Valley. Although the water from wells near the lake is fresh (see well (C-34-9)5abc-1 in table 5 and pl. 8) evaporation from the playa surface has resulted in an accumulation of salt. In 1940, Thomas and Taylor (1946, p. 171-172) estimated an annual ground-water discharge of 5,800 acre-ft (7.2 hm^3) from the playa, 700 acre-ft (0.9 hm^3) from seeps along the western margin, and 1,000 acre-ft (1 hm^3) from phreatophytes within 0.25 mi (0.4 km) of the lake. Today the annual discharge of ground water from the playa surface and seeps along its margin probably is not more than 2,000 acre-ft (2 hm^3). The potentiometric surface of the ground-water reservoir has declined 10 to 20 ft (3 to 6 m) in the general area (fig. 11) and the seasonal decline during the pumping season is probably an additional 10 ft (3 m) or more. The March 1974 water levels in the vicinity of Little Salt Lake are still above the land surface (pl. 4) so some ground-water discharge by evaporation from the playa occurs during the non-pumping season. Some discharge still takes place at the seeps along the western margin.

Cedar City Valley.--About 2,000 acre-ft (2 hm^3) of ground water is estimated to be discharged annually by evapotranspiration by phreatophytes in Cedar City Valley and evaporation from the playas of Quichapa and Rush Lakes. This figure is substantially less than the 12,000 acre-ft (15 hm^3) estimated for Parowan Valley mainly because the potentiometric surface has declined to below land surface in virtually all of Cedar City Valley; whereas, it is still above land surface in about a third of Parowan Valley (pl. 4).

About 1,600 acre-ft (2.0 hm^3) of ground water, or about 0.2 ft (0.06 m), is estimated to be discharged by evapotranspiration from about 15 mi^2 (39 km^2) situated in three areas in Cedar City Valley where the potentiometric surface of the ground-water reservoir is less than 10 ft (3 m) below land surface. These areas include about 8 mi^2 (20 km^2) surrounding Quichapa Lake, 6 mi^2 (16 km^2) at and near Rush Lake, and 1 mi^2 (3 km^2) about 1 mi (1.6 km) west of Enoch. Evapotranspiration of ground water by native vegetation in the rest of the valley is negligible because of greater depths to ground water (pl. 4).

It is estimated that not more than 500 acre-ft (0.6 hm^3) of ground water is discharged by evaporation from the playa surface of Quichapa Lake annually. Although the potentiometric surface of the ground-water reservoir is near the playa surface of the lake, and may be above it in places, there is very little hydrostatic head, or pressure, to force ground water through the lakebed silt and clay to the surface to replace evaporated water. Some ground-water discharge, which wets several acres, occurs at seeps at the northeast edge of the playa. The playa surface is usually dry, but it was inundated by the heavy runoff of surface water from snowmelt in May and June 1973, and water remained in the lake until August 1975 when the last of it was consumed by evaporation.

A large amount of water, probably as much as 1,000 acre-ft (1 hm^3) annually, is estimated to have been consumed by phreatophytes and evaporation during recent years in parts of secs. 16, 17, 20, and 21, T. 35 S., R. 11 W. An annual accumulation of surface water has resulted in a growth of willow (*Salix* sp.) and rabbitbrush. Other brush appears to have been killed by excess water. As the depth to ground water in this area is more than 10 ft (3 m) below land surface (pl. 4), very little of the water discharged by vegetation is from the ground-water reservoir.

Wells

The largest means of ground-water discharge in the Parowan-Cedar City drainage basin during recent decades is the withdrawal of water from wells. During 1974 approximately 73,000 acre-ft (90 hm^3) of water was pumped from wells, the greatest annual pumpage of record. Most of this water was used for irrigation. Records of 382 representative wells are given in Bjorklund, Sumsion, and Sandberg (1977, table 1).

Parowan Valley.--Approximately 30,700 acre-ft (37.8 hm^3) of ground water was discharged from wells in Parowan Valley during 1974, the largest annual withdrawal of record. This figure includes 29,500 acre-ft (36.4 hm^3) for irrigation, 1,010 acre-ft (1.25 hm^3) for public supply, and 150 acre-ft (0.18 hm^3) for domestic and stock use. The annual withdrawal of water from wells in the valley, shown in figure 2, has more than tripled since 1945, and it has doubled since 1960 despite the fact that precipitation has been greater than average during most years since 1960.

Cedar City Valley.--The withdrawal of ground water from wells in Cedar City Valley totaled approximately 42,300 acre-ft (52.1 hm^3) in 1975. This is the greatest quantity of water pumped for any year to date (1975). Of this amount 39,800 acre-ft (49.1 hm^3) was pumped for irrigation, 1,850 acre-ft (2.28 hm^3) for municipal supply, 500 acre-ft (0.6 hm^3) for industry, and 150 acre-ft (0.18 hm^3) for domestic and stock use. Annual pumpage from wells has increased progressively in Cedar City Valley since the mid-1930's when large amounts of water were first pumped from wells for irrigation. About 13,000 acre-ft (16 hm^3) of water was pumped in 1940, 17,000 acre-ft (21 hm^3) in 1950, and 22,000 acre-ft (27 hm^3) in 1960. The annual withdrawal of ground water in Cedar City Valley since 1938 is illustrated in figure 3.

Subsurface outflow

A relatively small amount of ground water, estimated to be about 500 acre-ft (0.6 hm^3) per year, leaves the Parowan-Cedar City drainage basin by subsurface outflow. Ground water moves out of the basin through three topographic outlets--Mud Springs Wash, Iron Springs Gap, and the valley of Kanarra Creek west of Kanarraville. The underflow through Mud Springs Wash was estimated by Thomas and Taylor (1946, p. 104) to be only 20 acre-ft (0.02 hm^3) per year on the basis of a moderately low permeability, a small saturated section of the aquifer, and a hydraulic gradient of 10 ft (3 m) to 1 mi (2 km). The underflow through Iron Springs Gap, based on the discharge of the springs plus some underflow, was estimated to be about 500 acre-ft (0.6 hm^3) per year (Thomas and Taylor, 1946, p. 103). The underflow into Kanarra Creek valley from Cedar City Valley is estimated to be negligible because the area between a low topographic divide, a short distance north of Kanarraville, and a ground-water divide, a short distance further north, is too small to provide much water by recharge. Springs west of Kanarraville are believed to derive most of their discharge from recharge on the Kanarra Creek alluvial fan near Kanarraville which occupies an area outside of the Parowan-Cedar City drainage basin.

The mountain block between Parowan Valley and Cedar City Valley is an effective barrier to prevent the subsurface movement of water between the valleys. Thus, subsurface outflow from Parowan is regarded to be negligible. The altitude of the ground-water reservoir in Parowan Valley at its lowest point near Little Salt Lake is approximately 280 ft (85 m) higher than the ground-water reservoir in Cedar City Valley near Rush Lake, 6 mi (10 km) to the southwest. Likewise, ground-water levels near Summit, in Parowan Valley, are 240 ft (73 m) higher than they are near Enoch in Cedar City Valley, less than 4 mi (6.4 km) to the west. Ground-water contours in Parowan Valley (pls. 5 and 6) indicate that the ground water moves toward Little Salt Lake, the area of natural discharge. Some water may move into Cedar City Valley through Parowan Gap, which once drained Little Salt Lake, but the amount would be small because the gap is narrow and its alluvial fill apparently is shallow. Surface water no longer flows through the gap, partly because alluvial fans from side canyons have created dams by raising the canyon floor; also, the mountain block may have been raised by faulting of Quaternary age.

Quality

Data on the chemical quality of ground water in the Parowan and Cedar City drainage basins assembled as a part of this investigation are given in Bjorklund, Sumsion, and Sandberg (1977, table 5). Much of that information is shown in generalized form on illustrations in this section. Representative chemical analyses are given in table 5.

The chemical quality of surface water in the study area has been reported by Connor, Mitchell, and others (1958, p. 275-276), and more recently by U.S. Geological Survey (1967, p. 108; 1972, p. 131-133; and 1973, p. 127-129).

Table 5.--Representative chemical analyses of water from selected wells and springs

Location: See explanation of numbering system.
Agency reporting analysis: GS, U.S. Geological Survey; SH, Utah Division of Health.

Location	Date of collection	Depth of well or sampling depth (ft)	Temperature (°C)	Milligrams per liter: Dissolved silica (SiO_2)	Dissolved iron (Fe)	Dissolved calcium (Ca)	Dissolved magnesium (Mg)	Dissolved sodium (Na)	Dissolved potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Dissolved sulfate (SO_4)	Dissolved chloride (Cl)	Dissolved fluoride (F)	Dissolved nitrite plus nitrate (NO_2+NO_3) as nitrogen (N)	Dissolved boron (B)	Hardness as $CaCO_3$	Noncarbonate hardness as $CaCO_3$	Dissolved solids: Residue on evaporation	Dissolved solids: Sum	Specific conductance (micromhos/cm at 25°C)	pH	Sodium-adsorption ratio	Agency making analysis
PAROWAN VALLEY DRAINAGE BASIN																								
(C-32-8)12bac-1	5-21-74	440	20.0	58	0	31	6.8	15	5.3	130	0	11	15	0.2	0.75	0.04	110	0	-	210	260	8.0	0.6	GS
35bcb-1	6-11-74	250	12.5	43	.01	22	6.5	21	1.0	120	0	7.6	16	.2	.55	.05	82	0	-	179	250	8.3	1.0	GS
(C-32-9)14abd-S1	10- 3-74	-	13.5	49	.02	71	19	16	3.6	297	-	12	20	.1	1.0	.51	260	12	-	342	520	7.5	.4	GS
(C-33-8)19ddd-1	6-11-74	204	11.5	20	.02	40	22	18	2.3	239	0	13	15	.2	1.8	.04	190	0	-	256	446	8.0	.6	GS
(C-33-9)1dad-1	6-11-74	270	15.5	46	.00	11	3.2	30	3.2	108	1	8.1	12	.3	.61	.05	41	0	-	171	234	8.4	2.0	GS
34dcd-1	6-11-74	405	12.5	26	.02	49	29	8.9	2.8	279	0	17	6.7	.1	2.5	.03	240	13	-	288	492	7.7	.3	GS
(C-34-9)5abc-1	6-11-74	340	14.0	32	.01	28	17	13	3.3	182	0	18	5.7	.0	.36	.02	140	0	-	208	333	8.0	.5	GS
16cdd-2	8- 7-74	331	10.5	35	-	79	35	11	3.2	379	-	32	11	.3	2.7	.05	340	31	-	405	650	7.4	.3	GS
24abb-1	1-10-68	180	-	14	.00	46	33	36	7.0	271	1.1	60	44	.38	.18	.00	250	-	382	-	625	7.9	1.0	SH
36dbb-1	4-28-69	125	-	15	.04	60	24	9	2.0	268	1.3	36	16	.3	.0	.00	250	-	316	-	515	8.0	.2	SH
(C-34-10)13cbd-1	10- 2-73	360	12.0	40	-	72	53	25	4.5	440	0	46	24	-	-	-	400	37	-	481	816	7.7	.5	GS
	5-22-74	360	11.5	42	.01	47	29	16	4.8	267	0	29	17	.2	1.9	.05	240	18	-	325	480	7.9	.5	GS
24abc-1	6-11-74	162	13.0	40	.01	53	37	19	4.7	315	0	43	23	.3	2.7	.07	280	26	-	387	629	8.0	.5	GS
35acb-1	5-22-74	250	15.5	31	.02	76	42	27	5.7	445	0	47	16	.2	2.0	.07	360	0	-	473	730	7.9	.6	GS
(C-35-8)9b-S1	4-29-69	-	-	13	.04	42	18	5.0	3.0	210	1.8	12	13	.27	.00	.08	178	-	245	-	365	8.2	.2	SH
(C-36-9)11dca-S1	8-26-69	-	-	21	.00	40	8.0	4.0	2.0	164	.91	2.0	13	.01	.14	.14	134	-	162	-	290	8.0	.2	SH
	10- 1-74	-	7.0	24	.02	39	7.4	1.7	2.1	159	-	3.5	1.0	.1	.02	.63	130	0	-	158	260	8.1	.1	GS
CEDAR CITY VALLEY DRAINAGE BASIN																								
(C-33-11)30bca-1	6-25-74	80	13.5	43	0.08	120	.87	170	12	339	0	520	130	0.7	0.03	0.34	660	380	-	1,250	1,860	7.5	2.9	GS
(C-34-10)31caa-1	5-23-74	365	16.0	34	.01	55	38	57	6.4	284	0	67	81	.1	2.6	.09	290	61	-	490	800	7.9	1.4	GS
(C-34-11)1daa-1	7- 9-74	120	13.5	36	.02	47	22	68	6.7	157	-	80	110	.4	1.2	.12	210	79	-	453	800	7.6	2.1	GS
9ccd-1	9-10-74	130	13.5	23	.05	42	33	69	5.5	168	-	190	36	.4	.22	.16	240	100	-	483	800	8.0	1.9	GS
23bdd-1	6-13-74	302	13.0	43	.02	120	72	61	7.5	202	0	470	51	.0	1.1	.13	600	430	-	929	1,350	7.7	1.1	GS
(C-34-12)36abb-1	9-10-74	-	20.0	26	.04	80	52	50	4.3	139	-	330	40	.2	.35	.12	410	300	-	653	1,000	7.9	1.1	GS
(C-35-10)18cca-1	8- 5-69	285	-	39	.00	43	26	20	5.0	243	1.3	33	25	.24	.99	.14	214	-	330	-	535	8.0	.6	SH
(C-35-11)26acd-1	9-13-74	700	14.0	33	.02	93	62	40	5.8	304	-	220	42	.3	14.0	.13	490	240	-	708	1,100	7.4	.8	GS
33aac-1	5-22-74	236	12.5	17	-	180	74	22	3.6	334	0	470	19	.2	4.0	.06	750	480	-	968	1,050	7.5	.3	GS
(C-35-12)20abc-S1	9-12-74	-	15.0	30	.22	210	180	230	26	431	-	830	380	1.5	.05	.83	1,300	910	-	2,100	3,000	7.2	2.8	GS
27bcd-1	10- 2-74	255	13.5	33	.02	57	37	44	4.4	205	-	190	23	.3	.26	.61	290	130	-	492	740	7.8	1.1	GS
(C-36-10)18bcb-1	10-24-74	147	-	13	.80	360	75	110	6.7	250	-	900	210	.5	.69	.14	1,200	1,000	-	1,800	2,470	7.5	1.4	GS
(C-36-11)11bac-1	8- 5-69	670	-	21	.00	400	183	55	5.0	279	.77	1,542	44	.25	8.4	.41	1,750	-	2,752	-	2,800	7.7	.6	SH
(C-36-12)32ccb-1	8- 5-69	697	-	32	1.14	26	9.0	12	3.0	135	.94	1.0	20	.05	.00	.18	100	-	166	-	275	8.1	.5	SH
(C-37-12)11aaa-1	6-14-74	365	21.0	51	.02	47	30	31	4.1	180	0	140	12	.3	.9	.14	240	93	-	408	566	7.8	.9	GS

Surface water in the study area is of satisfactory chemical quality for irrigation and consumption by livestock.

Concentration of dissolved solids

Chemical analyses of ground water from wells in the Parowan and Cedar City drainage basins indicate that the concentration of dissolved solids ranges from about 158 to 2,752 mg/L (table 5). Terms used in this report to classify water according to the concentration of dissolved solids and specific conductance, as follows, are modified from Hem (1970, p. 219):

		Dissolved solids (mg/L)	Approximate specific conductance (micromhos/cm at 25°C)
Freshwater		Less than 1,000	Less than 1,700
Saline water	Slightly saline	1,000-3,000	1,700-5,000
	Moderately saline	3,000-10,000	5,000-17,000
	Very saline	10,000-35,000	17,000-58,000
Brine		More than 35,000	More than 58,000

Specific conductance

Specific conductance, which is a measure of the ability of water to conduct electrical current, is related to the concentration of dissolved solids. The relation depends on the particular constituents in solution, but is generally consistent in a particular area or aquifer. The relation in the Parowan and Cedar City drainage basins is shown graphically in figure 12. The concentration of dissolved solids, expressed in milligrams per liter, is about 63 percent of specific conductance for ground water from selected wells in the Parowan drainage basin, and about 70 percent of specific conductance for ground water from selected wells in the Cedar City drainage basin, expressed in micromhos per centimeter at 25°C. The ratio of dissolved solids to specific conductance in ground water from these wells ranges from 57 to 98 percent in the Parowan and Cedar City drainage basins. A map showing the specific conductance of ground water from wells in the area reflects the quality of ground-water recharge and the change in chemical quality of ground water as it moves through the drainage basins (pl. 8).

Major constituents

The concentrations of major chemical constituents in ground water from selected wells are shown by modified Stiff diagrams on plate 8. The ground water from selected wells in the Parowan drainage basin may be classified as a sodium, calcium, or magnesium bicarbonate type water, but calcium is the predominant cation. Ground water in the Cedar City drainage basin may be classified generally as a calcium or magnesium sulfate type water. However, variations include a sodium chloride type water from well (C-34-11)1daa-1 near Rush Lake and calcium bicarbonate type water from municipal well (C-36-12)32ccb-1 southwest of Quichapa Lake.

The source of dissolved solids in ground water is commonly from solution of the rocks through which the water passes or is in contact. Rocks consisting of much gypsum ($CaSO_4 \cdot 2H_2O$) contribute calcium and sulfate ions to ground water. Rocks of volcanic or igneous origin appear to contribute the least dissolved material to ground water in the study area. Ground water recirculated by irrigation may continually increase its content of dissolved solids. Areas of concentrated waste disposal may contribute to the dissolved solids in ground water.

Relation to geology

An inspection of the modified Stiff diagrams (Stiff, 1951) on plate 8, denoting the type and chemical quality of ground water, will show that the diagrams representing water samples collected in Parowan Valley have generally similar shapes; whereas, diagrams of samples from Cedar City Valley have a wider diversity of shapes. In Parowan Valley most of the diagrams indicate calcium bicarbonate or magnesium bicarbonate waters, but a few diagrams indicate sodium bicarbonate waters, and all of the diagrams indicate a comparatively low concentration of dissolved solids. In Cedar City Valley the diagrams represent all the water types

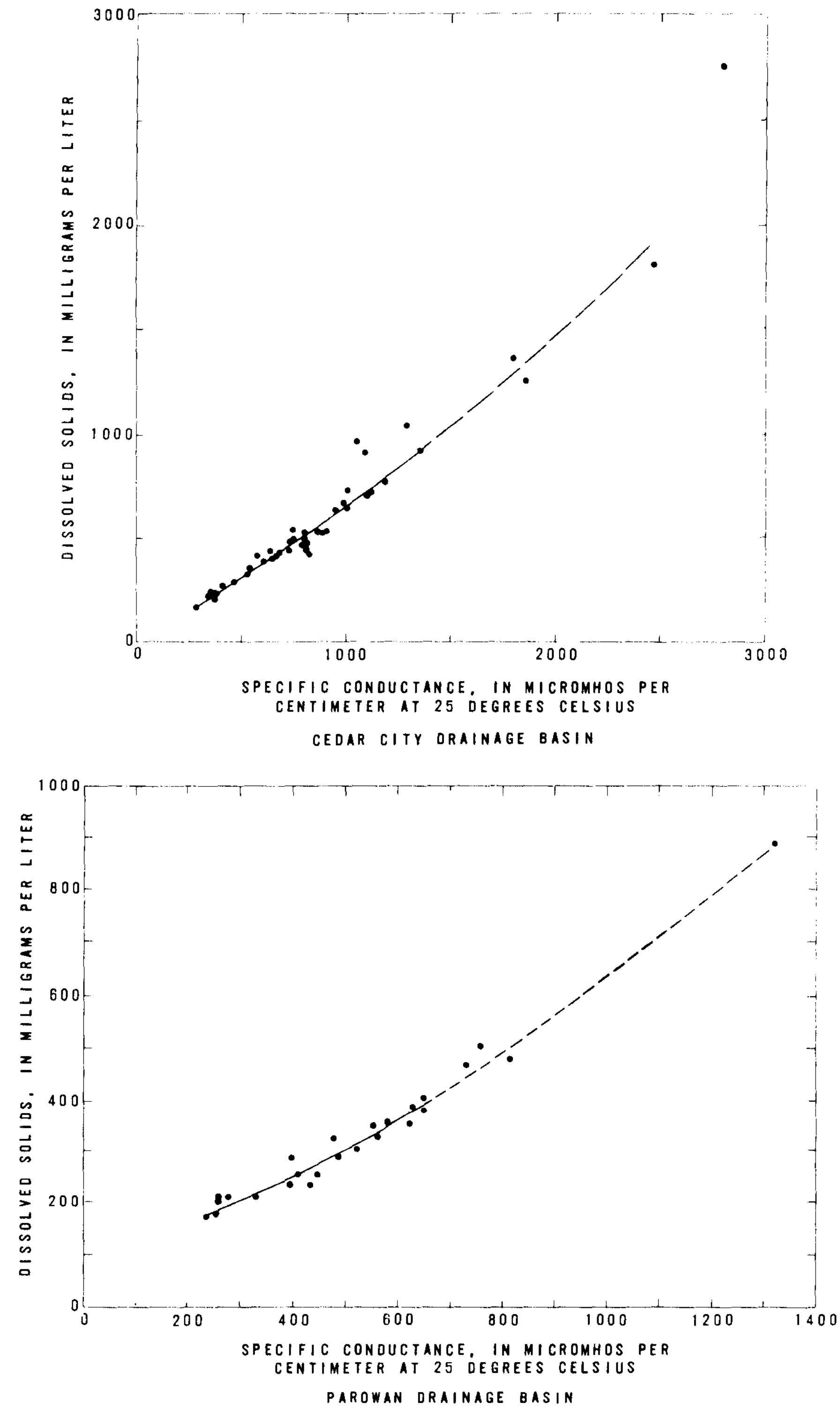


Figure 12.— Relation of specific conductance to the concentration of dissolved solids in selected ground-water samples, Parowan and Cedar City drainage basins.

listed for Parowan Valley, and in addition they represent calcium sulfate, magnesium sulfate, sodium sulfate, and sodium chloride waters. Many of the diagrams for Cedar City Valley indicate a relatively high concentration (greater than 1,000 mg/L) of dissolved solids.

The water type and chemical quality of ground water in Parowan Valley differ from that in parts of Cedar City Valley because the geologic environment differs. The rocks exposed in the Parowan drainage basin, the source of the Quaternary valley fill, consist mainly of Cretaceous sandstone and limestone, Tertiary limestone, conglomerate, and volcanic rock, and Quaternary volcanics and alluvium. These rocks contain much calcium and magnesium carbonate but little calcium sulfate. Rocks exposed in the Cedar City drainage basin include all the rocks exposed in the Parowan basin and also Triassic mudstone and siltstone including beds of gypsum, and Jurassic sandstone and shale also with beds of gypsum (table 3). Coal Creek, the largest source of surface water in the area (see table 2), is cut into Jurassic and Triassic rocks, and detrital materials from these rocks are mixed throughout most of the Cedar City Valley fill, especially that constituting the Coal Creek alluvial fan. Jurassic and Triassic rocks are also exposed along the face of the mountain between Cedar City and Kanarraville. Consequently, ground water in parts of Cedar City Valley has a relatively high concentration of calcium sulfate and other dissolved constituents that are scarce in Parowan Valley ground water.

Calcium bicarbonate water of relatively low chemical concentration (generally less than 400 mg/L) in Cedar City Valley west of Quichapa Lake is similar in type and concentration to ground water in the northern part of Parowan Valley (pl. 8). In both of these areas the nearby mountains, the source of the local valley fill, consist of Tertiary volcanic rock. Thus the local valley fill and the ground water west of Quichapa Lake are derived from the Harmony Mountains to the west.

Water of relatively high mineral concentration consisting mostly of sodium chloride occupies the shallow playa deposits of silt and clay underlying Little Salt Lake in Parowan Valley and Quichapa and Rush Lakes in Cedar City Valley. This water is not represented by modified Stiff diagrams in figure 12 because the shallow playa deposits are not tapped by wells. The three playas are areas of natural ground-water discharge through evaporation; sodium chloride, being the most soluble chemical constituent of ground water, has remained in solution and accumulated in the playa lakes. When the lakes become dry, encrusted salt forms in the soil and on the playa surface. If and when high seasonal ground-water levels at and adjacent to the playas decline to altitudes lower than the playa surface, the lakes, when containing water, will become sources of recharge and contamination to nearby aquifers.

Relation to use

Water quality may be evaluated according to intended use. Generally, the best water has the least concentration of dissolved solids; however, for some uses the concentrations of particular ions in water may be more significant than the total concentrations of dissolved solids.

Hardness of water is a consideration for domestic and for many industrial uses. In the past, the property of hardness has been associated with effects observed in the use of soap or with encrustations left by some types of "hard" water when heated. Because these effects are related to the presence of calcium and magnesium, hardness is now generally defined in terms of these constituents; hardness is computed by multiplying by 50 the sum of the milliequivalents per liter of calcium and magnesium. Hem (1970, p. 224-226) presents a discussion of hardness and gives a classification of water with respect to hardness as follows:

Classification	Hardness as $CaCO_3$ (mg/L)
Soft	0-60
Moderately hard	61-120
Hard	121-180
Very hard	More than 180

Most ground water in the Parowan and Cedar City drainage basins is classified as very hard, but a few samples were hard, moderately hard, or soft (table 6).

Quality standards for potable water used by public carriers and others subject to Federal quarantine regulations have been recommended by the U.S. Public Health Service (1962). These standards concern bacteria, radioactivity, and chemical constituents that may be objectionable in a water supply. The following list of standards pertain to those constituents for which analyses are given in this report:

> "The following chemical substances should not be present in a water supply in excess of the listed concentrations where * * * other more suitable supplies are or can be made available." (U.S. Public Health Service, 1962, p. 7.)

Substance	Recommended limit (mg/L)
Chloride (Cl)	250
Fluoride (F)	1.3[1]
Iron (Fe)	.3
Nitrate (NO_3)	45
Sulfate (SO_4)	250
Dissolved solids	500

[1]Based on the annual average of maximum daily air temperature of 63.3°F (17.4°C) at Parowan and 63.5°F (17.5°C) at Cedar City FAA during 1964-73.

Ground water from those areas shown on plate 8, where the specific conductance is less than 800 micromhos per cm at 25°C, generally contains concentrations of the listed substances that are below the recommended maximum limits. The public supply systems in the Parowan and Cedar City drainage basins obtain water from these areas. Ground water obtained from other parts of the Parowan and Cedar City drainage basins generally exceeds the recommended limit for dissolved solids and for some of the individual constituents. The recommended limit for dissolved solids is influenced primarily by considerations of taste (U.S. Public Health Service, 1962, p. 34), and water exceeding the recommended limit is used in many homes for domestic purposes without problems related to the concentration of dissolved solids.

The quality requirements for industrial water supplies range widely, as almost every industrial application has its individual standards. Hem (1970, p. 334-335) shows the limit for total dissolved solids to range from 0.5 to 1,000 mg/L for various industrial uses under differing conditions.

The upper limits of concentrations of dissolved solids in water for livestock vary according to the tolerance of the animals. An upper limit of 5,000 mg/L for water used by livestock is recommended by some investigators. Hem (1970, p. 324) quotes individual upper limits as follows:

Stock	Concentration (mg/L)
Poultry	2,860
Pigs	4,290
Horses	6,435
Cattle (dairy)	7,150
Cattle (beef)	10,100
Sheep (adult)	12,900

Some of the principal factors determining the suitability of water for irrigation are the concentrations of boron, the concentrations of dissolved solids, and the proportions of sodium to calcium and magnesium. Boron in more than trace concentrations is toxic to plants. Only one of the analyses of ground water in the study area shows a boron concentration exceeding the lower tolerable limit for permissible water for crops raised in the project area as given by Hem (1970, p. 329); well (C-32-8)24adb-1 produced water containing 0.73 mg/L boron (Bjorklund and others, 1977, table 5). However, this is only 0.06 mg/L in excess of the least tolerable limit for permissible use. The concentration of dissolved solids (salinity hazard) affects plant growth by limiting the ability of the plant to take in water. The proportion of sodium to calcium and magnesium (sodium hazard) affects the extent to which soil minerals will absorb sodium from the water. The adsorption of sodium breaks down the flocculation of the soil and makes it gummy and less permeable. An index to the sodium hazard is the sodium-adsorption ratio (SAR); it is expressed as:

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{++} + Mg^{++}}{2}}}$$

where the concentrations of sodium, calcium, and magnesium are expressed in milliequivalents per liter.

The sodium and salinity hazards of ground water from selected wells and springs in the study area were classified according to the method of the U.S. Salinity Laboratory Staff (1954, p. 79-81). In this classification it is assumed that an average quantity of water will be used under average conditions of soil texture, salt tolerance of crops, climate, drainage and infiltration. As shown in figure 13, ground water in the Parowan drainage basin has a low sodium hazard, and a low-to-high range of salinity hazard, but generally within the medium classification. The Cedar City drainage basin has ground water of low sodium hazard (fig. 14), and salinity hazard ranging from medium to very high, but generally within the medium and high classification.

Changes in chemical quality

The concentration of dissolved solids in ground water tends to increase with time in areas where large quantities of water are pumped for irrigation. In the process, part of the water is consumed by evapotranspiration and the remaining water, containing most of the original dissolved minerals, is recirculated into the ground-water reservoir. This is especially true in closed basins or areas like the Parowan-Cedar City basin where perennial streams do not exist to carry excess minerals away from the basin. The more soluble minerals such as sodium chloride persist in solution whereas the less-soluble minerals precipitate out of solution as the solution becomes concentrated. Changes in the concentration of dissolved chloride, therefore, would seem to be a dependable criterion for evaluating the change in chemical quality over the years. At or very near 15 sites in Cedar City Valley where ground-water samples were collected for analysis during 1938-40 (Thomas and Taylor, 1946, p. 107-109), samples were collected during 1973-74; the analyses of these samples (Bjorklund and others, 1977, table 5) indicated changes in chloride ranging from an increase of 91 mg/L to a decrease of 51 mg/L with an average gain of 10 mg/L in the 30-plus year period. These figures, while reasonable, are only approximate because: (1) some of the sampling sites could have changed greatly in the 30-year period, as many wells have been replaced or deepened since 1940; and (2) seasonal changes in chemical concentration could not be considered because the collection dates for the 1938-40 data were omitted.

Temperature

The temperatures of ground water from 62 wells in the Parowan drainage basin range from 8.5° to 20.0°C (47° to 68°F) and average 13.5°C (56°F). Ground-water temperatures in 74 wells in the Cedar City drainage basin range from 10.0° to 21.0°C (50° to 70°F) and average 13.5°C (56°F). Ground water in the valleys of the study area having temperatures of more than 18.5°C (65°F) may be described as thermal or "warm" water (Waring, 1965, p. 4). Thermal water in this area probably results from deep circulation of ground water locally.

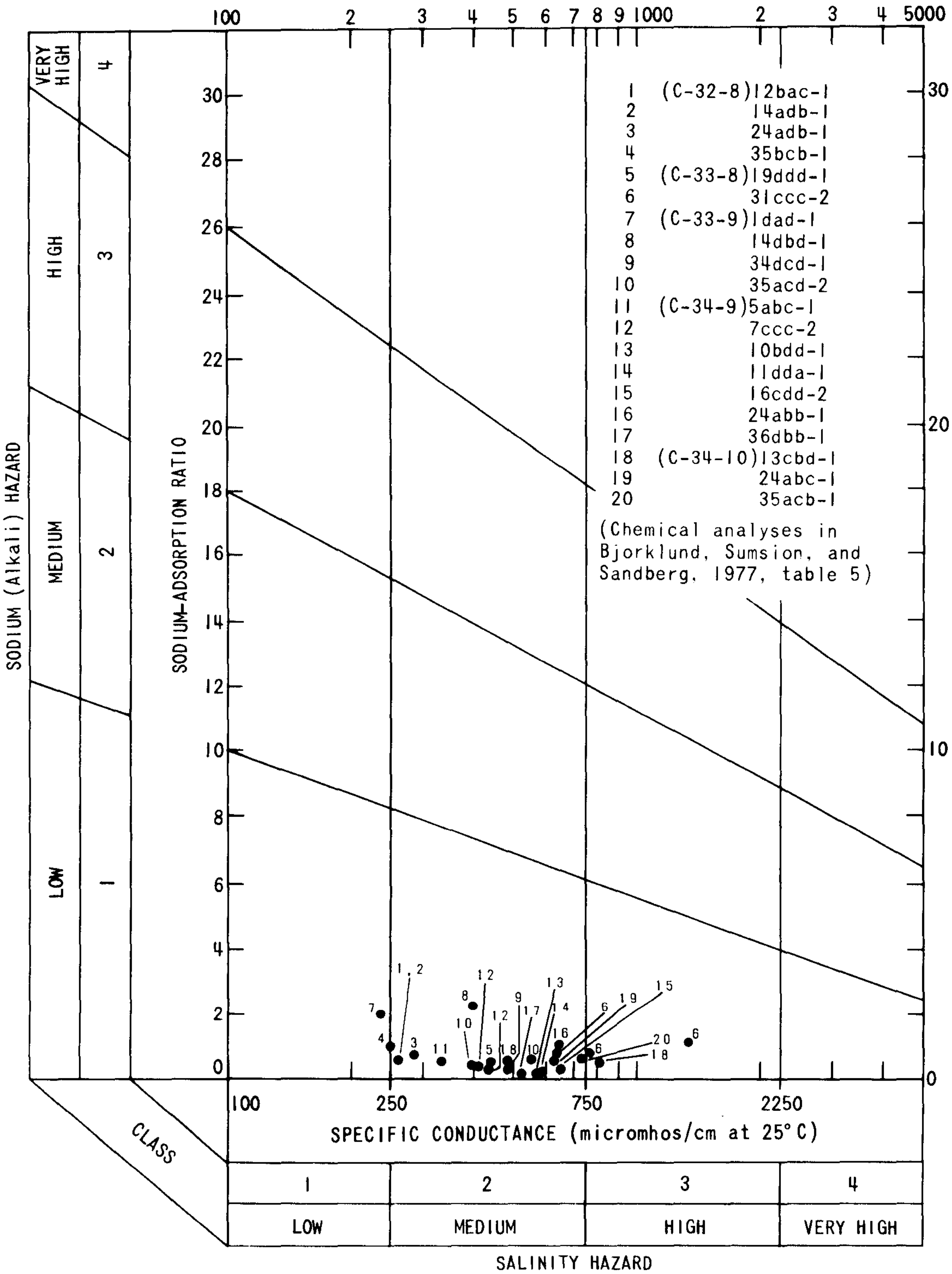


Figure 13.—Classification of ground water in Parowan Valley for irrigation. (Adapted from U.S. Salinity Laboratory Staff, 1954.)

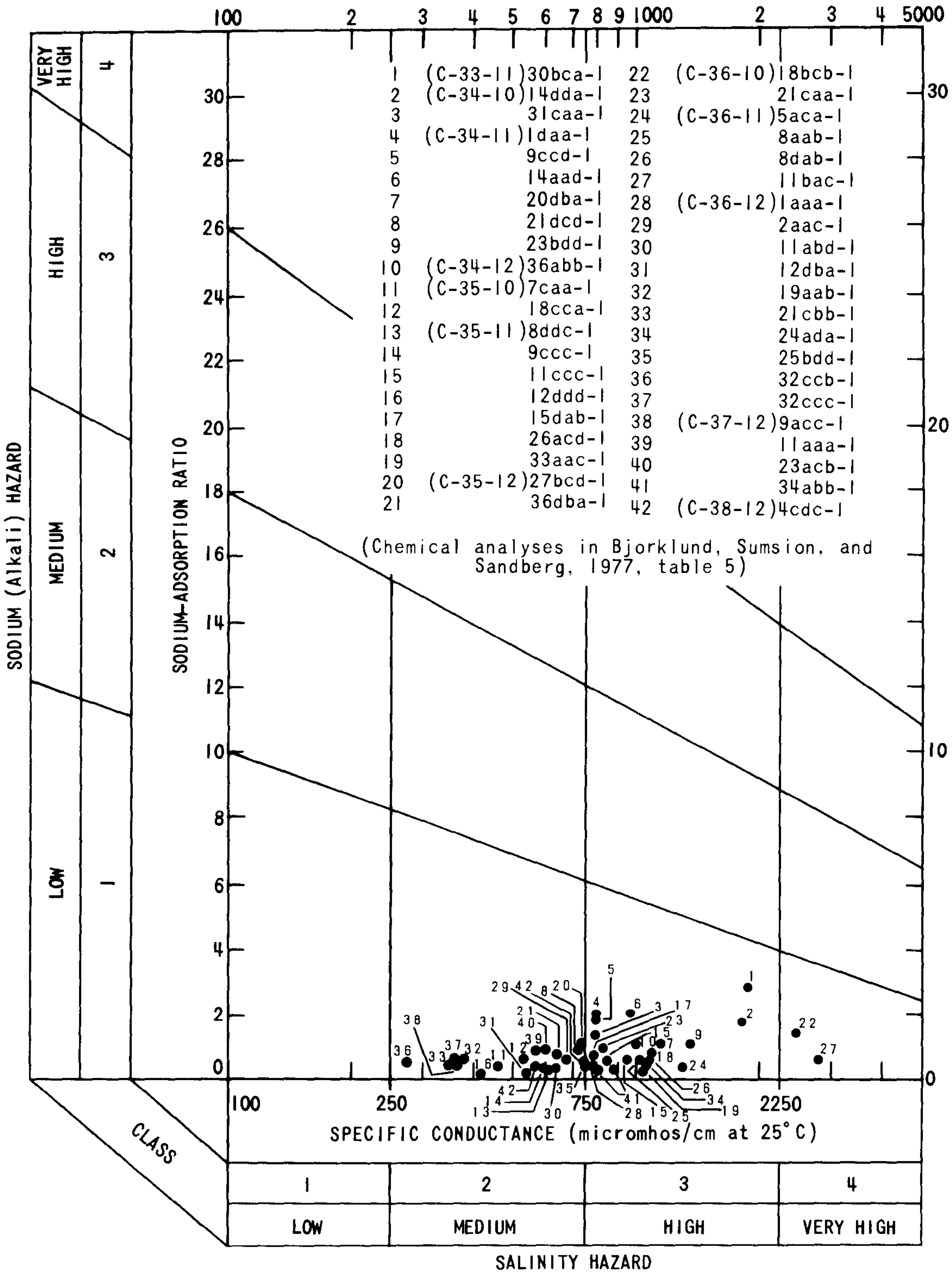


Figure 14.— Classification of ground water in Cedar City Valley for irrigation. (Adapted from U.S. Salinity Laboratory Staff, 1954.)

Ground-water temperatures are shown in figure 15. Warmer-than-normal ground water in the northern part of Parowan Valley probably is related to past volcanic activity in or near that vicinity. Warmer-than-normal ground water south of Hamilton Fort in Cedar City Valley may be related to heat generated at depth in the nearby Hurricane fault system. Colder-than-normal ground water in both valleys is related to recharge from streams and surface-water irrigation; this is illustrated in figure 15 northwest of Cedar City on the middle and lower parts of the alluvial fan of Coal Creek, and northwest of Parowan on the alluvial fan of Parowan Creek.

Development and utilization

Ground water is utilized in the Parowan-Cedar City basin for irrigation, public supply, industry, domestic purposes, and livestock. The locations of 382 selected wells, with symbols designating uses, and 22 selected springs are shown on plate 3. Detailed data for these wells and springs are given in Bjorklund, Sumsion, and Sandberg (1977, tables 1 and 2). The estimated annual pumpage for the above uses is given in table 6.

Table 6.--Water discharged from wells in the Parowan-Cedar City basin, in acre-feet, 1970-74

	1970	1971	1972	1973	1974
Parowan Valley					
Irrigation	25,300	23,500	27,500	24,400	29,500
Industry	0	300	300	0	0
Public supply	100	100	100	1,000	1,010
Domestic and stock	150	150	150	150	150
Subtotal (rounded)	25,600	24,000	28,000	25,600	30,700
Cedar City Valley					
Irrigation	30,000	34,200	33,500	24,900	39,800
Industry	500	500	500	500	500
Public supply	800	800	800	1,250	1,850
Domestic and stock	150	150	150	150	150
Subtotal (rounded)	31,400	35,600	35,000	26,800	42,300
Total (rounded)	57,000	59,600	63,000	52,400	73,000

Irrigation supply

Privately owned wells tapping the Quaternary valley fill provided about 69,000 acre-ft (85 hm^3) of water for irrigation in the Parowan-Cedar City basin during 1974. Irrigated areas are shown on plate 7 and the locations of 85 irrigation wells in Parowan Valley and 113 irrigation wells in Cedar City Valley are shown on plate 3. Some

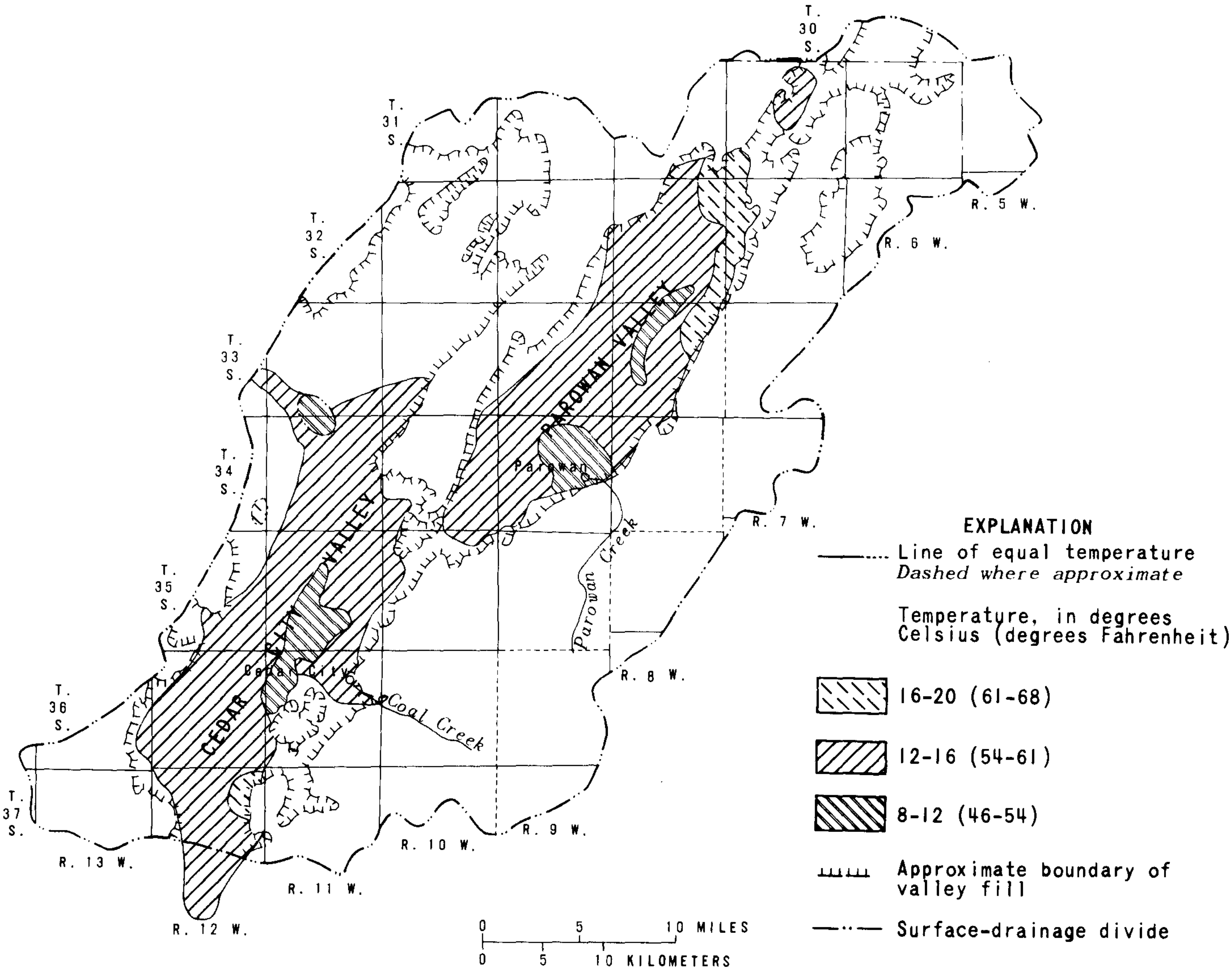


Figure 15.—Temperature of ground water in Parowan and Cedar City Valleys.

irrigated areas near Cedar City, Parowan, Paragonah, and Summit use surface water from perennial creeks (the annual discharge of the principal streams in the area is given in table 2). Some areas north and west of Cedar City are irrigated partly from Coal Creek and partly from wells, but the amount of available surface water for irrigation decreases drastically after the runoff season in May and June. During the last half of the irrigation season almost all irrigation depends on water pumped from wells.

Public supply

The basic source of water for the principal cities and towns in Parowan and Cedar City Valleys is springs in the mountains to the east. From the springs, which discharge from Tertiary and Mesozoic rocks, the water is transported to the communities through pipelines by gravity. Wells provide a supplementary source of water for Parowan, Cedar City, and Kanarraville. At Parowan, two wells tap water from Quaternary gravel and a third well taps Tertiary gravel. At Cedar City, two wells in Coal Creek Canyon, a well northeast of the city, and two wells across the valley west of Quichapa Lake tap Quaternary fill; a sixth well within the city is used mostly to water a cemetery and a golf course. At Kanarraville, a well taps supplementary water from the valley fill.

Several housing-development sites in Cedar City Valley obtain their water supply from community wells tapping the valley fill. Farmland, as well as undeveloped land, is being converted to residential areas. Some of the wells that serve these areas were drilled after the field-investigation period for the current study and are not included in the tabulated data for this report. Some of these communities are growing rapidly and may become towns in the future.

Domestic and stock supply

Residents at farms or country homes located outside of the areas served by community water-distribution systems obtain potable water from wells tapping the Quaternary valley fill. Many of these wells also furnish water for the livestock at the farm. In outlying areas many wells equipped with windmills provide water for livestock. In the mid-northern part of Parowan Valley, flowing wells provide water for livestock.

Industrial use

The chief industrial use of ground water in the Parowan-Cedar City basin is for washing gravel and for construction. Water is pumped from wells, used, and then ponded in the gravelly terrain near the excavation area. Most of it presumably seeps back to the ground-water reservoir. Some of the water goes into concrete mix which is delivered to construction sites. Also, temporary industrial wells were drilled for use in the construction of Interstate Highway 15 through the basin.

Ground-water areas

The ground-water areas shown in figure 16 were chosen to indicate where ground-water conditions are generally similar, or areas where ground-water conditions can conveniently be discussed together. The areas are all limited on the surface to the Quaternary valley fill in Parowan and Cedar City Valleys. For general information regarding the surrounding upland or bedrock areas, the reader is referred to table 3. None of the areas are independent of adjacent areas and the boundary lines separating the areas are approximate and arbitrary.

Parowan Valley

Upper Buckhorn Flats area (Area 1).--The Upper Buckhorn Flats area is the northernmost area in Parowan Valley. It includes about 22 mi^2 (57 km^2) mostly in T. 32 S., R. 8 W. The altitude of the area ranges from about 5,760 to 5,900 ft (1,760 to 1,800 m) above sea level, and in midvalley the general land surface slopes southwestward at 20 to 30 ft/mi (4 to 6 m/km). About 1,600 acres (6.5 km^2) of land is irrigated by water pumped from wells. The principal crops are alfalfa and small grain.

