Ground-Water Conditions and Potential for Artificial Recharge in Lucerne Valley, San Bernardino County, California

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Prepared in cooperation with the Mojave Water Agency

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UNITED STATES DEPARTMENT OF THE INTERIOR

CECIL D. ANDRUS, SECRETARY

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CONVERSION FACTORS

The inch-pound system of units is used in this report. For those readers who prefer metric units, the conversion factors for the terms used in this report are listed below:

Multiply inch-pound unit	By	To obtain metric unit
acre	4,047	m^2 (square meter)
acre-ft (acre-foot)	1,233	m^3 (cubic meter)
acre-ft/yr (acre-foot per year)	1,233	m^3/yr (cubic meter per year)
ft (foot)	0.3048	m (meter)
ft^2/d (foot squared per day)	0.09290	m^2/d (meter squared per day)
gal/min (gallon per minute)	0.06309	L/s (liter per second)
inch	25.40	mm (millimeter)
mi (mile)	1.609	km (kilometer)
mi^2 (square mile)	2.590	km^2 (square kilometer)
ton	907.2	kg (kilogram)

GROUND-WATER CONDITIONS AND POTENTIAL FOR ARTIFICIAL RECHARGE IN LUCERNE VALLEY, SAN BERNARDINO COUNTY, CALIFORNIA

By Donald H. Schaefer

ABSTRACT

The water level in two areas of Lucerne Valley has declined more than 100 feet since 1917, including 60 feet from 1954 to 1976. These declines are the result of pumping for the irrigation of alfalfa. The lowering of water levels has caused many shallow domestic wells to go dry.

Well yields in the valley generally are between 10 and 1,000 gallons per minute. About 240,000 acre-feet of ground water was extracted between 1950 and 1976. About 1,750,000 acre-feet remains in storage.

Water of poor quality underlies the valley around Lucerne Lake. There was no definable movement of this water from 1954 to 1976, but the possibility exists for future movement toward centers of pumping.

Lucerne Valley may be hydrologically suitable for artificial-recharge operations. Preliminary data suggest an area in T. 4 N., R. 1 E. as suitable for artificial recharge that would benefit most of the areas affected by the water-level declines. Detailed investigation is needed before recharge operations are begun.

INTRODUCTION

Lucerne Valley is an alluvial basin of 150 mi^2 about 75 mi northeast of Los Angeles and about 20 mi southeast of Victorville (fig. 1).

The valley is bordered by the San Bernardino Mountains on the south, the Granite Mountains on the west, the Ord Mountains on the north, and unnamed mountains on the east. Lucerne Lake occupies the lowest part of the valley at an altitude of about 2,850 ft. The altitude along the higher edges of the valley fill is about 3,500 ft.

The climate, typical of the Mojave Desert region, is characterized by abundant sunshine and little rainfall, with hot summers and cold winters.

Agriculture is the major economic endeavor in the valley and the primary consumer of ground water. About 2,500 acres of land was under cultivation in 1976. Alfalfa and permanent pasture are produced in the 192-day growing season. Industry is limited to cement manufacturing on the flank of the San Bernardino Mountains where limestone is quarried. Mining has been of periodic importance in the valley.

The Mojave Water Agency is concerned with the continuing lowering of water levels in wells in parts of Lucerne Valley. Levels have declined as much as 60 ft in 23 years (1954-76) in the area of greatest pumping. Pumping of deep high-capacity irrigation wells reportedly has caused many shallow domestic wells to go dry. Water of poor quality in the northern part of the valley may migrate into the area of greatest pumping if the pumping depression persists.

The Agency has proposed that a pipeline be built to bring water from the California State Water Project aqueduct to the Mojave Desert area where it would be used to artificially recharge the aquifers.

Purpose and Scope

The purpose of this investigation, prepared in cooperation with the Mojave Water Agency, was to evaluate the amount and effects of ground-water-level decline and the potential for artificial recharge in Lucerne Valley. Of particular importance are:

1. The location and extent of the water-level decline.
2. The depletion of storage in each aquifer in each subbasin.
3. The effect of declining water levels on water quality.
4. The probable effects of water-level decline if the trend is continued.
5. The potential for artificial recharge to alleviate or halt the decline.

The study involved:

1. Collecting basic data in the valley, including ground-water levels, drillers' logs, and chemical analyses of water.
2. Determining ground-water flow patterns and locating areas of ground-water-level decline.
3. Evaluating the subsurface geology to define the hydrologic properties by:
   a. Determining extent and thickness of sand and clay layers.
   b. Appraising the effect of faults on ground-water movement by the use of surface-geophysical methods and hydraulic analyses.
4. Defining the chemical quality of ground water, both areally and vertically.
5. Appraising the need for future investigative work in the area.

Acknowledgments

The author thanks the staff of the Mojave Water Agency for their assistance in obtaining data. The cooperation of many well owners, ranchers, and well drillers in Lucerne Valley is also gratefully acknowledged.

Well-Numbering System

The well-numbering system used by the U.S. Geological Survey in California indicates the location of wells according to the rectangular system for the subdivision of public land. For example, in the well number 4N/1W-2H1, the first two segments designate the township (T. 4 N.) and the range (R. 1 W.); the third number gives the section (sec. 2); and the letter indicates the 40-acre subdivision of the section, as shown in the accompanying diagram. The final digit is a serial number for wells in each 40-acre subdivision.

D	C	B	A
E	F	G	H
M	L	K	J
N	P	Q	R

Where the location of the well is questioned or the well is plotted with poor control, the letter X is substituted for the 40-acre subdivision of the section, as in 5N/1E-19X1.