Ground water occurs mainly under leaky artesian conditions. The potentiometric surface of the ground-water reservoir is almost level, resulting in flowing wells at the lower parts of the area and depths to water of more than 100 ft (30 m) at the higher parts. The water-bearing materials in the principal aquifers consist mainly of gravels derived from Tertiary and Quaternary volcanic rocks exposed on both sides of the valley. An aquifer test indicated a general transmissivity of more than 100,000 ft^2/d (9,300 m^2/d) (table 4 and pl. 2). Interference between pumped wells is relatively small but prompt and far reaching. (See sections on aquifer tests and interference between wells). Yields from wells range from about 400 to 4,000 gal/min (25 to 250 L/s) but some of the wells could produce more if necessary. Specific capacities of wells are as much as 150 (gal/min)/ft [31.0 (L/s)/m] of drawdown. The March 1974-March 1975 decline of water level in an observation well, due to pumping from wells in the area, was slightly less than 1 ft (0.3 m) but, owing to the high transmissivity, this decline was widespread, affecting practically all of the area. The chemical quality of the ground water is very good, generally containing less than 300 mg/L of dissolved solids, and is a calcium bicarbonate type. Water contributing recharge to the area is from precipitation in the northeastern part of the drainage basin, an area of approximately 200 mi^2 (500 m^2). Some additional development in this part of Parowan Valley is feasible.

Willow-Little-Red Creeks fans area (Area 2).--The Willow-Little-Red Creeks fans area includes about 47 mi^2 (120 km^2) mostly in Tps. 32 and 33 S., R. 8 W. The altitude ranges from about 5,690 to 6,000 ft (1,730 to 2,000 m) above sea level and the land generally slopes northwestward to westward from the mountain front toward the lowlands northeast of Little Salt Lake at gradients ranging from more than 50 ft/mi (10 m/km) near the mountains to less than 10 ft/mi (2 m/km) in the lowlands. Scattered farms along the mountain front are irrigated in part

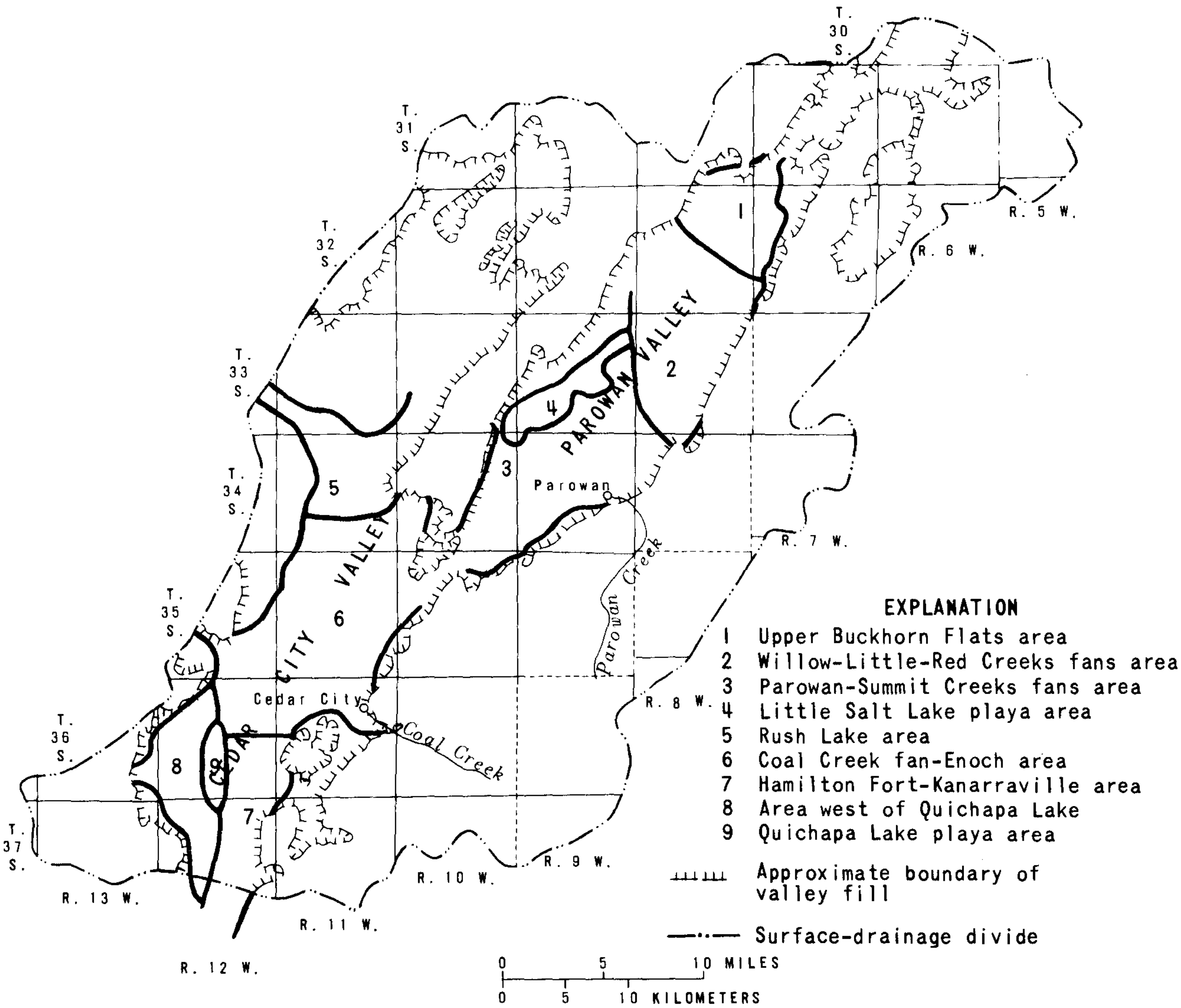


Figure 16.—Map showing ground-water areas in Parowan and Cedar City Valleys.

from relatively small flows from Little and Red Creeks (table 2) but mostly from irrigation wells. Most of the area, however, is covered by greasewood, rabbitbrush, saltgrass meadows, and sagebrush.

Ground water occurs mostly under leaky artesian conditions. In the western half of the area, the potentiometric surface of the ground-water reservoir is a few feet above, and generally follows, the contour of the land surface, resulting in discharge of water from flowing wells and evapotranspiration. These wells generally flow throughout the year; they are little affected by pumping in the concentrated well development to the north and south. Pumping from wells along the mountain front to the east affects some of the flowing wells, according to reports from local residents. In the higher eastern half of the area, the water table slopes westward 10 to 20 ft/mi (2 to 4 m/km), and depths to water in wells increase eastward from near the land surface to more than 100 ft (30 m) below land surface. The water-bearing materials of the valley fill consist mostly of detritus eroded from Tertiary and Mesozoic sedimentary rocks exposed in the mountains to the east. The chemical quality of the ground water is good (pl. 7 and table 5), generally less than 300 mg/L of dissolved solids, and is a calcium bicarbonate type. However, shallow water in the lowlands may contain more than 2,000 mg/L of dissolved solids, much of which would be sodium chloride. The estimated transmissivity of the aquifer ranges from about 1,000 ft^2/d (90 m^2/d) in the lowlands to about 10,000 to 20,000 ft^2/d (900 to 1,800 m^2/d) on higher parts of the alluvial slopes. Water contributing recharge to the area is from precipitation on about 90 mi^2 (200 km^2) of the drainage basin plus underflow from the upper Buckhorn Flats area. Some additional development of the ground-water resource is feasible, and some water could be salvaged from evapotranspiration by lowering ground-water levels in greasewood and meadow areas, but this would stop or retard the flow from some flowing wells.

Parowan-Summit Creeks fans area (Area 3).--The Parowan-Summit Creeks fans area includes about 55 mi^2 (140 km^2) at the south end of Parowan Valley. The altitude of the land surface ranges from about 5,700 ft (1,700 m) near the Little Salt Lake to about 6,000 ft (2,000 m) on the Parowan and Summit Creek alluvial fans. The land slopes northward and northwestward toward the Little Salt Lake at gradients ranging from about 10 ft/mi (2 m/km) in the lowlands to more than 50 ft/mi (10 km) near the mountain front. About half of the area is cleared and farmed, mostly for alfalfa and small grains; uncleared land is covered mostly with sagebrush. Farmland near Parowan and Summit is irrigated with surface water from Parowan and Summit Creeks, but most of the area is irrigated with ground water pumped from wells.

Ground water occurs in the unconsolidated valley fill mostly under leaky confined (artesian) conditions. Depths to water in wells range from near and above the land surface in the lowlands to more than 250 ft (76 m) below land surface near Summit (pl. 4). Water levels decline rapidly and flowing wells in the lowlands stop flowing during the pumping season and recover to almost pre-pumping levels between pumping seasons. The average annual decline near the center of the pumping area for the period 1940-74 was about 1 ft (0.3 m) a year (fig. 11). Wells generally yield from 500 to 2,000 gal/min (30 to 130 L/s) and interference between pumped wells is common and prompt. Measured and estimated transmissivity ranges from 1,000 ft^2/d (90 m^2/d) near Little Salt Lake to 20,000 ft^2/d (2,000 m^2/d) about midway on the alluvial slopes (pl. 2). Three aquifer tests (table 4) indicate confined conditions and transmissivities ranging from 1,400 to 17,900 ft^2/d (130 to 1,660 m^2/d). The chemical quality of the ground water is good, generally less than 500 mg/L of dissolved solids (table 5 and pl. 8), and is mainly a calcium bicarbonate or magnesium bicarbonate type. Water contributing recharge to the area is from precipitation on approximately 160 mi^2 (410 km^2) in the drainage basin. Additional high-capacity pumpage in the area may increase the rate at which water levels are declining and increase the size of the affected area.

Little Salt Lake playa area (Area 4).--The Little Salt Lake playa is an area of natural ground-water discharge for the Parowan basin as well as a place to collect excess surface-water runoff. The playa plus some adjacent low flatlands ranges in altitude from approximately 5,685 to 5,800 ft (1,733 to 1,740 m) above sea level and it includes about 10 mi^2 (30 km^2). The land surface when dry is covered with an accumulation of salt, and winds at times cause clouds of white salty dust. The natural circulation of ground water is upward from depth toward the land surface where it is eventually consumed by evaporation, leaving an accumulation of dissolved minerals. Shallow ground water, therefore, probably is highly mineralized, probably with sodium chloride; whereas, water in deep aquifers underlying the playa probably is fresh, as it is in wells less than a mile from the playa. At the present time the potentiometric surface of the ground-water reservoir apparently is above the playa surface during the springtime when water levels in the valley are highest, but it probably is lower than the land surface during the pumping season. When and if water levels in the valley decline permanently to positions lower in altitude than the playa surface, the natural circulation of ground water would be reversed, and runoff water in the playa would move from the land surface toward the underlying aquifers. In this manner the playa could become a source of ground-water contamination.

Cedar City Valley

Rush Lake area (Area 5).--The Rush Lake area includes about 30 mi^2 (80 km^2) extending from the Red Hills on the east to Mud Springs Wash on the west. Altitudes range from about 5,360 ft (1,630 m) in Mud Springs Wash to about 5,380 ft (1,640 m) at Rush Lake playa and 5,470 ft (1,670 m) about 3 mi (5 km) northeast of Rush Lake. The land slopes toward the area from the north, east, and south and thence northwest toward Mud Springs Wash. Irrigated farms depending on water from wells exist northeast and south of the playa.

Ground water occurs presumably under confined leaky conditions in the unconsolidated gravel and sand of the Quaternary valley fill. Northeast of Rush Lake the ground water is in gravels both above and below and within a layer of volcanic rock which may be a buried lava flow.

Depths to water range from less than 10 ft (3 m) in the playa to more than 50 ft (15 m) a few miles to the northeast. Recharge to the ground-water reservoir probably is mostly from subsurface inflow from east, south, and possibly from the north. The playa is sometimes covered with water from flash floods. Areas at the north end of the Cedar City drainage basin that drain toward Rush Lake are about 210 mi^2 (540 km^2). Yields to wells in the area are as much as 1,700 gal/min (110 L/s) and estimated transmissivities range from less than 5,000 to more than 20,000 ft^2/d (500 to 2,000 m^2/d). In past ages ground water was discharged by evapotranspiration from the playa and nearby meadows and by direct discharge from springs at the eastern end of the lake, but today (1975) the springs and the playa surface are dry due to the decline of water levels caused by pumping from wells in the valley. The total decline of water level in the area since 1940 is generally less than 10 ft (3 m) (fig. 11). Dissolved solids in water collected for analysis range from 453 to 1,360 mg/L (Bjorklund, Sumsion, and Sandberg, 1977, table 5); most of the ground water is typed as magnesium sulfate (pl. 8). Shallow water beneath the playa is assumed to be heavily mineralized, probably mostly with sodium chloride. Some additional development of the ground-water resource may be feasible.

Coal Creek-Enoch area (Area 6).--Most of the ground-water development in Cedar City Valley is on the alluvial slope which extends westward from the mountain front between Cedar City and Enoch in an area including about 82 mi^2 (210 m^2). Most of this area is on the Coal Creek alluvial fan which forms a low topographic divide across the valley. Altitudes range from about 5,430 ft (1,660 m) in midvalley at the north end of the area to about 5,800 ft (1,800 m) in Cedar City. Some farms are irrigated with surface water diverted from Coal Creek and supplemented by water pumped from wells, but most of the farms are irrigated exclusively with water from wells.

In most of the area ground water exists in the unconsolidated valley fill under leaky confined (artesian) conditions, but along the mountain front at, and north of, Cedar City it exists under unconfined conditions. Yields to wells are greatest on the alluvial slopes, a moderate distance (about 1 mi [1.6 km]) from the mountain front, and they decrease westward and northward as the materials in the Coal Creek fan become finer. Estimated and determined transmissivities range from less than 5,000 ft^2/d (500 m^2/d) in the lower parts of the area to more than 20,000 ft^2/d (2,000 m^2/d) near Cedar City and northward. An aquifer test near Enoch indicated a transmissivity of 5,200 ft^2/d (480 m^2/d) and water-table conditions. Depths to water in wells range from about 10 ft (3 m) in the lower areas to more than 200 ft (60 m) near Cedar City (pl. 4). Declines of water level since 1940 range from less than 10 ft (3 m) in the western and northern parts of the area to more than 30 ft (9 m) about 3 mi (5 km) northwest of Cedar City (fig. 11). Recharge to the ground-water reservoir is mostly from precipitation in the highlands to the east, particularly the Coal Creek drainage basin. Precipitation in about 230 mi^2 (600 km^2) contributes water to the area. The dissolved solids in sampled ground water range from less than 200 to more than 2,700 mg/L (Bjorklund, Sumsion, and Sandberg, 1977, table 5); most of the water is a calcium magnesium sulfate or calcium magnesium bicarbonate type. The source of the sulfate minerals is gypsum and other evaporites in Triassic and Jurassic rocks exposed in the Coal and Shurtz Creeks drainage basins. Increased ground-water usage will result in increased water-level declines and larger areas of well interference.

Hamilton Fort-Kanarraville area (Area 7).--From Hamilton Fort southward to Kanarraville the land surface in the valley slopes westward toward Quichapa Lake and the valley axis to the south. The area, which comprises about 28 mi^2 (72 km^2), ranges in altitude from about 5,450 ft (1,660 m) near the lake to about 5,600 ft (1,700 m) near the mountain front. The westward slope ranges from about 15 ft/mi (2.8 m/km) near the lake to more than 50 ft/mi (9.5 m/km) near the mountains. Scattered farms along the alluvial slope use irrigation water pumped from wells. Near Kanarraville some farms use water diverted from Kanarra Creek, supplemented by water pumped from wells. Much of the land is cleared but not cultivated and some of it is dry farmed.

Ground water in the unconsolidated valley fill exists under leaky artesian conditions. Transmissivities based on estimates and two aquifer tests range from less than 2,000 to 10,000 ft^2/d (200 to 900 m^2/d). Yields from irrigation wells range from about 400 to 1,200 gal/min (20 to 75 L/s). Interference between wells is common. Depths to water in wells range from about 10 to about 150 ft (3 to 46 m) and are greatest near the mountain front. Declines of water level due to pumping since 1940 range from about 10 ft (3 m) in the lowlands to more than 30 ft (9 m) near the mountain front. A water-table divide is near a low topographic divide that crosses the valley near and north of Kanarraville and separates the Great Basin from the Virgin River basin. Precipitation in about 70 mi^2 (200 km^2) contributes water to the area. The chemical quality of the ground water is generally good; it ranges from about 300 to about 700 mg/L in dissolved solids, and is generally of a calcium sulfate or calcium bicarbonate type. The sulfate minerals are derived from gypsum deposits in Jurassic and Triassic rocks exposed along the mountain front. Some additional ground-water development probably is feasible near Kanarraville where Kanarra Creek, a perennial stream, provides some recharge.

Area west of Quichapa Lake (Area 8).--The valley fill in the area west of Quichapa Lake is derived mostly from the Tertiary volcanic rocks of the Harmony Mountains to the west, a condition which results in a different type of ground water from that of other parts of the Cedar City Valley. The water is of a good chemical quality, is of a calcium bicarbonate type, (pl. 8), and has less than 300 mg/L of dissolved solids. Missing are the sulfate minerals which are characteristic of ground water in other parts of the valley. The area ranges in altitude from about 5,450 ft (1,660 m) near Quichapa Lake to about 5,640 ft (1,720 m) near the mountains and the land slopes eastward at gradients ranging from about 30 ft/mi (6 m/km) near the lake to more than 100 ft/mi (20 m/km) near the mountains. Scattered farms are irrigated by water pumped from wells and wells provide part of the public water supply for Cedar City.

Ground water exists in the valley fill under leaky confined (artesian) conditions and probably under unconfined (water-table) conditions near the mountain front. An aquifer test in the area indicated a transmissivity of about 42,000 ft^2/d (3,900 m^2/d). Yields to wells are reported to be as much as 1,600 gal/min (100 L/s). Interference between pumped wells is common. Depths to water range from about 10 ft (3 m) near Quichapa Lake to about 100 ft (30 m) near the mountains. Changes in water level since 1940 range from declines of less than 10 ft (3 m) near Quichapa Lake to more than 20 ft (6 m) about midway on the alluvial slopes. Precipitation in about 68 mi^2 (180 km^2) contributes water for recharge to the area. Some additional development may be feasible.

Quichapa Lake playa area (Area 9).--Excess runoff water from Coal and Shirts Creeks to the east as well as some runoff from the Harmony Mountains to the west collects in Quichapa Lake causing water to cover all or part of the playa surface at intervals. Large amounts of runoff during the spring and early summer of 1973 caused water to stand in the lake until midsummer of 1975 when it again became a dry playa. In the past, ground-water discharge through flowing wells, springs, and seeps in the area contributed water to the lake, but today (1975) this discharge has virtually ceased due to the decline of ground-water levels caused by pumping from wells. This decline is estimated to be less than 10 ft (3 m). A small seep area at the northeast edge of the playa still wets a few acres. The playa, plus some adjacent lowland meadow, includes about 4 mi^2 (10 km^2) slightly below an altitude of 5,450 ft (1,660 m).

The potentiometric surface beneath the playa is estimated to be less than 10 ft (3 m) deep. As the natural circulation of ground water during past ages has been from the water-bearing beds toward the land surface, the water at depth probably is fresh, and the water near the land surface is slightly saline or moderately saline due to an accumulation of mineral salts caused by evaporation. As the depth to water continues to decline, the playa could become a source of contamination to the ground-water reservoir. Floodwaters covering the playa would dissolve the accumulated mineral salts in the shallow silt and then percolate to the ground-water reservoir.

WATER-BUDGET ANALYSES

The quantity of water entering the Parowan-Cedar City drainage basins is equal to the quantity leaving the basins plus or minus the change in storage within the basins. Water enters the basins by precipitation and leaves by streamflow, ground-water flow, and evapotranspiration. Change in storage is caused by recharge (gain) or discharge (loss) of water to or from the ground-water reservoir. A separate budget analysis is made for each basin. Parowan basin is regarded to be a closed basin with no outlet; whereas, Cedar City basin has three outlets but almost negligible outflow. Land use, natural vegetation, and precipitation for the basins are shown on plate 7. Areas of land use and types of natural vegetation are tabulated in tables 7 and 8 and the budget analyses are presented in tables 9 and 10.

Table 7.--Approximate areas of land use and natural vegetation, in square miles, in Parowan Valley drainage basin

	Altitude, in feet above mean sea level					
	5,000-6,000	6,000-7,000	7,000-8,000	8,000-9,000	9,000-10,000	10,000-11,000+
Irrigated land:						
Alfalfa	19					
Other (mostly small grains)	11					
Brushlands:						
Greasewood, rabbitbrush, sagebrush, and grass; some cleared land	49					
Sagebrush and grass; some cleared land	52	29	19			
Playa (mudflats); open water at times	6					
Woodlands:						
Juniper with some oakbrush above 7,000 ft	2	113	103	2		
Pine, aspen, fir, and spruce with some oak and mahogany brush			23	55	31	6
Totals:	139	142	145	57	31	6
Total:	520 square miles					

Table 8.--Approximate areas of land use and natural vegetation, in square miles, in Cedar City Valley drainage basin

	Altitude, in feet above mean sea level					
	5,000-6,000	6,000-7,000	7,000-8,000	8,000-9,000	9,000-10,000	10,000-11,000+
Irrigated land:						
Alfalfa	24					
Other (mostly small grains)	11					
Brushlands:						
Greasewood, rabbitbrush, sagebrush, and grass; some cleared land	55					
Sagebrush and grass; some cleared land	148	42	7			
Playa (mudflats); open water at times	3					
Woodlands:						
Juniper with some oakbrush above 7,000 ft	52	125	38			
Pine, aspen, fir, and spruce with some oak and mahogany brush			10	45	14	6
Totals:	293	167	55	45	14	6
Total:	580 square miles					

Table 9.--Water-budget analysis of Parowan Basin

	Thousands of acre-feet per year
Inflow	
Precipitation[1]	484
Outflow	
Evapotranspiration[2]	
Irrigated land (mostly alfalfa and small grains, includes urban areas)[3]	48
Brushlands (greasewood, rabbitbrush, sagebrush, and grass, includes urban areas)[4]	102
Brushlands (sagebrush and grass)[5]	72
Woodlands (juniper, some oakbrush)[6]	152
Woodlands (pine, aspen, fir, spruce, some oakbrush and mahogany brush)[7]	94
Playa mudflats and open water[8]	12
Change in ground-water storage (decrease)[9]	4
Change in surface-water storage	neg.
Subsurface outflow[10]	neg.
Total	484

[1]The average annual precipitation on the area was estimated from the 1931-60 normal annual precipitation map of Utah. (U.S. Weather Bureau, no date). (See pl. 7.)

[2]Evapotranspiration values for various land classifications were developed with the assistance of the Utah Water Research Laboratory, Utah State University, on the basis of a modified Blaney-Criddle formula (Hill and others, 1970, p. 17-19).

[3]Average annual evapotranspiration, alfalfa 33.25 in., small grains 23.72 in.

[4]Regarded as phreatophytes in wet areas with average annual evapotranspiration as 42.04 in. and as sagebrush in dry areas. (see [5] below.)

[5]Average annual evapotranspiration at altitudes of 5,000-6,000 ft = 10.68 in., 6,000-7,000 = 12.68 in., 7,000-8,000 = 13.74 in.

[6]Average annual evapotranspiration at altitudes of 5,000-6,000 ft = 10.61 in., 6,000-7,000 = 12.43 in., 7,000-8,000 = 13.22 in., 8,000-9,000 = 12.10 in.

[7]Average annual evapotranspiration at altitudes of 7,000-8,000 ft = 14.94 in., 8,000-9,000 = 14.97 in., 9,000-10,000 = 15.24 in., 10,000-11,000+ = 12.74 in.

[8]Average annual evapotranspiration = 42.04 in., includes some phreatophytes around margin of the area.

[9]See section on fluctuation of ground-water levels, long-term trends.

[10]See section on subsurface outflow.

Table 10.--Water-budget analysis of Cedar City Basin

	Thousands of acre-feet per year
Inflow	
Precipitation[1]	452
Outflow	
Evapotranspiration[2]	
Irrigated land (mostly alfalfa and small grains, includes urban areas)[3]	55
Brushlands (greasewood, rabbitbrush, sagebrush, and grass, includes urban areas)[4]	50
Brushlands (sagebrush and grass)[5]	127
Woodlands (juniper, some oakbrush)[6]	147
Woodlands (pine, aspen, fir, spruce, some oakbrush and mahogany brush)[7]	62
Playa mudflats and open water[8]	7
Change in ground-water storage (decrease)[9]	3
Surface outflow	neg.
Subsurface outflow[10]	1
Total	452

[1]The average annual precipitation on the area was estimated from the 1931-60 normal annual precipitation map of Utah. (U.S. Weather Bureau, no date). (See pl. 7.)

[2]Evapotranspiration values for various land classifications were developed with the assistance of the Utah Water Research Laboratory, Utah State University, on the basis of a modified Blaney-Criddle formula (Hill and others, 1970, p. 17-19).

[3]Average annual evapotranspiration, alfalfa 32.84 in., small grains 23.21 in.

[4]Regarded as phreatophytes in wet areas, with average annual evapotranspiration as 41.52 in. and as sagebrush in dry areas. (see [5] below.)

[5]Average annual evapotranspiration at altitudes of 5,000-6,000 ft = 12.39 in., 6,000-7,000 = 13.89 in., 7,000-8,000 = 14.51 in.

[6]Average annual evapotranspiration at altitudes of 5,000-6,000 ft = 12.26 in., 6,000-7,000 = 13.35 in., 7,000-8,000 = 13.37 in.

[7]Average annual evapotranspiration at altitudes of 7,000-8,000 ft = 15.96 in., 8,000-9,000 = 15.86 in., 9,000-10,000 = 14.27 in., 10,000-11,000+ = 11.72 in.

[8]Average annual evapotranspiration = 41.52 in., includes some phreatophytes around margin of the area.

[9]See section on fluctuation of ground-water levels, long-term trends.

[10]See section on subsurface outflow.

SUMMARY AND CONCLUSIONS

The Parowan-Cedar City basin is a structural depression formed by faulting and modified by erosion. The geologic units exposed in the basin total more than 16,000 ft (4,900 m) in thickness. Ground water and surface water are derived almost exclusively from precipitation within the basin, which normally amounts to about 936,000 acre-ft (1,154 hm^3) annually. Recharge to the ground-water reservoir amounts to about 80,000 acre-ft (100 hm^3) annually, of which about half is in Parowan Valley and about half is in Cedar City Valley.

Ground water exists under both confined (artesian) and unconfined (water-table) conditions. Transmissivities determined from nine aquifer tests ranged from near 1,000 to 400,000 ft^2/d (90 to 40,000 m^2/d). Interference between pumped wells is common and usually prompt. Previously inferred faulting in the unconsolidated valley fill in a tested area had little damming, blocking, or restricting effect on water levels during an aquifer test.

Ground-water development during 1940-74 has resulted in depressed water levels in wells in most of Parowan and Cedar City Valleys. Maximum declines of more than 30 ft (9 m) existed in 9 mi^2 (23 km^2) in Parowan Valley and in 8 mi^2 (21 km^2) in Cedar City Valley. The estimated average annual depletion of storage in the ground-water reservoir for the period, based on a specific yield of 0.1 for the dewatered sediments, is about 3,600 acre-ft (4.4 hm^3) in Parowan Valley and 3,300 acre-ft (4.1 hm^3) in Cedar City Valley.

Ground water in the basin is hard but generally is satisfactory for most uses. In parts of the area of concentrated well development in Cedar City Valley, the water contains greater concentrations of some chemical constituents and dissolved solids than is recommended by the U.S. Public Health Service (1962) for public use. In Parowan Valley the water is generally classified as a sodium, calcium, or magnesium bicarbonate type; whereas, in Cedar City Valley it is generally classified as a calcium or magnesium sulfate type. The difference in chemical type is attributed to the occurrence of soluble Jurassic and Triassic gypsum-bearing rocks which are exposed in the Cedar City basin but are not exposed in the Parowan basin.

Pumpage in the basin has tripled since 1940 and most of this increase has taken place since 1960. Pumpage during 1974 amounted to approximately 73,000 acre-ft (90 hm^3), of which 30,700 acre-ft (38 hm^3) was in Parowan Valley and 42,300 acre-ft (52 hm^3) was in Cedar City Valley. Most of the pumpage was for irrigation.

Ground water of higher-than-normal temperature occurs in the northern part of Parowan Valley and south of Hamilton Fort in Cedar City Valley and probably is related to past volcanic activity or heat generated at depth in the Hurricane fault system. Relatively cold water, northwest of Parowan and northwest of Cedar City, is related to recharge from water in Parowan and Coal Creeks.

The ground-water resource in the heavily pumped areas in Parowan and Cedar City Valleys should be regarded as fully developed so far as large discharges are concerned. However, some additional development in outlying areas may be feasible.

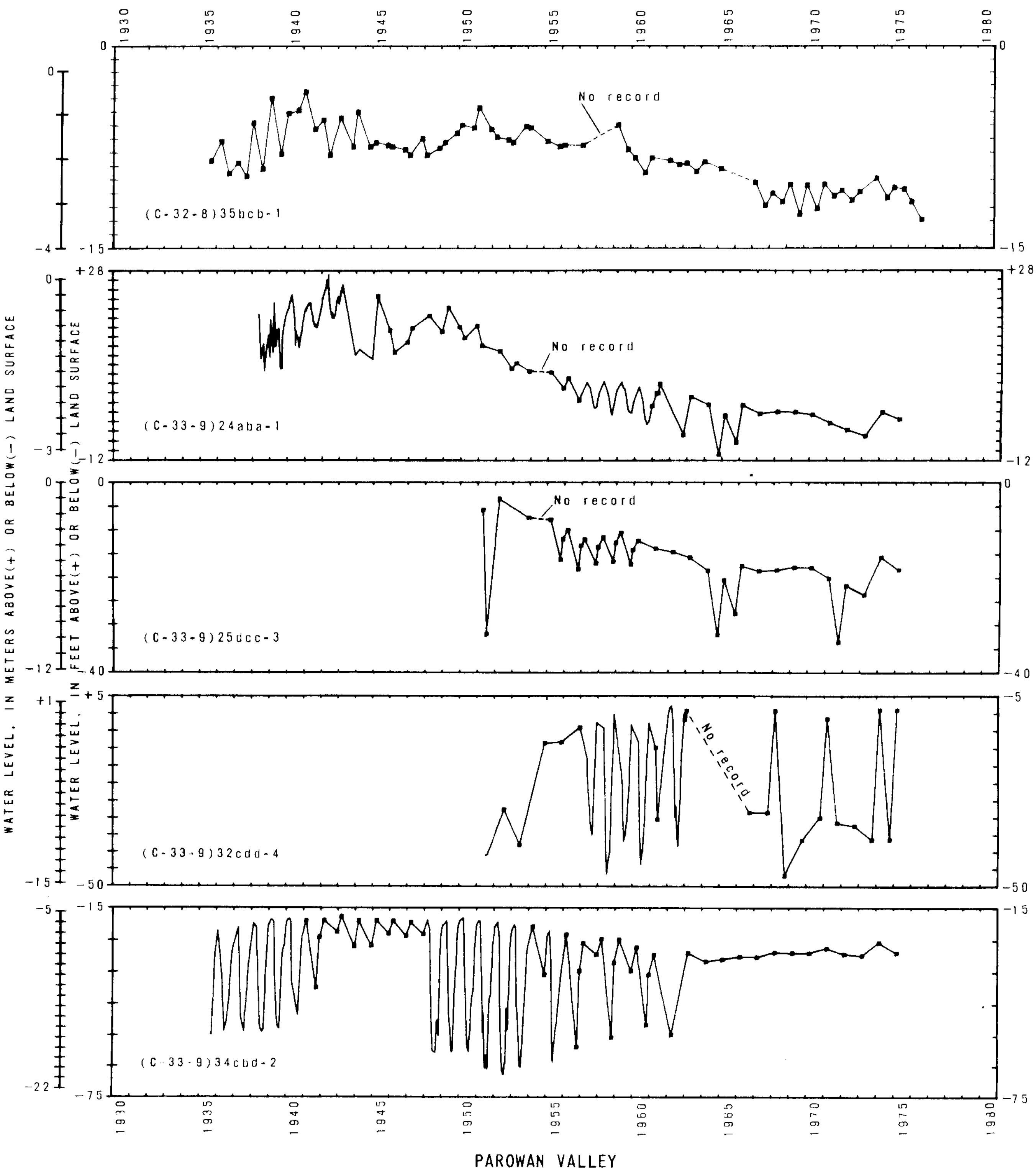
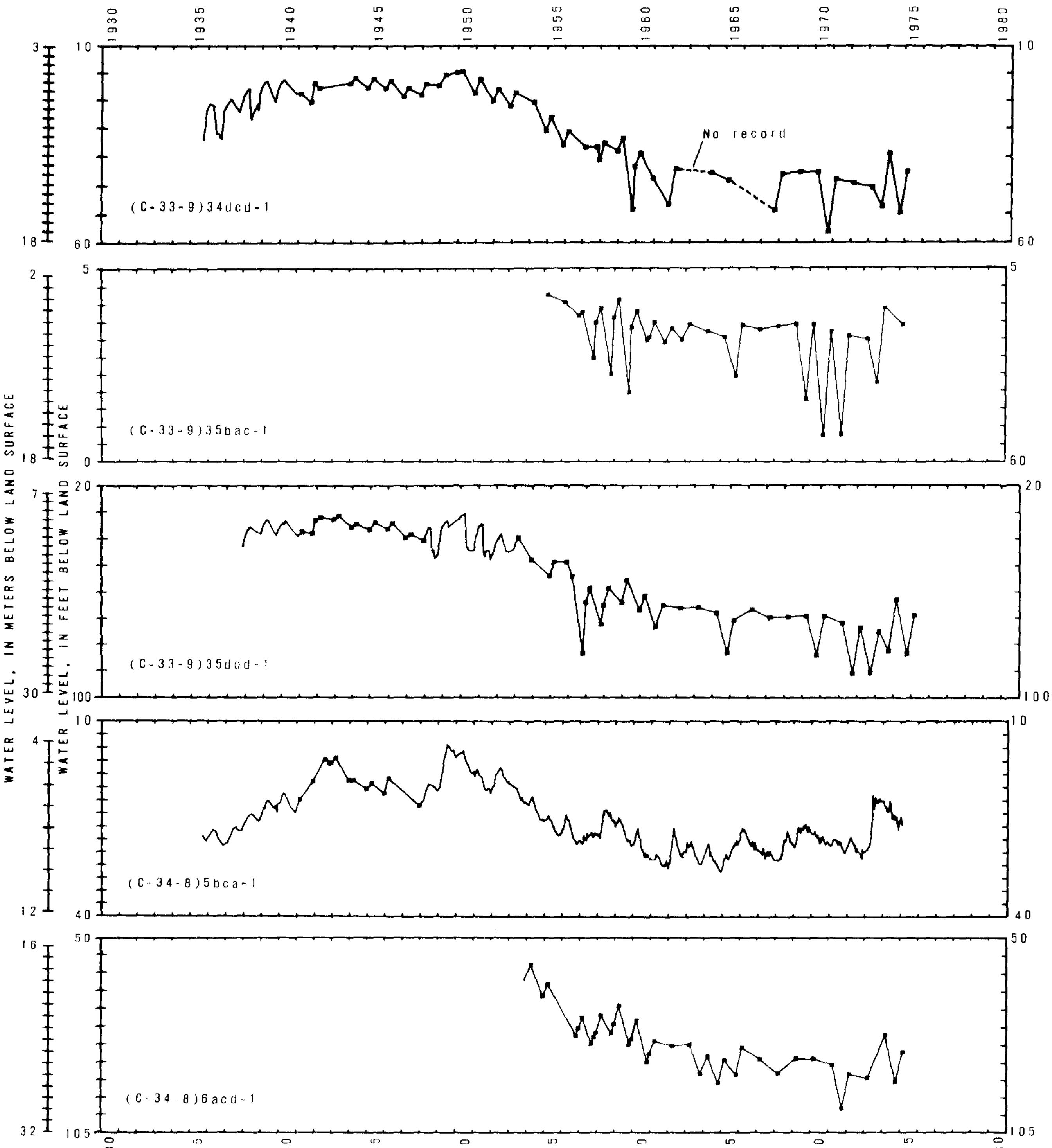
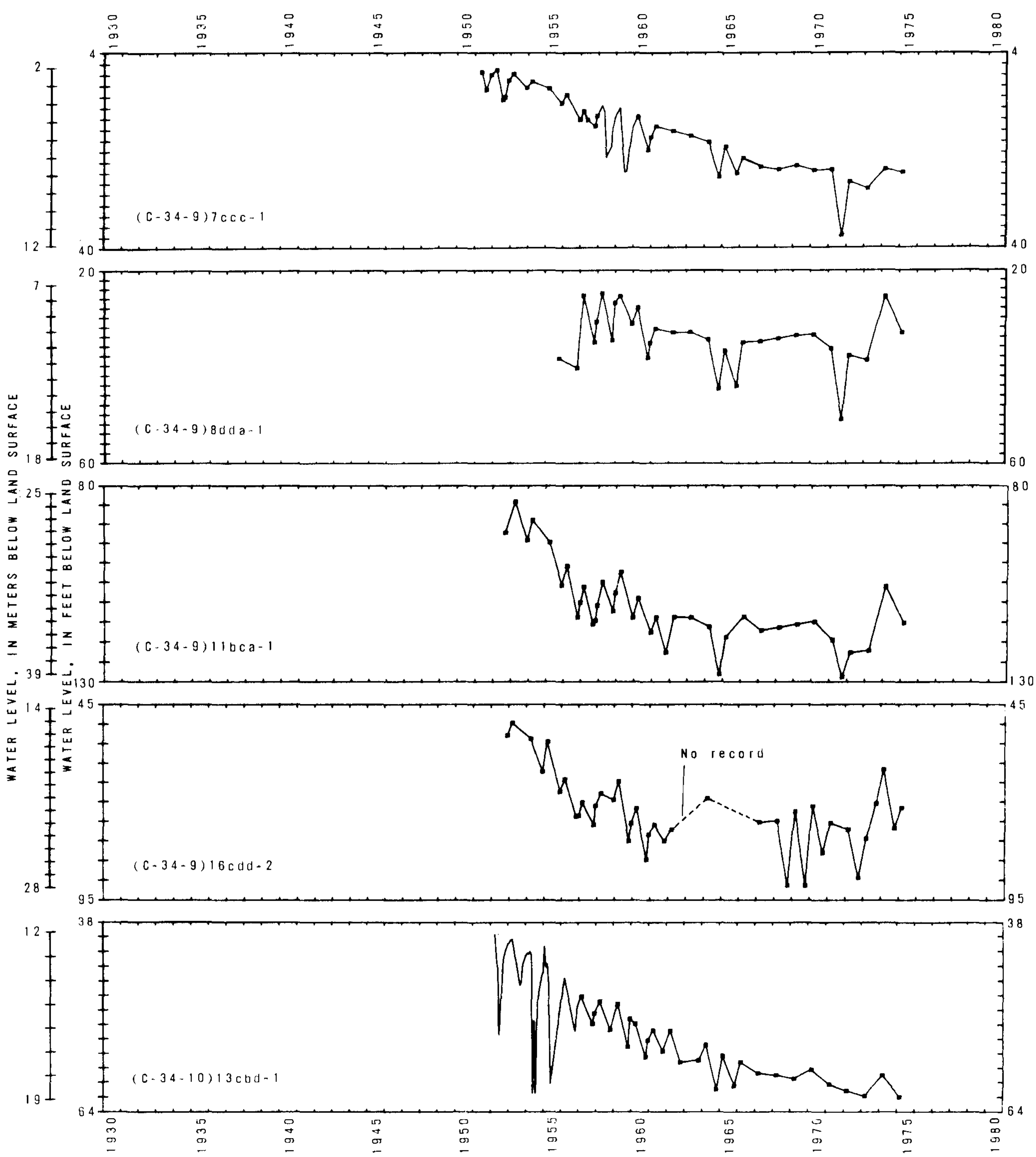


Figure 17.—Water-level fluctuations in selected observation wells in Parowan and Cedar City Valleys.



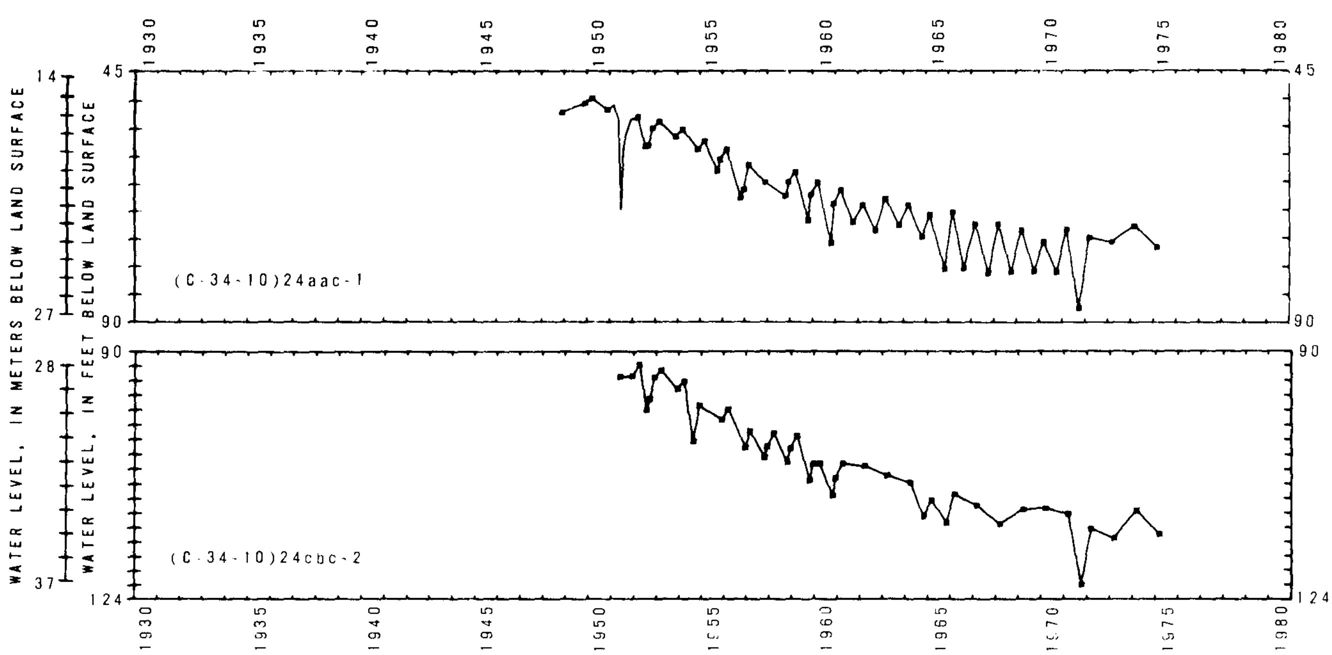
PAROWAN VALLEY—Continued

Figure 17.— Continued.



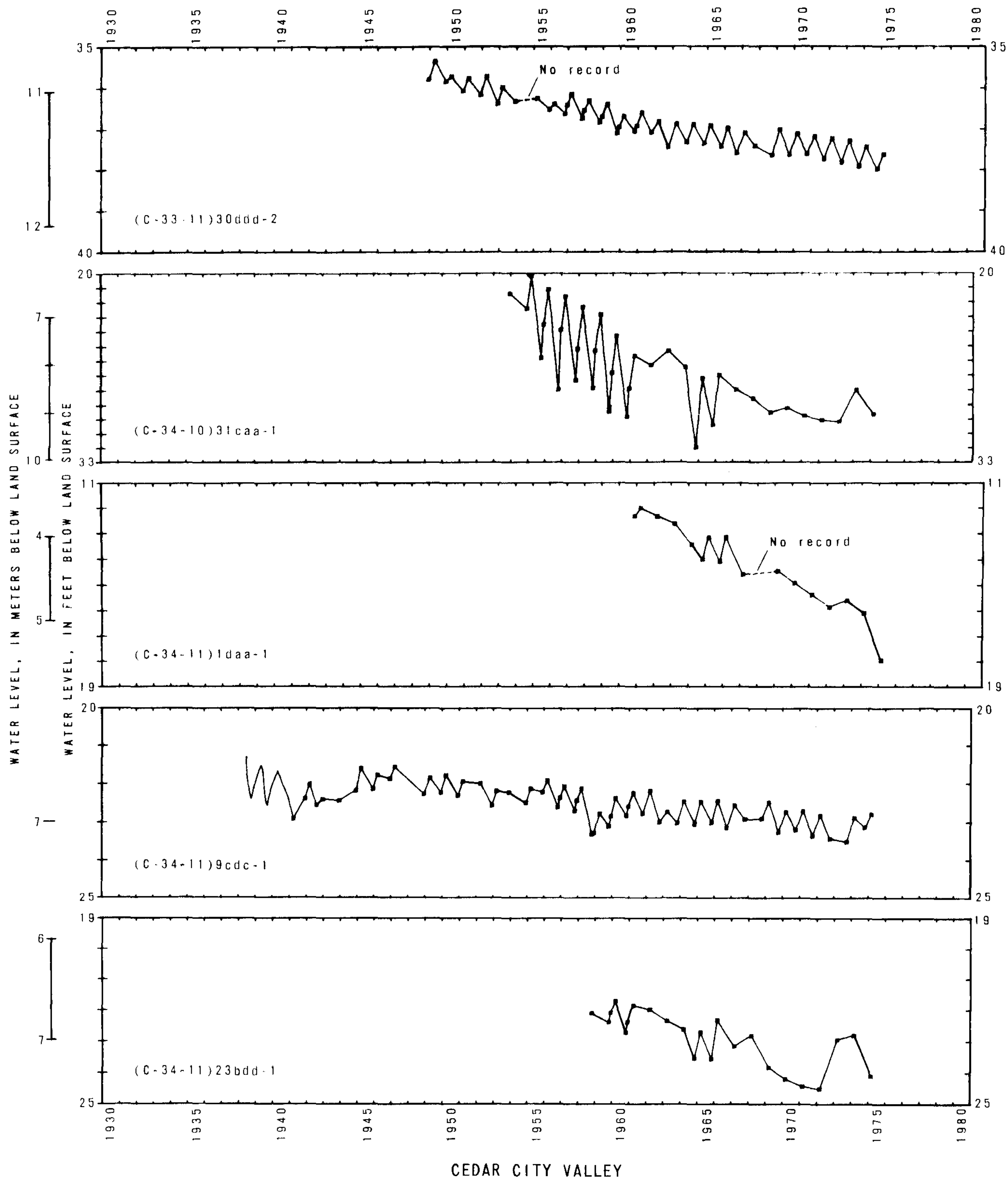
PARTOWAN VALLEY—Continued

Figure 17.—Continued.



PAROWAN VALLEY—Continued

Figure 17.— Continued



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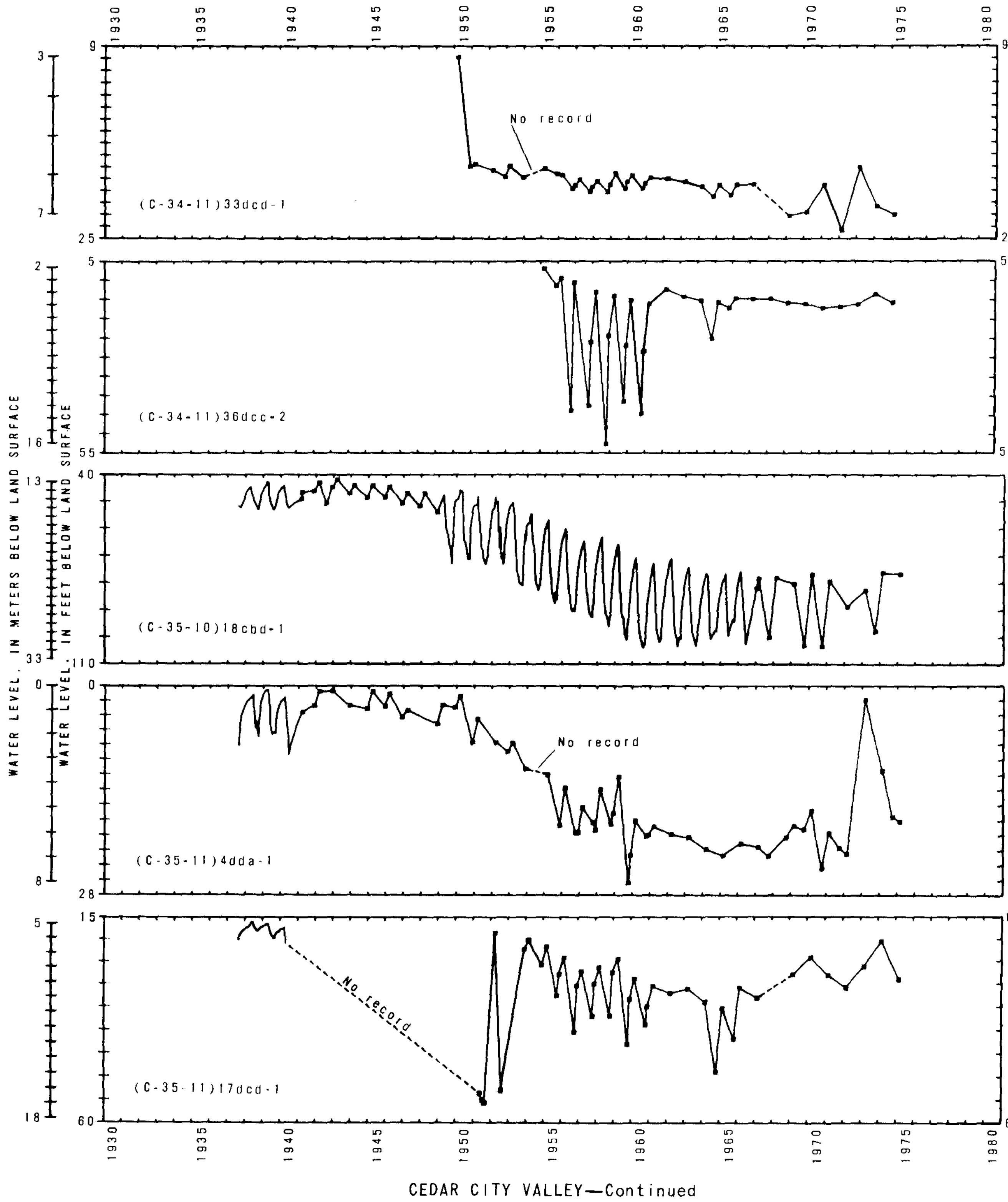

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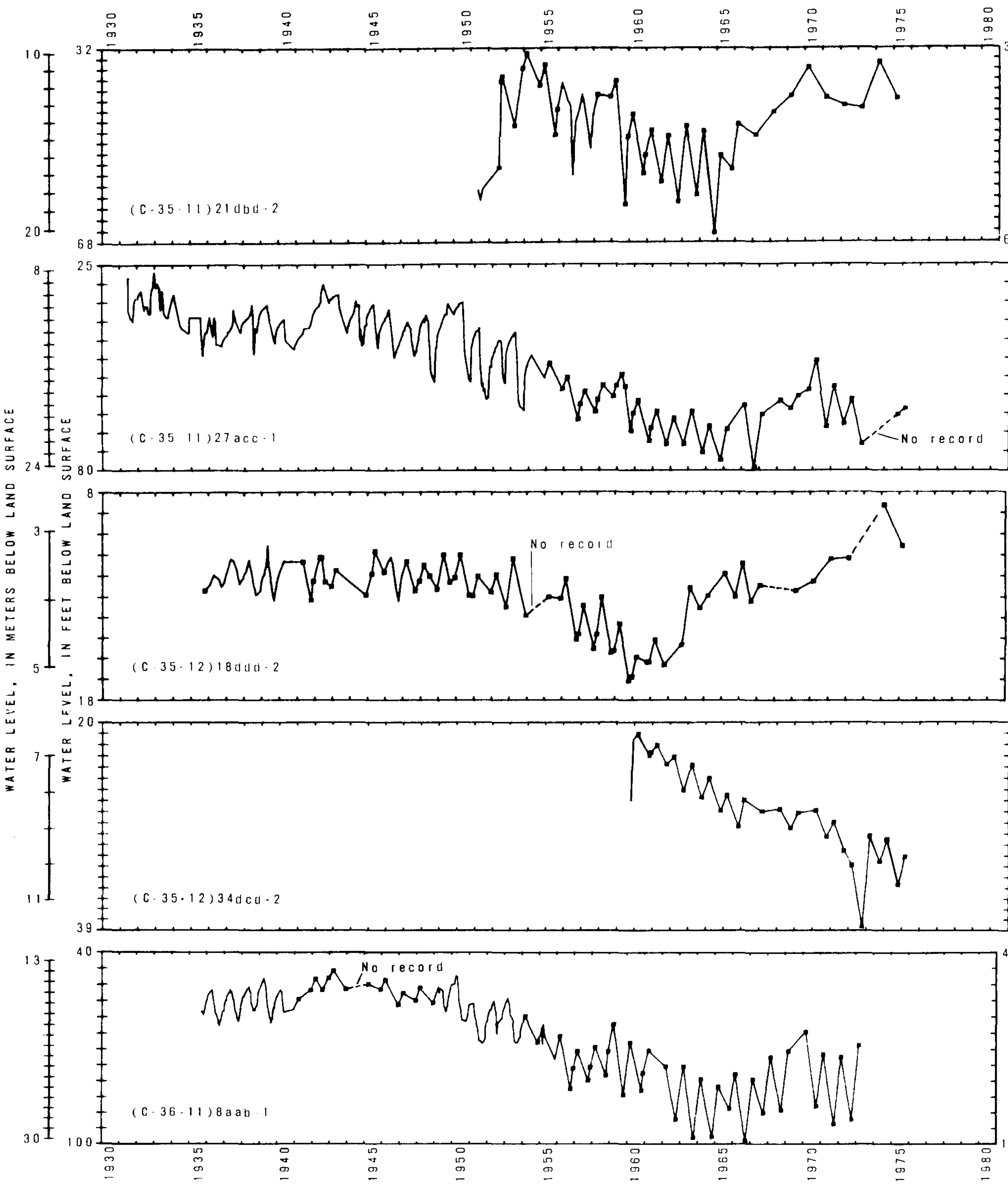
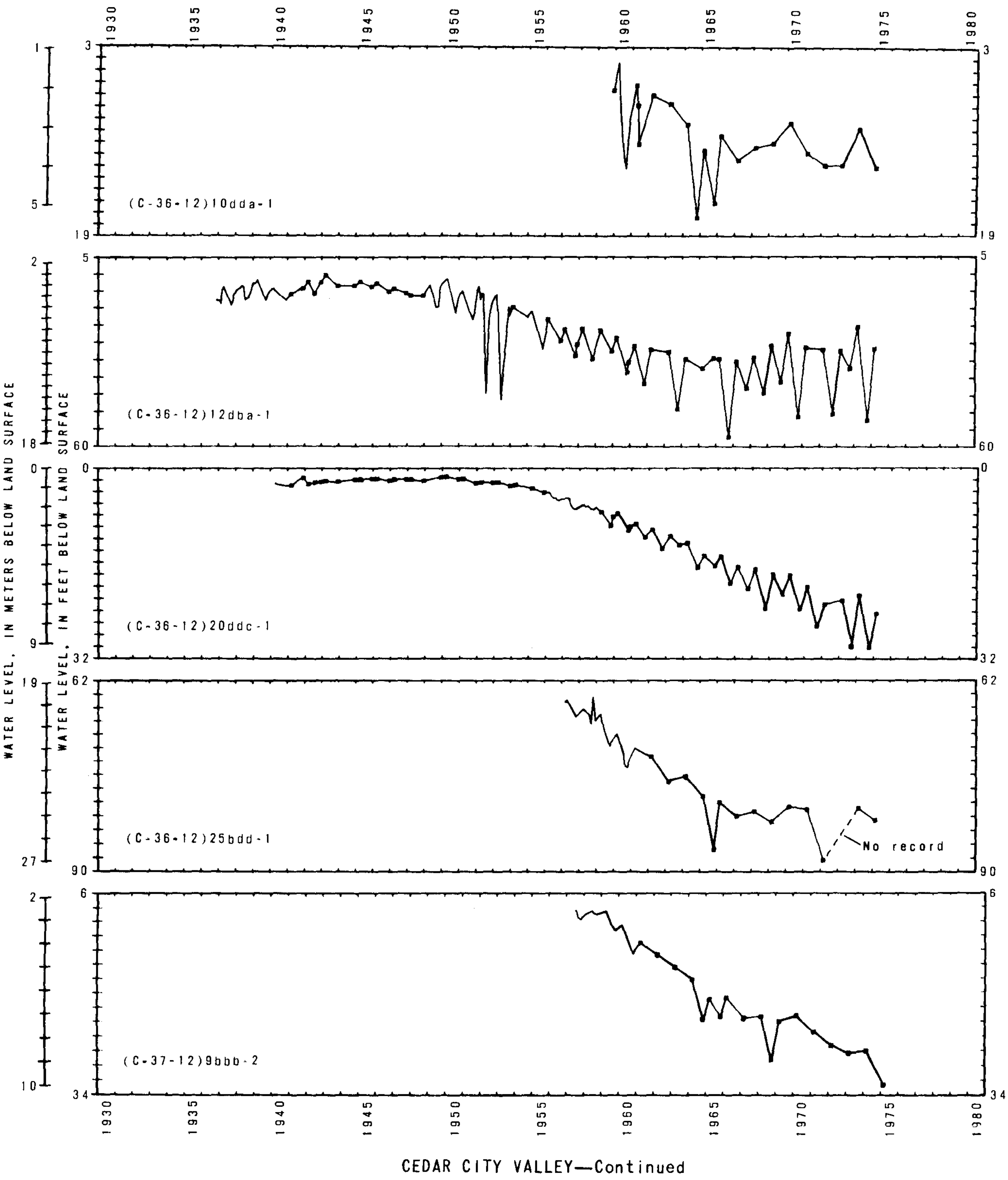


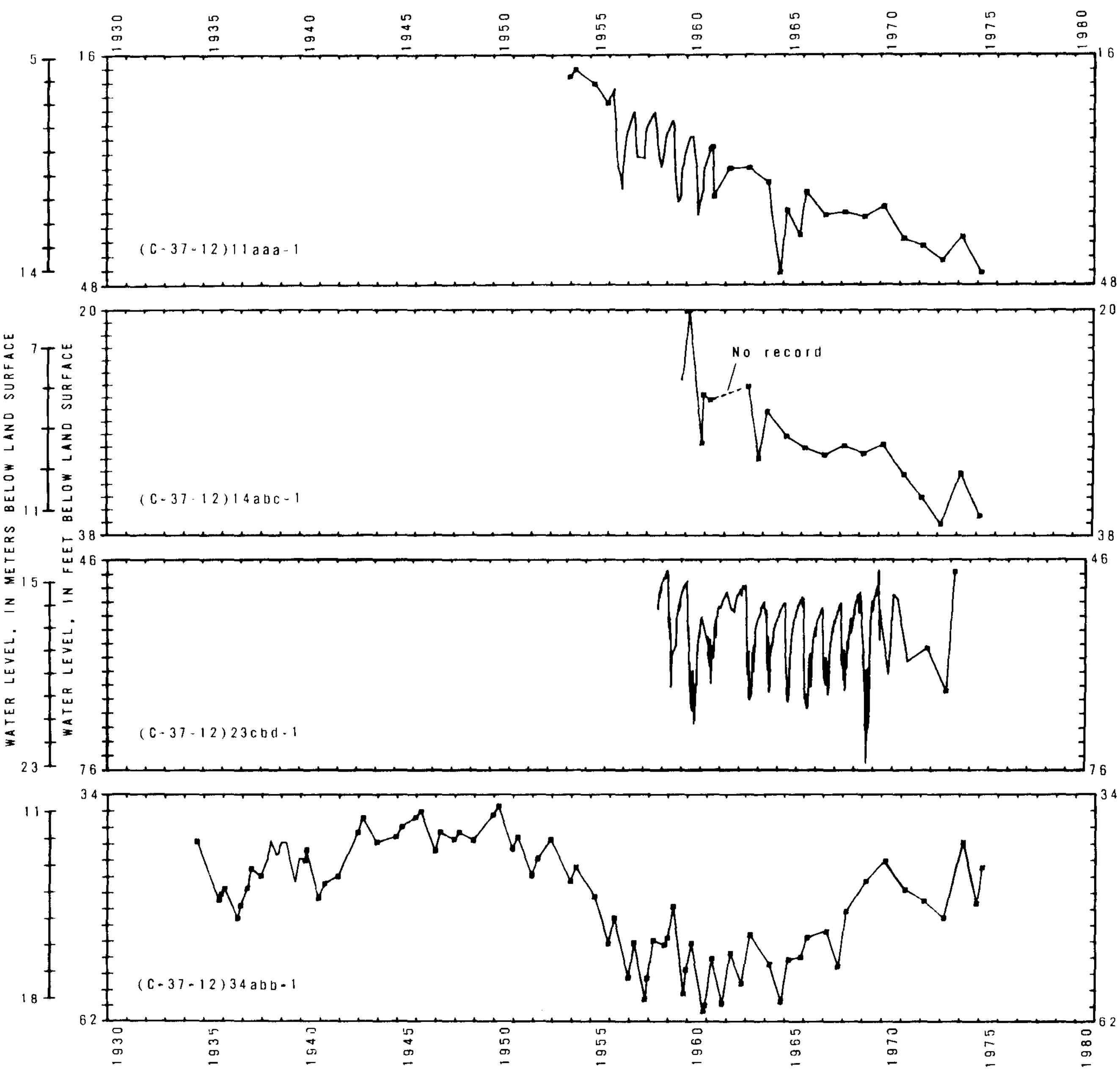
CEDAR CITY VALLEY—Continued

Figure 17.— Continued.



CEDAR CITY VALLEY—Continued

Figure 17.— Continued.



CEDAR CITY VALLEY—Continued

Figure 17.— Continued.

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STATE OF UTAH
DEPARTMENT OF NATURAL RESOURCES

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GROUND-WATER RESOURCES OF THE PAROWAN-CEDAR CITY DRAINAGE BASIN, IRON COUNTY, UTAH

by

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Prepared by
the United States Geological Survey
in cooperation with
the Utah Department of Natural Resources
Division of Water Rights

1978

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ENGLISH-TO-METRIC CONVERSION FACTORS

Most values are given in this report in English units followed by metric units. The conversion factors used are shown to four significant figures. In the text, however, the metric equivalents are shown only to the number of significant figures consistent with the accuracy of the value in English units.

English Units (Multiply)	English Abbreviation	(by)	Metric Units (to obtain)	Metric Abbreviation
Acre		0.4047	Square hectometer	hm^2
Acre-foot	acre-ft	.001233	Cubic hectometer	hm^3
Cubic foot per second	ft^3/s	.02832	Cubic meter per second	m^3/s
Foot	ft	.3048	Meter	m
Foot per mile	ft/mi	.1894	Meter per kilometer	m/km
Gallon	gal	3.785	Liter	L
		.003785	Cubic meter	m^3
Gallon per minute	gal/min	.06309	Liter per second	L/s
Mile	mi	1.609	Kilometer	km
Square foot	ft^2	.09290	Square meter	m^2
Square mile	mi^2	2.590	Square kilometer	km^2

Chemical concentration and water temperature are given only in metric units. Chemical concentration is given in milligrams per liter (mg/L). For concentrations less than 7,000 mg/L, the numerical value is about the same as for concentrations in the English unit, 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 the English unit, equivalents per million.

Water temperature is given in degrees Celsius (°C), which can be converted to degrees Fahrenheit (°F) by the following equation: °F = 1.8 (°C) + 32.

GROUND-WATER RESOURCES OF THE PAROWAN-CEDAR CITY DRAINAGE BASIN, IRON COUNTY, UTAH

by

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ABSTRACT

The Parowan-Cedar City drainage basin, Iron County, Utah, includes about 1,100 mi^2 (square miles)(2,800 km^2 [square kilometers])--520 mi^2 (1,300 km^2) in the Parowan basin and 580 mi^2 (1,500 km^2) in the Cedar City basin. Parowan and Cedar City Valleys are structural depressions formed by northeast-trending faults. Parowan Valley is essentially a closed basin, whereas Cedar City Valley is drained by two gaps in the mountains bordering the west side of the valley, and a small part of Cedar City Valley is drained at a gap at the south end. Water flowing into the basin from the highlands to the east is used to irrigate lands near Cedar City, Parowan, Paragonah, and Summit. The surface-water outflow from the basin is negligible.

The geologic units exposed in the basin attain a maximum total thickness of more than 16,000 ft (feet) (4,900 m [meters]). The oldest formation is the Kaibab Limestone of Permian Age.

Ground water in the basin is derived almost exclusively from precipitation within the basin which normally amounts to about 936,000 acre-ft (acre-feet) (1,150 hm^3 [cubic hectometers]) annually. Most of the wells in the area derive water from the unconsolidated valley fill of Quaternary age. Annual recharge to the alluvial deposits in the basin is about 80,000 acre-ft (98 hm^3), approximately half of which is to Parowan Valley and half is to Cedar City Valley. Recharge is mostly from streams, irrigation, and subsurface inflow from the mountains to the east.

Ground water occurs in the valley fills under both confined (artesian) and unconfined (water-table) conditions. The most productive aquifers are beds of well-sorted gravel and sand. Flowing wells in 1975 existed in an area of about 36 mi^2 (93 km^2) in Parowan Valley, although they existed in an area of 46 mi^2 (120 km^2) in 1940. No flowing wells now exist in Cedar City Valley although they existed throughout an area of more than 50 mi^2 (130 km^2) in 1939. Local perched ground-water bodies are common in the valley fill. More than 40 million acre-ft (50,000 hm^3) of water is estimated to be stored in the unconsolidated fills of Parowan and Cedar City Valleys.

Transmissivity of the valley fill as determined from nine aquifer tests ranged from about 1,000 to 400,000 feet squared per day (90 to 40,000 meters squared per day). Transmissivity was also estimated from specific-capacity data at 110 wells. The highest transmissivity and potential yield were determined in the Buckhorn Flats area where the valley fill consists largely of volcanic rocks. High transmissivity is indicated also in the Coal Creek alluvial fan from Cedar City about 3 miles (5 kilometers) northward and northwestward.

Interference between pumped wells is common and prompt. The drawdown impulse in one instance traveled 3,060 ft (933 m) in 5 minutes. Mutual interference among pumped wells in parts of Parowan and Cedar City Valleys during an irrigation season is considerable. Inferred faults in the valley fill in Parowan Valley, however, had no observed damming, blocking, or restricting effects on water levels during an aquifer test.

The potentiometric surface of the ground-water reservoir slopes generally westward to northward, and the ground water moves from the mountain front of the Markagunt Plateau generally northwestward to the lower parts of the valleys where most of the natural discharge of ground water takes place. The potentiometric surface ranges from 16 ft (4.9 m) above land surface to 266 ft (81.1 m) below land surface in Parowan Valley and from 2 to 250 ft (0.7 to 76.2 m) below land surface in Cedar City Valley. Water levels generally decline during the irrigation season and recover most of the decline between irrigation seasons. Declines during 1940-74 of more than 30 ft (9 m) occurred in areas of 9 mi^2 (23 km^2) in Parowan Valley and of 8 mi^2 (20 km^2) in Cedar City Valley. The estimated average annual depletion of ground water is about 3,600 acre-ft (4.4 hm^3) in Parowan Valley and about 3,300 acre-ft (4.1 hm^3) in Cedar City Valley.

Discharge of ground water from the area occurs in several ways. Springs in the mountains bordering the basin on the east discharge more than 25,000 acre-ft (30.82 hm^3) annually. Springs in the valleys discharge less than 1,000 acre-ft (1 hm^3). The evapotranspiration of ground water amounts to about 14,000 acre-ft (17 hm^3) of which about 12,000 acre-ft (15 hm^3) is in Parowan Valley and about 2,000 acre-ft (2 hm^3) is in Cedar City Valley. The largest means of ground-water discharge are wells, amounting to approximately 73,000 acre-ft (90 hm^3) in the basin in 1974. Subsurface outflow in Parowan Valley is negligible and amounts to less than 500 acre-ft (0.6 hm^3) a year in Cedar City Valley.

Ground water in Parowan basin is classified generally as sodium, calcium, or magnesium bicarbonate type, whereas in Cedar City basin it is classified as a calcium or magnesium sulfate type. Ground water in both basins generally is very hard. Public water-supply systems in the area provide water that is below the concentration limits recommended by the U.S. Public Health Service for various chemical constituents which have been analyzed. For irrigation, ground water in the area generally has a low sodium hazard and low-to-high salinity hazard. Wells in Cedar City Valley sampled during 1938-40 and again in 1973-74 indicate an average increase in chloride of 10 milligrams per liter.

Total pumpage from wells in the basin during 1974 was 73,000 acre-ft (90 hm^3), of which 30,700 acre-ft (38 hm^3) was in Parowan Valley and 42,300 acre-ft (52 hm^3) was in Cedar City Valley. Most of the pumpage was for irrigation. In most areas, ground water alone was used for irrigation, but in some localities ground water was used to supplement surface-water supplies. Public water supplies are obtained primarily from springs in the mountains and usually supplemented by wells in the valley. Several housing-development sites use community wells for water supplies.

INTRODUCTION

Purpose and scope of the study

This report is intended to assist public officials and water users in the Cedar City-Parowan drainage basin, Iron County, Utah, to develop, conserve, and administer their water resources. The report primarily describes the ground-water resources in the alluvial fill of Cedar City and Parowan Valleys, but it also presents information about the water in the bedrock formations in the highlands surrounding the valleys. It discusses the relation of ground water to surface water in the basin and presents a general water-budget analysis. It includes information on the source, occurrence, availability, quantity, movement, chemical quality, and development of the ground water and the effects of climate, geology, and development on the resource.

Selected hydrologic data collected for the study are given in Bjorklund, Sumsion, and Sandberg (1977), which contains information regarding selected wells and springs, including water levels, chemical quality of water, and drillers' logs of wells. Both the data report and this one were prepared by the U.S. Geological Survey in cooperation with the Utah Department of Natural Resources, Division of Water Rights. Fieldwork for the investigation began in July 1973 and continued through June 1975.

Location and general features

Topography and drainage

The Parowan-Cedar City drainage basin in southwestern Utah (fig. 1) is primarily a structural basin including approximately 1,100 mi^2 (2,800 km^2) of which 520 mi^2 (1,300 km^2) is in the Parowan Basin and 580 mi^2 (1,500 km^2) is in the Cedar City Basin. Most of this area is in the Great Basin section of the Basin and Range physiographic province (Fenneman, 1931). It is bounded on the south and east by the Markagunt Plateau, on the north by the Black Mountains, and on the west by relatively low mountains and hills. About 70 percent of the basin is mountainous or hilly and is underlain with bedrock covered in most places with a thin mantle of soil. About 30 percent of the basin is in Parowan and Cedar City Valleys; this area consists of flatlands and alluvial fans and slopes underlain by Quaternary alluvium composed of boulders, cobbles, gravel, sand, silt, and clay eroded from the surrounding highlands. Altitudes range from 11,307 ft (3,446 m) at Brian

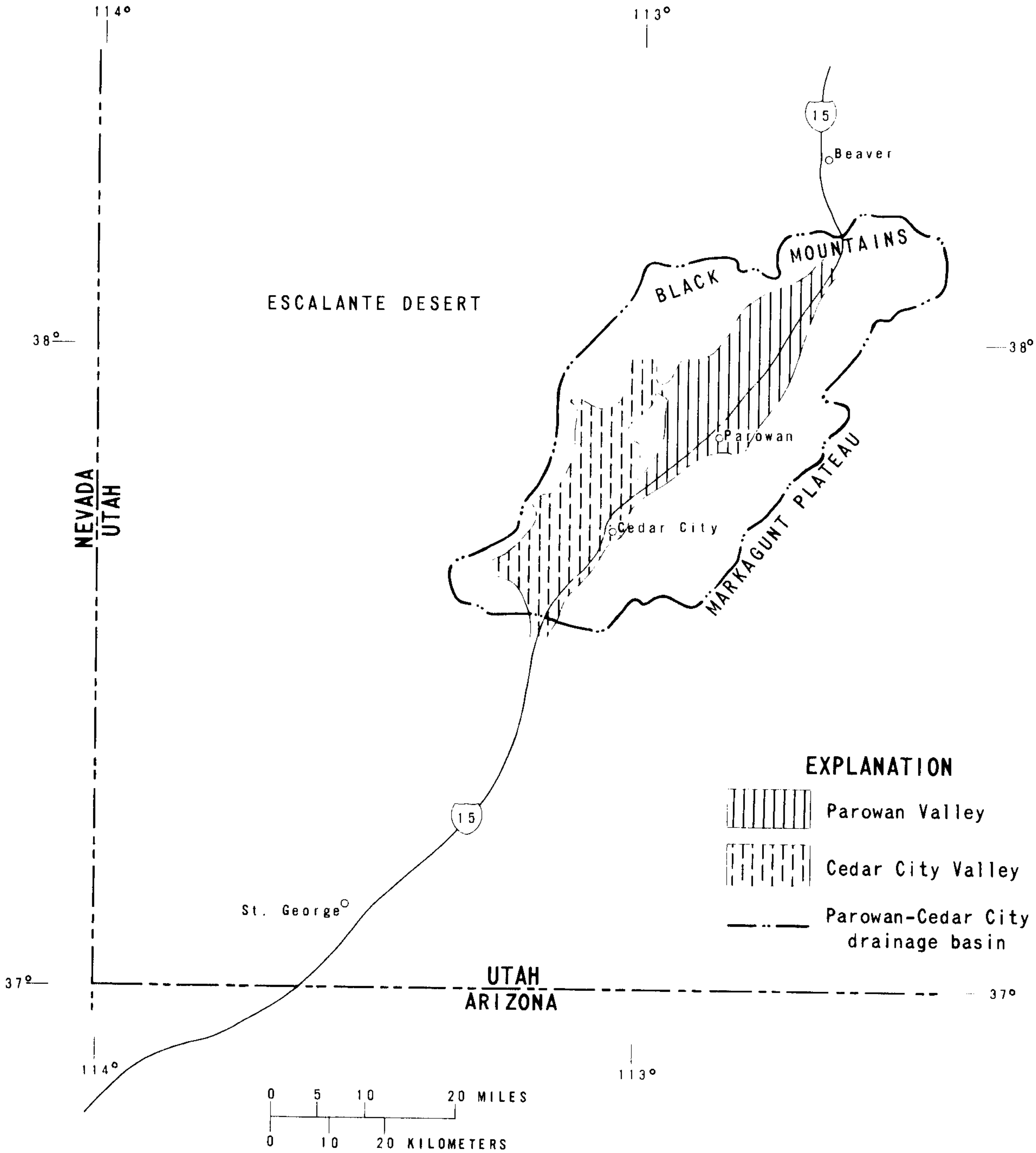

Figure 1.—Location of Parowan and Cedar City Valleys and the Parowan-Cedar City drainage basin.

Head, the highest point on the Markagunt Plateau, to 5,350 ft (1,631 m) at the edge of Cedar City Valley, at the outlet at Mud Springs Wash. The lowest altitude in Parowan Valley is about 5,690 ft (1,734 m) at the Little Salt Lake Playa.

Parowan and Cedar City Valleys are structural depressions primarily formed and bounded by faults generally trending northeast-southwestward. The highlands bordering the valleys consist of elevated fault blocks, modified by erosion, and the valleys are underlain by downthrown blocks blanketed by materials eroded from the highlands. The two valleys are separated by a southward extension of the Black Mountains, which is lower in altitude southward and ends at a low pass at the southwestern end of Parowan Valley. Each valley is about 32 mi (51 km) long and ranges from about 1 to about 8 mi (1.6 to 13 km) wide. Parowan Valley covers about 160 mi^2 (410 km^2) and Cedar City Valley covers about 170 mi^2 (440 km^2). Parowan Valley is considerably higher than Cedar City Valley, the lowest points in the valleys differing by 340 ft (104 m).

Most of the water flowing into the valleys originates as snowmelt runoff from the highlands along the eastern side of the drainage basin. The principal perennial streams are Coal Creek in Cedar City Valley and Parowan Creek in Parowan Valley. Both streams have built large alluvial fans that extend to the center of the valleys. Other important but smaller streams are Shirts Creek[1] in Cedar City Valley and Willow, Little, Red, and Summit Creeks in Parowan Valley. Excess spring runoff accumulates in three shallow playa lakes--Little Salt Lake in Parowan Valley and Quichapa and Rush Lakes in Cedar City Valley.

Parowan Valley is essentially a closed basin, although a small part of the valley at the southwestern end drains through Winn Gap into Cedar City Valley. In ages past the main part of the valley drained into Cedar City Valley through Parowan Gap. Today, however, the main outlet in Parowan Gap is blocked by alluvial fans from branch canyons and possibly by uplift of the mountain block separating the valleys. Some ground water may seep through the gap or through the mountain block into Cedar City Valley, but the quantity would be small.

Cedar City Valley is drained by three gaps in the surrounding hills. Two areas along the western side of the valley slope toward gaps or openings in the westward bordering mountains, and one area at the southern end of the valley slopes southward toward the Virgin River. Thus, Mud Springs Wash and Iron Springs Gap on the west side of the valley conduct water at times toward the Escalante Desert basin to the northwest, and Kanarra Creek drainage conducts some water from the southern parts of the valley toward the Virgin River basin to the south. These drainages conduct surface water from the valley during flash floods that occur during or following excessive local precipitation. These gaps also continually conduct a relatively small amount of ground water through the permeable alluvial fills in the gaps toward areas of lower elevation.

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[1]Also known as Shurtz Creek.

Quichapa Lake in recent years contained water and has given the impression to some that it is the lowest part of Cedar City Valley. Rush Lake, however, is approximately 60 ft (20 m) lower in altitude, but in recent years has been dry. The general northward slope of the valley toward Rush Lake and Mud Springs Wash has been interrupted by the alluvial fan of Coal Creek isolating the Quichapa Lake basin which receives excess runoff from Coal and Shirts Creeks.

Climate

The climate of the area ranges from semiarid in Parowan and Cedar City Valleys to humid on the highlands to the east. Moderate to meager precipitation, large daily temperature changes, moderately cold winters, and warm dry summers are characteristic of the valleys. In parts of Cedar City Valley annual precipitation normally varies from 8 to 14 in. (200 to 360 mm) and in Parowan Valley, from 10 to 16 in. (250 to 410 mm). In the highlands precipitation generally varies with the altitude and ranges from about 16 in. (410 mm) near the base to about 40 in. (1,000 mm) at the crest of the Markagunt Plateau at Cedar Breaks (pl. 7). Most of the precipitation results from humid air masses that move southeastward from the north Pacific during winter and spring; much of it falls as snow in the mountains, but some precipitation in late summer and early fall results from humid air moving northwestward from the Gulf of Mexico. Snow usually covers the valley floors during winter months, but snowstorms may persist into April or May. Runoff from spring snowmelt reaches its maximum in May or June. The growing season--the number of consecutive days above -2°C (28°F)--during 1964-73 has ranged from 128 to 181 days and averaged 154 days at the Cedar City airport and has ranged from 123 to 175 days and averaged 151 days at Parowan. The normal monthly precipitation and temperature at Parowan and Cedar City are given in table 1.

Climatological data are collected by the National Weather Service (formerly U.S. Weather Bureau). Other available climatological data collected in or near the project area but not shown herein are collected at the Cedar City powerhouse in Coal Creek Canyon, at Blowhard Mountain Radar Station near the crest of Markagunt Plateau, and at New Harmony in Washington County. Graphs showing the relation of annual precipitation, cumulative departure from average precipitation at Cedar City and Parowan, discharge in Coal Creek, and ground-water levels in selected wells are shown in figures 2 and 3.

Culture and population

Approximately 12,000 people live within the project area; about 10,000 people live in Cedar City Valley and 2,000 in Parowan Valley. Cedar City (pop. 1970, 8,946) and Parowan (pop. 1970, 1,423) are the principal towns and business centers. Mining, agriculture, tourism, and diversified manufacturing are the principal industries. Iron ore is mined in the mountains west of Cedar City and shipped by rail to smelting centers. Gravel is mined and processed near Cedar City and Parowan for use in construction. The principal agricultural products are livestock products, alfalfa, grain, and timber. Nearby National Parks and other recreation areas bring many travelers to the area.

Table 1.--Normal 1941-70 monthly precipitation and temperature at Parowan and Cedar City

	Parowan Airport		Cedar City FAA-AP	
	Precipitation (in.)	Temperature (°F)	Precipitation (in.)	Temperature (°F)
January	0.84	29.6	0.65	28.7
February	1.05	34.1	.76	33.1
March	1.48	38.7	1.12	38.4
April	1.26	47.3	1.05	47.1
May	.88	56.2	.68	56.2
June	.63	64.6	.54	65.0
July	1.11	72.0	.96	73.2
August	1.39	69.8	1.22	71.3
September	.69	62.8	.72	63.2
October	.92	52.1	.89	51.5
November	1.01	40.0	.96	38.8
December	.99	32.2	.78	30.8
Annual Total	12.25		10.33	
Average		50.0		49.8

Previous investigations

The earliest descriptions of the geology and physiography of the area were published during the latter part of the 19th century as the results of reconnaissance studies that covered wide areas, including parts of Arizona and Nevada as well as southwestern Utah (Gilbert, 1875, p. 17-187; Howell, 1875, p. 227-301; Powell, 1879; and Dutton, 1880).

Detailed studies of geology in and near the Parowan-Cedar City area during the early part of the 20th century were related principally to mineral deposits, mainly coal and iron ore (Lee, 1907; Leith and Harder, 1908; and Richardson, 1909). More recent studies of geology in and near the area have been completed by Mackin (1954), Averitt (1962; 1964, p. 901-903; and 1967), Threet (1963, p. 104-117), Wright and Dickey (1963, p. E63-E67), Lawrence (1965, p. 71-91), Stewart, Poole, and Wilson (1972a, 1972b), and Averitt and Threet (1973). A geologic map of Utah was compiled and edited by Stokes (1964).

Two of the earliest studies of water resources were reconnaissance investigations intended to serve as guides in a large area of arid western and southwestern Utah by Lee (1908) and Meinzer (1911). The first comprehensive investigation of geology and ground water in the Parowan and Cedar City drainage basins was by Thomas and Taylor (1946).

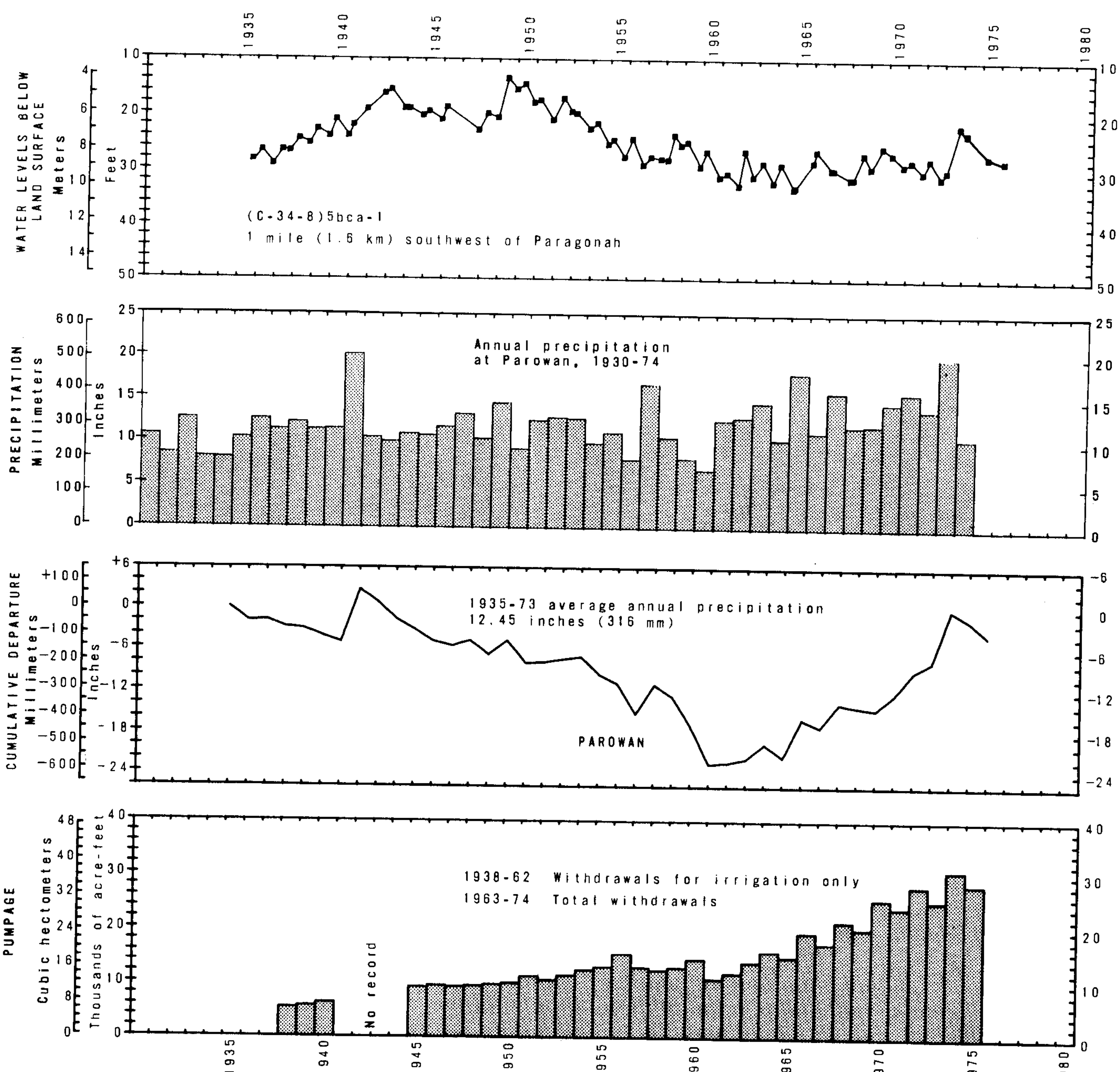

Figure 2.— Relation of water levels in well (C-34-8)5bca-1 in Parowan Valley to annual precipitation at Parowan, to cumulative departure from average annual precipitation, and to withdrawals from wells.

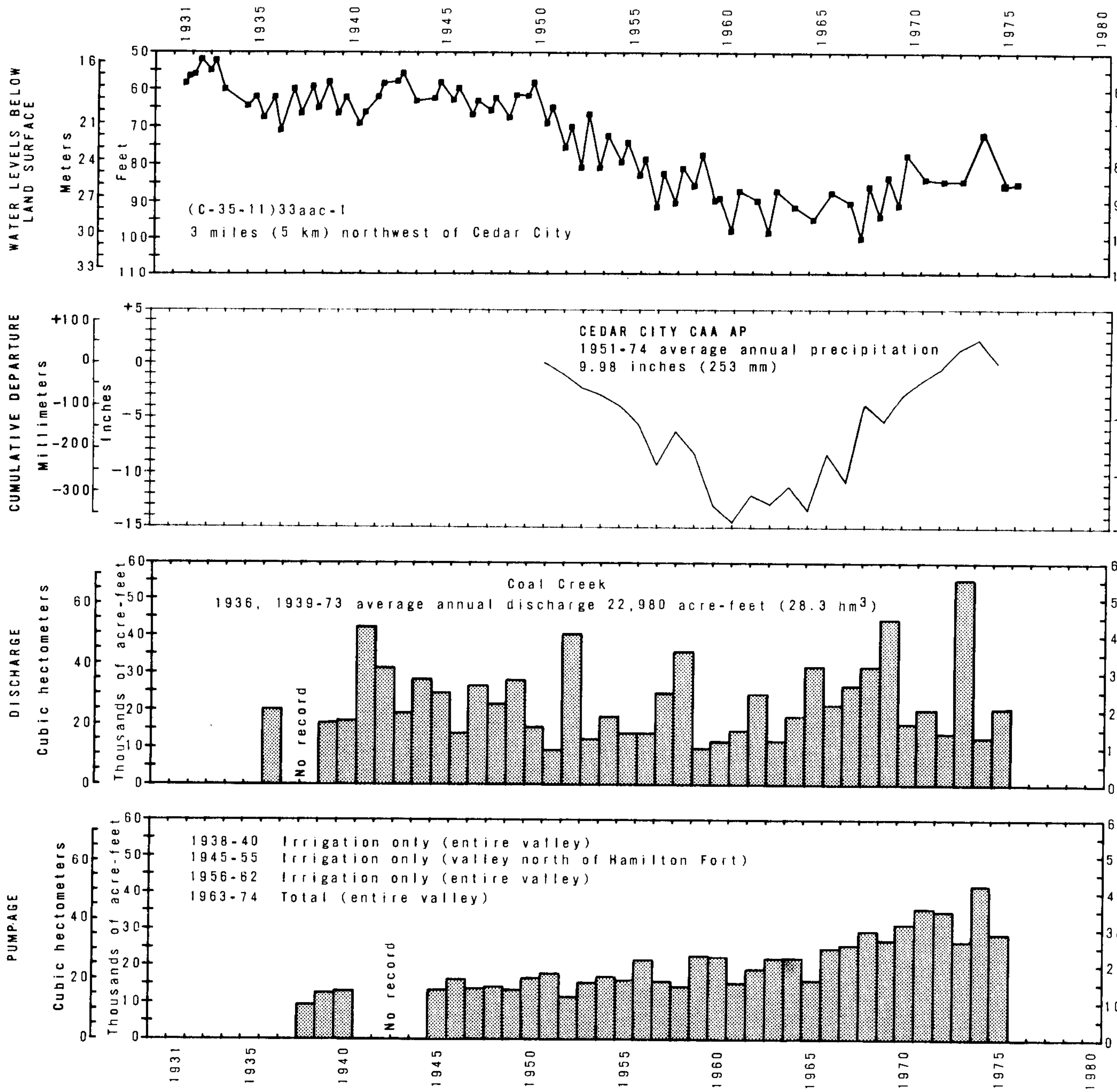

Figure 3.— Relation of water levels in well (C-35-11)33aac-1 in Cedar City Valley to cumulative departure from the average annual precipitation at the Cedar City airport, to discharge of Coal Creek near Cedar City, and to pumpage from wells.

The progress of ground-water development in Parowan Valley is discussed by Nelson, in Thomas and others (1952, p. 34-39), and in Cedar City Valley by Thomas, in Thomas and others (1952, p. 22-34). Subsequent reports on ground-water development in these same areas are given by Barnell and Nelson, in Waite and others (1954, p. 75-84), and by Butler and Barnell, in Waite and others (1954, p. 84-93). The economics of pumping ground water in southwestern Utah is discussed by Nelson, in Waite and others (1954, p. 95-104). Sandberg (1966) describes the ground-water resources of selected ground-water basins in southwestern Utah, including Parowan and Cedar City Valleys.

Well- and spring-numbering system

The system of numbering wells and springs in Utah is based on the cadastral land-survey system of the U.S. Government. The number, in addition to designating the well or spring, describes its position in the land net. 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 (4 hm^2);[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 (4-hm^2) tract; the letter "S" preceding the serial number denotes a spring. If a well or spring cannot be located within a 10-acre (4-hm^2) tract, one or two location letters are used and the serial number is omitted. Thus (C-35-12)24ada-1 designates the first well constructed or visited in the NE¼SE¼NE¼ sec. 24, T. 36 S., R. 12 W. The numbering system is illustrated in figure 4.

SURFACE WATER

Water diverted from perennial streams flowing into the Parowan-Cedar City basin, mostly from the highlands to the east, is used to irrigate some lands near Cedar City, Parowan, Paragonah, and Summit. The measured or estimated annual discharge of the principal streams for water years 1960-74 is shown in table 2. During this period the average annual surface-water discharge into Parowan and Cedar City Valleys from the principal streams is estimated to be about 46,000 acre-ft (57 hm^3).

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[1]Although the basic land unit, the section, is theoretically 1 mi^2 (2.6 km^2), many sections are irregular. Such sections are subdivided into 10-acre (4-hm^2) tracts, generally beginning at the southeast corner, and the surplus or shortage is taken up in the tracts along the north and west sides of the section.

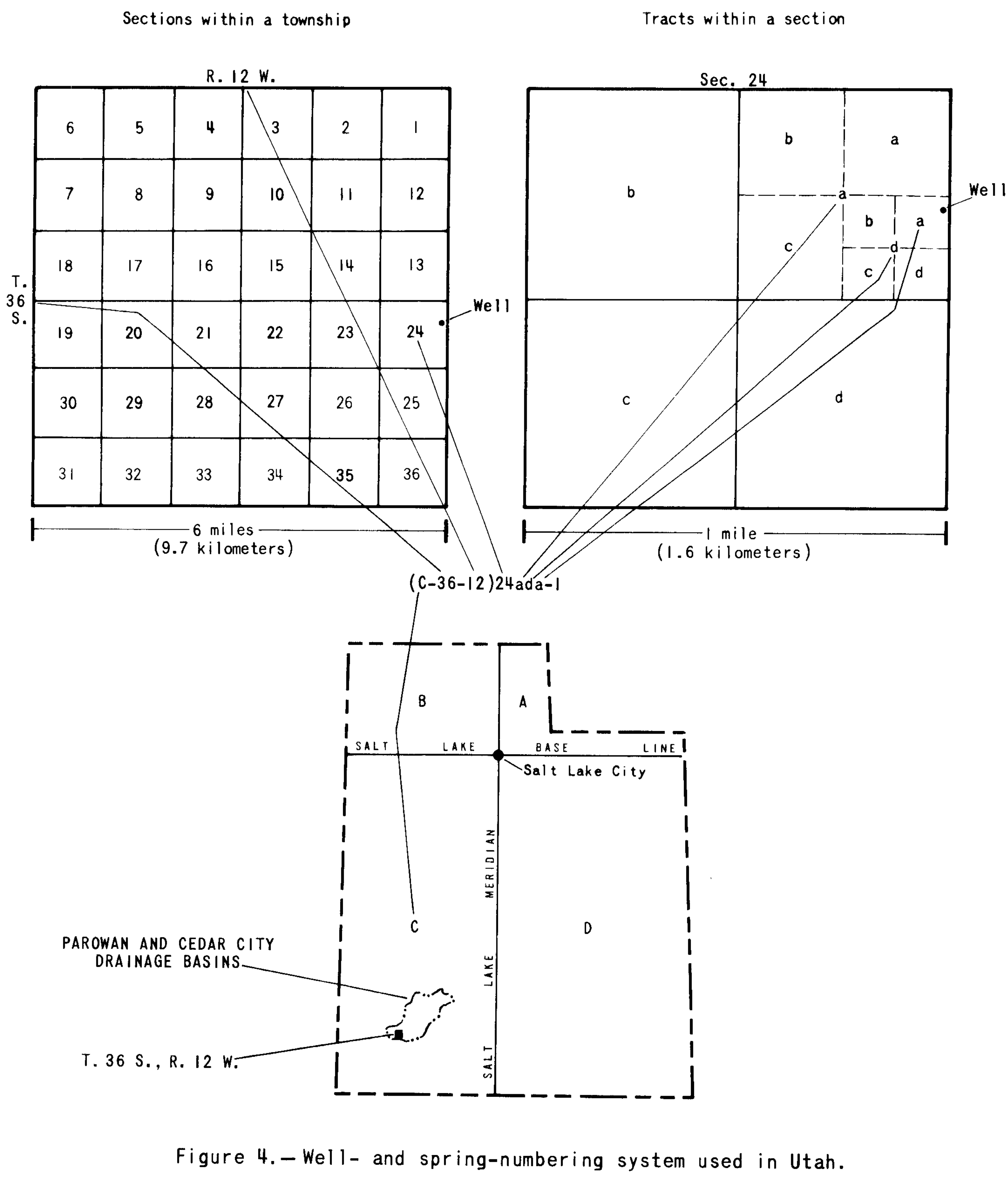

Figure 4.—Well- and spring-numbering system used in Utah.

Table 2.--Discharge of principal streams, in acre-feet, at gaging stations in the Parowan-Cedar City drainage basin, 1960-74

[E, estimated]

	Gaging stations on streams entering Cedar City and Parowan Valleys					Gaging stations on tributary streams	
Water year	Coal Creek near Cedar City	Parowan Creek near Parowan	Red Creek at Paragonah	Little Creek near Paragonah	Summit Creek near Summit	Center Creek above Parowan Creek (tributary to Parowan Creek)	Red Creek near Paragonah (6 miles upstream from Red Creek at Paragonah)
1960	11,180	6,400E	-	475	1,400E	2,700E	750E
1961	15,110	8,600	-	1,080	1,800E	3,200E	880E
1962	24,360	14,000E	-	1,350	2,900E	4,300E	1,100E
1963	11,970	6,800E	-	524	1,500E	3,000E	800E
1964	18,470	10,500E	-	649	2,200E	3,600E	920E
1965	30,870	17,000E	-	2,010	4,280	5,030	1,200E
1966	21,630	12,300E	-	1,110	2,170	4,030	1,050
1967	26,660	15,000E	-	936	2,050	4,510	1,010
1968	31,720	18,000E	-	1,540	3,900	5,790	1,070
1969	43,900	25,000E	-	1,730	4,310	5,750	1,280
1970	17,080	9,700E	-	914	2,830	4,530	1,000
1971	19,540	11,000E	3,600E	1,240	2,150	3,510	921
1972	14,240	8,000E	3,500E	688	1,480	3,160	748
1973	57,320	33,000E	8,000E	4,050	7,770	8,550	2,340
1974	13,400	7,300E	4,200E	1,280	2,190	4,270	1,440
Average	23,830	13,507	4,800	1,305	2,862	4,396	1,101

Explanation of stations and basis of estimates

Coal Creek near Cedar City - near mouth of Coal Creek Canyon - Measured and gaged by U.S. Geological Survey.
Parowan Creek near Parowan (formerly Center Creek near Parowan) - near mouth of Parowan Creek Canyon. Estimates based on correlation of Center Creek near Parowan (Parowan Creek) with Coal Creek (1943-50).
Red Creek at Paragonah - Estimates based on miscellaneous measurements by U.S. Geological Survey in 1938-39 and 1940 (Thomas and Taylor, 1946, p. 69) and hydroelectric powerplant records.
Little Creek near Paragonah - near mouth of Little Creek Canyon - Measured and gaged by U.S. Geological Survey.
Summit Creek near Summit - near mouth of Summit Creek Canyon. Estimates based on correlation with Coal Creek. Measured and gaged by U.S. Geological Survey.
Center Creek above Parowan Creek - tributary to Parowan Creek - Measured by U.S. Geological Survey.
Red Creek near Paragonah - about 5 miles above mouth of Red Creek Canyon. Only part of outflow of Red Creek at Paragonah - Measured by U.S. Geological Survey.

The surface-water discharge during the snowmelt season in the highlands is largest in parts of May and June. During years of unusually large runoff, such as 1969 and 1973 (see table 2), some water flows into Little Salt Lake and Quichapa Lake or runs onto uncultivated lands where it is used by native vegetation. After the snowmelt season the discharge in the streams decreases to base flow and the surface-water supply is supplemented with ground water pumped from wells.

Coal Creek, the largest stream in the basin, discharges almost all surface water used in Cedar City Valley and about half of the surface water used in the Parowan-Cedar City basin. Since 1960 the annual discharge in Coal Creek has ranged from 11,180 acre-ft (13.8 hm^3) in 1960 to 57,320 acre-ft (70.7 hm^3) in 1973 and has averaged 23,830 acre-ft (29.4 hm^3) (table 2). The median annual discharge for the 1960-74 period was 19,540 acre-ft (24.1 hm^3) in 1971. Discharge in Coal Creek since 1935 is shown graphically in figure 3. Other perennial, but relatively small, streams in Cedar City Valley are Shirts Creek, which enters the valley from the east near Hamilton Fort, and Quichapa Creek, which enters the valley from the Harmony Mountains on the western side of the valley. The water from Quichapa Creek is diverted into a pond and is used for irrigation.

In Parowan Valley the principal streams are Parowan, Red, Little, and Summit Creeks (see table 2), and water from each of these streams is used for irrigation. Because the base flow in Parowan and Red Creeks is quite constant these streams are also used to generate electric power in municipally owned hydroelectric plants at Parowan and Paragonah. Parowan Creek discharges more than half the surface water used in Parowan Valley. Its annual discharge since 1960 ranged from about 6,400 acre-ft (7.9 hm^3) in 1960 to 33,000 acre-ft (41 hm^3) in 1973 and averaged about 13,500 acre-ft (16.6 hm^3). Its median annual discharge was 11,000 acre-ft (14 hm^3). Some areas at and near Parowan, Paragonah, and Summit rely exclusively on water from Parowan, Red, and Summit Creeks for irrigation water; surface-water supplies for adjacent areas are supplemented with water pumped from wells. Municipal water supplies for Parowan, Paragonah, and Summit are derived from springs normally feeding Parowan, Red, and Summit Creeks.

In addition to the four principal streams in Parowan Valley, several small streams flow toward the valley but generally disappear into the underlying alluvial sediments near the edge of the valley. The largest of these minor streams is Cottonwood Creek which discharged 1.25 ft^3/s (0.035 m^3/s) on May 19, 1975. The average discharge is probably less than 1 ft^3/s (0.028 m^3/s). The water is diverted into a pond and used for irrigation and livestock.

Many intermittent and ephemeral streams enter Parowan and Cedar City Valleys from the mountains on all sides. Water from the intermittent streams, which drain minor subbasins and usually flow only during or following snowmelt or excessive rainfall, seeps into the permeable alluvial fill near the valley edge or is consumed by evaporation or transpiration. Ephemeral streams, however, may discharge large quantities of water into the valley for short periods of time during flash floods caused by excessive rainfall. Some of this water is caught in stock ponds for range cattle and sheep, but most of it evaporates, supports native vegetation, or seeps into the earth to recharge the ground-water reservoir.

The surface-water outflow from the Parowan-Cedar City basin is regarded as negligible although small flows originate near the valley edge at Iron Springs Gap and near Kanarraville. The flows form at small springs and seeps near the edge of the drainage basin and indicate ground-water discharge from the basin rather than surface-water discharge. Ephemeral discharge of surface water from the basin during flash floods caused by heavy local precipitation, however, is indicated by dry stream channels in Mud Springs Wash and Iron Springs Gap. These floods are infrequent and their duration is short. The quantity of water discharged by surface-water outflow, therefore, would be small.

GEOLOGIC SETTING

Throughout the Parowan-Cedar City drainage basins, geologic controls on all aspects of drainage-basin hydrology are readily apparent. Landforms affect the pattern and amount of precipitation. Relief and land-surface materials regulate surface drainage, infiltration, and evapotranspiration. Geologic structural and stratigraphic characteristics control the recharge and subsequent movement of ground water.

Those geologic controls most directly related to surface drainage and to ground-water occurrence are described in this report. Previous investigators have described other aspects of the geology of the area in more detail, and their publications have been extensively consulted to assemble this geologic summary. More detailed geologic information about the area may be obtained by consulting the publications cited in the section on "Previous investigations." Geologic units are listed in table 3, and areas of outcrop are shown on plate 1.

Structure and stratigraphy

Parowan and Cedar City Valleys are within the Basin and Range physiographic province (Fenneman and Johnson, 1946); the eastern margin of their drainage-basin divide is approximately the western demarcation of the Colorado Plateau province. Structurally, parts of the valleys and their adjacent eastern uplands represent a zone of transition between the physiographic provinces, with some structural features of both. A small area of thrust faults is present in the southwest, but the valleys are characterized by fault-block structure common to the Basin and Range province. The uplands east of the valleys have been elevated by displacement along the Hurricane fault zone. East of the fault zone, rock strata dip gently eastward; gently inclined strata characterize much of the Colorado Plateau province.

The geologic units exposed in the area attain a maximum total thickness of more than 16,000 ft (4,900 m). The oldest formation exposed is the Kaibab Limestone of Permian age, along the Hurricane fault zone in the southern part of the area. Formations overlying the Kaibab span geologic periods from Triassic through Tertiary. Igneous laccoliths of Tertiary age intrude formations west of Cedar City Valley. Deposits of alluvium as valley fill, with some interbedded lava flows locally, attain thicknesses of more than 1,000 ft (300 m) in Parowan and Cedar City Valleys (Bjorklund and others, 1977, table 4). A summarized description of geologic units in the area and their water-bearing characteristics is given in table 3.

Alluvium deposited as valley fill is the principal aquifer of Parowan and Cedar City Valleys. The sources of valley fill are the adjacent hills and upland areas. The principal transporting medium is runoff in streams when sufficient volume and velocity occur to carry debris that may range in size from clay to boulders. As the streams enter the valleys and lose velocity with decreasing gradient, and decrease in flow due to spreading, division, seepage, and evaporation, alluvial material is deposited. Coarser material is deposited in the higher valley areas and progressively finer material is deposited toward the valley bottoms. The stream discharge and amount of deposition are irregular and vary over a wide range. The fluvial deposits of clay, silt, sand, and coarser material thus vary in thickness and extent. The aquifers within the valley fill are discontinuous or irregularly connected, as a labyrinth of water-yielding materials.

Table 3.--Generalized section of geologic units and their characteristics

(Dashed lines separate units that may be contemporaneous in part.) [Adapted from Averitt (1962, 1967), Averitt and Threet (1973), Lawrence (1965), Mackin (1954), Rowley, Anderson, and Williams (1975), Stewart, Poole, and Wilson (1972a, 1972b), and Thomas and Taylor (1946).]

System	Series	Group	Geologic units	Approximate maximum thickness (ft)	Lithologic and water-bearing characteristics
QUATERNARY	Holocene and Pleistocene		Dune sand	30	Light-orange to tan, fine-grained eolian sand deposits in irregularly shaped dunes, mostly stablized by natural vegetation; unit does not yield water to wells or springs in this area, but may add water to ground-water reservoir through infiltration from precipitation.
			Lakebed deposits	50 (?)	Compacted beds of evaporites, clay, and silt exposed seasonally on the floors of Quichapa and Rush Lakes in Cedar City Valley and Little Salt Lake in Parowan Valley; do not yield water to wells or springs in this area.
			Valley-fill deposits, undifferentiated	1,000 +	Valley-fill and stream-channel deposits of clay, silt, sand, gravel, cobbles, and boulders mainly of fluvial origin. but include lava flows and older lakebed deposits; the lenticular deposits of sand and coaser material yield from 1 to 4,000 gal/min to wells for domestic, stock, irrigation, industrial, and public supplies; valley-fill alluvium is the principal aquifer of the area.
			Basalt and other volcanic rocks, undifferentiated	800 +	Basaltic lava flows; also includes ignimbrites, pyroclastic layers, cinder-cone debris, and related volcanic deposits; unit yields water to springs and to a few wells where basalt is within the valley-fill deposits.
QUATERNARY and TERTIARY			Older alluvium, undifferentiated	500 +	Fanglomerate, older stream-terrace deposits, landslide debris, and colluvium; material ranges in size from clay to very large boulders; not reported to yield water to wells or springs in this area.
			Unconformity		
TERTIARY	Miocene and Oligocene		Volcanic rocks, undifferentiated; include Roger Park Basaltic Breccia, Mount Dutton and Bear Valley Formations, Bullion Canyon Volcanics, Page Ranch and Rencher Formations of Cook (1957), Quichapa Group, and Isom and Needles Range Formations.	2,500	Undifferentiated basalt, rhyolite, and latite lava flows, ignimbrites, pyroclastic layers, tuffs, eolian deposits of volcanic arenite, fluvial deposits of volcanic debris, mudflow breccia, and related deposits of volcanic origin; fractures in volcanic rocks yield water to springs in a few places.
			Unconformity		
	Oligocene and Paleocene		Claron and Wasatch Formations	1,400	Varicolored lacustrine limestone, marl, subaqueous tuff, and medium to coarse basal conglomerate in red clay matrix; yields as much as 900 gal/min of water to indivdual contact springs through joints and solutions channels. Provides recharge to ground-water reservoir in upland areas by infiltration of precipitation and snowmelt.
			Unconformity		
			Quartz-monzonite porphyry	-	Laccolithic intrusive rock; fractures may be permeable, but not reported to yield water.
			Unconformity		

Table 3.--Generalized section of geologic units and their characteristics--continued

System	Series	Group	Geologic units	Approximate maximum thickness (ft)	Lithologic and water-bearing characteristics
CRETACEOUS and CRETACEOUS(?)	Upper Cretaceous and Upper Cretaceous(?)		Cretaceous rocks, undifferentiated; include Kaiparowits and Iron Springs Formations; Wahweap and Straight Cliffs Sandstones, Tropic Shale, Dakota Formation, and Marshall Creek Breccia	2,700	Brown, yellow, and white sandstone, dark-gray shale, coal beds, coquina, conglomeratic sandstone, and limestone breccia; of marine, near-shore, paludal, and fluvial origins; yield water to springs and to a few wells.
			Unconformity		
JURASSIC	Middle Jurassic	San Rafael Group	Carmel Formation; includes Winsor Member and gypsiferous, banded, and limestone members	1,000	Red-brown thin-bedded sandstone and shale, white or gray gypsum in massive beds, orange and red-brown sandstone and shale, and tan-gray thin-to-medium bedded limestone; not reported to yield water in this area.
			Unconformity		
JURASSIC	Lower Jurassic and Triassic(?)	Glen Canyon Group	Navajo Sandstone	1,700	Red-orange medium-grained sandstone in massive sets of eolian crossbeds; yields water to springs in nearby areas.
TRIASSIC	Upper Triassic(?)	Glen Canyon Group	Kayenta Formation; includes Cedar City Tongue, Shurtz Sandstone Tongue of Navajo Sandstone, and lower member	1,600	Red, brown, and orange siltstone and very fine sandstone; not reported to yield water in this area.
TRIASSIC	Upper Triassic(?)	Glen Canyon Group	Moenave Formation; includes Springdale Sandstone, Whitmore Point(?), and Dinosaur Canyon Members	500	Red-brown siltstone and sandstone, thin to medium beds; not reported to yield water in this area.
			Unconformity		
TRIASSIC	Upper Triassic		Chinle Formation; includes Petrified Forest and Shinarump Members	400	Red-brown to red-gray and lavender mudstone, siltstone, and sandstone, with a basal green-gray conglomeratic sandstone; the basal sandstone is permeable, but the formation is not reported to yield water in this area.
			Unconformity		
TRIASSIC	Middle(?) and Lower Triassic		Moenkopi Formation; includes upper red member, Shnabkaib Member, middle red members, Virgin Limestone Member, lower red member, and Timpoweap Member	1,800	Dark red-brown and dark red mudstone, siltstone, and sandstone with sparse to abundant gypsum as veinlets and layers; light gray thin bedded limestone (Virgin Limestone Member) and yellow siltstone, gray limestone, and pebble to cobble conglomerate (Timpoweap Member); not reported to yield water in this area.
			Unconformity		
PERMIAN	Lower Permian		Kaibab Limestone (uppermost part of beta member)	125 (incomplete exposure)	Gray dense limestone with abundant gray and white chert nodules; not reported to yield water in this area.

Geologic units and their hydrologic characteristics

Geologic units that are exposed in the Parowan-Cedar City basin are listed and described and their water-bearing properties are summarized in table 3. Most of the wells in the area derive water from the unconsolidated valley fill of Quaternary age. Most of the larger springs discharge from Tertiary rocks but many springs issue from Mesozoic rocks, and some small springs and seeps issue from the Quaternary valley fill.

The ability of rocks to transmit water depends on their permeability which in turn depends on the size, number, and interconnection of the open spaces in the rock. The most productive water-bearing materials in an aquifer are generally well-sorted gravel and sand or consolidated rocks where permeability has been increased by fracturing or solution. Clay and silt or consolidated rocks with little or no interconnected open space have low permeability and do not readily yield water to wells or springs.

GROUND WATER

Source and recharge

Precipitation

Ground water in the Parowan-Cedar City drainage basin is derived almost exclusively from the precipitation within the basin. Normal annual precipitation within the basin, calculated from data on a map of Utah published by the U.S. Weather Bureau (no date), amounts to about 936,000 acre-ft (1,150 hm^3) of water of which about 484,000 acre-ft (597 hm^3) falls in the Parowan basin and about 452,000 acre-ft (557 hm^3) falls in the Cedar City basin. The amount of water falling in the basin during a particular year could be much greater or much less than the calculated normal. Most of the precipitation is consumed by evaporation and transpiration by vegetation in the basin, but some of it reaches the ground-water reservoirs. A greater percentage of the precipitation would go to recharge during a wet year than it would during a dry year.

The total annual recharge to the alluvial deposits in the basin, assuming it is equal to discharge plus or minus change in storage (see section on discharge), is about 80,000 acre-ft (98 hm^3). About half of the recharge is in Parowan Valley and half is in Cedar City Valley.

Recharge directly from precipitation occurs mostly in and near the mountains at places where rain or snowmelt enter permeable earth materials. Springs discharging from bedrock on mountain slopes indicate recharge from precipitation on the rocks at higher altitudes. Thus many springs discharging from or near the base of the Tertiary Wasatch Formation, at or near its contact with the underlying Cretaceous Kaiparowits Formation, indicates recharge to the Wasatch Formation higher on the mountain slope. Springs of this type are Warm Spring, (C-33-8)36b-S1, and Five-Mile Spring, (C-35-8)5c-S1; other springs are listed in Bjorklund, Sumsion, and Sandberg (1977, table 2).

Streams

Most of the recharge to the unconsolidated deposits in the valleys is by infiltration from perennial streams flowing from mountain canyons into permeable gravelly alluvial fans extending into the valleys from the mouths of canyons. Such streams are Parowan, Summit, Red, and Little Creeks in Parowan Valley and Coal Creek in Cedar City Valley. Intermittent and ephemeral streams also flow for brief periods onto the permeable gravelly soils along the valley edges during and following rainstorms and periods of snowmelt, and some of this water infiltrates to the ground-water reservoir. Ground-water mounds underlying alluvial fans, indicated by water-table slopes radiating away from the axis of the fans (pls. 2 and 3), are evidence of recharge on the fans.

Irrigation

Recharge to the valley fills in Parowan and Cedar City Valleys has been increased substantially by diverting water from streams for irrigation. An average of about 24,000 acre-ft (30 hm^3) of water flows in Coal Creek into Cedar City Valley annually and about 22,000 acre-ft (27 hm^3) flows into Parowan Valley in Parowan, Summit, Red, and Little Creeks (see table 2). Most of this water is diverted from the creeks for irrigation. Because the land surface on the alluvial fans where irrigation takes place is gravelly and quite permeable, between one-fourth and one-half of the water applied is believed to infiltrate to the ground-water reservoirs in the valley fill.

Subsurface inflow

Some recharge to the alluvial valley fills occurs by inflow from adjacent mountain blocks, especially those of the Markagunt Plateau southeast of Parowan Valley and east of the southern half of Cedar City Valley. Elevated ground-water levels, high above the valleys, are indicated by many springs and seeps in the mountains; and they probably result in ground-water movement toward the valleys. Some water presumably discharges from the mountain block directly into the alluvium. The greatest amount of water probably would be discharged into the valley fill in places where the limestone and conglomerate of the Tertiary Wasatch Formation, Tertiary and Quaternary volcanic rocks, and the Mesozoic Navajo Sandstone are in contact with the Quaternary valley fill.

Some water may enter the topographic basin from adjoining basins by subsurface inflow, but the amount probably is not significant. The ground-water divide between basins generally coincides with or is near the topographic divide, but under some conditions it may be offset from the topographic divide, thus indicating ground-water movement beneath the topographic divide. The principal area where some ground water could move from an adjoining topographic basin into the Parowan-Cedar City basin would be along the western edge of the Markagunt Plateau in the general Cedar Breaks area where the western slope of the plateau is much steeper than the eastern slope. This condition would tend to offset the ground-water divide eastward from the topographic divide, resulting in some ground-water movement westward in the intervening area.

The offset distance would not be large because the water-bearing formations on the plateau dip gently toward the east, and major ground-water movement is eastward toward the Sevier River.

Occurrence

Ground water in the unconsolidated valley fill in Parowan and Cedar City valleys occurs under both confined (artesian) and unconfined (water-table) conditions. The most productive aquifers are beds of coarse, clean, well-sorted gravel and sand that absorb water readily, store it in large quantities, and yield it readily to wells. Beds of silt and clay store much water but will not yield it readily to wells. Saturated silt and clay, however, will yield some water slowly to beds of gravel and sand. A diagram of the general occurrence of ground water in the project area is shown in figure 5. Conditions shown in the diagram most nearly resemble those near the Hurricane fault, but the principles and relations apply to the entire valley.

Confined conditions

Confined ground water occurs in the unconsolidated valley fill of both Parowan and Cedar City Valleys in localities where water-bearing beds of permeable gravel and sand are confined by capping or intervening beds of relatively impermeable clay or silt. The confining beds extend from the middle of the valley toward the sides of the valley (see fig. 5). As the water moves from recharge areas near the sides of the valleys through the permeable beds of gravel and sand toward lower areas near the center of the valley, the confining beds retard the upward movement of water toward the land surface, resulting in hydrostatic pressure in the aquifer. Confined ground-water conditions are believed to exist in all the valley except near the edges of the valley floor. However, the water-bearing beds are not completely confined as water under pressure will seep slowly through the confining beds of clay or silt, and the ground water is regarded as being under leaky confined, or leaky artesian, conditions.

Area of flowing wells

In about 36 mi^2 (93 km^2) of Parowan Valley during March 1974, the artesian pressure in the valley fill was great enough to cause water to flow from wells (see pl. 4). Measured hydrostatic heads ranged from less than 1 to 16 ft (0.3 to 4.9 m) above land surface. In October of the same year the flowing-well area had been reduced by about one-third by irrigation pumpage during the summer, but by March 1975 the artesian pressure had recovered and the flowing-well area was again about the same as it was in March 1974. The size of the flowing-well area has been declining since 1940. In 1940 Thomas and Taylor (1946, pl. 25) mapped flowing wells in Parowan Valley in a maximum area of 46 mi^2 (120 km^2).

In Cedar City Valley no flowing wells exist today (1975), although Thomas and Taylor (1946, pl. 18) indicated a maximum flowing-well area of more than 50 mi^2 (130 km^2) in 1939. Confined conditions in

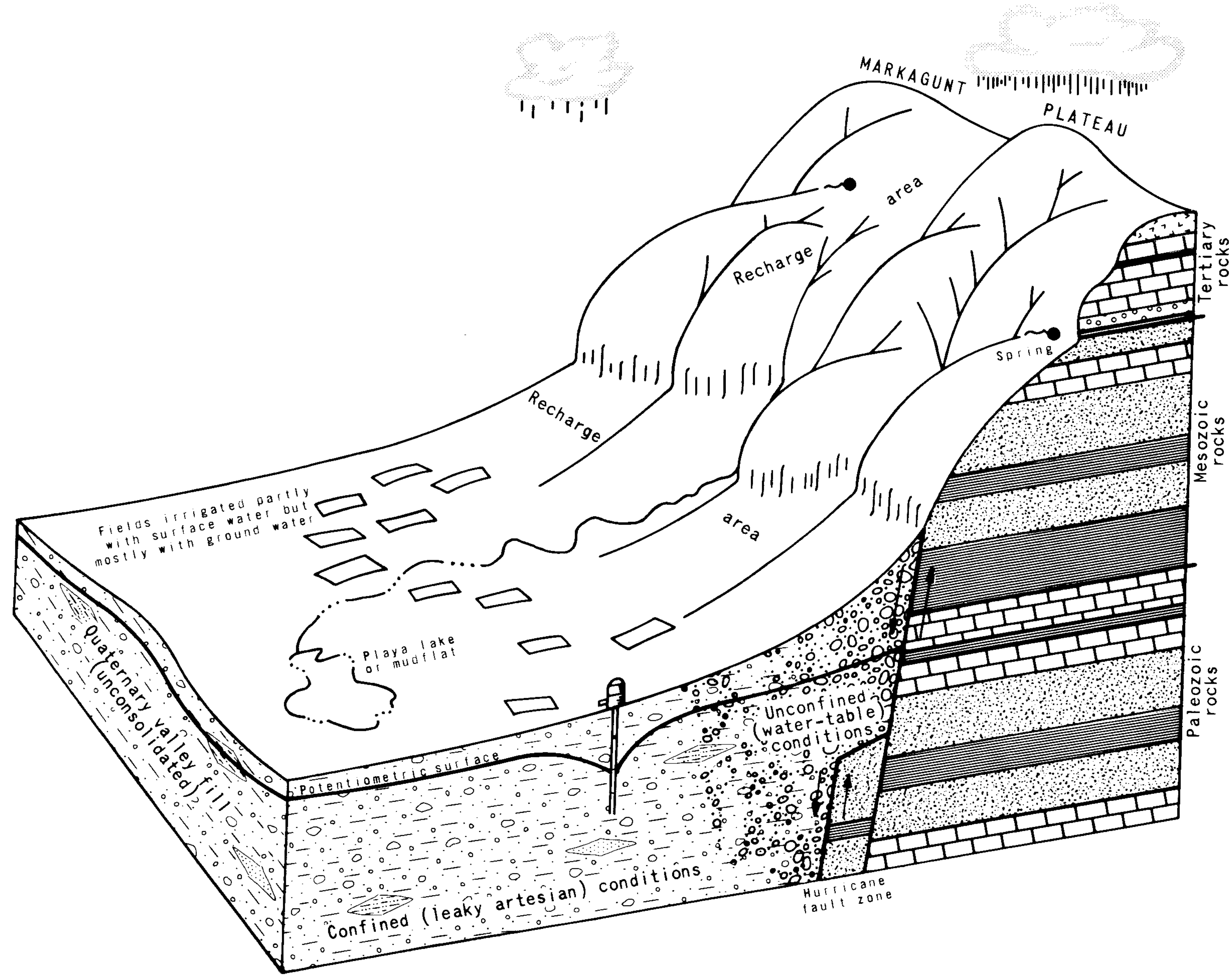

Figure 5.— General occurrence of ground water in the Parowan-Cedar City basin.

the aquifer continue to exist in the area, but artesian pressures are not great enough to cause flow at the land surface.

Unconfined conditions

Unconfined, or water-table, ground-water conditions exist in the unconsolidated valley fill in many places near the edge of the valley where the fill consists largely of coarse, granular, permeable material and the confining beds of clay and silt are absent or discontinuous (see fig. 5). The boundary between confined and unconfined ground water is indefinite and generally gradational rather than abrupt, and it changes in position as the potentiometric surface of the ground-water reservoir rises or declines. Unconfined conditions were indicated in the vicinity of the site of a test made at well (C-35-10)18cca-1 located 4 mi (6.4 km) north of Cedar City and about 0.5 mi (0.8 km) from the mountain front. This and other tests are discussed more fully in the section on aquifer characteristics and tests to determine hydrologic coefficients.

Perched conditions

Local perched ground-water bodies are common in the valley fill. They develop above the main ground-water reservoir in localities where beds of clay or other materials of low permeability intercept water percolating downward, or where water levels in lower aquifers are lowered by the withdrawal of water and the upper aquifers are less affected. Thus in two wells in Parowan Valley, (C-36-9)36daa-1 and (C-34-9) 16cdd-2, water was observed to cascade continually from an upper level in the well to the standing water in the well. At other wells, (C-34-9) 9bbd-1 and (C- 34-9)9bcc-1, water cascaded within the wells only during the irrigation season when many wells in the general vicinity were being pumped. Water would probably cascade into many wells in the area if it were not for the general practice of local drillers to seal off shallow or perched water-bearing zones and perforate well casings only in the more productive lower zones. No attempt was made to map perched ground-water bodies because they are usually poorly defined, some are seasonal, and they are not generally tapped by wells. Water in perched reservoirs eventually moves into the main and more productive reservoir.

Estimate of water in storage

More than 40 million acre-ft (50,000 hm^3) of water is estimated to be stored in the unconsolidated valley fills in Parowan and Cedar City Valleys with about half of the water in each valley, and additional water is stored in the consolidated rocks in the mountains adjoining the valleys. This estimate is based on the assumptions that the saturated fill in each valley is more than 1,000 ft (300 m) thick and that the average total porosity of the unconsolidated fill material is about 20 percent. Only a small percentage of the total water, however, is economically available for development. Bodies of gravel or sand yield water readily to wells; whereas, clay or silt bodies retain most of their stored water because of capillarity and low permeability. Changes in storage due to declining water levels will be discussed in the section on fluctuations of water levels and long-term trends.

Aquifer characteristics and tests

The capacity of an aquifer to transmit and store water is described by the transmissivity of the aquifer, the hydraulic conductivity of the water-bearing material, and the storage coefficient of the aquifer. These terms are defined below.

Transmissivity (T) is the rate at which water is transmitted through a unit width of the aquifer under a unit hydraulic gradient. The units for T are cubic feet per day per foot ($ft^3/d/ft$), which reduces to ft^2/d. The term transmissivity replaces the term coefficient of transmissibility, which was formerly used by the U.S. Geological Survey and which was reported in units of gallons per day per foot. To convert a value for coefficient of transmissibility to the equivalent value of transmissivity, divide by 7.48; to convert from transmissivity to coefficient of transmissibility, multiply by 7.48.

The hydraulic conductivity (K) of a water-bearing material is the volume of water that will move through a unit cross section of the material in unit time under a unit hydraulic gradient. The units for K are cubic feet per day per square foot ($ft^3/d/ft^2$), which reduces to ft/d. The term hydraulic conductivity replaces the term field coefficient of permeability, which was formerly used by the U.S. Geological Survey and which was reported in units of gallons per day per square foot. To convert a value for field coefficient of permeability to the equivalent value of hydraulic conductivity, divide by 7.48; to convert from hydraulic conductivity to coefficient of permeability, multiply by 7.48.

The storage coefficient (S) of an aquifer is the volume of water it releases from or takes into storage per unit surface area of the aquifer per unit change in head. S is a dimensionless number. Under confined conditions, S is typically small, generally between 0.00001 and 0.001. Under unconfined conditions, S is much larger, typically from 0.05 to 0.30.

The transmissivity, hydraulic conductivity, and storage coefficient of aquifers in the unconsolidated fill of Parowan and Cedar City Valleys were determined by aquifer tests. The tests consisted of observing the drawdown effects of pumping a well on other wells in the same vicinity and analyzing the data using methods described by Ferris and others (1962, p. 91-103), Cooper (1963, p. C43-C55), and Lohman (1972, p. 11-21, 30-34). The results of four aquifer tests in Parowan Valley and five in Cedar City Valley are given in table 4. The transmissivity was also estimated for pumped wells from specific capacity (rate of discharge per foot of drawdown) data for 55 wells in Parowan Valley and 55 wells in Cedar City Valley using a method described by Theis, Brown, and Meyer (1963, p. 331-340).

Table 4.--Results of aquifer tests

Storage coefficient: E, estimated.

Pumped well	Observation well	Date and length of test	Distance to pumped well (ft)	Discharge of well (gal/min)	Trans-missivity (T) (ft^2/d)	Average hydraulic conductivity (K) (ft/d)	Storage coeffi-cient (S)	Water-bearing material	Saturated section open to well (ft)	Type of test	Rating of test
					PAROWAN VALLEY						
(C-32-8)12bac-1		May 13-31, 1974 430 hrs		2,651				Volcanic debris			
	(C-31-7)31acc-1		12,000			-	-	Gravel	24		
	31cca-1		8,976		406,000	-	0.0056	Volcanic debris		Drawdown	Good
	(C-32-7)6cda-1		6,706		677,000	-	.0028	do	153	do	Do.
	(C-32-8)12adb-1		3,060		193,000	476	.0011	do	405	do	Do.
	12cdb-1		3,040		202,000	700	.0007	do	288	do	Do.
	12dba-1		3,010		102,000	-	.014	-		do	Fair
	13bca-1		5,550		330,000	-	.018	Volcanic debris	154	do	Good
(C-33-9)14dbd-1	(C-33-9)14dbd-1	Oct. 18-21, 1974 76 hrs		1,000	1,400			Gravel, sand, and silt		Recovery	Do.
	14adc-1		3,700		11,000	37	.02		298	do	Poor
(C-34-9)7ccc 2		July 31-Aug. 2, 1974 17 hrs		575				Gravel			
	(C-34-9)7ccc-1		95		6,300	26	.00007	do	245	do	Good
(C-34-9)9bca-1		Mar. 25-27, 1975 50 hrs		1,310				do	560		
	(C-34-9)8aaa-1		2,200		17,900	35	.003	do	607	Drawdown	Do.
	8acc-1		3,900		-		-	do		do	Poor
	8dda-1		2,600		9,100	37	.0006	do	246	do	Good
	9bba-1		2,050		13,400	20	.0005	do	664	do	Do.
	9bbd-1		600		6,030	26	.0003	do	232	do	Do.
	9bcc-1		1,050		8,920	32	.0004	do	278	do	Do.
	9dba-1		2,600		11,300	21	.0005	do	540	do	Fair
					CEDAR CITY VALLEY						
(C-35-10)18cca-1		Apr. 16-17, 1975 24 hrs		863				Gravel	188		
	(C-35-10)18cbd-1		850		-	-	0.2E	do	-	Drawdown	Fair
	18ccb-1		1,000		-		.2E	do	116	do	Do.
	(C-35-11)13ada-1		2,650		-	-	.2E	do	201	do	Do.
	13ddb-1		2,300		-	-	.2E	do	716	do	Do.
	24aab-1		2,900		-	-	.2E	do	-	do	Do.
(C-35-10)18cca-1	(C-35-10)18cca-1	Apr. 17-21, 1975 95 hrs	0	863	5,200	28	.2E	do	188	Recovery	Good
(C-36-12)32ccb-1		Jan. 22-23, 1975 30 hrs		1,345				do	507		
	(C-36-12)32ccc-1		652		42,000	169	.0013	do	249	Drawdown	Very good
	32dcc-1		2,700		-		-	do	218	do	Poor
	32dcd-1		3,900		-		-	do	254	do	Do.
	(C-37-12)5bbb-1		1,372		52,000	251	.01	do	207	do	Fair
	5bcb-1		3,100		15,000	82	.0015	do	182	do	Good
(C-36-12)32ccc-1	(C-36-12)32ccc-1	Jan. 23-25, 1975 44 hrs	652		46,000	185	.0015	do	249	Recovery	Do.
(C-37-12)14abc-1	(C-37-12)14abc-1	July 23-24, 1974 14 hrs	0	600	10,000	44	-	do	226	do	Do.
(C-37-12)23acb-1		Apr. 20-22, 1959 86 hrs	0	845				do	254		
	(C-37-12)23aca-1		1,000		2,540	13	.0005	do	193	Drawdown	Do.
	23cbd-1		2,650		2,700	14	.013	do	197	do	Do.

Transmissivity pattern of valley fills

A map showing lines connecting points of approximately equal transmissivity in Parowan and Cedar City Valleys is shown on plate 2. The map was constructed from transmissivity data collected during aquifer tests (table 4) and from adjusted transmissivities estimated from the specific capacity at 110 wells. At several wells where transmissivity was determined by both aquifer tests and specific-capacity data, the more dependable aquifer tests indicated transmissivities 40 to 60 percent greater than the specific-capacity data. This was probably due to excessive drawdown in the pumped wells caused by insufficient perforation, or partially clogged perforation, in the well casings. The transmissivities estimated from specific capacities were therefore increased to adjust for that difference.

In Parowan Valley the area of greatest transmissivity and greatest potential yield is in the northern part of the valley. The aquifer in the unconsolidated valley fill in this area consists largely of volcanic detritus. High transmissivity in this area was also indicated by a very flat potentiometric surface of the ground-water reservoir (pl. 5). Static water-level altitudes at wells in the area show local hydraulic gradients to be less than 1 ft/mi (0.2 m/km). Moderately high transmissivity is indicated northwest of Parowan on the middle and lower parts of the Parowan Creek alluvial fan. Comparatively low transmissivity is indicated in the lowest part of the valley in the vicinity of Little Salt Lake where most of the unconsolidated valley fill is silt and clay.

In Cedar City Valley the greatest transmissivity probably is that of the Coal Creek alluvial fan about 3 mi (5 km) northward and north-westward from Cedar City where the valley fill is coarse and graded. Moderately high transmissivity exists northward, southward, and westward for several miles and then decreases northward with distance from the Coal Creek fan. High transmissivity occurs also in the vicinity of and northeast of Rush Lake in the northern part of the valley where volcanic rocks in the valley fill are permeable. High transmissivity occurs also southwest of Quichapa Lake where the alluvial fill is derived from Tertiary volcanic mountains on the western side of the valley. Little is known of the extreme northern part of Cedar City Valley between Rush Lake and the Black Mountains, but the few wells that have been drilled in the area had low yields, which suggests that it is generally an area of low transmissivity.

Artesian and water-table areas

Of the nine aquifer tests listed in table 4, six resulted in storage coefficients ranging from 0.01 to 0.00007 which indicated confined conditions in the aquifer; one test indicated unconfined conditions. Leaky artesian conditions are inferred, from the results of the aquifer tests and other considerations, to underlie most of the valley floor in both Parowan and Cedar City Valleys.

Water-table conditions were indicated by results of a pumping test at well (C-35-10)18cca-1 near the edge of the valley fill about 4 mi (6.4 km) northeast of Cedar City. Water levels in observation wells located 850 to 2,900 ft (260 to 880 km) from the pumped well were not affected by pumping at a rate of 863 gal/min (54.4 L/s) for 24 hours; all the wells penetrated coarse gravel in the same aquifer.[1] These data

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[1]Seasonal drawdown does reach well (C-35-10)18cbd-1, a non-pumped observation well, 850 ft (260 m) from the pumped well. A hydrograph of the well (see fig. 17) indicated seasonal fluctuation of more than 20 ft (6 m) because of pumping from other wells in the vicinity. In recent years the October-November water-level measurements at the well have been discontinued because the well is dry for a period following the irrigation season, but the well contains water when measurements are made in March.

showed that the cone of depression around the pumped well expanded at a rate of less than 850 ft (259 m) in 24 hours, or less than 35.4 ft (10.8 m) per hour. This relatively slow spreading rate indicated water-table conditions, although the test was not long enough to yield data from which the storage coefficient could be computed. An estimated storage coefficient of 0.2 was used for this well, which is about the average for an unconfined aquifer (Lohman, 1972, p. 8).

Interference between wells

Well interference occurs when a pumped well induces drawdown of water level in other wells in the vicinity. In artesian areas, such as most of Parowan and Cedar City Valleys, drawdown by interference and recovery when pumping stops is relatively rapid and far-reaching because the interference is caused mostly by a reduction of hydrostatic pressure in the confined aquifer and does not necessarily require the withdrawal of a large amount of water from the aquifer. In water-table areas, drawdown and recovery of water levels are relatively slow and localized. They are related mostly to the removal of water from the cone of depression surrounding the pumped well. Mutual interference between wells occurs when two or more pumped wells induce additional drawdown in each other. Mutual interference among pumped wells is common in both Parowan and Cedar City Valleys during the summer when many wells are pumped for irrigation.

Interference between wells in Parowan Valley was observed in several aquifer tests. At Buckhorn Flats, pumping from well (C-32-8) 12bac-1 at an average rate of 2,651 gal/min (167.3 L/s) caused measurable drawdown in well (C-32-8)12adb-1, at a distance of 3,060 ft (933 m) 5 minutes after pumping began; the drawdown was 1.27 ft (0.387 m) after 18 days of pumping. The velocity of the drawdown impulse, therefore, was greater than 600 ft (200 m) per minute. In the same test, drawdown started in well (C-31-7)31cca-1, at a distance of 8,976 ft (2,736 m) in less than 160 minutes and developed to 0.41 ft (0.12 m) at 16 days of pumping. In the southern part of the valley, pumping of well (C-34-9) 9bca-1 at 1,310 gal/min (82.7 L/s) caused drawdown in well (C-34-9) 9bbd-1 at a distance of 600 ft (200 m) to start in less than 3 minutes and increase to 19.30 ft (5.88 m) in 46 hours. At the same test, the water level in well (C-34-9)9bcc-1, 1,050 ft (320 m) from the pumped well, started to decline in 5 minutes and declined to 10.64 ft (3.24 m) in 48 hours. The average drawdown impulse velocity in these instances was greater than 200 ft (60 m) per minute. Drawdowns were observed at distances from the pumped well ranging to 2,600 ft (790 m).

In Cedar City Valley, pumping of well (C-36-12)32ccb-1 at 1,345 gal/min (84.86 L/s) caused drawdown to start at well (C-36-12)32ccc-1, 652 ft (199 m) away in 3 minutes and increase to 2.76 ft (0.84 m) in 30 hours. Also, well (C-37-12)23acb-1, when pumped at 845 gal/min (53.3 L/s), induced drawdown in well (C-37-12)23aca-1, 1,000 ft (300 m) away within 2 minutes, and the drawdown increased to 15.16 ft (4.62 m) in 46.1 hours. It took 3 hours, however, for the drawdown impulse to reach an automatic recording gage at well (C-37-12)23cbd-1, 2,650 ft (808 m) from the pumped well, but the drawdown then increased to 5.50 ft (1.7 m) in 86 hours.

From the facts presented in the two preceding paragraphs, it is evident that the effects of mutual interference among pumped wells in parts of Parowan and Cedar City Valleys during an irrigation season is substantial. Heavy and continuous pumping from a well withdrawing water from a confined aquifer can induce additional drawdown in another pumped well a mile or more away during a pumping season. As additional wells within the effective radius are pumped, the drawdown in an affected well will increase.

Possible effects of faulting in the valley fill on an aquifer test

An aquifer test was conducted at the site of pumped well (C-34-9) 9bca-1 and seven other wells to be observed in its general vicinity, about 2.5 mi (4.0 km) west-northwest of Parowan, partly to determine the effects of inferred fault in the saturated valley fill (table 4). Two faults--the Summit Creek fault and the Culver fault--were mapped as inferred by Thomas and Taylor (1946, pl. 3) and were shown to pass through the prospective aquifer-test area. Thomas and Taylor (1946, p. 51-64, p. 88, p. 155) discussed faults in Parowan and Cedar City Valleys and suggested that some faults in the valley fill probably have a subsurface damming effect, thus restricting the movement of ground water from one part of the alluvial basin to another part. The effect of pumping a well on one side of a fault on water levels in wells on the other side was considered.

During the test pumping of well (C-34-9)9bca-1, drawdown was observed at two wells on the opposite side of the inferred Culver fault and at one well on the opposite side of the inferred Summit Creek fault. At well (C-34-9)9dba-1, 2,600 ft (790 m) east-southeast of the pumped well and about 2,000 ft (600 m) east-southeast of the Culver fault, 0.19 ft (0.068 m) of drawdown was measured 19 minutes after the start of pumping; drawdown was 5.45 ft (1.66 m) after 50 hours. The average velocity of the drawdown impulse in the aquifer, therefore, was greater than 130 ft (40 m) per minute. Likewise, at well (C-34-9)8dda-1, 2,600 ft (790 m) south-southwest of the pumped well and about 1,500 ft (460 m) south-southwest of the intervening Culver fault, 0.31 ft (0.09 m) of drawdown was measured after 35 minutes of pumping; the drawdown increased to 4.35 ft (1.33 m) after 49.5 hours of pumping.

At well (C-34-9)8acc-1, 3,900 ft (1,200 m) west of the pumped well and about 500 ft (150 m) west of the inferred Summit Creek fault, drawdown was 0.06 ft (0.02 m) after 70 minutes of pumping, and increased to 0.64 ft (0.20 m) in 24.7 hours. The average velocity of the initial drawdown impulse, therefore, was about 56 ft (17 m) per minute.

The inferred faults involved in the aquifer test apparently did not have any noteworthy damming, blocking, or restricting effect on water in the unconsolidated valley fill. The drawdown impulse in the aquifer, induced by pumping the well, crossed the faults. Thus the inferred faults would have little bearing on well interference in the vicinity. The average velocity of the drawdown impulse was less in the instances where the fault lines were crossed, mostly because the total distances were greater and the velocity apparently decreases with distance from the pumped well.

Movement

Ground water is seldom stationary, but moves by force of gravity in the direction of a hydraulic gradient. The direction it moves in almost any part of Parowan and Cedar City Valleys can be inferred from plate 5 which shows the configuration of the potentiometric surface of the ground-water reservoir during March 1974.

The arrows on the map, which are perpendicular to the water-level contours, indicate the general direction the ground water moves. A map showing the configuration and direction of ground-water movement during October-November 1974 is presented on plate 6.

The pattern of water-level contours and ground-water movement directions for March and October-November 1974, shown on plates 5 and 6, are generally similar, but differ locally. A general decline of water levels due to pumping for irrigation during the summer of 1974 caused most of the contours to move toward the margins of the valleys for distances ranging from a few hundred feet to more than a mile. These contours moved back toward the March position when water levels recover between pumping seasons. Locally the direction of movement is altered or even reversed by pumping from wells. Water-level fluctuations are discussed in a later section.

In comparison to movement of surface water, the rate of ground-water movement through the unconsolidated valley fill is slow, generally ranging from less than 1 ft (0.3 m) to a few feet per day. The quantity of water moving through a section of the fill, however, may be large or small, depending on several factors, and it may be expressed by a form of Darcy's law:

$$Q = T\ I\ L$$

in which Q is the discharge in cubic feet per day, T is the coefficient of transmissivity, I is the hydraulic gradient in feet per foot, and L is the width of the cross section in feet through which the discharge moves.

Configuration of the potentiometric surface

The potentiometric surface of the ground-water reservoir includes (1) the surface of the saturated zone, or water table, in areas where the ground water is not confined and (2) the imaginary surface defined by the hydrostatic head of the ground water in areas where it is confined. In Parowan and Cedar City Valleys the potentiometric surface is irregular and sloping (pls. 5 and 6); it generally slopes from the mountain front of the Markagunt Plateau east of the valleys, where most of the recharge to the ground-water reservoir takes place, toward the lower parts of the valleys, where most of the discharge of ground water occurs. Hence, the slope of the potentiometric surface indicates the movement of ground water from the areas of recharge to the areas of discharge.

Relation of the potentiometric surface to land surface

The relation of ground-water levels to land surface during March 1974 is shown on plate 4. Water-level data given in Bjorklund, Sumsion, and Sandberg (1977, table 3) show a range from 16 ft (5 m) above land surface to 266 ft (81 m) below land surface in Parowan Valley and from 2 to 250 ft (0.6 to 76 m) below land surface in Cedar City Valley. Some deeper water levels are reported in the mountainous areas within the drainage basin. However, the static water level in most wells in both valleys is less than 100 ft (30 m) below land surface. In the area where the potentiometric surface is above the land surface, about 36 mi^2 (93 km^2), in Parowan Valley, the wells flow and some water moves upward through the confining silts and clays toward the land surface where it is consumed by evaporation and by the transpiration of phreatophytes, mainly greasewood.

Movement of ground water in the mountain areas

In the consolidated rocks of the mountains bordering Parowan and Cedar City Valleys, ground water presumably moves mainly through fractures, joints, solution channels, and along bedding planes where permeable rocks overlie relatively impermeable rocks. Much of the water moves in perched zones. For example, many contact springs discharge near the base of the Wasatch Formation which is mostly limestone and is known to contain many solutional openings. Also some volcanic beds contain many joints which were formed by shrinkage when the hot lava cooled, and these provide channels through which the water can move. Likewise, the Mesozoic sandstones, particularly the Navajo Sandstone, have enough porosity and permeability to permit the movement of water.

Little is known regarding the configuration of the main (lowermost) zone of saturation in the mountains, but its potentiometric surface is generally higher in altitude than the valley floors, and thus the hydraulic gradients in the mountains slope toward the valleys and the ground water moves toward the valleys. Some of the water discharges at springs and seeps along the way, but the remainder eventually discharges directly into the valley fill.

Fluctuation of water levels

Ground-water levels in Parowan and Cedar City Valleys are caused to rise mainly by recharge from streams and surface-water irrigation; they decline during periods of drought and by pumping from wells for irrigation. In areas where water levels are not affected greatly by development, they usually rise in years when annual precipitation is greater than average and decline when precipitation is less than average. This is illustrated in both Parowan and Cedar City Valleys in figures 2 and 3. Also note the same general form in the hydrographs of wells (C-34-8)5bca-1, (C-34-9)16cdd-1, (C-35-11)17dcd-1, (C-35-11)27bbc-1, (C-35-12)18ddd-2, and (C-36-11)8aab-1 in figure 17.

Water-level data have been collected at selected wells in Parowan Valley since 1931 and in Cedar City Valley since 1935. Water-level fluctuations for selected wells are shown in figure 17. During the current investigation, water levels were measured at approximately 240 wells in March 1974, October and November 1974, and March 1975 to determine the relation of water level to land surface (pl. 4) and the general annual and seasonal changes in water levels (fig. 17). Monthly water levels were measured at 12 selected wells and 2 wells were equipped with automatic water-level recording gages. Basic water-level data for this report are given in Bjorklund, Sumsion, and Sandberg (1977). Changes in water level in wells from March 1974 to October-November 1974 are shown in figure 6. The declines are generally the result of residual drawdowns from pumping for irrigation, most of which recovered by the following March. Compare figure 6 with figures 9 and 10 which show general changes in water levels from March 1974 to March 1975 and contain some additional recovery from residual drawdown and some recovery due to recharge during the winter and early spring of 1974-75.

Seasonal fluctuations

Seasonal changes of ground-water level are caused by seasonal changes of recharge and discharge. In Parowan and Cedar City Valleys the hydrographs of water level in wells follow a similar pattern but differ greatly in magnitude. The pattern is drawdown (or decline) of water levels during the irrigation season which occurs mostly during May through September when many irrigation wells are pumped, and recovery (or rise) of water levels occurs mostly during October-May. All the hydrographs in both valleys show rising water levels throughout the recovery season, which indicate that recovery from the preceding pumping season is not complete when pumping starts late in the spring.

Parowan Valley.--Figure 7 illustrates seasonal fluctuations in Parowan Valley. The hydrographs of wells (C-31-7)31cca-1 and (C-32-8) 13bca-1 are typical of seasonal fluctuations in the Buckhorn Flats area in the northern part of the valley. Here, water is pumped from highly transmissive valley fill composed largely of volcanic debris. Although the fluctuations are relatively small, the interference effects of pumping are far reaching (see sections on aquifer tests and interference). Water levels throughout this area, which includes more than 20 mi^2 (50 km^2), apparently fluctuate according to the same pattern.

The hydrograph of well (C-33-9)24cdd-1 in figure 7 shows relatively large seasonal fluctuation due to interference from pumped irrigation wells more than a mile to the south. After the pumping season of 1974, the water level rose steadily from more than 15 ft (5 m) below land surface and reached land surface late in the winter when the well started to flow. The flow then increased steadily until pumping started in the other wells late in the spring; then it stopped flowing abruptly a few hours after pumping started. Other flowing wells 0.5 to 2 mi (0.8 to 3 km) to the east do not seem to be affected by interference from pumped wells to the south.

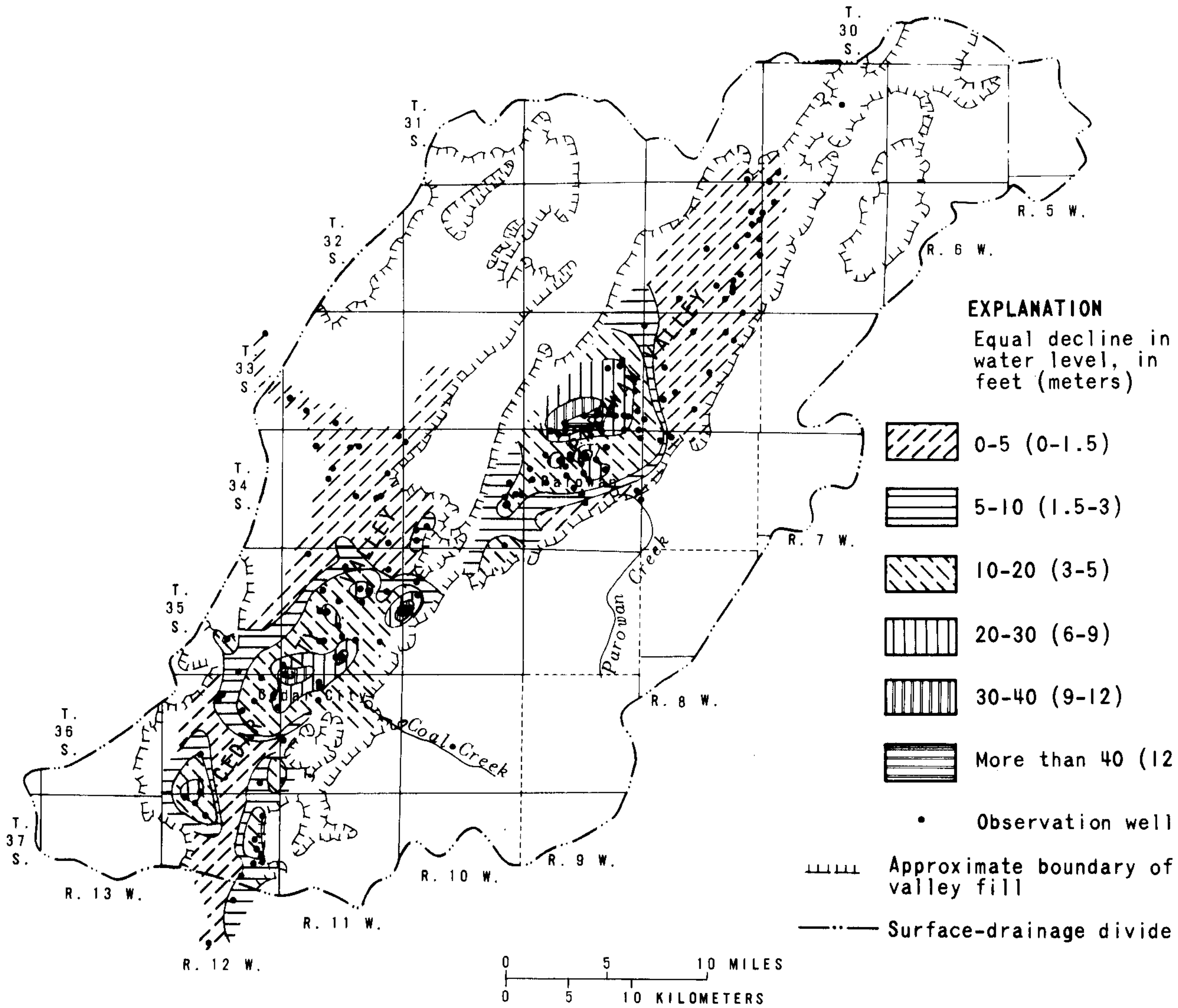


Figure 6.—Water-level declines in Parowan and Cedar City Valleys from March 1974 to October-November 1974.

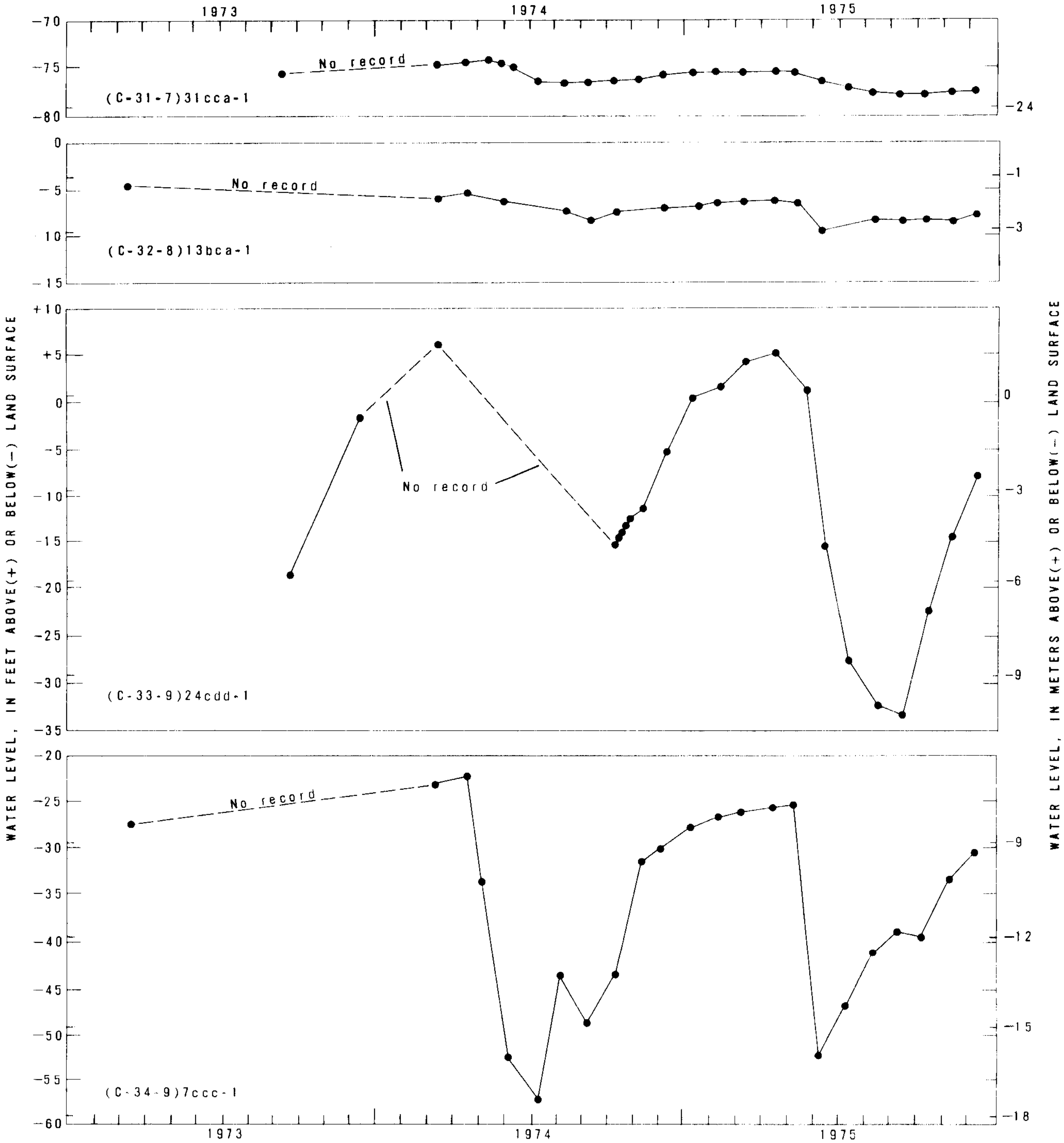


Figure 7.— Seasonal fluctuation of water levels in selected wells in Parowan Valley, 1973-75.

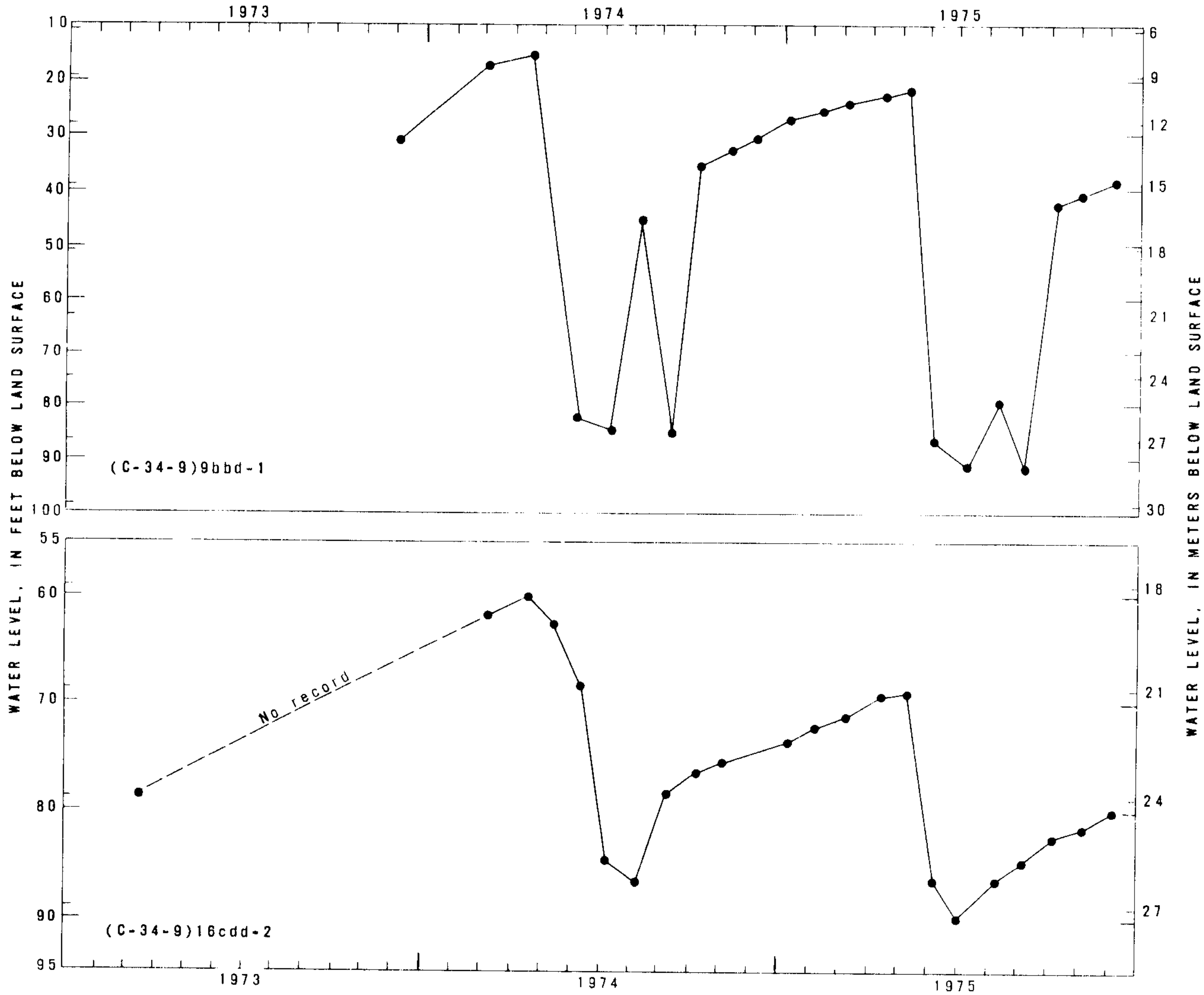


Figure 7.— Continued.

Seasonal water-level fluctuations in the heavily pumped parts of Parowan Valley north and west of Parowan are illustrated in figure 7 by the hydrographs of wells (C-34-9)16cdd-1, (C-34-9)9bbd-1, and (C-34-9) 7ccc-1. All these hydrographs show interference effects caused by pumped wells less than 0.25 mi (0.4 km) away, and all show steadily rising water levels just before they start to decline because of pumping of other wells.

Cedar City Valley.--Seasonal water-level fluctuations in wells in Cedar City Valley are shown by hydrographs in figure 8. Well (C-35-11) 4dda-1 is remote from areas of concentrated pumping and is affected only slightly by interference. Most of the general decline shown in the 3-year period, 1973-75, is probably adjustment from recharge in the vicinity which occurred during the winter and spring of 1972-73 and brought water levels almost to the land surface in the vicinity in March 1973.

Fluctuations at the margins of pumped areas in Cedar City Valley, but quite remote from the center of heaviest pumping, are shown by the hydrographs of wells (C-36-12)10dda-1, (C-36-12)20ddc-1, and (C-37-12) 9bbb-1. Although these wells are more than 2 mi (3 km) apart, the hydrographs have the same general shape. They all show interference (drawdown) from pumped wells 0.25 to 2 mi (0.4 to 3 km) away, and they all show recovery taking place immediately prior to the following pumping season.

Long-term trends

During most of the years since 1940, the amount of water discharged from the ground-water reservoir by wells, springs, and evapotranspiration has been greater than the amount of water added to the reservoir by recharge. Consequently, the overall trend of ground-water levels (see section on recharge) has been downward. The principal cause of the downward trend has been the withdrawal of water by wells. The decline has been greatest during and following dry years as a consequence of lessened recharge plus additional pumping. It has been least during and following wet years as a consequence of greater recharge and reduced pumping. In March 1974, following a period of excessive precipitation, most water levels were several feet higher than they were a year earlier, but they declined to new lows in March 1975 because of less-than-average precipitation and record pumping during 1974 (figs. 9 and 10).

The approximate decline of ground-water levels for the 35-year period, 1940-74, in Parowan and Cedar City Valleys is shown as areas on a map in figure 11. This illustration was constructed by comparing 1974 potentiometric water-level contour maps (pls. 5 and 6) with maps showing similar data for 1940 (Thomas and Taylor, 1946, pls. 13 and 23). Declines in Parowan Valley are based on data collected during September and October in 1940 and 1974, whereas declines in Cedar City Valley are based on data collected in March and April for the same years. Estimates of declines were made also from the hydrographs in figure 17. As some of the hydrographs show little decline between 1940 and 1950, some estimates of decline were based on 1950-74 hydrographs.

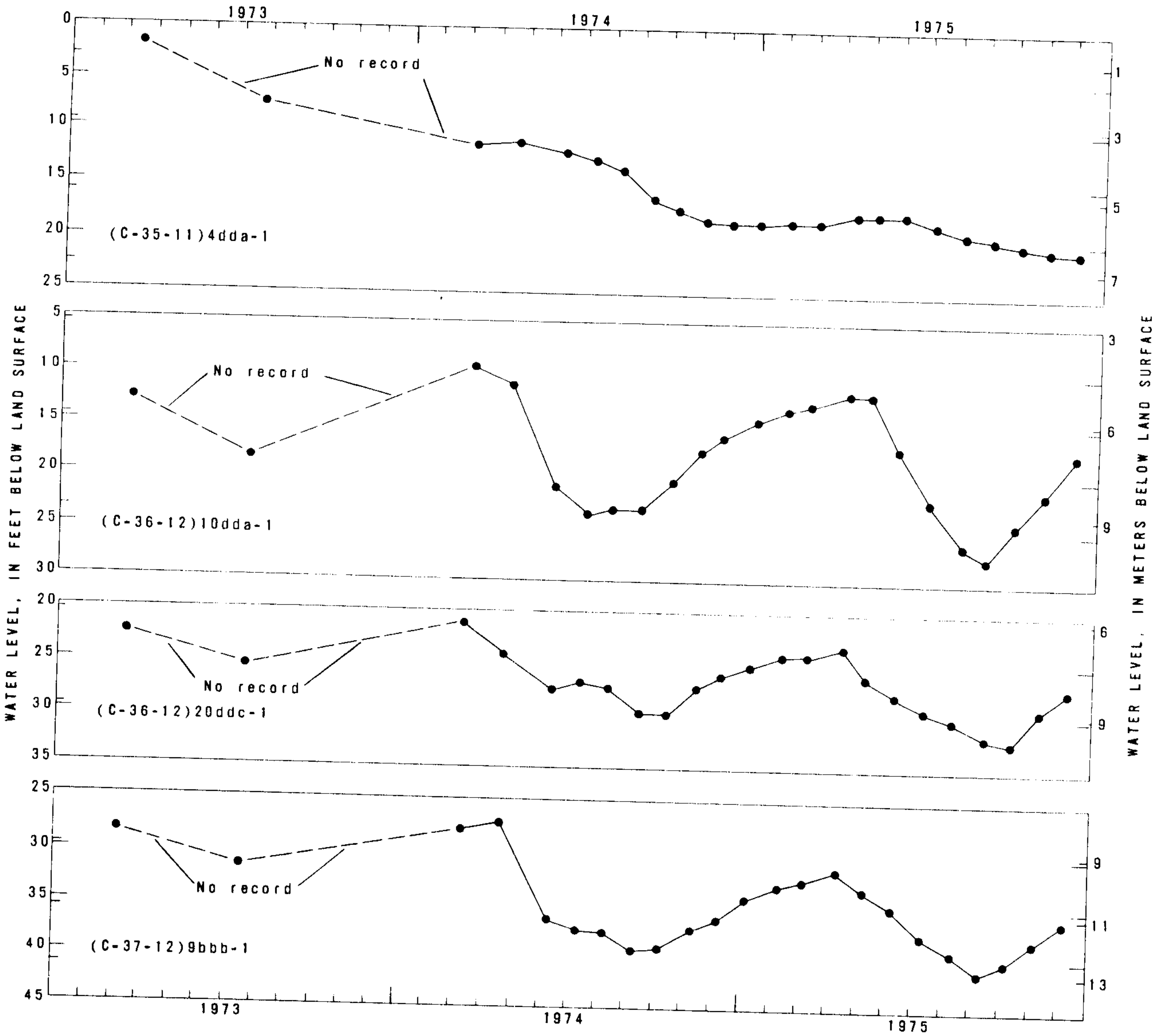


Figure 8.— Seasonal fluctuation of water levels in selected wells in Cedar City Valley, 1973-75.

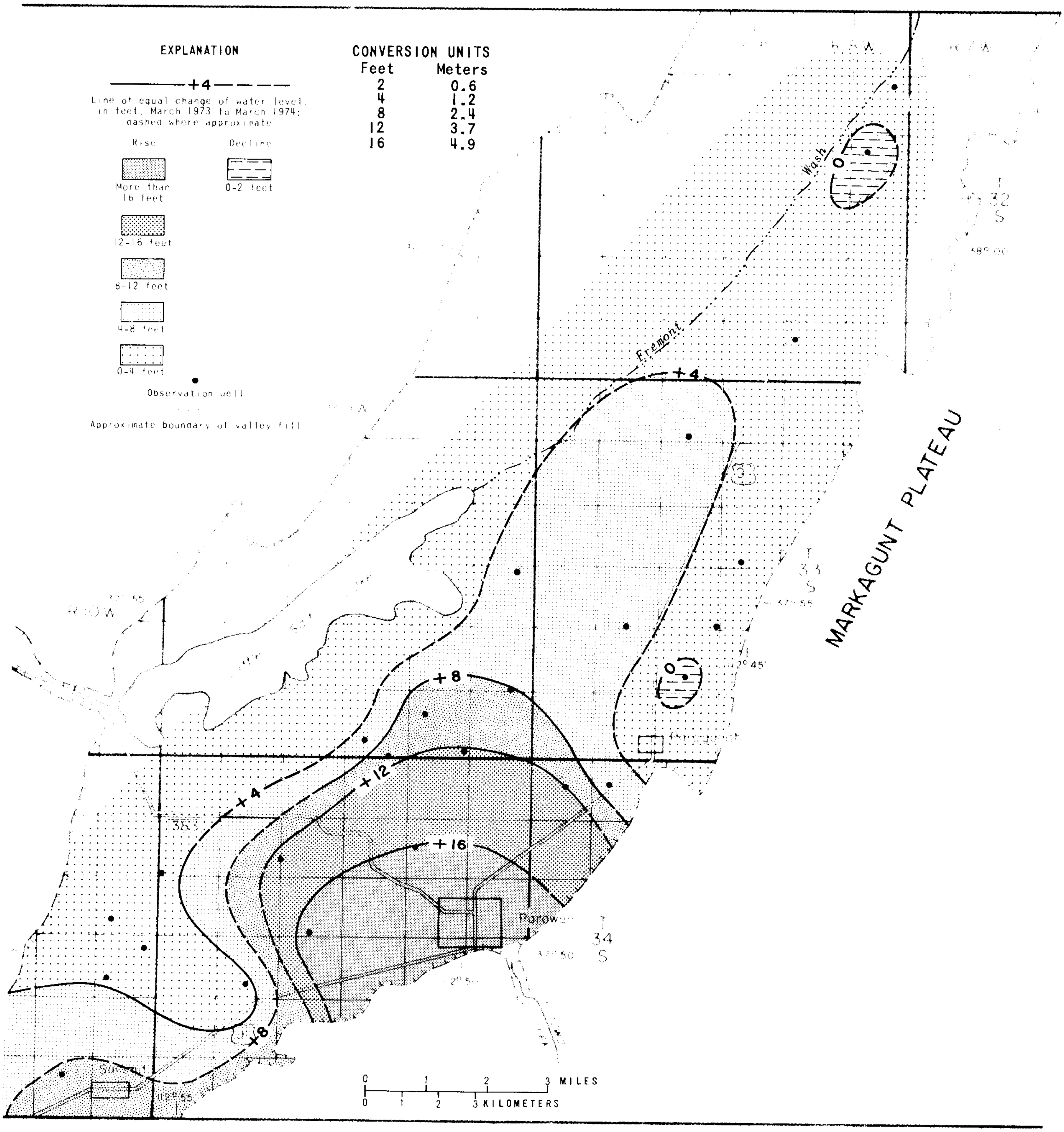


Figure 9.—Maps of Parowan Valley showing changes in ground-water levels, March 1973 to March 1974 and March 1974 to March 1975.

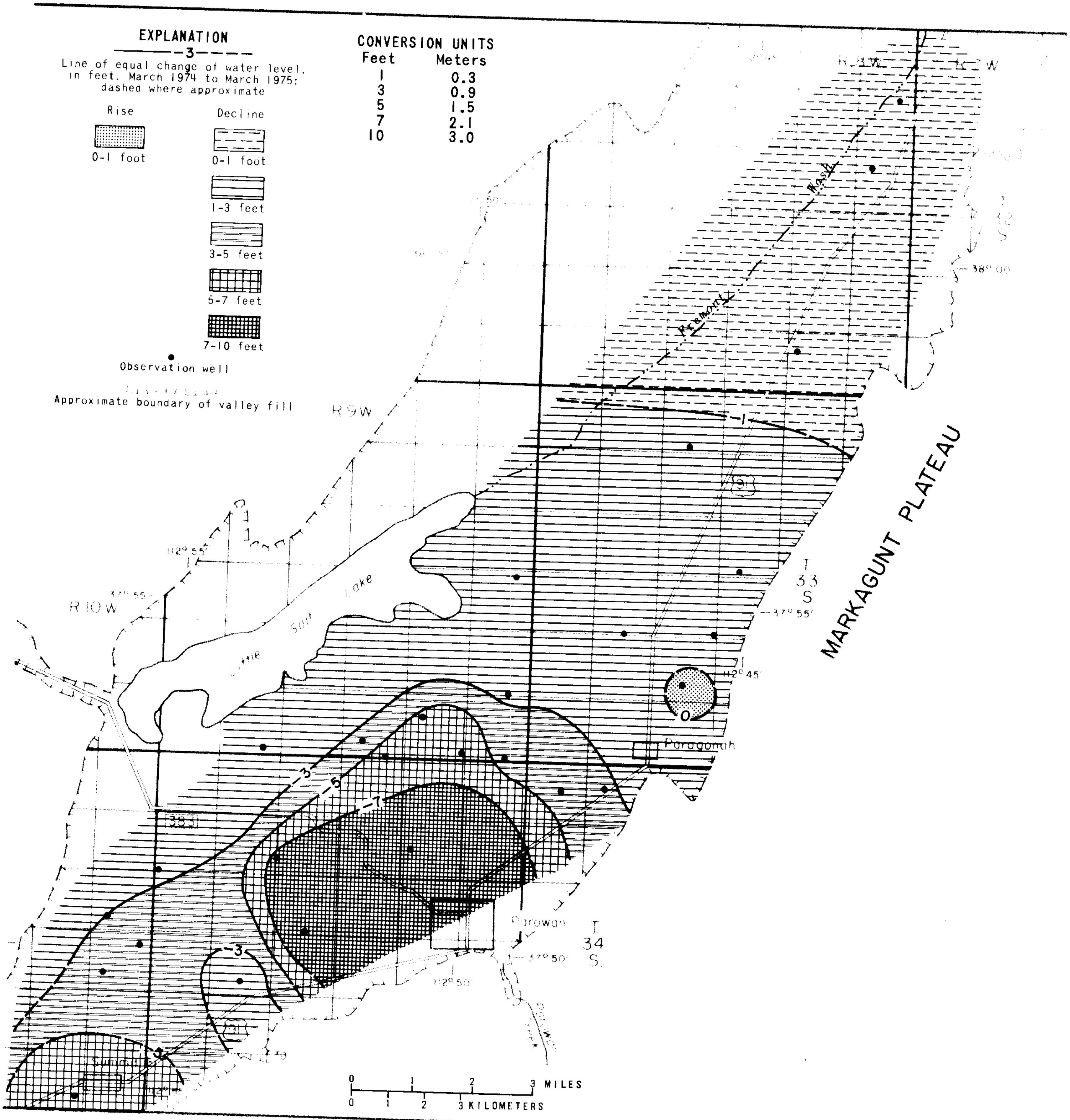


Figure 9.— Continued.

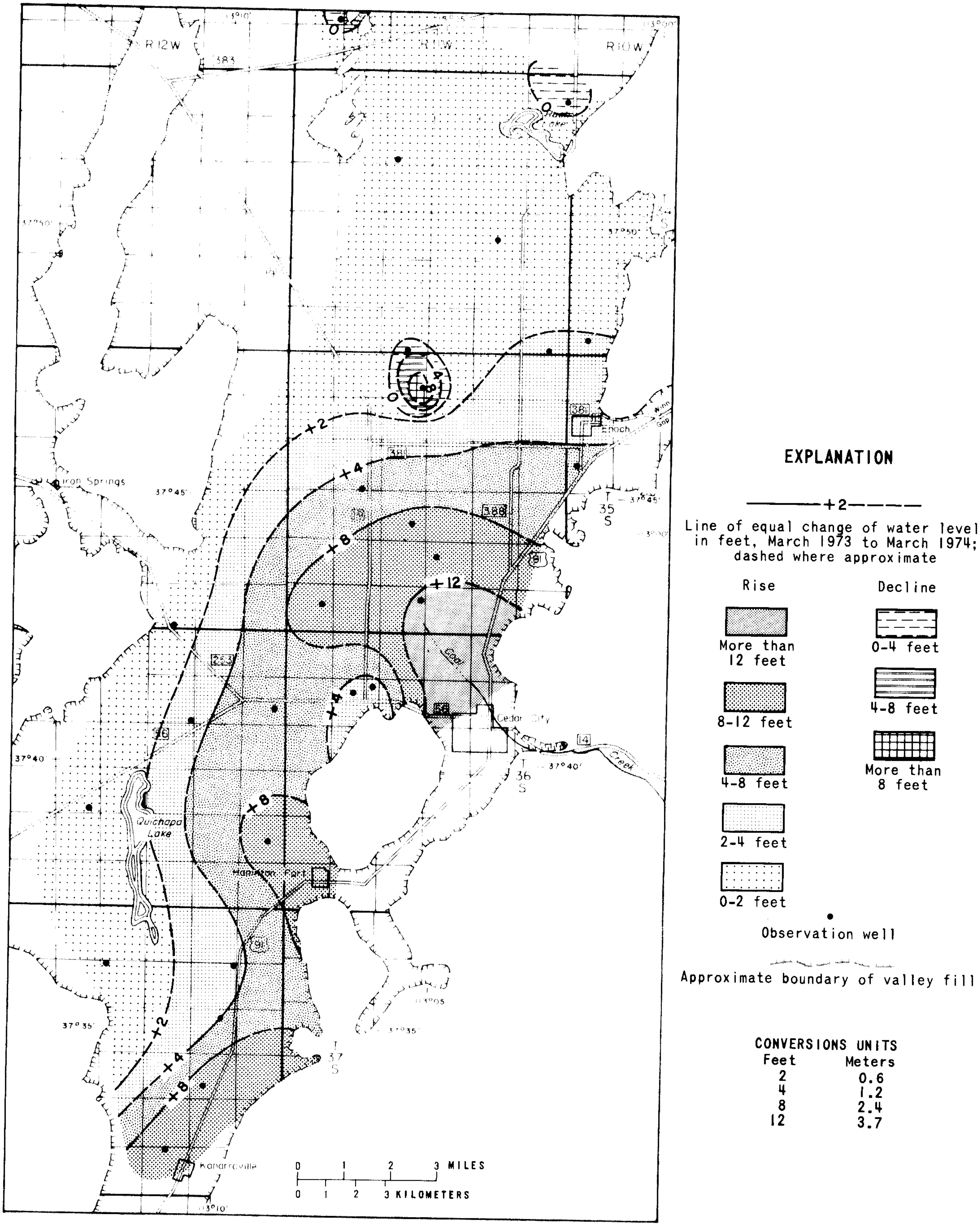
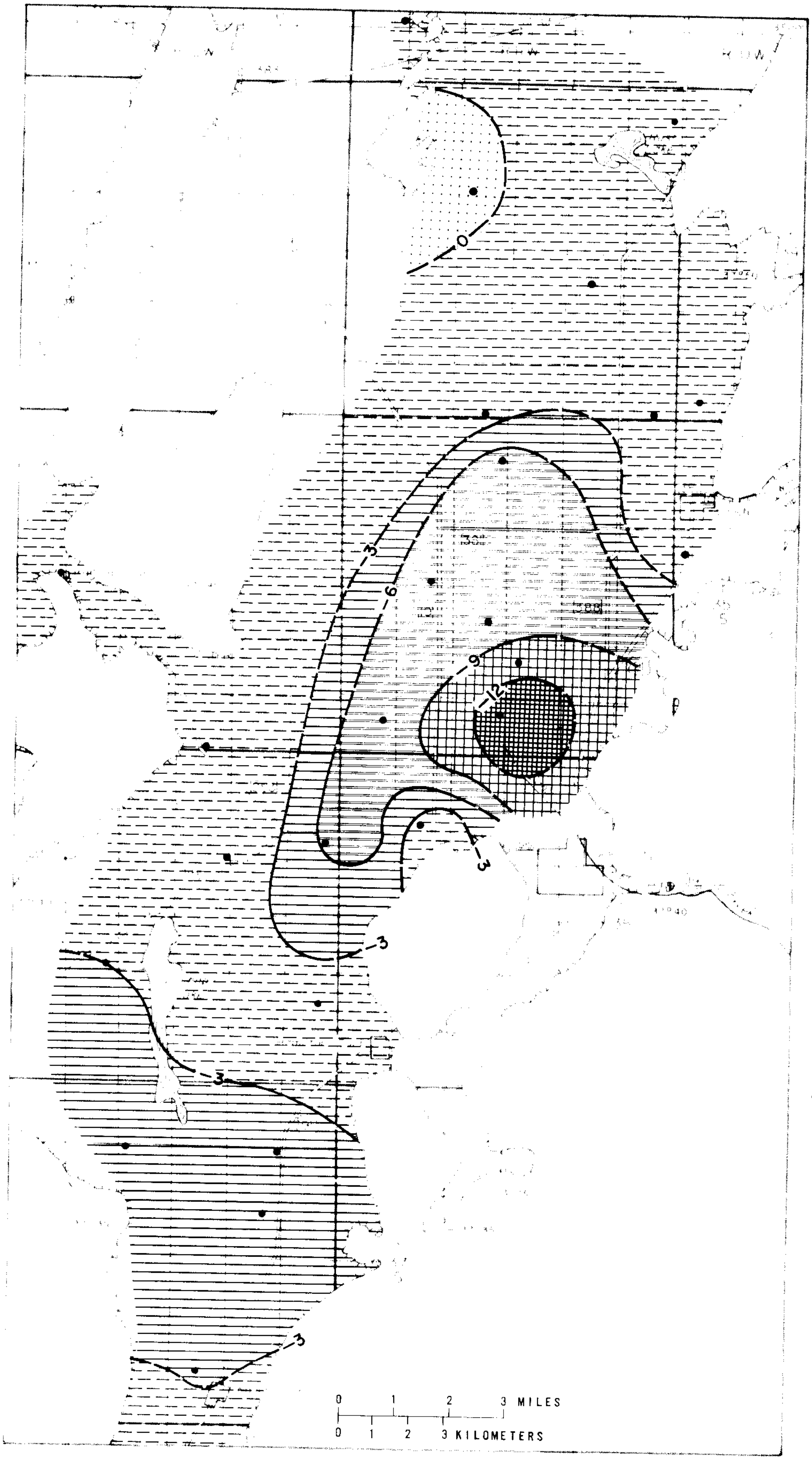


Figure 10.— Maps of Cedar City Valley showing changes in ground-water levels, March 1973 to March 1974 and March 1974 to March 1975.



EXPLANATION

—3—

Line of equal change of water level, in feet, March 1974 to March 1975; dashed where approximate

Rise

0-1 foot

Decline

0-3 feet

3-6 feet

6-9 feet

9-12 feet

More than 12 feet

Observation well

Approximate boundary of valley fill

CONVERSION UNITS

Feet	Meters
1	0.3
3	0.9
6	1.8
9	2.7
12	3.7

Figure 10.— Continued.

In both Parowan and Cedar City Valleys major water-level declines (fig. 11) exist in areas where large amounts of water are pumped from wells to irrigate crops. The principal pumpage areas are north and west of Parowan and north and west of Cedar City (pl. 3). Recharge in Parowan Valley from Parowan Creek and from diversions for irrigation and in Cedar City Valley from Coal Creek and diversions has prevented long-term declines of water level in these areas from being greater than they are.

Major long-term declines are indicated in figure 11 in three areas marginal to Cedar City Valley. These areas are: (1) near the edge of the valley about 7 mi (11 km) northeast of Cedar City, (2) near the edge of the valley about 6 mi (10 km) southwest of Cedar City, and (3) west of Quichapa Lake. The decline of water levels in these areas is attributed partly to moderately heavy pumpage and partly to an apparent lack of recharge, as no large perennial streams flow in these areas. The drawdown effects of pumping reflected from the nearby bedrock at the edge of the valley fill may account for part of the decline. Also water-table conditions along the edge of the valley fill may tend to localize the decline.

The approximate areal extent of the water-level declines during 1940-74, as shown in figure 11, is given in the following table:

Decline of ground-water level 1940-74	Size of area affected: Parowan Valley	Size of area affected: Cedar City Valley
More than 30 ft (9 m)	9 mi^2 (23 km^2)	8 mi^2 (20 km^2)
20 to 30 ft (6 to 9 m)	20 mi^2 (50 km^2)	18 mi^2 (47 km^2)
10 to 20 ft (3 to 6 m)	63 mi^2 (160 km^2)	49 mi^2 (130 km^2)
0 to 10 ft (0 to 3 m)	33 mi^2 (85 km^2)	75 mi^2 (190 km^2)

The approximate volume of water represented by the declines listed above is 1,220,000 acre-ft (1,500 hm^3) in Parowan Valley and about 1,110,000 acre-ft (1,370 hm^3) in Cedar City Valley. If the volume of decline represents a dewatered volume with an average specific yield of 0.1, the ground-water loss from storage in 35 years would be about 122,000 acre-ft (150 hm^3) in Parowan Valley and 111,000 acre-ft (137 hm^3) in Cedar City Valley. This would amount to an average annual loss from storage of about 3,600 acre-ft (4.4 hm^3) of ground water in Parowan Valley and about 3,300 acre-ft (4.1 hm^3) in Cedar City Valley.

The estimates of average annual depletion given in the preceding paragraphs, although apparently reasonable, should be regarded as only approximate. The largest error in the calculations could be in the estimated average specific yield of the dewatered rocks, regarded to be 0.1. As leaky artesian conditions exist in most of the valleys, much of the long-term declines could be only a decline in hydrostatic pressure and the storage coefficient may be smaller.

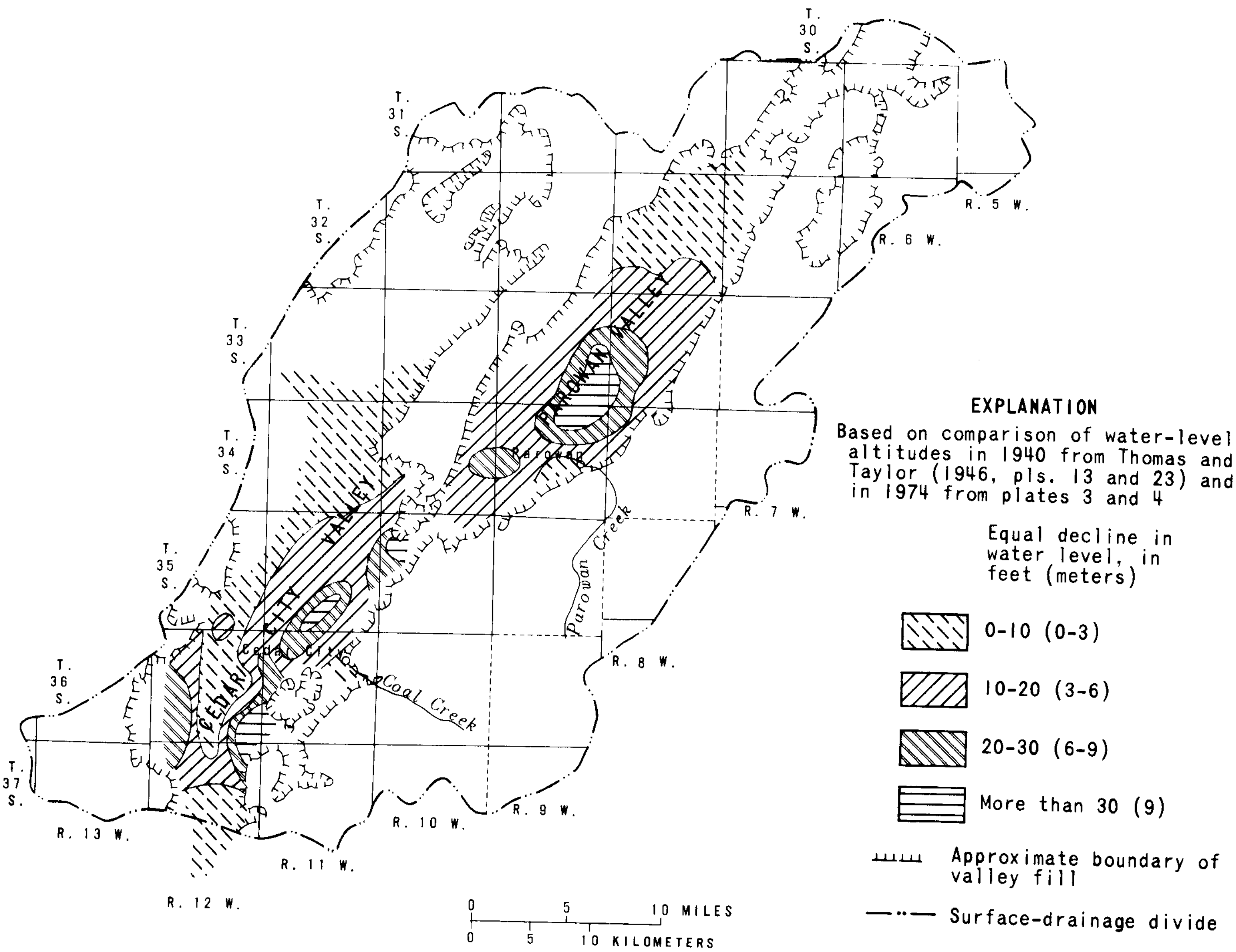


Figure 11.— Approximate decline of ground-water levels in Parowan and Cedar City Valleys, 1940-74 (based on September-October data in Parowan Valley and March-April data in Cedar City Valley).

Discharge

Ground water is discharged in the Parowan-Cedar City drainage basin by springs, seeps, evapotranspiration, wells, and subsurface outflow. The average annual discharge from the valleys is estimated to be about 87,000 acre-ft (110 hm^3). About half of this amount is discharged from each valley.

Springs in the mountains

Most of the discharge of water by springs and seeps takes place in the highlands bordering the valleys, especially on the western slope of the Markagunt Plateau. Here the discharge from springs is estimated to amount to more than 25,000 acre-ft (30 hm^3) annually; it forms the base flow of Coal Creek, Parowan Creek, and all the perennial streams in the basin (see table 2), and provides most of the water for the municipal water systems in the basin. Many contact springs issue from the bedrock of Tertiary and Mesozoic age. Most of the large springs discharge from joints and solution channels in limestone and conglomerate near the base of the Tertiary Wasatch Formation; these include Warm Spring, (C-33-8)36b-S1, South Fork Spring, (C-34-8)2a-S1, and Box Elder Spring, (C-35-8)9b-S1, each of which discharge about 2 ft^3/s (0.5 m^3/s) in the mountains east of Parowan Valley. Some large springs also issue from rocks of Cretaceous age; these include Right Hand Spring, (C-36-10) 21cda-S1, which discharges about 2 ft^3/s (0.5 m^3/s) from sandstone beds in the mountains east of Cedar City Valley.

Springs and seeps in the valleys

Only a relatively small amount of water, probably less than 1,000 acre-ft (1 hm^3) per year, is discharged from springs and seeps on the floors of Parowan and Cedar City Valleys. Many springs and seeps existed in both valleys prior to 1940 (Thomas and Taylor, 1946, p. 102-106, 168-172) but few of these remain due to the decline of ground-water levels. (See section on the fluctuation of water levels.)

Scattered marshy meadow areas and a few small springs and seeps exist in the artesian lowlands of Parowan Valley northwest of Paragonah (see area where the potentiometric surface of the ground-water reservoir is above land surface on plate 4). The largest spring on the valley floor is Willow Spring, (C-33-8)32bbc-S1, estimated to discharge about 40 gal/min (2 L/s). Also some ground-water discharge by seeps is indicated by patches of damp earth and saltgrass along the western margins of Little Salt Lake. The artesian area of Parowan Valley is an area of ground-water discharge with most of the discharge taking place by evapotranspiration and by flowing and pumped wells rather than springs.

Very little water discharges by springs in Cedar City Valley today, although in 1940 Thomas and Taylor (1946, p. 106) estimated an average annual discharge of about 4,700 acre-ft (5.8 hm^3). Many springs and seeps that discharged near Rush Lake and near Enoch in 1940 are dry today. Some ground water continues to discharge from seeps at the northeast edge of Quichapa Lake where several acres of land are wet and muddy. About 1 gal/min (0.06 L/s) was estimated to seep to the surface at Mud Springs, (C-37-12)3ccc-S1, and about 10 gal/min (0.6 L/s) was estimated to discharge from each of two springs near Kanarraville, (C-37-12)33aad-S1 and (C-37-12)33dcb-S1. The largest spring discharge, 225 gal/min (14.2 L/s), was estimated at Iron Springs, (C-35-12)20abc-S1, which is outside of the valley floor at one of the topographic outlets from the valley. The total discharge by springs and seeps in Cedar City Valley is estimated to be less than 500 acre-ft (0.6 hm^3) per year and most of this is consumed by evapotranspiration near the points of discharge.

Evapotranspiration

Evapotranspiration values for various land classifications were developed with the assistance of the Utah Water Research Laboratory, Utah State University, on the basis of a modified Blaney-Criddle formula (Hill and others, 1970, p. 17-19). These values were used in estimating evapotranspiration.

The discharge of ground water by evapotranspiration in the Parowan-Cedar City Valleys amounts to about 14,000 acre-ft (17 hm^3) annually. Evapotranspiration occurs where the water table is shallow enough to cause evaporation from a moist land surface or where roots of plants extend into the wet zone at or near the water table and get water from the ground-water reservoir. Plants that habitually obtain their water supply from the zone of saturation, either directly or through the capillary fringe, are called phreatophytes (Meinzer, 1923, p. 55). The principal native phreatophytes that consume ground water in the Parowan and Cedar City Valleys are greasewood (*Sarcobatus vermiculatus*), rabbitbrush (*Chrysothamnus* sp.) and desert saltgrass (*Distichlis stricta*). Communities of these plants may be segregated, mixed with other phreatophytes, or mixed with big sagebrush (*Artemesia tridentata*). The approximate outer limit of phreatophytes, shown on plate 7, encompasses about 45 mi^2 (120 km^2) in Parowan Valley and about 55 mi^2 (140 km^2) in Cedar City Valley; these areas include tracts of phreatophytes, phreatophytes mixed with sagebrush, dry-farm land, and cleared uncultivated land.

<u>Parowan Valley</u>.--About 12,000 acre-ft (15 hm^3) of ground water is estimated to be discharged annually by evapotranspiration from phreatophytes in the Parowan Valley and by evaporation from the Little Salt Lake.

Saltgrass grows in several wet meadow areas in Parowan Valley and is estimated to cover an area of about 3.5 mi^2 (9.1 km^2). The annual evapotranspiration of ground water is estimated to be about 2 ft (0.6 m), which would amount to about 4,500 acre-ft (5.5 hm^3). The estimate is based on White's experiments with saltgrass grown in tanks in Escalante Valley (Robinson, 1958, p. 58).

The area of phreatophyte growth in Parowan Valley coincides generally with the area of flowing wells but is slightly larger (pls. 4 and

7). Although the position of the potentiometric surface of the ground-water reservoir is known to be above the land surface in most of this area, little is known regarding the position of the shallow water table. The flowing wells in the area generally are more than 200 ft (60 m) deep and upward movement of ground water from this depth through many layers of clay, silt, sand, and gravel to near the land surface would be slow. As the land surface is generally dry, it is assumed that greasewood would have to extend their roots 5 to 10 ft (2 to 3 m) below land surface to obtain water in most of the area. The seasonal use of ground water under these conditions in Escalante Valley was estimated by White to range from 0.08 to 0.38 ft (0.02 to 0.12 m) (Robinson, 1958, p. 69). An inferred average seasonal use of 0.2 ft (0.07 m) applied to the approximate area of phreatophytes (including rabbitbrush and sagebrush but excluding the area already calculated for saltgrass) would amount to about 5,300 acre-ft (6.5 hm^3).

Little Salt Lake, covering an area of 6 mi^2 (16 km^2), is a natural ground-water discharge area for Parowan Valley. Although the water from wells near the lake is fresh (see well (C-34-9)5abc-1 in table 5 and pl. 8) evaporation from the playa surface has resulted in an accumulation of salt. In 1940, Thomas and Taylor (1946, p. 171-172) estimated an annual ground-water discharge of 5,800 acre-ft (7.2 hm^3) from the playa, 700 acre-ft (0.9 hm^3) from seeps along the western margin, and 1,000 acre-ft (1 hm^3) from phreatophytes within 0.25 mi (0.4 km) of the lake. Today the annual discharge of ground water from the playa surface and seeps along its margin probably is not more than 2,000 acre-ft (2 hm^3). The potentiometric surface of the ground-water reservoir has declined 10 to 20 ft (3 to 6 m) in the general area (fig. 11) and the seasonal decline during the pumping season is probably an additional 10 ft (3 m) or more. The March 1974 water levels in the vicinity of Little Salt Lake are still above the land surface (pl. 4) so some ground-water discharge by evaporation from the playa occurs during the non-pumping season. Some discharge still takes place at the seeps along the western margin.

Cedar City Valley.--About 2,000 acre-ft (2 hm^3) of ground water is estimated to be discharged annually by evapotranspiration by phreatophytes in Cedar City Valley and evaporation from the playas of Quichapa and Rush Lakes. This figure is substantially less than the 12,000 acre-ft (15 hm^3) estimated for Parowan Valley mainly because the potentiometric surface has declined to below land surface in virtually all of Cedar City Valley; whereas, it is still above land surface in about a third of Parowan Valley (pl. 4).

About 1,600 acre-ft (2.0 hm^3) of ground water, or about 0.2 ft (0.06 m), is estimated to be discharged by evapotranspiration from about 15 mi^2 (39 km^2) situated in three areas in Cedar City Valley where the potentiometric surface of the ground-water reservoir is less than 10 ft (3 m) below land surface. These areas include about 8 mi^2 (20 km^2) surrounding Quichapa Lake, 6 mi^2 (16 km^2) at and near Rush Lake, and 1 mi^2 (3 km^2) about 1 mi (1.6 km) west of Enoch. Evapotranspiration of ground water by native vegetation in the rest of the valley is negligible because of greater depths to ground water (pl. 4).

It is estimated that not more than 500 acre-ft (0.6 hm^3) of ground water is discharged by evaporation from the playa surface of Quichapa Lake annually. Although the potentiometric surface of the ground-water reservoir is near the playa surface of the lake, and may be above it in places, there is very little hydrostatic head, or pressure, to force ground water through the lakebed silt and clay to the surface to replace evaporated water. Some ground-water discharge, which wets several acres, occurs at seeps at the northeast edge of the playa. The playa surface is usually dry, but it was inundated by the heavy runoff of surface water from snowmelt in May and June 1973, and water remained in the lake until August 1975 when the last of it was consumed by evaporation.

A large amount of water, probably as much as 1,000 acre-ft (1 hm^3) annually, is estimated to have been consumed by phreatophytes and evaporation during recent years in parts of secs. 16, 17, 20, and 21, T. 35 S., R. 11 W. An annual accumulation of surface water has resulted in a growth of willow (*Salix* sp.) and rabbitbrush. Other brush appears to have been killed by excess water. As the depth to ground water in this area is more than 10 ft (3 m) below land surface (pl. 4), very little of the water discharged by vegetation is from the ground-water reservoir.

Wells

The largest means of ground-water discharge in the Parowan-Cedar City drainage basin during recent decades is the withdrawal of water from wells. During 1974 approximately 73,000 acre-ft (90 hm^3) of water was pumped from wells, the greatest annual pumpage of record. Most of this water was used for irrigation. Records of 382 representative wells are given in Bjorklund, Sumsion, and Sandberg (1977, table 1).

Parowan Valley.--Approximately 30,700 acre-ft (37.8 hm^3) of ground water was discharged from wells in Parowan Valley during 1974, the largest annual withdrawal of record. This figure includes 29,500 acre-ft (36.4 hm^3) for irrigation, 1,010 acre-ft (1.25 hm^3) for public supply, and 150 acre-ft (0.18 hm^3) for domestic and stock use. The annual withdrawal of water from wells in the valley, shown in figure 2, has more than tripled since 1945, and it has doubled since 1960 despite the fact that precipitation has been greater than average during most years since 1960.

Cedar City Valley.--The withdrawal of ground water from wells in Cedar City Valley totaled approximately 42,300 acre-ft (52.1 hm^3) in 1975. This is the greatest quantity of water pumped for any year to date (1975). Of this amount 39,800 acre-ft (49.1 hm^3) was pumped for irrigation, 1,850 acre-ft (2.28 hm^3) for municipal supply, 500 acre-ft (0.6 hm^3) for industry, and 150 acre-ft (0.18 hm^3) for domestic and stock use. Annual pumpage from wells has increased progressively in Cedar City Valley since the mid-1930's when large amounts of water were first pumped from wells for irrigation. About 13,000 acre-ft (16 hm^3) of water was pumped in 1940, 17,000 acre-ft (21 hm^3) in 1950, and 22,000 acre-ft (27 hm^3) in 1960. The annual withdrawal of ground water in Cedar City Valley since 1938 is illustrated in figure 3.

Subsurface outflow

A relatively small amount of ground water, estimated to be about 500 acre-ft (0.6 hm^3) per year, leaves the Parowan-Cedar City drainage basin by subsurface outflow. Ground water moves out of the basin through three topographic outlets--Mud Springs Wash, Iron Springs Gap, and the valley of Kanarra Creek west of Kanarraville. The underflow through Mud Springs Wash was estimated by Thomas and Taylor (1946, p. 104) to be only 20 acre-ft (0.02 hm^3) per year on the basis of a moderately low permeability, a small saturated section of the aquifer, and a hydraulic gradient of 10 ft (3 m) to 1 mi (2 km). The underflow through Iron Springs Gap, based on the discharge of the springs plus some underflow, was estimated to be about 500 acre-ft (0.6 hm^3) per year (Thomas and Taylor, 1946, p. 103). The underflow into Kanarra Creek valley from Cedar City Valley is estimated to be negligible because the area between a low topographic divide, a short distance north of Kanarraville, and a ground-water divide, a short distance further north, is too small to provide much water by recharge. Springs west of Kanarraville are believed to derive most of their discharge from recharge on the Kanarra Creek alluvial fan near Kanarraville which occupies an area outside of the Parowan-Cedar City drainage basin.

The mountain block between Parowan Valley and Cedar City Valley is an effective barrier to prevent the subsurface movement of water between the valleys. Thus, subsurface outflow from Parowan is regarded to be negligible. The altitude of the ground-water reservoir in Parowan Valley at its lowest point near Little Salt Lake is approximately 280 ft (85 m) higher than the ground-water reservoir in Cedar City Valley near Rush Lake, 6 mi (10 km) to the southwest. Likewise, ground-water levels near Summit, in Parowan Valley, are 240 ft (73 m) higher than they are near Enoch in Cedar City Valley, less than 4 mi (6.4 km) to the west. Ground-water contours in Parowan Valley (pls. 5 and 6) indicate that the ground water moves toward Little Salt Lake, the area of natural discharge. Some water may move into Cedar City Valley through Parowan Gap, which once drained Little Salt Lake, but the amount would be small because the gap is narrow and its alluvial fill apparently is shallow. Surface water no longer flows through the gap, partly because alluvial fans from side canyons have created dams by raising the canyon floor; also, the mountain block may have been raised by faulting of Quaternary age.

Quality

Data on the chemical quality of ground water in the Parowan and Cedar City drainage basins assembled as a part of this investigation are given in Bjorklund, Sumsion, and Sandberg (1977, table 5). Much of that information is shown in generalized form on illustrations in this section. Representative chemical analyses are given in table 5.

The chemical quality of surface water in the study area has been reported by Connor, Mitchell, and others (1958, p. 275-276), and more recently by U.S. Geological Survey (1967, p. 108; 1972, p. 131-133; and 1973, p. 127-129).

Table 5.--Representative chemical analyses of water from selected wells and springs

Location: See explanation of numbering system.
Agency reporting analysis: GS, U.S. Geological Survey; SH, Utah Division of Health.

Location	Date of collection	Depth of well or sampling depth (ft)	Temperature (°C)	Milligrams per liter															Dissolved solids		Specific conductance (micromhos/cm at 25°C)	pH	Sodium-adsorption ratio	Agency making analysis
				Dissolved silica (SiO_2)	Dissolved iron (Fe)	Dissolved calcium (Ca)	Dissolved magnesium (Mg)	Dissolved sodium (Na)	Dissolved potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Dissolved sulfate (SO_4)	Dissolved chloride (Cl)	Dissolved fluoride (F)	Dissolved nitrate plus nitrate (NO_2+NO_3) as nitrogen (N)	Dissolved boron (B)	Hardness as $CaCO_3$	Noncarbonate hardness as $CaCO_3$	Residue on evaporation	Sum				
PAROWAN VALLEY DRAINAGE BASIN																								
(C-32-8)12bac-1	5-21-74	440	20.0	58	0	31	6.8	15	5.3	130	0	11	15	0.2	0.75	0.04	110	0	-	210	260	8.0	0.6	GS
35bcb-1	6-11-74	250	12.5	43	.01	22	6.5	21	1.0	120	0	7.6	16	.2	.55	.05	82	0	-	179	250	8.3	1.0	GS
(C-32-9)14abd-S1	10- 3-74	-	13.5	49	.02	71	19	16	3.6	297	-	12	20	.1	1.0	.51	260	12	-	342	520	7.5	.4	GS
(C-33-8)19ddd-1	6-11-74	204	11.5	20	.02	40	22	18	2.3	239	0	13	15	.2	1.8	.04	190	0	-	256	446	8.0	.6	GS
(C-33-9)1dad-1	6-11-74	270	15.5	46	.00	11	3.2	30	3.2	108	1	8.1	12	.3	.61	.05	41	0	-	171	234	8.4	2.0	GS
34dcd-1	6-11-74	405	12.5	26	.02	49	29	8.9	2.8	279	0	17	6.7	.1	2.5	.03	240	13	-	288	492	7.7	.3	GS
(C-34-9)5abc-1	6-11-74	340	14.0	32	.01	28	17	13	3.3	182	0	18	5.7	.0	.36	.02	140	0	-	208	333	8.0	.5	GS
16cdd-2	8- 7-74	331	10.5	35	-	79	35	11	3.2	379	-	32	11	.3	2.7	.05	340	31	-	405	650	7.4	.3	GS
24abb-1	1-10-68	180	-	14	.00	46	33	36	7.0	271	1.1	60	44	.38	.18	.00	250	-	382	-	625	7.9	1.0	SH
36dbb-1	4-28-69	125	-	15	.04	60	24	9	2.0	268	1.3	36	16	.3	.0	.00	250	-	316	-	515	8.0	.2	SH
(C-34-10)13cbd-1	10- 2-73	360	12.0	40	-	72	53	25	4.5	440	0	46	24	-	-	-	400	37	-	481	816	7.7	.5	GS
	5-22-74	360	11.5	42	.01	47	29	16	4.8	267	0	29	17	.2	1.9	.05	240	18	-	325	480	7.9	.5	GS
24abc-1	6-11-74	162	13.0	40	.01	53	37	19	4.7	315	0	43	23	.3	2.7	.07	280	26	-	387	629	8.0	.5	GS
35acb-1	5-22-74	250	15.5	31	.02	76	42	27	5.7	445	0	47	16	.2	2.0	.07	360	0	-	473	730	7.9	.6	GS
(C-35-8)9b-S1	4-29-69	-	-	13	.04	42	18	5.0	3.0	210	1.8	12	13	.27	.00	.08	178	-	245	-	365	8.2	.2	SH
(C-36-9)11dca-S1	8-26-69	-	-	21	.00	40	8.0	4.0	2.0	164	.91	2.0	13	.01	.14	.14	134	-	162	-	290	8.0	.2	SH
	10- 1-74	-	7.0	24	.02	39	7.4	1.7	2.1	159	-	3.5	1.0	.1	.02	.63	130	0	-	158	260	8.1	.1	GS
CEDAR CITY VALLEY DRAINAGE BASIN																								
(C-33-11)30bca-1	6-25-74	80	13.5	43	0.08	120	87	170	12	339	0	520	130	0.7	0.03	0.34	660	380	-	1,250	1,860	7.5	2.9	GS
(C-34-10)31caa-1	5-23-74	365	16.0	34	.01	55	38	57	6.4	284	0	67	81	.1	2.6	.09	290	61	-	490	800	7.9	1.4	GS
(C-34-11)1daa-1	7- 9-74	120	13.5	36	.02	47	22	68	6.7	157	-	80	110	.4	1.2	.12	210	79	-	453	800	7.6	2.1	GS
9ccd-1	9-10-74	130	13.5	23	.05	42	33	69	5.5	168	-	190	36	.4	.22	.16	240	100	-	483	800	8.0	1.9	GS
23bdd-1	6-13-74	302	13.0	43	.02	120	72	61	7.5	202	0	470	51	.0	1.1	.13	600	430	-	929	1,350	7.7	1.1	GS
(C-34-12)36abb-1	9-10-74	-	20.0	26	.04	80	52	50	4.3	139	-	330	40	.2	.35	.12	410	300	-	653	1,000	7.9	1.1	GS
(C-35-10)18cca-1	8- 5-69	285	-	39	.00	43	26	20	5.0	243	1.3	33	25	.24	.99	.14	214	-	330	-	535	8.0	.6	SH
(C-35-11)26acd-1	9-13-74	700	14.0	33	.02	93	62	40	5.8	304	-	220	42	.3	14.0	.13	490	240	-	708	1,100	7.4	.8	GS
33aac-1	5-22-74	236	12.5	17	-	180	74	22	3.6	334	0	470	19	.2	4.0	.06	750	480	-	968	1,050	7.5	.3	GS
(C-35-12)20abc-S1	9-12-74	-	15.0	30	.22	210	180	230	26	431	-	830	380	1.5	.05	.83	1,300	910	-	2,100	3,000	7.2	2.8	GS
27bcd-1	10- 2-74	255	13.5	33	.02	57	37	44	4.4	205	-	190	23	.3	.26	.61	290	130	-	492	740	7.8	1.1	GS
(C-36-10)18bcb-1	10-24-74	147	-	13	.80	360	75	110	6.7	250	-	900	210	.5	.69	.14	1,200	1,000	-	1,800	2,470	7.5	1.4	GS
(C-36-11)11bac-1	8- 5-69	670	-	21	.00	400	183	55	5.0	279	.77	1,542	44	.25	8.4	.41	1,750	-	2,752	-	2,800	7.7	.6	SH
(C-36-12)32ccb-1	8- 5-69	697	-	32	1.14	26	9.0	12	3.0	135	.94	1.0	20	.05	.00	.18	100	-	166	-	275	8.1	.5	SH
(C-37-12)11aaa-1	6-14-74	365	21.0	51	.02	47	30	31	4.1	180	0	140	12	.3	.9	.14	240	93	-	408	566	7.8	.9	GS

Surface water in the study area is of satisfactory chemical quality for irrigation and consumption by livestock.

Concentration of dissolved solids

Chemical analyses of ground water from wells in the Parowan and Cedar City drainage basins indicate that the concentration of dissolved solids ranges from about 158 to 2,752 mg/L (table 5). Terms used in this report to classify water according to the concentration of dissolved solids and specific conductance, as follows, are modified from Hem (1970, p. 219):

		Dissolved solids (mg/L)	Approximate specific conductance (micromhos/cm at 25°C)
Freshwater		Less than 1,000	Less than 1,700
Saline water	Slightly saline	1,000-3,000	1,700-5,000
	Moderately saline	3,000-10,000	5,000-17,000
	Very saline	10,000-35,000	17,000-58,000
Brine		More than 35,000	More than 58,000

Specific conductance

Specific conductance, which is a measure of the ability of water to conduct electrical current, is related to the concentration of dissolved solids. The relation depends on the particular constituents in solution, but is generally consistent in a particular area or aquifer. The relation in the Parowan and Cedar City drainage basins is shown graphically in figure 12. The concentration of dissolved solids, expressed in milligrams per liter, is about 63 percent of specific conductance for ground water from selected wells in the Parowan drainage basin, and about 70 percent of specific conductance for ground water from selected wells in the Cedar City drainage basin, expressed in micromhos per centimeter at 25°C. The ratio of dissolved solids to specific conductance in ground water from these wells ranges from 57 to 98 percent in the Parowan and Cedar City drainage basins. A map showing the specific conductance of ground water from wells in the area reflects the quality of ground-water recharge and the change in chemical quality of ground water as it moves through the drainage basins (pl. 8).

Major constituents

The concentrations of major chemical constituents in ground water from selected wells are shown by modified Stiff diagrams on plate 8. The ground water from selected wells in the Parowan drainage basin may be classified as a sodium, calcium, or magnesium bicarbonate type water, but calcium is the predominant cation. Ground water in the Cedar City drainage basin may be classified generally as a calcium or magnesium sulfate type water. However, variations include a sodium chloride type water from well (C-34-11)1daa-1 near Rush Lake and calcium bicarbonate type water from municipal well (C-36-12)32ccb-1 southwest of Quichapa Lake.

The source of dissolved solids in ground water is commonly from solution of the rocks through which the water passes or is in contact. Rocks consisting of much gypsum ($CaSO_4 \cdot 2H_2O$) contribute calcium and sulfate ions to ground water. Rocks of volcanic or igneous origin appear to contribute the least dissolved material to ground water in the study area. Ground water recirculated by irrigation may continually increase its content of dissolved solids. Areas of concentrated waste disposal may contribute to the dissolved solids in ground water.

Relation to geology

An inspection of the modified Stiff diagrams (Stiff, 1951) on plate 8, denoting the type and chemical quality of ground water, will show that the diagrams representing water samples collected in Parowan Valley have generally similar shapes; whereas, diagrams of samples from Cedar City Valley have a wider diversity of shapes. In Parowan Valley most of the diagrams indicate calcium bicarbonate or magnesium bicarbonate waters, but a few diagrams indicate sodium bicarbonate waters, and all of the diagrams indicate a comparatively low concentration of dissolved solids. In Cedar City Valley the diagrams represent all the water types

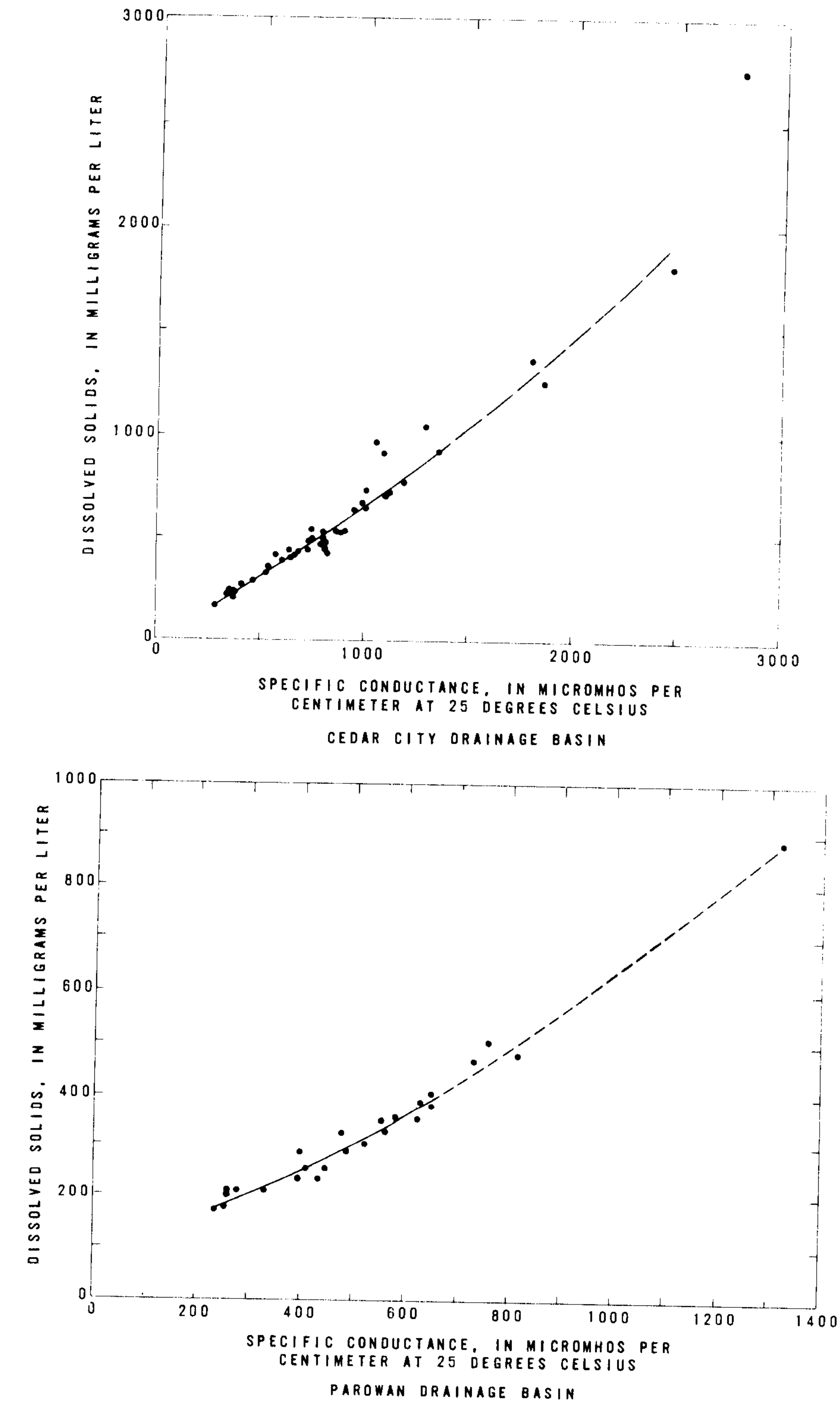


Figure 12.—Relation of specific conductance to the concentration of dissolved solids in selected ground-water samples, Parowan and Cedar City drainage basins.

listed for Parowan Valley, and in addition they represent calcium sulfate, magnesium sulfate, sodium sulfate, and sodium chloride waters. Many of the diagrams for Cedar City Valley indicate a relatively high concentration (greater than 1,000 mg/L) of dissolved solids.

The water type and chemical quality of ground water in Parowan Valley differ from that in parts of Cedar City Valley because the geologic environment differs. The rocks exposed in the Parowan drainage basin, the source of the Quaternary valley fill, consist mainly of Cretaceous sandstone and limestone, Tertiary limestone, conglomerate, and volcanic rock, and Quaternary volcanics and alluvium. These rocks contain much calcium and magnesium carbonate but little calcium sulfate. Rocks exposed in the Cedar City drainage basin include all the rocks exposed in the Parowan basin and also Triassic mudstone and siltstone including beds of gypsum, and Jurassic sandstone and shale also with beds of gypsum (table 3). Coal Creek, the largest source of surface water in the area (see table 2), is cut into Jurassic and Triassic rocks, and detrital materials from these rocks are mixed throughout most of the Cedar City Valley fill, especially that constituting the Coal Creek alluvial fan. Jurassic and Triassic rocks are also exposed along the face of the mountain between Cedar City and Kanarraville. Consequently, ground water in parts of Cedar City Valley has a relatively high concentration of calcium sulfate and other dissolved constituents that are scarce in Parowan Valley ground water.

Calcium bicarbonate water of relatively low chemical concentration (generally less than 400 mg/L) in Cedar City Valley west of Quichapa Lake is similar in type and concentration to ground water in the northern part of Parowan Valley (pl. 8). In both of these areas the nearby mountains, the source of the local valley fill, consist of Tertiary volcanic rock. Thus the local valley fill and the ground water west of Quichapa Lake are derived from the Harmony Mountains to the west.

Water of relatively high mineral concentration consisting mostly of sodium chloride occupies the shallow playa deposits of silt and clay underlying Little Salt Lake in Parowan Valley and Quichapa and Rush Lakes in Cedar City Valley. This water is not represented by modified Stiff diagrams in figure 12 because the shallow playa deposits are not tapped by wells. The three playas are areas of natural ground-water discharge through evaporation; sodium chloride, being the most soluble chemical constituent of ground water, has remained in solution and accumulated in the playa lakes. When the lakes become dry, encrusted salt forms in the soil and on the playa surface. If and when high seasonal ground-water levels at and adjacent to the playas decline to altitudes lower than the playa surface, the lakes, when containing water, will become sources of recharge and contamination to nearby aquifers.

Relation to use

Water quality may be evaluated according to intended use. Generally, the best water has the least concentration of dissolved solids; however, for some uses the concentrations of particular ions in water may be more significant than the total concentrations of dissolved solids.

Hardness of water is a consideration for domestic and for many industrial uses. In the past, the property of hardness has been associated with effects observed in the use of soap or with encrustations left by some types of "hard" water when heated. Because these effects are related to the presence of calcium and magnesium, hardness is now generally defined in terms of these constituents; hardness is computed by multiplying by 50 the sum of the milliequivalents per liter of calcium and magnesium. Hem (1970, p. 224-226) presents a discussion of hardness and gives a classification of water with respect to hardness as follows:

Classification	Hardness as $CaCO_3$ (mg/L)
Soft	0-60
Moderately hard	61-120
Hard	121-180
Very hard	More than 180

Most ground water in the Parowan and Cedar City drainage basins is classified as very hard, but a few samples were hard, moderately hard, or soft (table 6).

Quality standards for potable water used by public carriers and others subject to Federal quarantine regulations have been recommended by the U.S. Public Health Service (1962). These standards concern bacteria, radioactivity, and chemical constituents that may be objectionable in a water supply. The following list of standards pertain to those constituents for which analyses are given in this report:

> "The following chemical substances should not be present in a water supply in excess of the listed concentrations where * * * other more suitable supplies are or can be made available." (U.S. Public Health Service, 1962, p. 7.)

Substance	Recommended limit (mg/L)
Chloride (Cl)	250
Fluoride (F)	1.3[1]
Iron (Fe)	.3
Nitrate (NO_3)	45
Sulfate (SO_4)	250
Dissolved solids	500

[1]Based on the annual average of maximum daily air temperature of 63.3°F (17.4°C) at Parowan and 63.5°F (17.5°C) at Cedar City FAA during 1964-73.

Ground water from those areas shown on plate 8, where the specific conductance is less than 800 micromhos per cm at 25°C, generally contains concentrations of the listed substances that are below the recommended maximum limits. The public supply systems in the Parowan and Cedar City drainage basins obtain water from these areas. Ground water obtained from other parts of the Parowan and Cedar City drainage basins generally exceeds the recommended limit for dissolved solids and for some of the individual constituents. The recommended limit for dissolved solids is influenced primarily by considerations of taste (U.S. Public Health Service, 1962, p. 34), and water exceeding the recommended limit is used in many homes for domestic purposes without problems related to the concentration of dissolved solids.

The quality requirements for industrial water supplies range widely, as almost every industrial application has its individual standards. Hem (1970, p. 334-335) shows the limit for total dissolved solids to range from 0.5 to 1,000 mg/L for various industrial uses under differing conditions.

The upper limits of concentrations of dissolved solids in water for livestock vary according to the tolerance of the animals. An upper limit of 5,000 mg/L for water used by livestock is recommended by some investigators. Hem (1970, p. 324) quotes individual upper limits as follows:

Stock	Concentration (mg/L)
Poultry	2,860
Pigs	4,290
Horses	6,435
Cattle (dairy)	7,150
Cattle (beef)	10,100
Sheep (adult)	12,900

Some of the principal factors determining the suitability of water for irrigation are the concentrations of boron, the concentrations of dissolved solids, and the proportions of sodium to calcium and magnesium. Boron in more than trace concentrations is toxic to plants. Only one of the analyses of ground water in the study area shows a boron concentration exceeding the lower tolerable limit for permissible water for crops raised in the project area as given by Hem (1970, p. 329); well (C-32-8)24adb-1 produced water containing 0.73 mg/L boron (Bjorklund and others, 1977, table 5). However, this is only 0.06 mg/L in excess of the least tolerable limit for permissible use. The concentration of dissolved solids (salinity hazard) affects plant growth by limiting the ability of the plant to take in water. The proportion of sodium to calcium and magnesium (sodium hazard) affects the extent to which soil minerals will absorb sodium from the water. The adsorption of sodium breaks down the flocculation of the soil and makes it gummy and less permeable. An index to the sodium hazard is the sodium-adsorption ratio (SAR); it is expressed as:

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{++} + Mg^{++}}{2}}}$$

where the concentrations of sodium, calcium, and magnesium are expressed in milliequivalents per liter.

The sodium and salinity hazards of ground water from selected wells and springs in the study area were classified according to the method of the U.S. Salinity Laboratory Staff (1954, p. 79-81). In this classification it is assumed that an average quantity of water will be used under average conditions of soil texture, salt tolerance of crops, climate, drainage and infiltration. As shown in figure 13, ground water in the Parowan drainage basin has a low sodium hazard, and a low-to-high range of salinity hazard, but generally within the medium classification. The Cedar City drainage basin has ground water of low sodium hazard (fig. 14), and salinity hazard ranging from medium to very high, but generally within the medium and high classification.

Changes in chemical quality

The concentration of dissolved solids in ground water tends to increase with time in areas where large quantities of water are pumped for irrigation. In the process, part of the water is consumed by evapotranspiration and the remaining water, containing most of the original dissolved minerals, is recirculated into the ground-water reservoir. This is especially true in closed basins or areas like the Parowan-Cedar City basin where perennial streams do not exist to carry excess minerals away from the basin. The more soluble minerals such as sodium chloride persist in solution whereas the less-soluble minerals precipitate out of solution as the solution becomes concentrated. Changes in the concentration of dissolved chloride, therefore, would seem to be a dependable criterion for evaluating the change in chemical quality over the years. At or very near 15 sites in Cedar City Valley where ground-water samples were collected for analysis during 1938-40 (Thomas and Taylor, 1946, p. 107-109), samples were collected during 1973-74; the analyses of these samples (Bjorklund and others, 1977, table 5) indicated changes in chloride ranging from an increase of 91 mg/L to a decrease of 51 mg/L with an average gain of 10 mg/L in the 30-plus year period. These figures, while reasonable, are only approximate because: (1) some of the sampling sites could have changed greatly in the 30-year period, as many wells have been replaced or deepened since 1940; and (2) seasonal changes in chemical concentration could not be considered because the collection dates for the 1938-40 data were omitted.

Temperature

The temperatures of ground water from 62 wells in the Parowan drainage basin range from 8.5° to 20.0°C (47° to 68°F) and average 13.5°C (56°F). Ground-water temperatures in 74 wells in the Cedar City drainage basin range from 10.0° to 21.0°C (50° to 70°F) and average 13.5°C (56°F). Ground water in the valleys of the study area having temperatures of more than 18.5°C (65°F) may be described as thermal or "warm" water (Waring, 1965, p. 4). Thermal water in this area probably results from deep circulation of ground water locally.

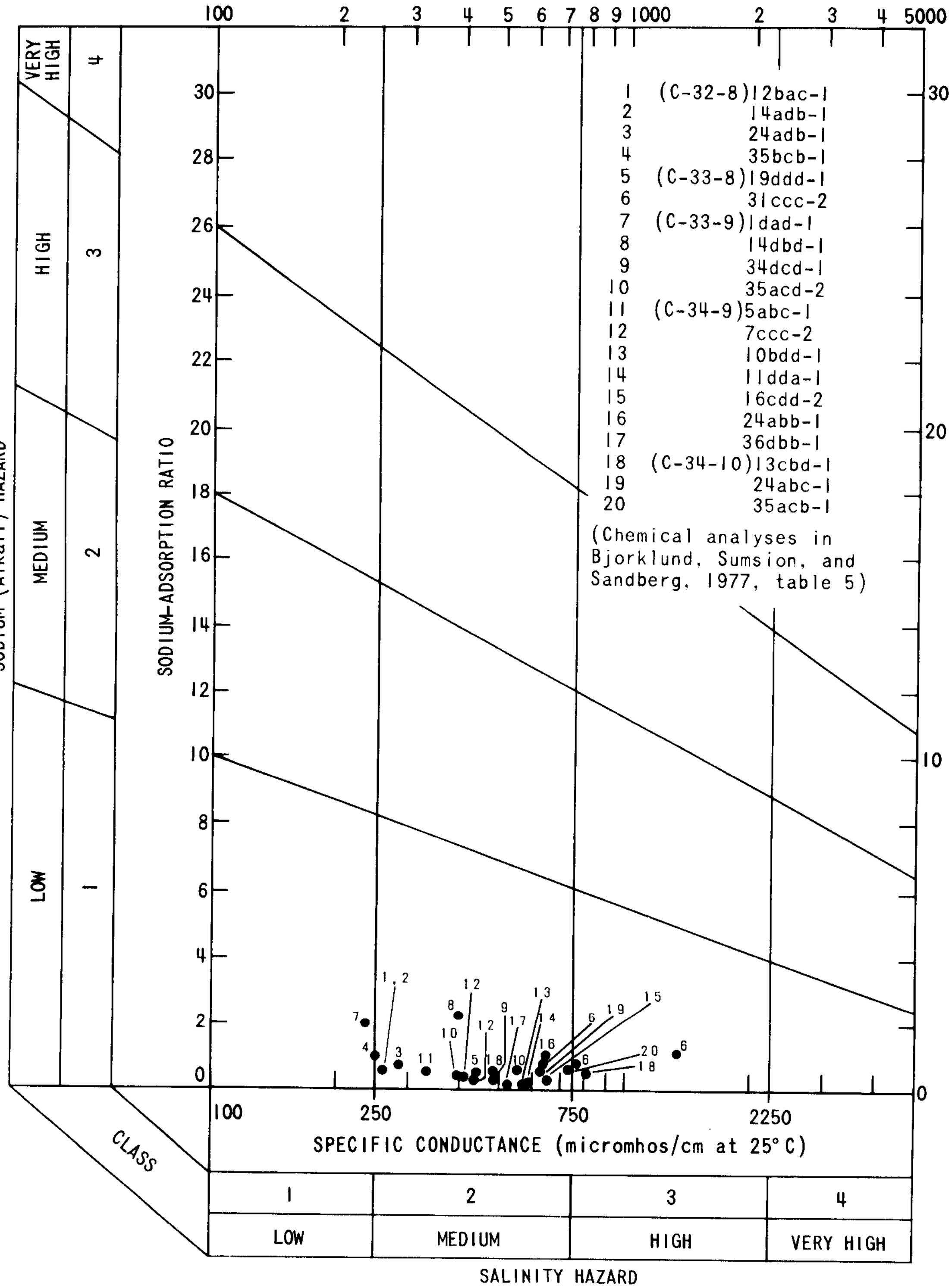


Figure 13.—Classification of ground water in Parowan Valley for irrigation. (Adapted from U.S. Salinity Laboratory Staff, 1954.)

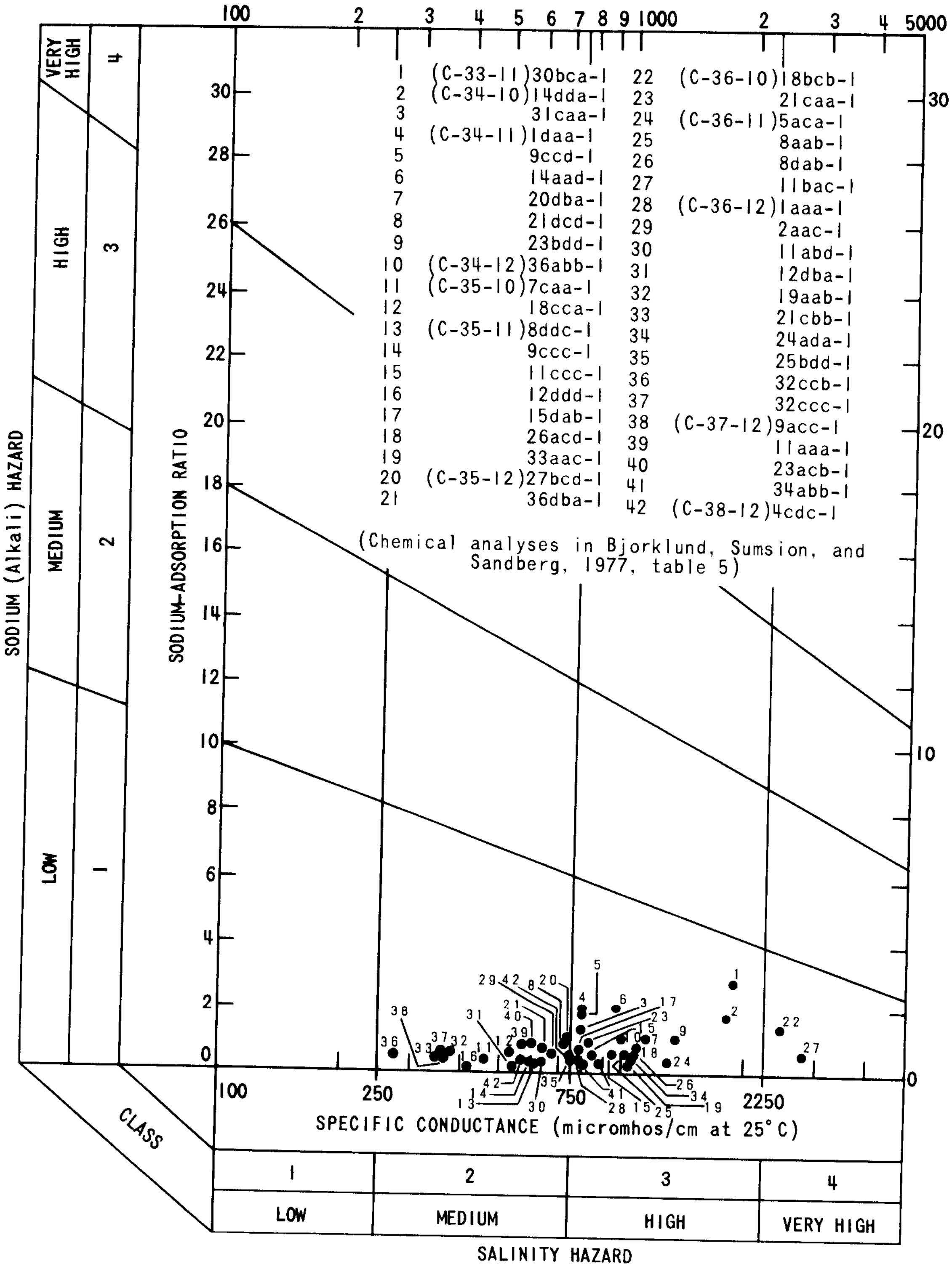


Figure 14.— Classification of ground water in Cedar City Valley for irrigation. (Adapted from U.S. Salinity Laboratory Staff, 1954.)

Ground-water temperatures are shown in figure 15. Warmer-than-normal ground water in the northern part of Parowan Valley probably is related to past volcanic activity in or near that vicinity. Warmer-than-normal ground water south of Hamilton Fort in Cedar City Valley may be related to heat generated at depth in the nearby Hurricane fault system. Colder-than-normal ground water in both valleys is related to recharge from streams and surface-water irrigation; this is illustrated in figure 15 northwest of Cedar City on the middle and lower parts of the alluvial fan of Coal Creek, and northwest of Parowan on the alluvial fan of Parowan Creek.

Development and utilization

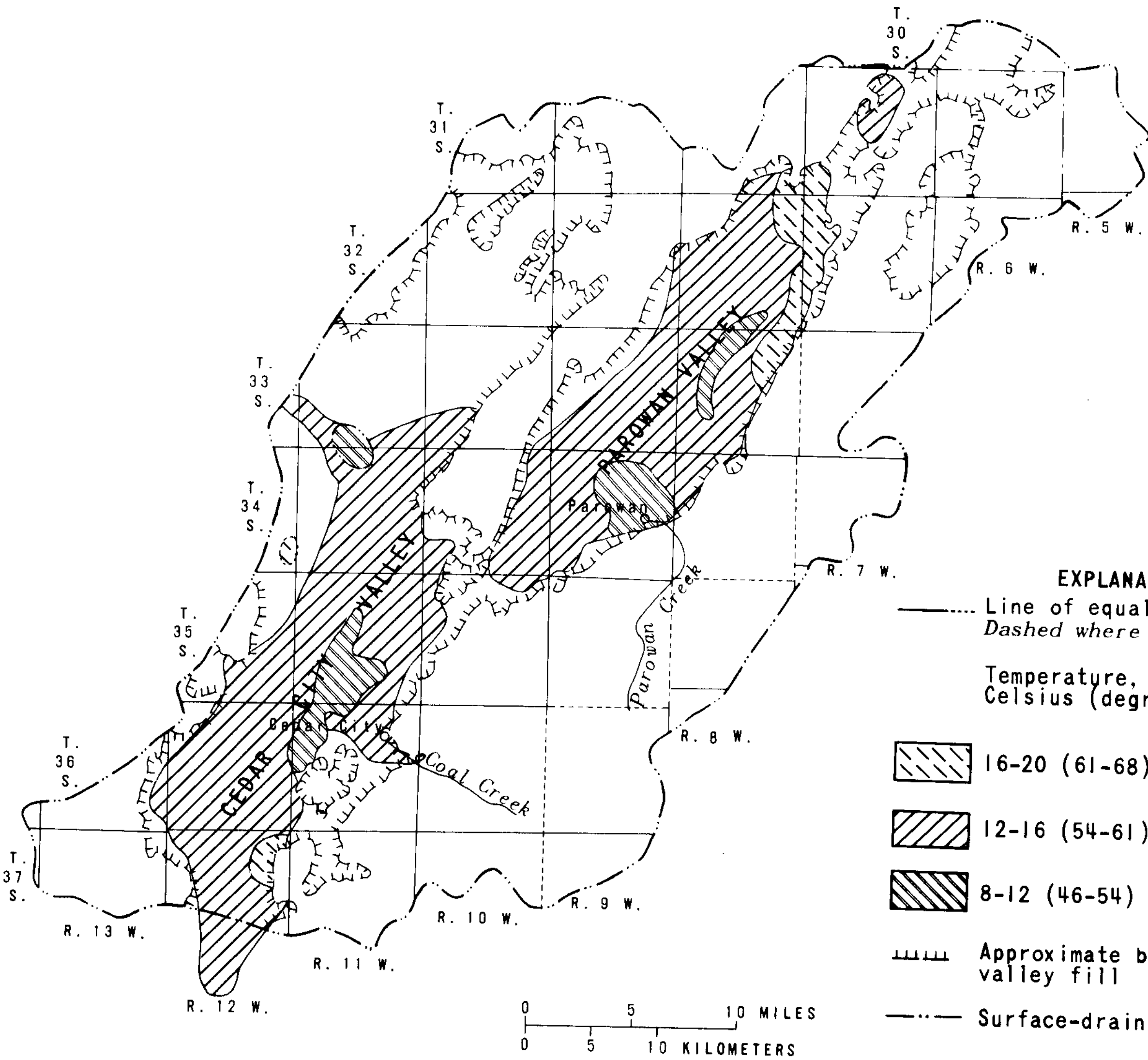
Ground water is utilized in the Parowan-Cedar City basin for irrigation, public supply, industry, domestic purposes, and livestock. The locations of 382 selected wells, with symbols designating uses, and 22 selected springs are shown on plate 3. Detailed data for these wells and springs are given in Bjorklund, Sumsion, and Sandberg (1977, tables 1 and 2). The estimated annual pumpage for the above uses is given in table 6.

Table 6.--Water discharged from wells in the Parowan-Cedar City basin, in acre-feet, 1970-74

	1970	1971	1972	1973	1974
Parowan Valley					
Irrigation	25,300	23,500	27,500	24,400	29,500
Industry	0	300	300	0	0
Public supply	100	100	100	1,000	1,010
Domestic and stock	150	150	150	150	150
Subtotal (rounded)	25,600	24,000	28,000	25,600	30,700
Cedar City Valley					
Irrigation	30,000	34,200	33,500	24,900	39,800
Industry	500	500	500	500	500
Public supply	800	800	800	1,250	1,850
Domestic and stock	150	150	150	150	150
Subtotal (rounded)	31,400	35,600	35,000	26,800	42,300
Total (rounded)	57,000	59,600	63,000	52,400	73,000

Irrigation supply

Privately owned wells tapping the Quaternary valley fill provided about 69,000 acre-ft (85 hm^3) of water for irrigation in the Parowan-Cedar City basin during 1974. Irrigated areas are shown on plate 7 and the locations of 85 irrigation wells in Parowan Valley and 113 irrigation wells in Cedar City Valley are shown on plate 3. Some



EXPLANATION

Line of equal temperature
Dashed where approximate

Temperature, in degrees Celsius (degrees Fahrenheit)

16-20 (61-68)

12-16 (54-61)

8-12 (46-54)

Approximate boundary of valley fill

Surface-drainage divide

Figure 15.—Temperature of ground water in Parowan and Cedar City Valleys.

irrigated areas near Cedar City, Parowan, Paragonah, and Summit use surface water from perennial creeks (the annual discharge of the principal streams in the area is given in table 2). Some areas north and west of Cedar City are irrigated partly from Coal Creek and partly from wells, but the amount of available surface water for irrigation decreases drastically after the runoff season in May and June. During the last half of the irrigation season almost all irrigation depends on water pumped from wells.

Public supply

The basic source of water for the principal cities and towns in Parowan and Cedar City Valleys is springs in the mountains to the east. From the springs, which discharge from Tertiary and Mesozoic rocks, the water is transported to the communities through pipelines by gravity. Wells provide a supplementary source of water for Parowan, Cedar City, and Kanarraville. At Parowan, two wells tap water from Quaternary gravel and a third well taps Tertiary gravel. At Cedar City, two wells in Coal Creek Canyon, a well northeast of the city, and two wells across the valley west of Quichapa Lake tap Quaternary fill; a sixth well within the city is used mostly to water a cemetery and a golf course. At Kanarraville, a well taps supplementary water from the valley fill.

Several housing-development sites in Cedar City Valley obtain their water supply from community wells tapping the valley fill. Farmland, as well as undeveloped land, is being converted to residential areas. Some of the wells that serve these areas were drilled after the field-investigation period for the current study and are not included in the tabulated data for this report. Some of these communities are growing rapidly and may become towns in the future.

Domestic and stock supply

Residents at farms or country homes located outside of the areas served by community water-distribution systems obtain potable water from wells tapping the Quaternary valley fill. Many of these wells also furnish water for the livestock at the farm. In outlying areas many wells equipped with windmills provide water for livestock. In the mid-northern part of Parowan Valley, flowing wells provide water for livestock.

Industrial use

The chief industrial use of ground water in the Parowan-Cedar City basin is for washing gravel and for construction. Water is pumped from wells, used, and then ponded in the gravelly terrain near the excavation area. Most of it presumably seeps back to the ground-water reservoir. Some of the water goes into concrete mix which is delivered to construction sites. Also, temporary industrial wells were drilled for use in the construction of Interstate Highway 15 through the basin.

Ground-water areas

The ground-water areas shown in figure 16 were chosen to indicate where ground-water conditions are generally similar, or areas where ground-water conditions can conveniently be discussed together. The areas are all limited on the surface to the Quaternary valley fill in Parowan and Cedar City Valleys. For general information regarding the surrounding upland or bedrock areas, the reader is referred to table 3. None of the areas are independent of adjacent areas and the boundary lines separating the areas are approximate and arbitrary.

Parowan Valley

Upper Buckhorn Flats area (Area 1).--The Upper Buckhorn Flats area is the northernmost area in Parowan Valley. It includes about 22 mi^2 (57 km^2) mostly in T. 32 S., R. 8 W. The altitude of the area ranges from about 5,760 to 5,900 ft (1,760 to 1,800 m) above sea level, and in midvalley the general land surface slopes southwestward at 20 to 30 ft/mi (4 to 6 m/km). About 1,600 acres (6.5 km^2) of land is irrigated by water pumped from wells. The principal crops are alfalfa and small grain.

Ground water occurs mainly under leaky artesian conditions. The potentiometric surface of the ground-water reservoir is almost level, resulting in flowing wells at the lower parts of the area and depths to water of more than 100 ft (30 m) at the higher parts. The water-bearing materials in the principal aquifers consist mainly of gravels derived from Tertiary and Quaternary volcanic rocks exposed on both sides of the valley. An aquifer test indicated a general transmissivity of more than 100,000 ft^2/d (9,300 m^2/d) (table 4 and pl. 2). Interference between pumped wells is relatively small but prompt and far reaching. (See sections on aquifer tests and interference between wells). Yields from wells range from about 400 to 4,000 gal/min (25 to 250 L/s) but some of the wells could produce more if necessary. Specific capacities of wells are as much as 150 (gal/min)/ft [31.0 (L/s)/m] of drawdown. The March 1974-March 1975 decline of water level in an observation well, due to pumping from wells in the area, was slightly less than 1 ft (0.3 m) but, owing to the high transmissivity, this decline was widespread, affecting practically all of the area. The chemical quality of the ground water is very good, generally containing less than 300 mg/L of dissolved solids, and is a calcium bicarbonate type. Water contributing recharge to the area is from precipitation in the northeastern part of the drainage basin, an area of approximately 200 mi^2 (500 m^2). Some additional development in this part of Parowan Valley is feasible.

Willow-Little-Red Creeks fans area (Area 2).--The Willow-Little-Red Creeks fans area includes about 47 mi^2 (120 km^2) mostly in Tps. 32 and 33 S., R. 8 W. The altitude ranges from about 5,690 to 6,000 ft (1,730 to 2,000 m) above sea level and the land generally slopes northwestward to westward from the mountain front toward the lowlands northeast of Little Salt Lake at gradients ranging from more than 50 ft/mi (10 m/km) near the mountains to less than 10 ft/mi (2 m/km) in the lowlands. Scattered farms along the mountain front are irrigated in part

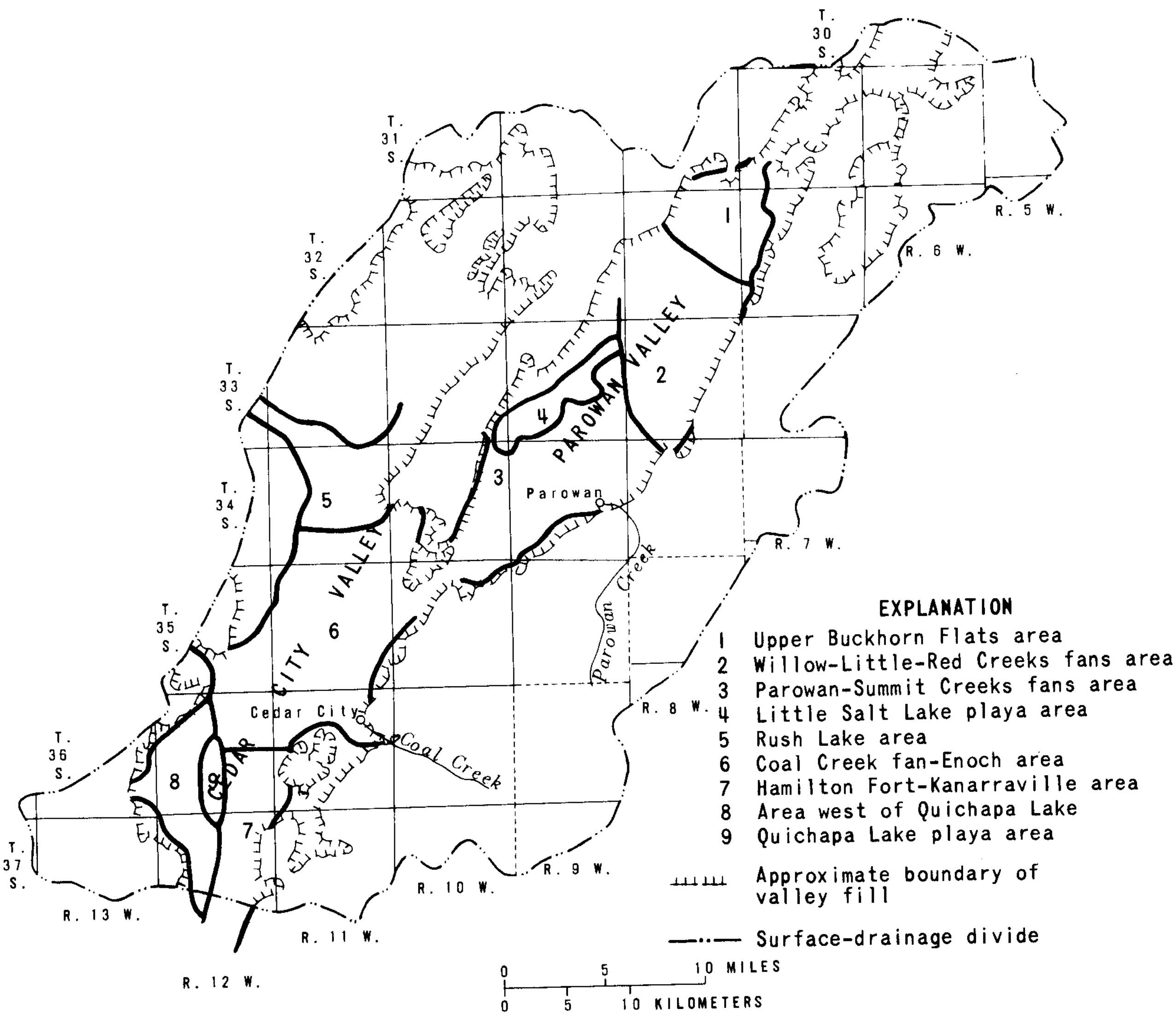


Figure 16.—Map showing ground-water areas in Parowan and Cedar City Valleys.

from relatively small flows from Little and Red Creeks (table 2) but mostly from irrigation wells. Most of the area, however, is covered by greasewood, rabbitbrush, saltgrass meadows, and sagebrush.

Ground water occurs mostly under leaky artesian conditions. In the western half of the area, the potentiometric surface of the ground-water reservoir is a few feet above, and generally follows, the contour of the land surface, resulting in discharge of water from flowing wells and evapotranspiration. These wells generally flow throughout the year; they are little affected by pumping in the concentrated well development to the north and south. Pumping from wells along the mountain front to the east affects some of the flowing wells, according to reports from local residents. In the higher eastern half of the area, the water table slopes westward 10 to 20 ft/mi (2 to 4 m/km), and depths to water in wells increase eastward from near the land surface to more than 100 ft (30 m) below land surface. The water-bearing materials of the valley fill consist mostly of detritus eroded from Tertiary and Mesozoic sedimentary rocks exposed in the mountains to the east. The chemical quality of the ground water is good (pl. 7 and table 5), generally less than 300 mg/L of dissolved solids, and is a calcium bicarbonate type. However, shallow water in the lowlands may contain more than 2,000 mg/L of dissolved solids, much of which would be sodium chloride. The estimated transmissivity of the aquifer ranges from about 1,000 ft^2/d (90 m^2/d) in the lowlands to about 10,000 to 20,000 ft^2/d (900 to 1,800 m^2/d) on higher parts of the alluvial slopes. Water contributing recharge to the area is from precipitation on about 90 mi^2 (200 km^2) of the drainage basin plus underflow from the upper Buckhorn Flats area. Some additional development of the ground-water resource is feasible, and some water could be salvaged from evapotranspiration by lowering ground-water levels in greasewood and meadow areas, but this would stop or retard the flow from some flowing wells.

Parowan-Summit Creeks fans area (Area 3).--The Parowan-Summit Creeks fans area includes about 55 mi^2 (140 km^2) at the south end of Parowan Valley. The altitude of the land surface ranges from about 5,700 ft (1,700 m) near the Little Salt Lake to about 6,000 ft (2,000 m) on the Parowan and Summit Creek alluvial fans. The land slopes northward and northwestward toward the Little Salt Lake at gradients ranging from about 10 ft/mi (2 m/km) in the lowlands to more than 50 ft/mi (10 m/km) near the mountain front. About half of the area is cleared and farmed, mostly for alfalfa and small grains; uncleared land is covered mostly with sagebrush. Farmland near Parowan and Summit is irrigated with surface water from Parowan and Summit Creeks, but most of the area is irrigated with ground water pumped from wells.

Ground water occurs in the unconsolidated valley fill mostly under leaky confined (artesian) conditions. Depths to water in wells range from near and above the land surface in the lowlands to more than 250 ft (76 m) below land surface near Summit (pl. 4). Water levels decline rapidly and flowing wells in the lowlands stop flowing during the pumping season and recover to almost pre-pumping levels between pumping seasons. The average annual decline near the center of the pumping area for the period 1940-74 was about 1 ft (0.3 m) a year (fig. 11). Wells generally yield from 500 to 2,000 gal/min (30 to 130 L/s) and interference between pumped wells is common and prompt. Measured and estimated transmissivity ranges from 1,000 ft^2/d (90 m^2/d) near Little Salt Lake to 20,000 ft^2/d (2,000 m^2/d) about midway on the alluvial slopes (pl. 2). Three aquifer tests (table 4) indicate confined conditions and transmissivities ranging from 1,400 to 17,900 ft^2/d (130 to 1,660 m^2/d). The chemical quality of the ground water is good, generally less than 500 mg/L of dissolved solids (table 5 and pl. 8), and is mainly a calcium bicarbonate or magnesium bicarbonate type. Water contributing recharge to the area is from precipitation on approximately 160 mi^2 (410 km^2) in the drainage basin. Additional high-capacity pumpage in the area may increase the rate at which water levels are declining and increase the size of the affected area.

Little Salt Lake playa area (Area 4).--The Little Salt Lake playa is an area of natural ground-water discharge for the Parowan basin as well as a place to collect excess surface-water runoff. The playa plus some adjacent low flatlands ranges in altitude from approximately 5,685 to 5,800 ft (1,733 to 1,740 m) above sea level and it includes about 10 mi^2 (30 km^2). The land surface when dry is covered with an accumulation of salt, and winds at times cause clouds of white salty dust. The natural circulation of ground water is upward from depth toward the land surface where it is eventually consumed by evaporation, leaving an accumulation of dissolved minerals. Shallow ground water, therefore, probably is highly mineralized, probably with sodium chloride; whereas, water in deep aquifers underlying the playa probably is fresh, as it is in wells less than a mile from the playa. At the present time the potentiometric surface of the ground-water reservoir apparently is above the playa surface during the springtime when water levels in the valley are highest, but it probably is lower than the land surface during the pumping season. When and if water levels in the valley decline permanently to positions lower in altitude than the playa surface, the natural circulation of ground water would be reversed, and runoff water in the playa would move from the land surface toward the underlying aquifers. In this manner the playa could become a source of ground-water contamination.

Cedar City Valley

Rush Lake area (Area 5).--The Rush Lake area includes about 30 mi^2 (80 km^2) extending from the Red Hills on the east to Mud Springs Wash on the west. Altitudes range from about 5,360 ft (1,630 m) in Mud Springs Wash to about 5,380 ft (1,640 m) at Rush Lake playa and 5,470 ft (1,670 m) about 3 mi (5 km) northeast of Rush Lake. The land slopes toward the area from the north, east, and south and thence northwest toward Mud Springs Wash. Irrigated farms depending on water from wells exist northeast and south of the playa.

Ground water occurs presumably under confined leaky conditions in the unconsolidated gravel and sand of the Quaternary valley fill. Northeast of Rush Lake the ground water is in gravels both above and below and within a layer of volcanic rock which may be a buried lava flow.

Depths to water range from less than 10 ft (3 m) in the playa to more than 50 ft (15 m) a few miles to the northeast. Recharge to the ground-water reservoir probably is mostly from subsurface inflow from east, south, and possibly from the north. The playa is sometimes covered with water from flash floods. Areas at the north end of the Cedar City drainage basin that drain toward Rush Lake are about 210 mi^2 (540 km^2). Yields to wells in the area are as much as 1,700 gal/min (110 L/s) and estimated transmissivities range from less than 5,000 to more than 20,000 ft^2/d (500 to 2,000 m^2/d). In past ages ground water was discharged by evapotranspiration from the playa and nearby meadows and by direct discharge from springs at the eastern end of the lake, but today (1975) the springs and the playa surface are dry due to the decline of water levels caused by pumping from wells in the valley. The total decline of water level in the area since 1940 is generally less than 10 ft (3 m) (fig. 11). Dissolved solids in water collected for analysis range from 453 to 1,360 mg/L (Bjorklund, Sumsion, and Sandberg, 1977, table 5); most of the ground water is typed as magnesium sulfate (pl. 8). Shallow water beneath the playa is assumed to be heavily mineralized, probably mostly with sodium chloride. Some additional development of the ground-water resource may be feasible.

<u>Coal Creek-Enoch area (Area 6)</u>.--Most of the ground-water development in Cedar City Valley is on the alluvial slope which extends westward from the mountain front between Cedar City and Enoch in an area including about 82 mi^2 (210 m^2). Most of this area is on the Coal Creek alluvial fan which forms a low topographic divide across the valley. Altitudes range from about 5,430 ft (1,660 m) in midvalley at the north end of the area to about 5,800 ft (1,800 m) in Cedar City. Some farms are irrigated with surface water diverted from Coal Creek and supplemented by water pumped from wells, but most of the farms are irrigated exclusively with water from wells.

In most of the area ground water exists in the unconsolidated valley fill under leaky confined (artesian) conditions, but along the mountain front at, and north of, Cedar City it exists under unconfined conditions. Yields to wells are greatest on the alluvial slopes, a moderate distance (about 1 mi [1.6 km]) from the mountain front, and they decrease westward and northward as the materials in the Coal Creek fan become finer. Estimated and determined transmissivities range from less than 5,000 ft^2/d (500 m^2/d) in the lower parts of the area to more than 20,000 ft^2/d (2,000 m^2/d) near Cedar City and northward. An aquifer test near Enoch indicated a transmissivity of 5,200 ft^2/d (480 m^2/d) and water-table conditions. Depths to water in wells range from about 10 ft (3 m) in the lower areas to more than 200 ft (60 m) near Cedar City (pl. 4). Declines of water level since 1940 range from less than 10 ft (3 m) in the western and northern parts of the area to more than 30 ft (9 m) about 3 mi (5 km) northwest of Cedar City (fig. 11). Recharge to the ground-water reservoir is mostly from precipitation in the highlands to the east, particularly the Coal Creek drainage basin. Precipitation in about 230 mi^2 (600 km^2) contributes water to the area. The dissolved solids in sampled ground water range from less than 200 to more than 2,700 mg/L (Bjorklund, Sumsion, and Sandberg, 1977, table 5); most of the water is a calcium magnesium sulfate or calcium magnesium bicarbonate type. The source of the sulfate minerals is gypsum and other evaporites in Triassic and Jurassic rocks exposed in the Coal and Shurtz Creeks drainage basins. Increased ground-water usage will result in increased water-level declines and larger areas of well interference.

Hamilton Fort-Kanarraville area (Area 7).--From Hamilton Fort southward to Kanarraville the land surface in the valley slopes westward toward Quichapa Lake and the valley axis to the south. The area, which comprises about 28 mi^2 (72 km^2), ranges in altitude from about 5,450 ft (1,660 m) near the lake to about 5,600 ft (1,700 m) near the mountain front. The westward slope ranges from about 15 ft/mi (2.8 m/km) near the lake to more than 50 ft/mi (9.5 m/km) near the mountains. Scattered farms along the alluvial slope use irrigation water pumped from wells. Near Kanarraville some farms use water diverted from Kanarra Creek, supplemented by water pumped from wells. Much of the land is cleared but not cultivated and some of it is dry farmed.

Ground water in the unconsolidated valley fill exists under leaky artesian conditions. Transmissivities based on estimates and two aquifer tests range from less than 2,000 to 10,000 ft^2/d (200 to 900 m^2/d). Yields from irrigation wells range from about 400 to 1,200 gal/min (20 to 75 L/s). Interference between wells is common. Depths to water in wells range from about 10 to about 150 ft (3 to 46 m) and are greatest near the mountain front. Declines of water level due to pumping since 1940 range from about 10 ft (3 m) in the lowlands to more than 30 ft (9 m) near the mountain front. A water-table divide is near a low topographic divide that crosses the valley near and north of Kanarraville and separates the Great Basin from the Virgin River basin. Precipitation in about 70 mi^2 (200 km^2) contributes water to the area. The chemical quality of the ground water is generally good; it ranges from about 300 to about 700 mg/L in dissolved solids, and is generally of a calcium sulfate or calcium bicarbonate type. The sulfate minerals are derived from gypsum deposits in Jurassic and Triassic rocks exposed along the mountain front. Some additional ground-water development probably is feasible near Kanarraville where Kanarra Creek, a perennial stream, provides some recharge.

Area west of Quichapa Lake (Area 8).--The valley fill in the area west of Quichapa Lake is derived mostly from the Tertiary volcanic rocks of the Harmony Mountains to the west, a condition which results in a different type of ground water from that of other parts of the Cedar City Valley. The water is of a good chemical quality, is of a calcium bicarbonate type, (pl. 8), and has less than 300 mg/L of dissolved solids. Missing are the sulfate minerals which are characteristic of ground water in other parts of the valley. The area ranges in altitude from about 5,450 ft (1,660 m) near Quichapa Lake to about 5,640 ft (1,720 m) near the mountains and the land slopes eastward at gradients ranging from about 30 ft/mi (6 m/km) near the lake to more than 100 ft/mi (20 m/km) near the mountains. Scattered farms are irrigated by water pumped from wells and wells provide part of the public water supply for Cedar City.

Ground water exists in the valley fill under leaky confined (artesian) conditions and probably under unconfined (water-table) conditions near the mountain front. An aquifer test in the area indicated a transmissivity of about 42,000 ft^2/d (3,900 m^2/d). Yields to wells are reported to be as much as 1,600 gal/min (100 L/s). Interference between pumped wells is common. Depths to water range from about 10 ft (3 m) near Quichapa Lake to about 100 ft (30 m) near the mountains. Changes in water level since 1940 range from declines of less than 10 ft (3 m) near Quichapa Lake to more than 20 ft (6 m) about midway on the alluvial slopes. Precipitation in about 68 mi^2 (180 km^2) contributes water for recharge to the area. Some additional development may be feasible.

Quichapa Lake playa area (Area 9).--Excess runoff water from Coal and Shirts Creeks to the east as well as some runoff from the Harmony Mountains to the west collects in Quichapa Lake causing water to cover all or part of the playa surface at intervals. Large amounts of runoff during the spring and early summer of 1973 caused water to stand in the lake until midsummer of 1975 when it again became a dry playa. In the past, ground-water discharge through flowing wells, springs, and seeps in the area contributed water to the lake, but today (1975) this discharge has virtually ceased due to the decline of ground-water levels caused by pumping from wells. This decline is estimated to be less than 10 ft (3 m). A small seep area at the northeast edge of the playa still wets a few acres. The playa, plus some adjacent lowland meadow, includes about 4 mi^2 (10 km^2) slightly below an altitude of 5,450 ft (1,660 m).

The potentiometric surface beneath the playa is estimated to be less than 10 ft (3 m) deep. As the natural circulation of ground water during past ages has been from the water-bearing beds toward the land surface, the water at depth probably is fresh, and the water near the land surface is slightly saline or moderately saline due to an accumulation of mineral salts caused by evaporation. As the depth to water continues to decline, the playa could become a source of contamination to the ground-water reservoir. Floodwaters covering the playa would dissolve the accumulated mineral salts in the shallow silt and then percolate to the ground-water reservoir.

WATER-BUDGET ANALYSES

The quantity of water entering the Parowan-Cedar City drainage basins is equal to the quantity leaving the basins plus or minus the change in storage within the basins. Water enters the basins by precipitation and leaves by streamflow, ground-water flow, and evapotranspiration. Change in storage is caused by recharge (gain) or discharge (loss) of water to or from the ground-water reservoir. A separate budget analysis is made for each basin. Parowan basin is regarded to be a closed basin with no outlet; whereas, Cedar City basin has three outlets but almost negligible outflow. Land use, natural vegetation, and precipitation for the basins are shown on plate 7. Areas of land use and types of natural vegetation are tabulated in tables 7 and 8 and the budget analyses are presented in tables 9 and 10.

Table 7.--Approximate areas of land use and natural vegetation, in square miles, in Parowan Valley drainage basin

	Altitude, in feet above mean sea level					
	5,000-6,000	6,000-7,000	7,000-8,000	8,000-9,000	9,000-10,000	10,000-11,000+
Irrigated land:						
Alfalfa	19					
Other (mostly small grains)	11					
Brushlands:						
Greasewood, rabbitbrush, sagebrush, and grass; some cleared land	49					
Sagebrush and grass; some cleared land	52	29	19			
Playa (mudflats); open water at times	6					
Woodlands:						
Juniper with some oakbrush above 7,000 ft	2	113	103	2		
Pine, aspen, fir, and spruce with some oak and mahogany brush			23	55	31	6
Totals:	139	142	145	57	31	6
Total:	520 square miles					

Table 8.--Approximate areas of land use and natural vegetation, in square miles, in Cedar City Valley drainage basin

	Altitude, in feet above mean sea level					
	5,000-6,000	6,000-7,000	7,000-8,000	8,000-9,000	9,000-10,000	10,000-11,000+
Irrigated land:						
Alfalfa	24					
Other (mostly small grains)	11					
Brushlands:						
Greasewood, rabbitbrush, sagebrush, and grass; some cleared land	55					
Sagebrush and grass; some cleared land	148	42	7			
Playa (mudflats); open water at times	3					
Woodlands:						
Juniper with some oakbrush above 7,000 ft	52	125	38			
Pine, aspen, fir, and spruce with some oak and mahogany brush			10	45	14	6
Totals:	293	167	55	45	14	6
Total:	580 square miles					

Table 9.--Water-budget analysis of Parowan Basin

	Thousands of acre-feet per year
Inflow	
Precipitation[1]	484
Outflow	
Evapotranspiration[2]	
Irrigated land (mostly alfalfa and small grains, includes urban areas)[3]	48
Brushlands (greasewood, rabbitbrush, sagebrush, and grass, includes urban areas)[4]	102
Brushlands (sagebrush and grass)[5]	72
Woodlands (juniper, some oakbrush)[6]	152
Woodlands (pine, aspen, fir, spruce, some oakbrush and mahogany brush)[7]	94
Playa mudflats and open water[8]	12
Change in ground-water storage (decrease)[9]	4
Change in surface-water storage	neg.
Subsurface outflow[10]	neg.
Total	484

[1]The average annual precipitation on the area was estimated from the 1931-60 normal annual precipitation map of Utah. (U.S. Weather Bureau, no date). (See pl. 7.)

[2]Evapotranspiration values for various land classifications were developed with the assistance of the Utah Water Research Laboratory, Utah State University, on the basis of a modified Blaney-Criddle formula (Hill and others, 1970, p. 17-19).

[3]Average annual evapotranspiration, alfalfa 33.25 in., small grains 23.72 in.

[4]Regarded as phreatophytes in wet areas with average annual evapotranspiration as 42.04 in. and as sagebrush in dry areas. (see [5] below.)

[5]Average annual evapotranspiration at altitudes of 5,000-6,000 ft = 10.68 in., 6,000-7,000 = 12.68 in., 7,000-8,000 = 13.74 in.

[6]Average annual evapotranspiration at altitudes of 5,000-6,000 ft = 10.61 in., 6,000-7,000 = 12.43 in., 7,000-8,000 = 13.22 in., 8,000-9,000 = 12.10 in.

[7]Average annual evapotranspiration at altitudes of 7,000-8,000 ft = 14.94 in., 8,000-9,000 = 14.97 in., 9,000-10,000 = 15.24 in., 10,000-11,000+ = 12.74 in.

[8]Average annual evapotranspiration = 42.04 in., includes some phreatophytes around margin of the area.

[9]See section on fluctuation of ground-water levels, long-term trends.

[10]See section on subsurface outflow.

Table 10.--Water-budget analysis of Cedar City Basin

	Thousands of acre-feet per year
Inflow	
Precipitation[1]	452
Outflow	
Evapotranspiration[2]	
Irrigated land (mostly alfalfa and small grains, includes urban areas)[3]	55
Brushlands (greasewood, rabbitbrush, sagebrush, and grass, includes urban areas)[4]	50
Brushlands (sagebrush and grass)[5]	127
Woodlands (juniper, some oakbrush)[6]	147
Woodlands (pine, aspen, fir, spruce, some oakbrush and mahogany brush)[7]	62
Playa mudflats and open water[8]	7
Change in ground-water storage (decrease)[9]	3
Surface outflow	neg.
Subsurface outflow[10]	1
Total	452

[1]The average annual precipitation on the area was estimated from the 1931-60 normal annual precipitation map of Utah. (U.S. Weather Bureau, no date). (See pl. 7.)

[2]Evapotranspiration values for various land classifications were developed with the assistance of the Utah Water Research Laboratory, Utah State University, on the basis of a modified Blaney-Criddle formula (Hill and others, 1970, p. 17-19).

[3]Average annual evapotranspiration, alfalfa 32.84 in., small grains 23.21 in.

[4]Regarded as phreatophytes in wet areas, with average annual evapotranspiration as 41.52 in. and as sagebrush in dry areas. (see [5] below.)

[5]Average annual evapotranspiration at altitudes of 5,000-6,000 ft = 12.39 in., 6,000-7,000 = 13.89 in., 7,000-8,000 = 14.51 in.

[6]Average annual evapotranspiration at altitudes of 5,000-6,000 ft = 12.26 in., 6,000-7,000 = 13.35 in., 7,000-8,000 = 13.37 in.

[7]Average annual evapotranspiration at altitudes of 7,000-8,000 ft = 15.96 in., 8,000-9,000 = 15.86 in., 9,000-10,000 = 14.27 in., 10,000-11,000+ = 11.72 in.

[8]Average annual evapotranspiration = 41.52 in., includes some phreatophytes around margin of the area.

[9]See section on fluctuation of ground-water levels, long-term trends.

[10]See section on subsurface outflow.

SUMMARY AND CONCLUSIONS

The Parowan-Cedar City basin is a structural depression formed by faulting and modified by erosion. The geologic units exposed in the basin total more than 16,000 ft (4,900 m) in thickness. Ground water and surface water are derived almost exclusively from precipitation within the basin, which normally amounts to about 936,000 acre-ft (1,154 hm^3) annually. Recharge to the ground-water reservoir amounts to about 80,000 acre-ft (100 hm^3) annually, of which about half is in Parowan Valley and about half is in Cedar City Valley.

Ground water exists under both confined (artesian) and unconfined (water-table) conditions. Transmissivities determined from nine aquifer tests ranged from near 1,000 to 400,000 ft^2/d (90 to 40,000 m^2/d). Interference between pumped wells is common and usually prompt. Previously inferred faulting in the unconsolidated valley fill in a tested area had little damming, blocking, or restricting effect on water levels during an aquifer test.

Ground-water development during 1940-74 has resulted in depressed water levels in wells in most of Parowan and Cedar City Valleys. Maximum declines of more than 30 ft (9 m) existed in 9 mi^2 (23 km^2) in Parowan Valley and in 8 mi^2 (21 km^2) in Cedar City Valley. The estimated average annual depletion of storage in the ground-water reservoir for the period, based on a specific yield of 0.1 for the dewatered sediments, is about 3,600 acre-ft (4.4 hm^3) in Parowan Valley and 3,300 acre-ft (4.1 hm^3) in Cedar City Valley.

Ground water in the basin is hard but generally is satisfactory for most uses. In parts of the area of concentrated well development in Cedar City Valley, the water contains greater concentrations of some chemical constituents and dissolved solids than is recommended by the U.S. Public Health Service (1962) for public use. In Parowan Valley the water is generally classified as a sodium, calcium, or magnesium bicarbonate type; whereas, in Cedar City Valley it is generally classified as a calcium or magnesium sulfate type. The difference in chemical type is attributed to the occurrence of soluble Jurassic and Triassic gypsum-bearing rocks which are exposed in the Cedar City basin but are not exposed in the Parowan basin.

Pumpage in the basin has tripled since 1940 and most of this increase has taken place since 1960. Pumpage during 1974 amounted to approximately 73,000 acre-ft (90 hm^3), of which 30,700 acre-ft (38 hm^3) was in Parowan Valley and 42,300 acre-ft (52 hm^3) was in Cedar City Valley. Most of the pumpage was for irrigation.

Ground water of higher-than-normal temperature occurs in the northern part of Parowan Valley and south of Hamilton Fort in Cedar City Valley and probably is related to past volcanic activity or heat generated at depth in the Hurricane fault system. Relatively cold water, northwest of Parowan and northwest of Cedar City, is related to recharge from water in Parowan and Coal Creeks.

The ground-water resource in the heavily pumped areas in Parowan and Cedar City Valleys should be regarded as fully developed so far as large discharges are concerned. However, some additional development in outlying areas may be feasible.

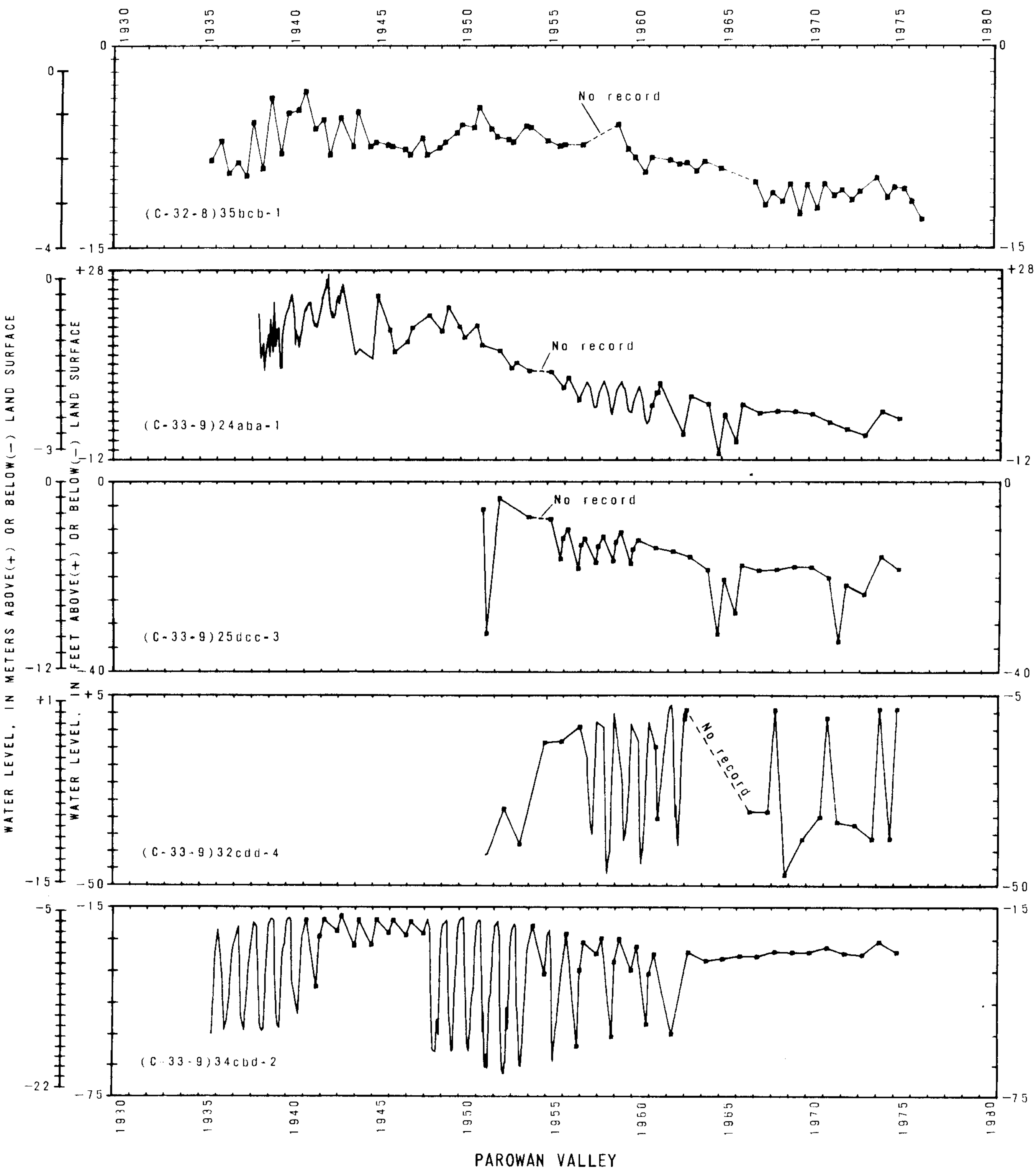
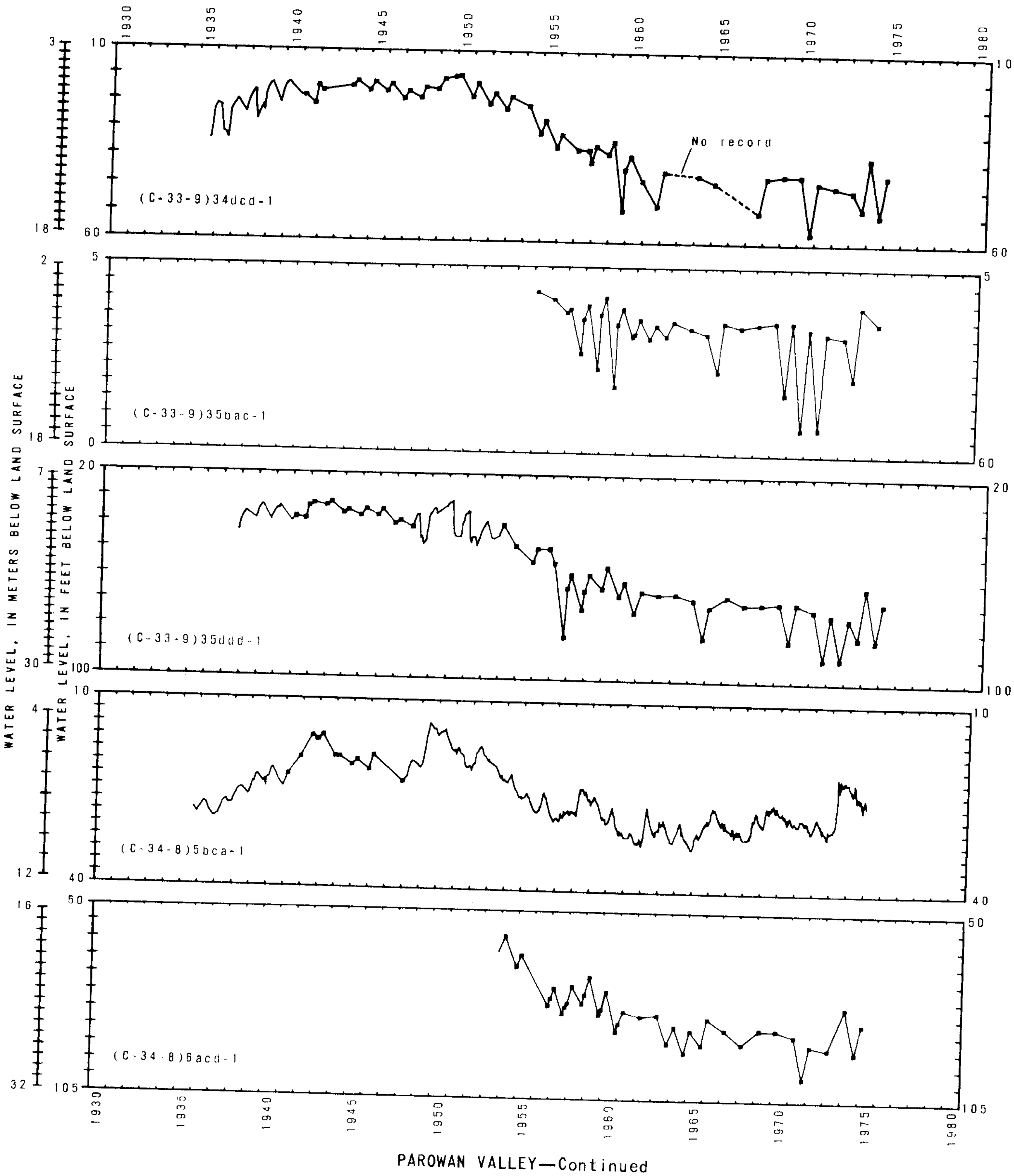


Figure 17.—Water-level fluctuations in selected observation wells in Parowan and Cedar City Valleys.



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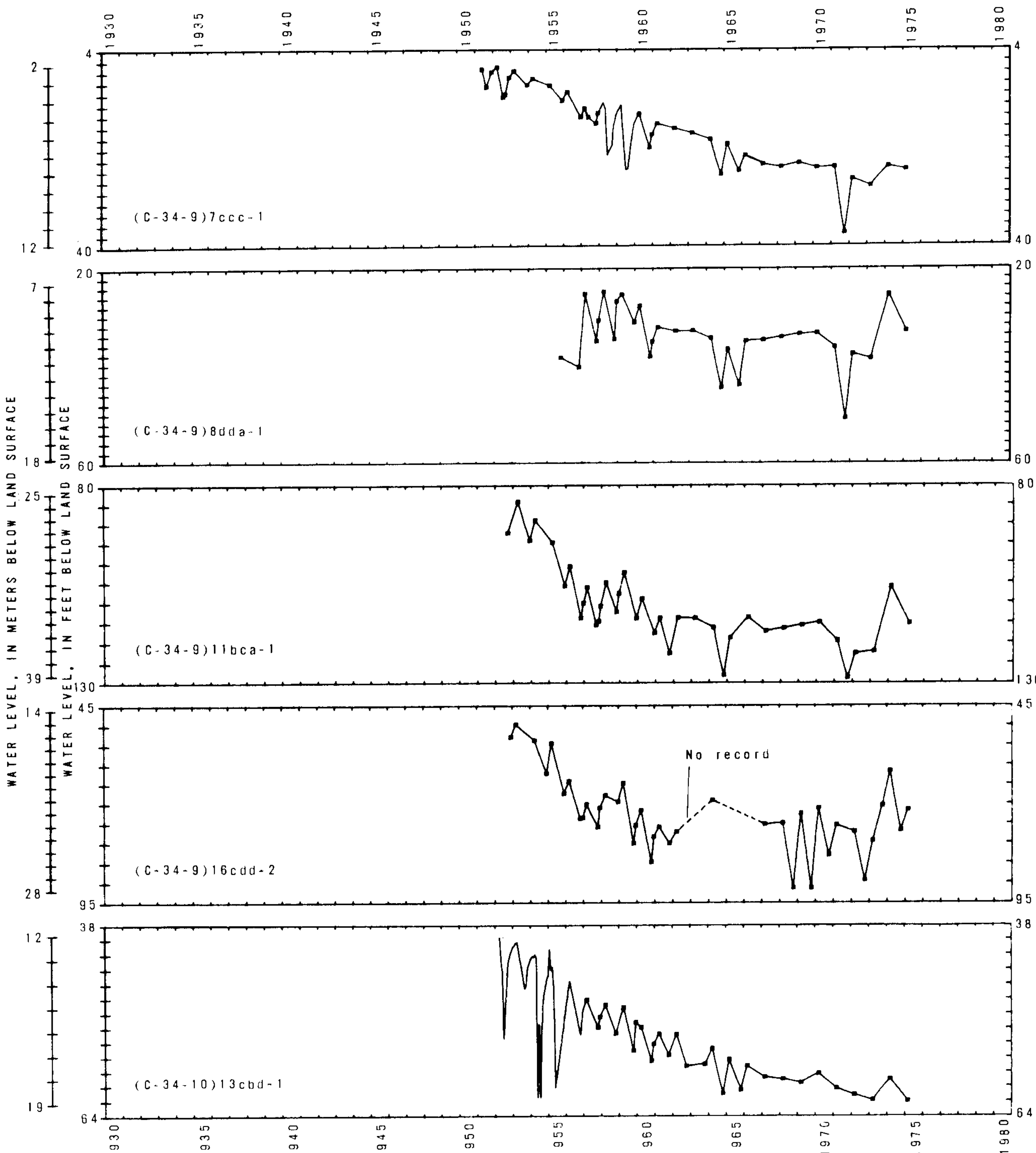
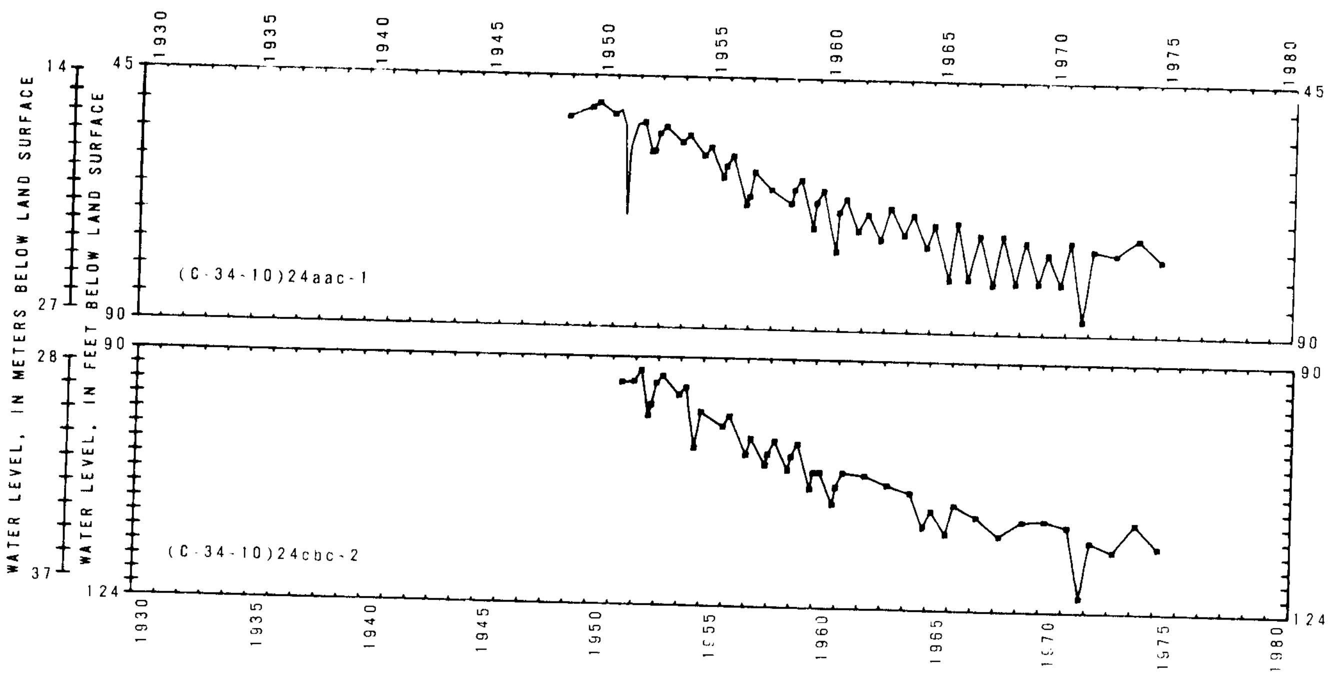


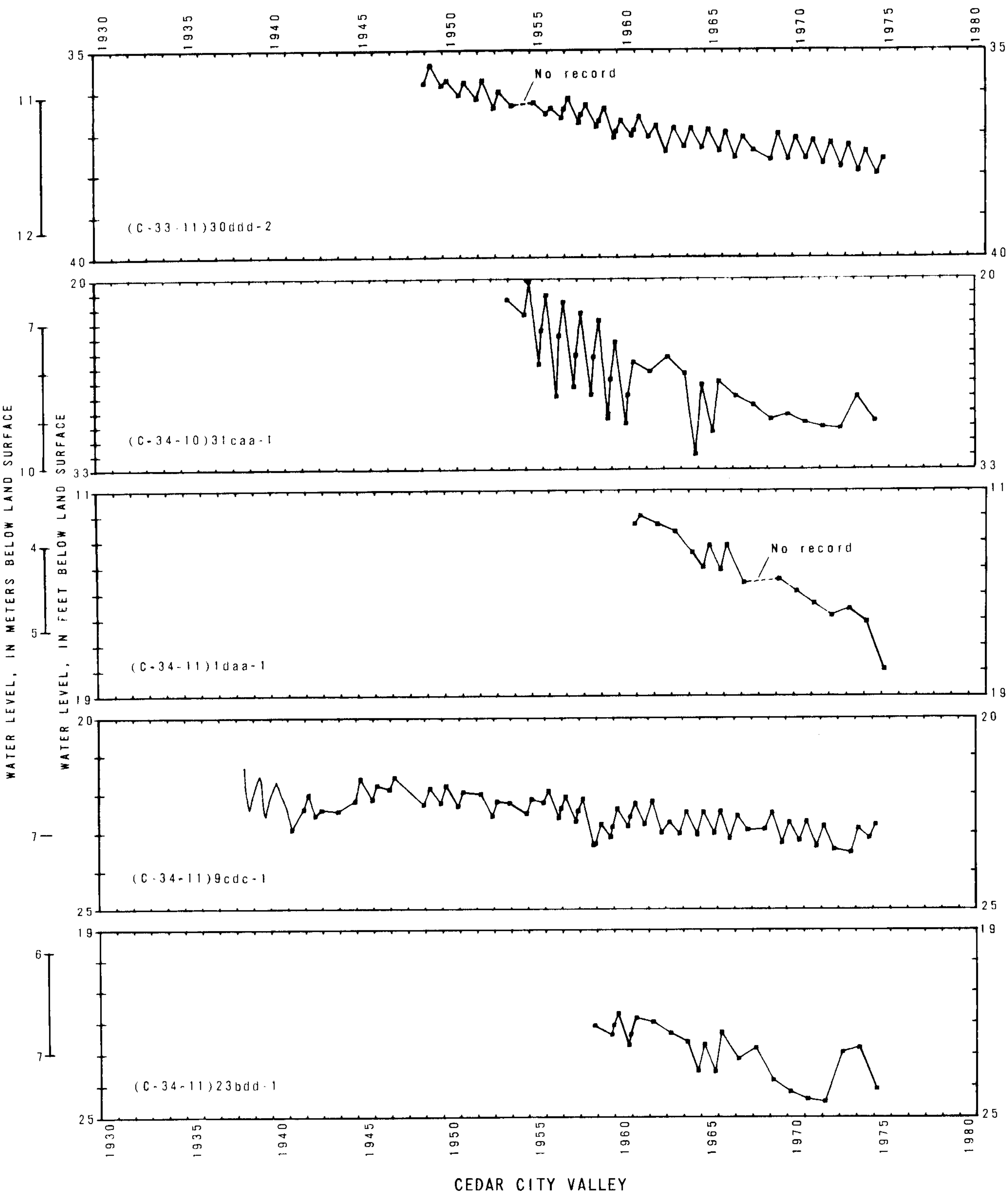
PAROWAN VALLEY—Continued

Figure 17.—Continued.



PAROWAN VALLEY—Continued

Figure 17.— Continued



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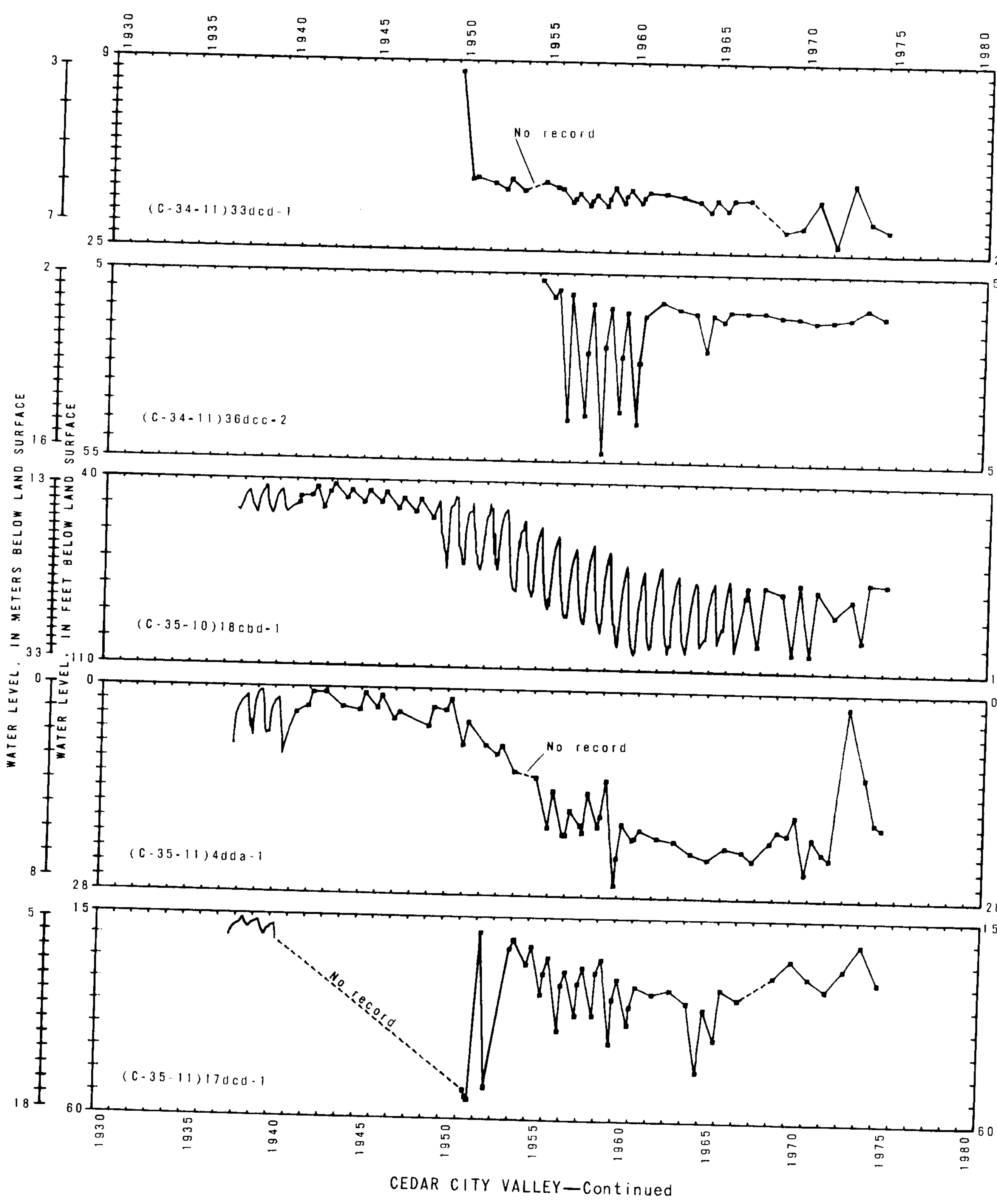
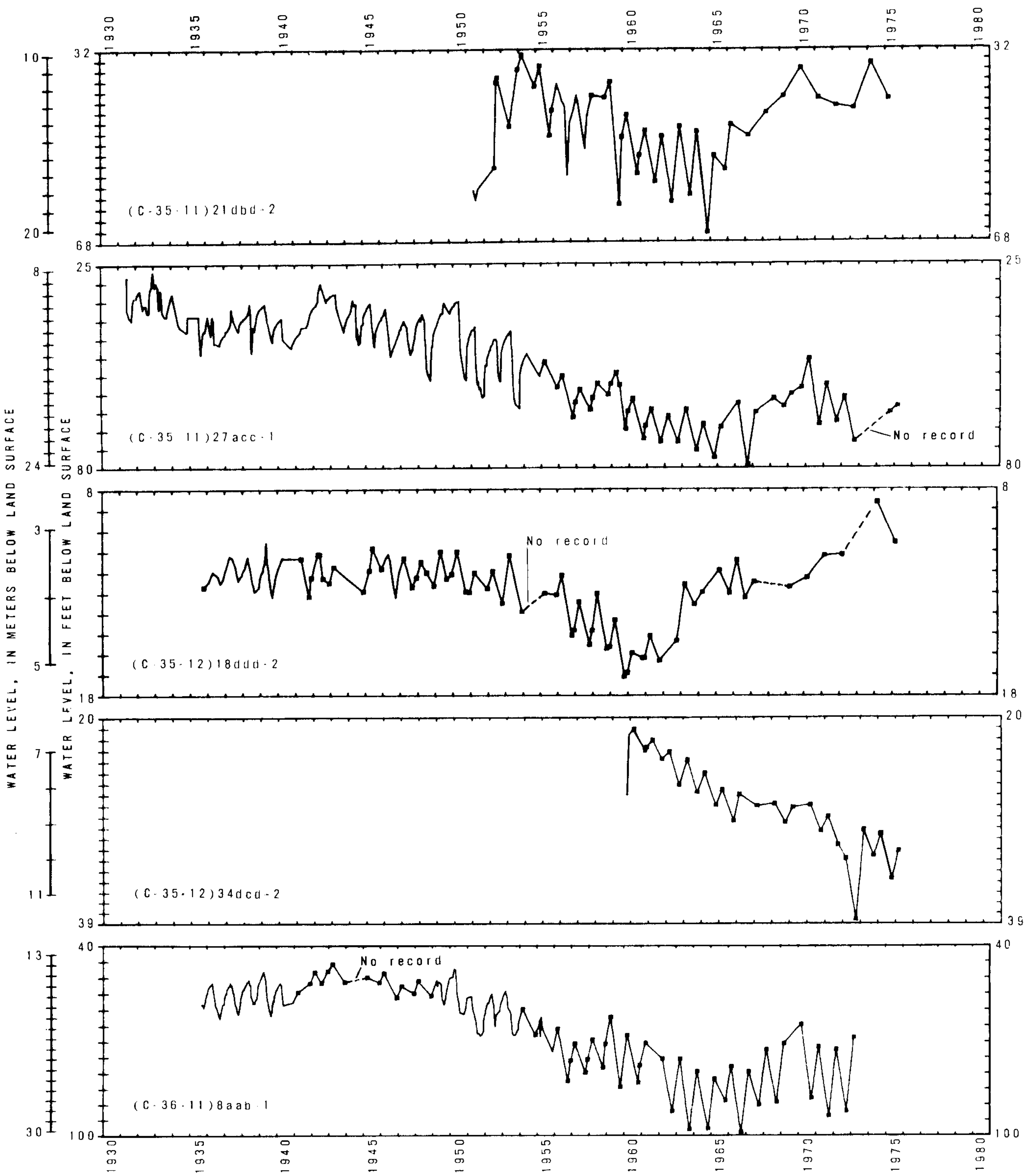
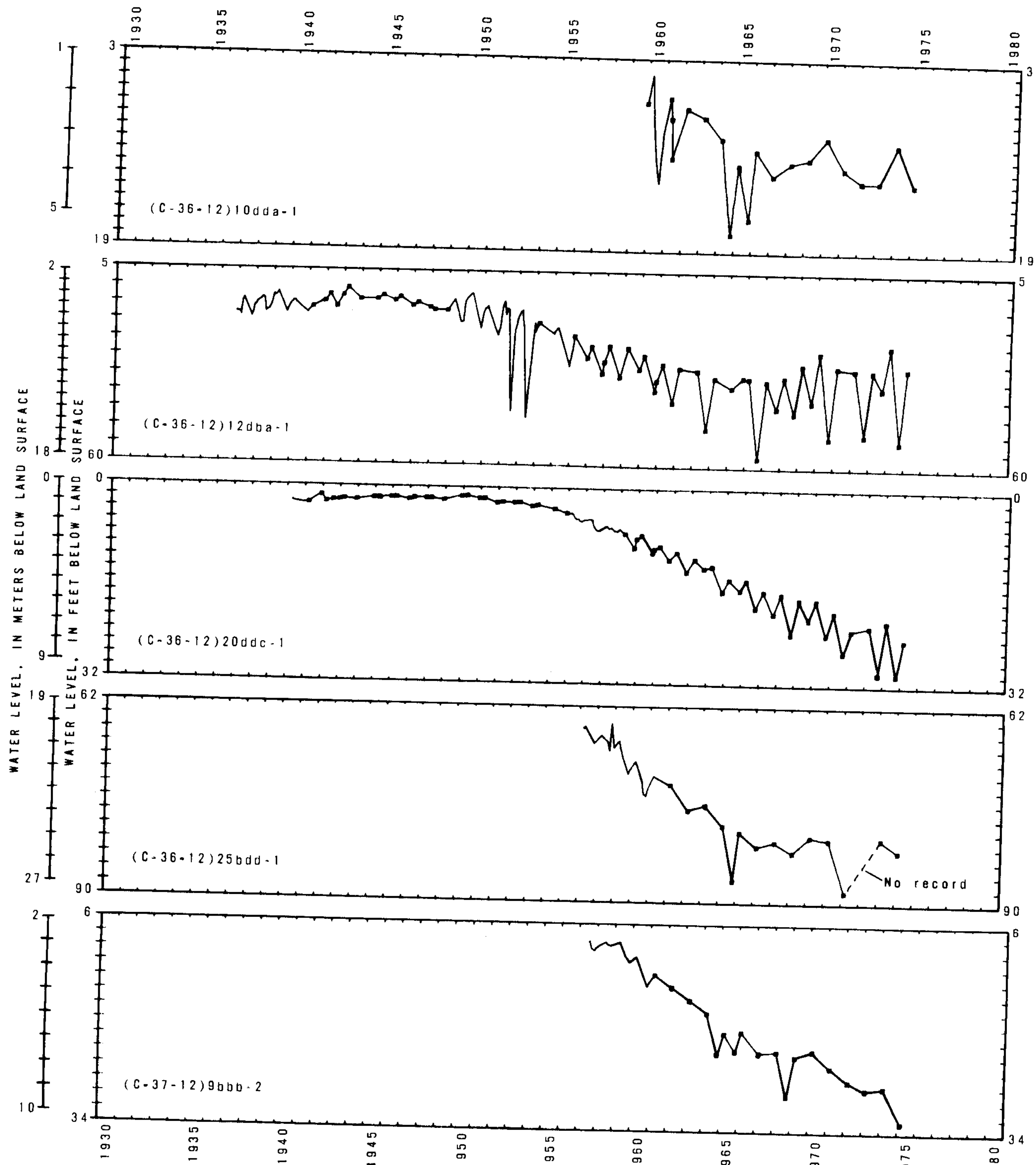


Figure 17.— Continued.



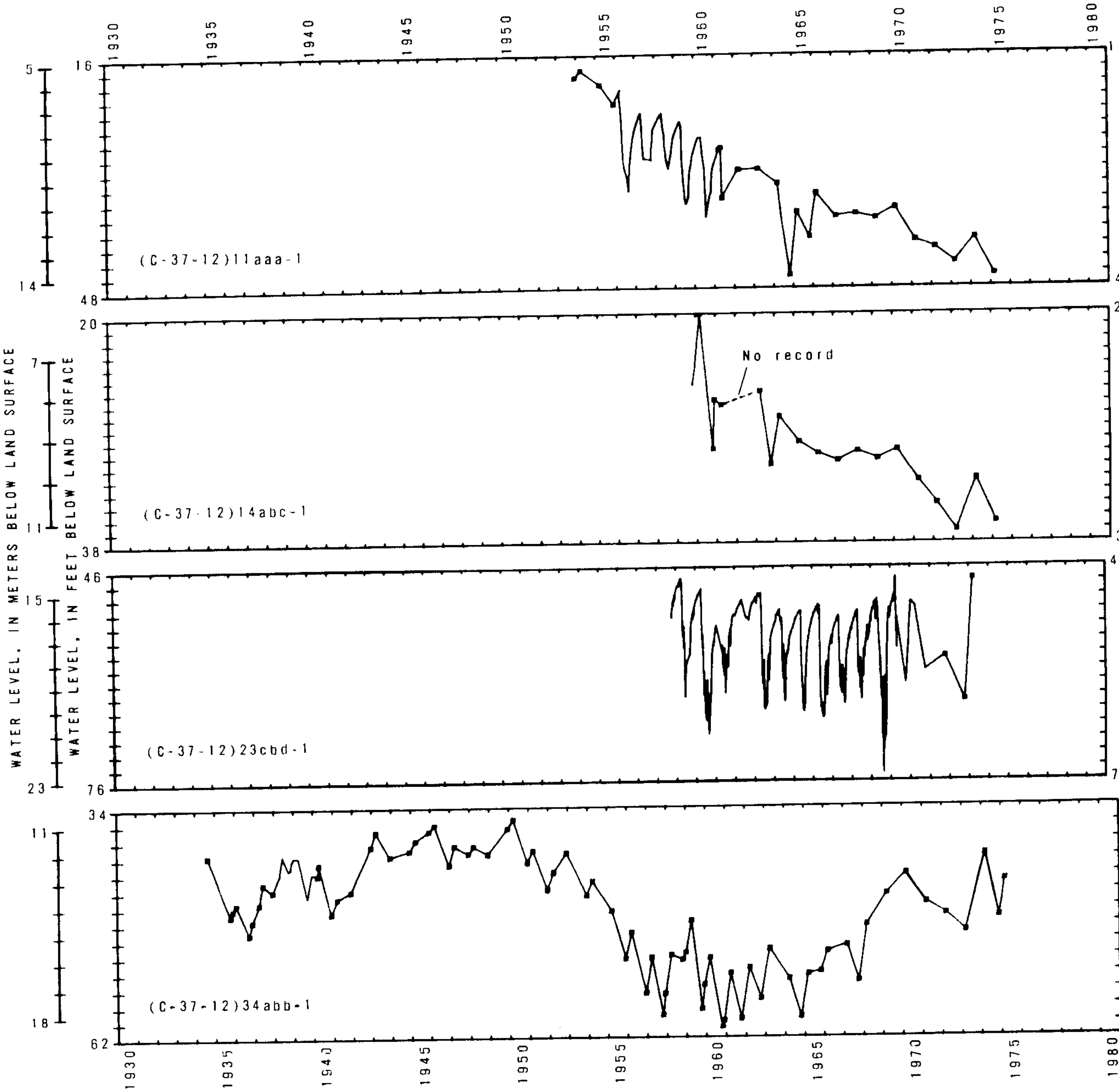
CEDAR CITY VALLEY—Continued

Figure 17.— Continued.



CEDAR CITY VALLEY—Continued

Figure 17.—Continued.



CEDAR CITY VALLEY—Continued

Figure 17.— Continued.

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UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

STATE OF UTAH
DEPARTMENT OF NATURAL RESOURCES

TECHNICAL PUBLICATION NO. 60
PLATE I 1978

EXPLANATION

QUATERNARY

Qds — Dune sand
Surficial deposits of eolian dune sand stabilized by natural vegetation

Ql — Lakebed deposits
Compacted silt and clay with some evaporites

Qa — Valley-fill deposits, undifferentiated
Mainly of fluvial origin but include older lakebed deposits and, locally, intra-alluvial basaltic lava flows

Qb — Basalt
Lava flows and related volcanic rocks

TERTIARY

QTu — Older alluvium, undifferentiated
Fanglomerate, older stream-terrace deposits, landslide debris, and colluvium

Tvu — Volcanic rocks, undifferentiated
Include Roger Park Basaltic Breccia, Mount Dutton and Bear Valley Formations, Bullion Canyon Volcanics, Page Ranch and Rencher Formations of Cook (1957), Quichapa Group, and Isom and Needles Range Formations

Tc
Tw
Claron and Wasatch Formations

Tqm — Quartz-monzonite porphyry

CRETACEOUS and CRETACEOUS(?)

Cretaceous rocks, undifferentiated
Kaiparowits and Iron Springs Formations, Wahweap and Straight Cliffs Sandstones, Tropic Shale, Dakota Formation, and Marshall Creek Breccia

JURASSIC

Jsr — San Rafael Group
Carmel Formation

Glen Canyon Group
Navajo Sandstone and Kayenta and Moenave Formations

TRIASSIC

Tru — Triassic rocks, undifferentiated
Chinle and Moenkopi Formations (uppermost part of Kaibab Limestone of Permian age, in local exposures too small to be shown separately, is included with formations of Triassic age)

Contact
Dashed where approximately located

Normal or reverse fault
Dashed where inferred

Thrust fault
Barbs on side of thrust sheet

Surface-drainage divide

Base from U.S. Geological Survey 1:250,000 series: Richfield, 1972, and Cedar City, 1953 (revised 1961 and 1971)

5 0 5 10 MILES
5 0 5 10 KILOMETERS

CONTOUR INTERVAL 200 FEET (60 METERS)
WITH SUPPLEMENTARY CONTOURS AT 100-FOOT (30-METER) INTERVALS
DATUM IS MEAN SEA LEVEL

Geology adapted from Averitt (1962, 1967), Averitt and Threet (1973), Machin (1954), and Thomas and Taylor 1946)

Geologic map of the Parowan-Cedar City drainage basin, Iron County, Utah

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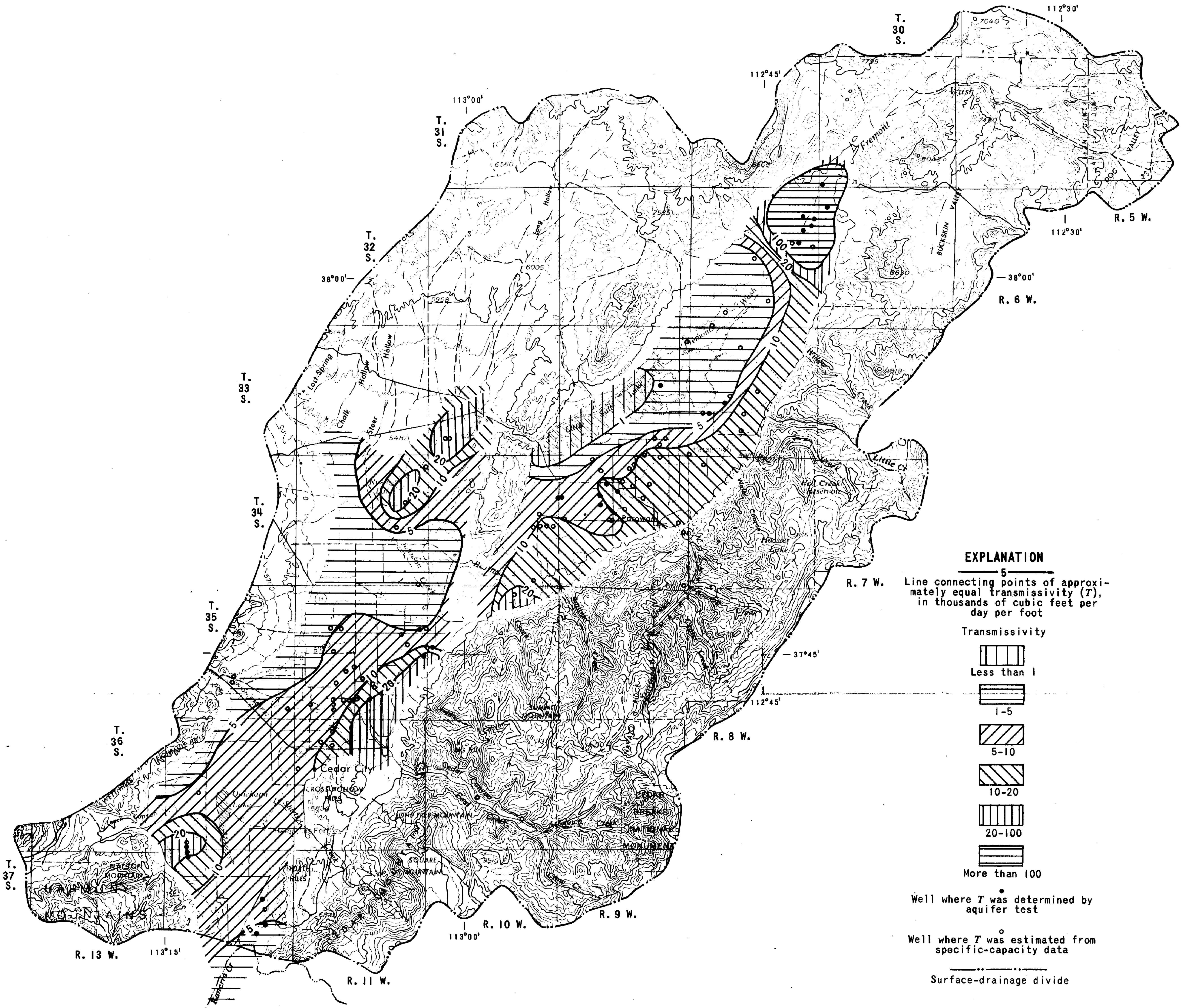

Base from U.S. Geological Survey 1:250,000 series: Richfield, 1972, and Cedar City, 1953 (revised 1961 and 1971)

5 0 5 10 MILES

5 0 5 10 KILOMETERS

CONTOUR INTERVAL 200 FEET (60 METERS)
WITH SUPPLEMENTARY CONTOURS AT 100-FOOT (30-METER) INTERVALS
DATUM IS MEAN SEA LEVEL

Hydrology by L. J. Bjorklund, 1975

Map showing distribution of transmissivity values of the valley fill in Parowan and Cedar City Valleys, Iron County, Utah

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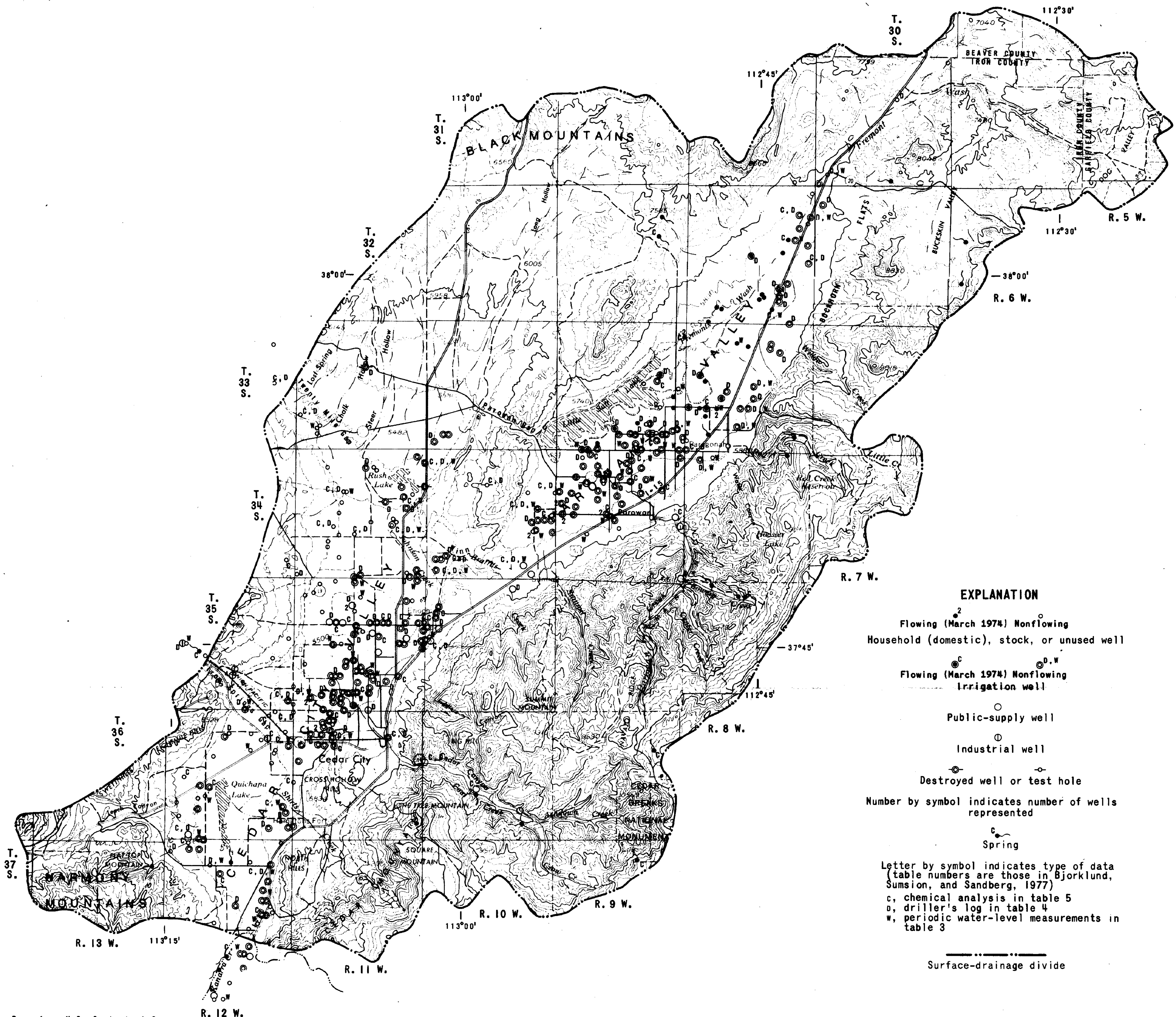

Base from U.S. Geological Survey 1:250,000 series: Richfield, 1972, and Cedar City, 1953 (revised 1961 and 1971)

5 0 5 10 MILES

5 0 5 10 KILOMETERS

CONTOUR INTERVAL 200 FEET (60 METERS)
WITH SUPPLEMENTARY CONTOURS AT 100-FOOT (30-METER) INTERVALS
DATUM IS MEAN SEA LEVEL

Hydrology by L. J. Bjorklund, 1975

Map showing the location of selected wells and springs in the Parowan-Cedar City drainage basin, Iron County, Utah

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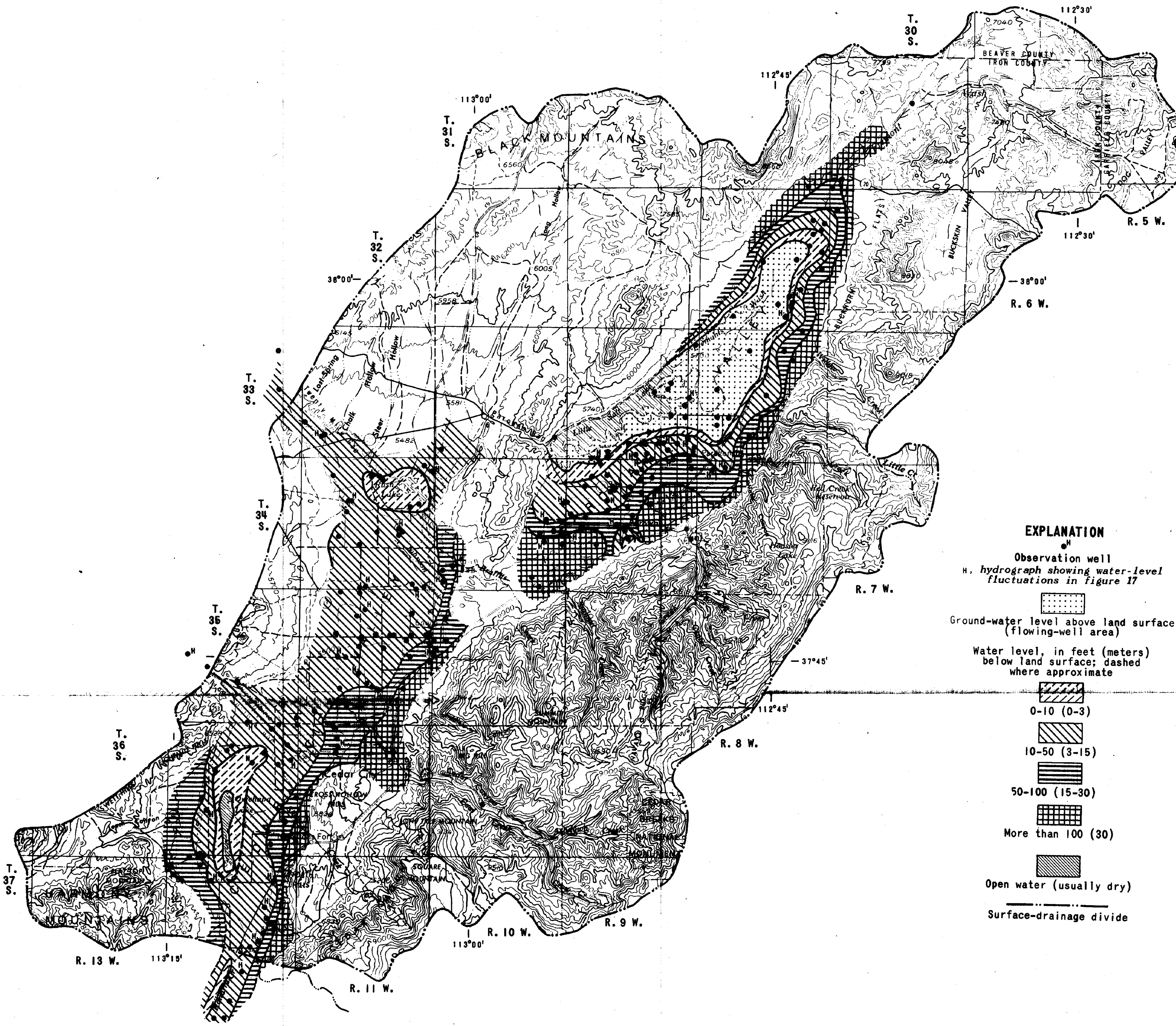


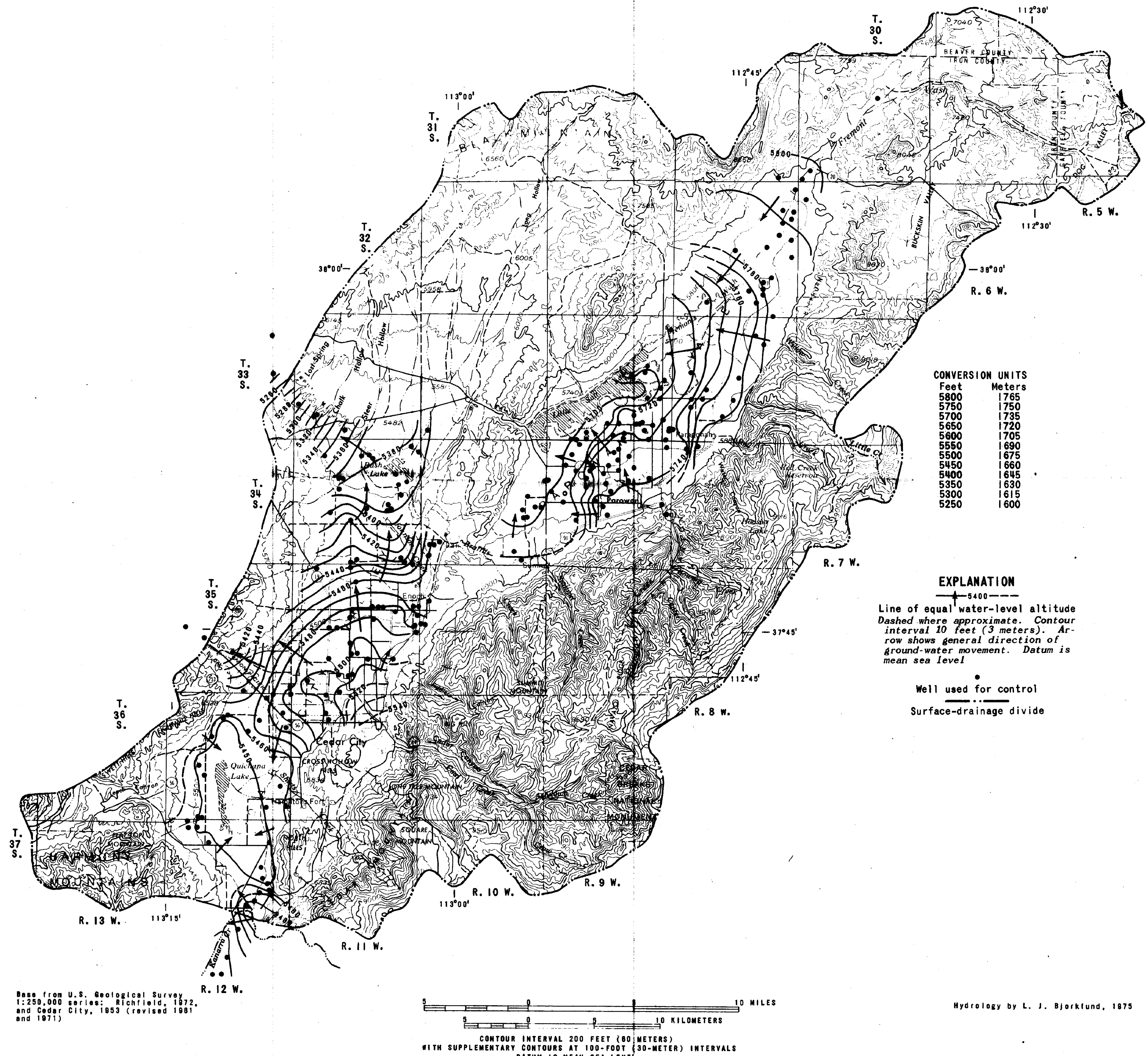
Base from U.S. Geological Survey 1:250,000 series: Richfield, 1972, and Cedar City, 1953 (revised 1961 and 1971)

5 0 5 10 MILES
5 0 5 10 KILOMETERS

CONTOUR INTERVAL 200 FEET (60 METERS)
WITH SUPPLEMENTARY CONTOURS AT 100-FOOT (30-METER) INTERVALS
DATUM IS MEAN SEA LEVEL

Hydrology by L. J. Bjorklund, 1975

Map showing relation of water levels to land surface during March 1974 in Parowan and Cedar City Valleys, Iron County, Utah



Map showing the configuration of the potentiometric surface and the direction of ground-water movement during March 1974 in Parowan and Cedar City Valleys, Iron County, Utah

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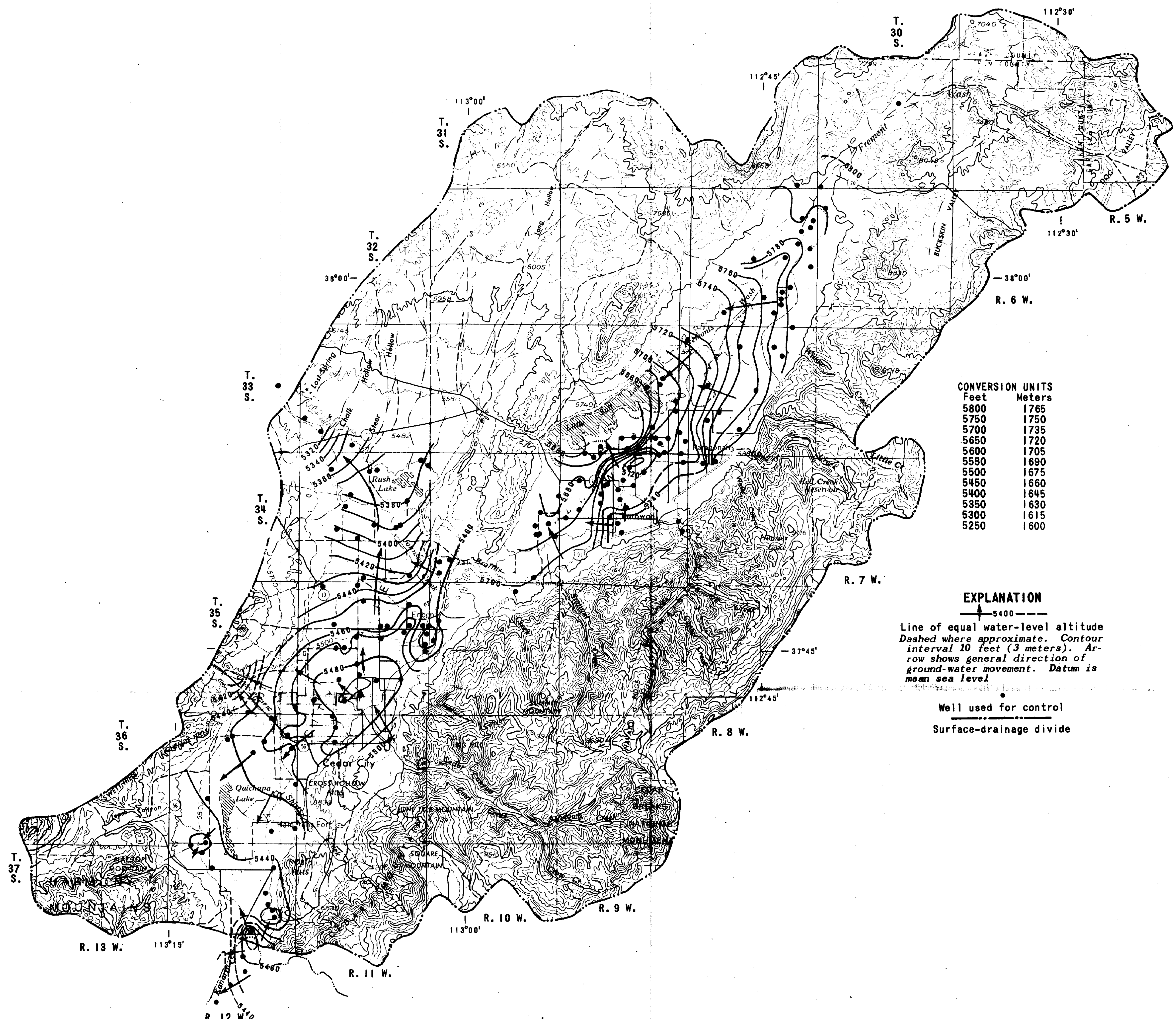
PLATE 6 1978



CONVERSION UNITS

Feet	Meters
5800	1765
5750	1750
5700	1735
5650	1720
5600	1705
5550	1690
5500	1675
5450	1660
5400	1645
5350	1630
5300	1615
5250	1600

EXPLANATION

5400

Line of equal water-level altitude
Dashed where approximate. Contour interval 10 feet (3 meters). Arrow shows general direction of ground-water movement. Datum is mean sea level

Well used for control

Surface-drainage divide

Base from U.S. Geological Survey 1:250,000 series: Richfield, 1972, and Cedar City, 1953 (revised 1961 and 1971)

5 0 5 10 MILES

5 0 5 10 KILOMETERS

CONTOUR INTERVAL 200 FEET (60 METERS)
WITH SUPPLEMENTARY CONTOURS AT 100-FOOT (30-METER) INTERVALS
DATUM IS MEAN SEA LEVEL

Hydrology by L. J. Bjorklund, 1975

Map showing the configuration of the potentiometric surface and the direction of ground-water movement during October and November 1974 in Parowan and Cedar City Valleys, Iron County, Utah

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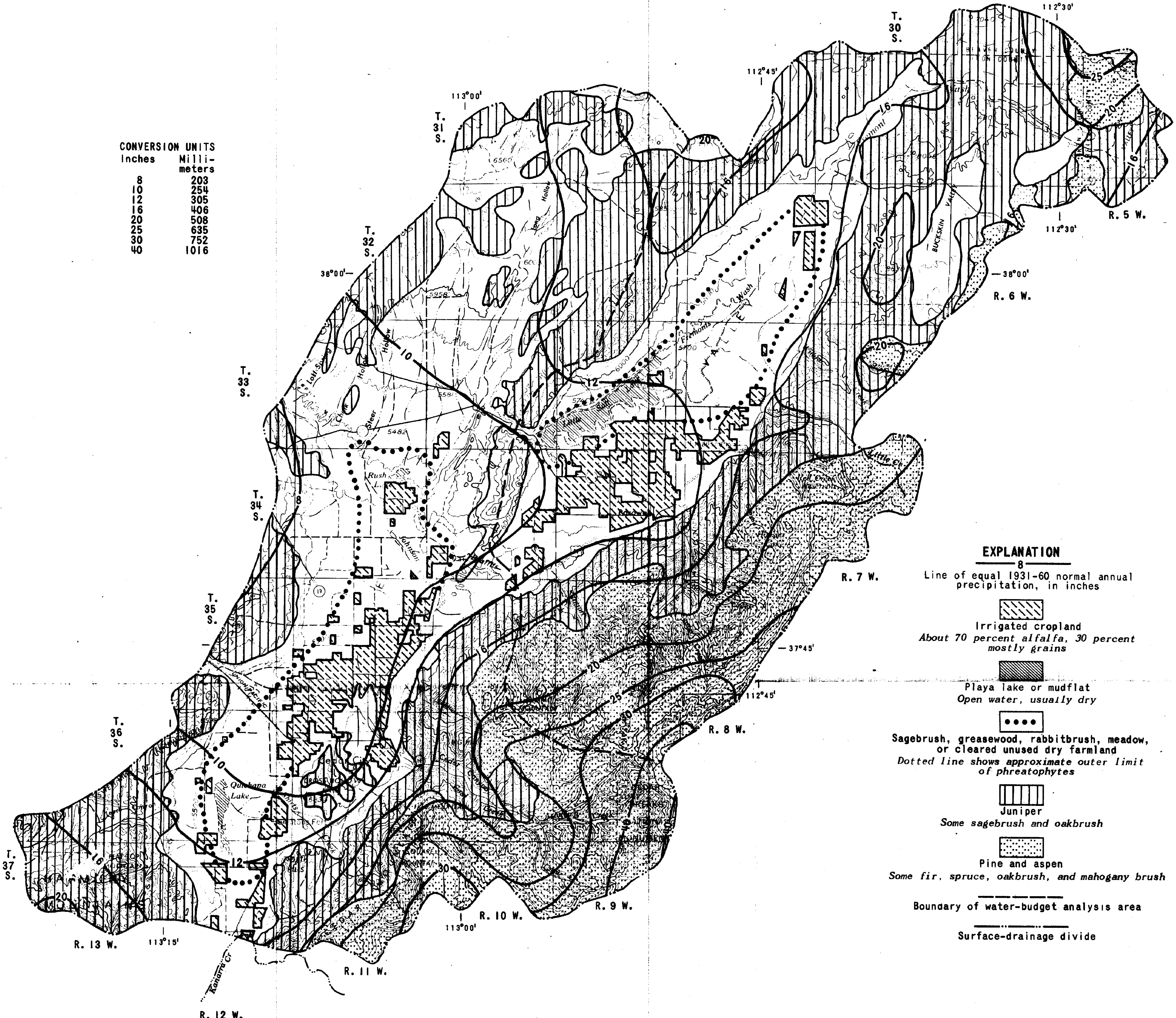
CONVERSION UNITS

Inches	Millimeters
8	203
10	254
12	305
16	406
20	508
25	635
30	752
40	1016



EXPLANATION

Line of equal 1931-60 normal annual precipitation, in inches

Irrigated cropland
About 70 percent alfalfa, 30 percent mostly grains

Playa lake or mudflat
Open water, usually dry

Sagebrush, greasewood, rabbitbrush, meadow, or cleared unused dry farmland
Dotted line shows approximate outer limit of phreatophytes

Juniper
Some sagebrush and oakbrush

Pine and aspen
Some fir, spruce, oakbrush, and mahogany brush

Boundary of water-budget analysis area

Surface-drainage divide

Base from U.S. Geological Survey 1:250,000 series: Richfield, 1972, and Cedar City, 1953 (revised 1961 and 1971)

5 0 5 10 MILES

5 0 5 10 KILOMETERS

CONTOUR INTERVAL 200 FEET (60 METERS)
WITH SUPPLEMENTARY CONTOURS AT 100-FOOT (30-METER) INTERVALS
DATUM IS MEAN SEA LEVEL

Hydrology by L. J. Bjorklund, 1975

Map showing land use, natural vegatation, water-budget analyses areas, and normal annual precipitation in the Parowan-Cedar City drainage basin, Iron County, Utah

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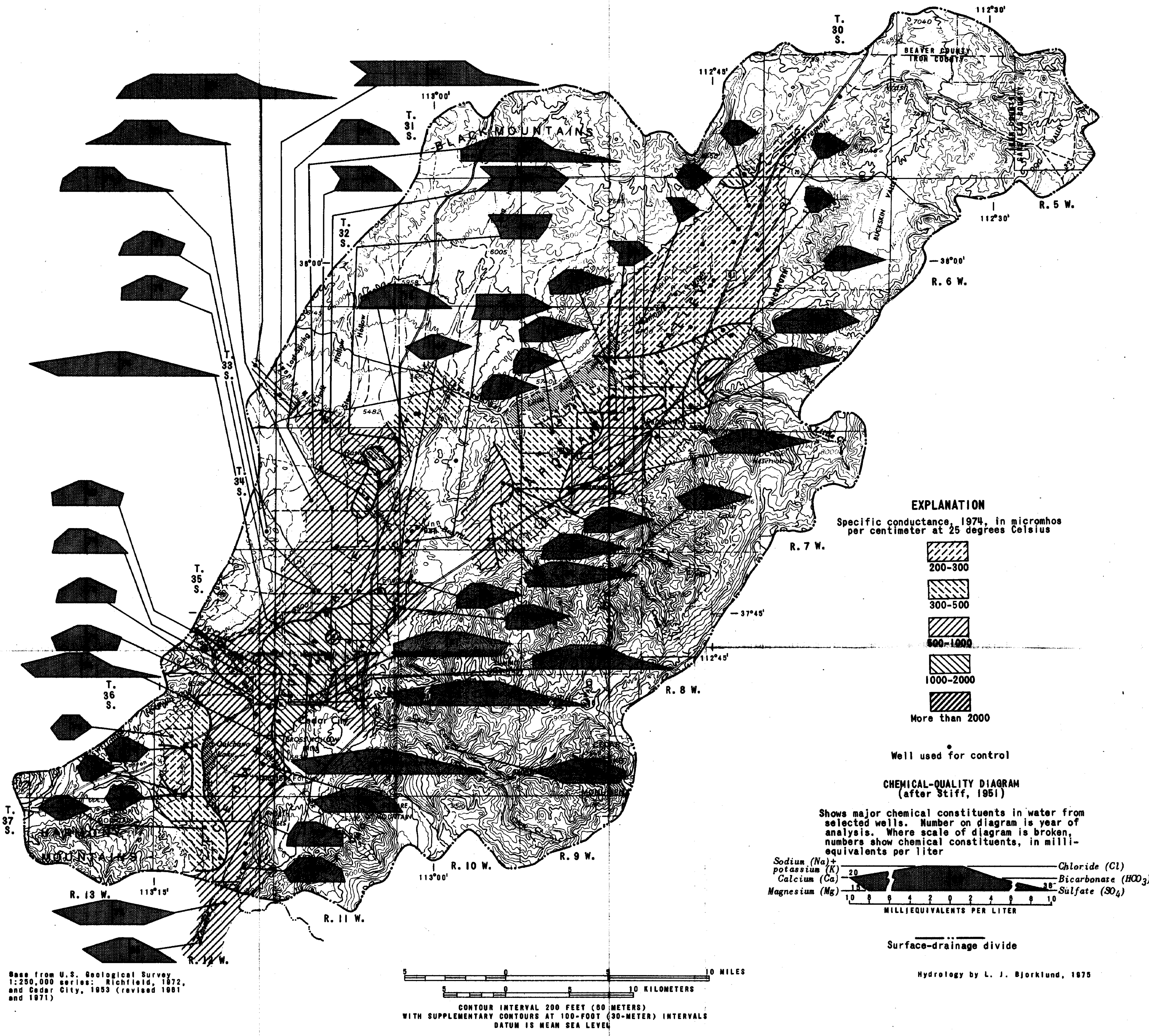

Map showing specific conductance and the chemical quality of the ground water in Parowan and Cedar City drainage basins, Iron County, Utah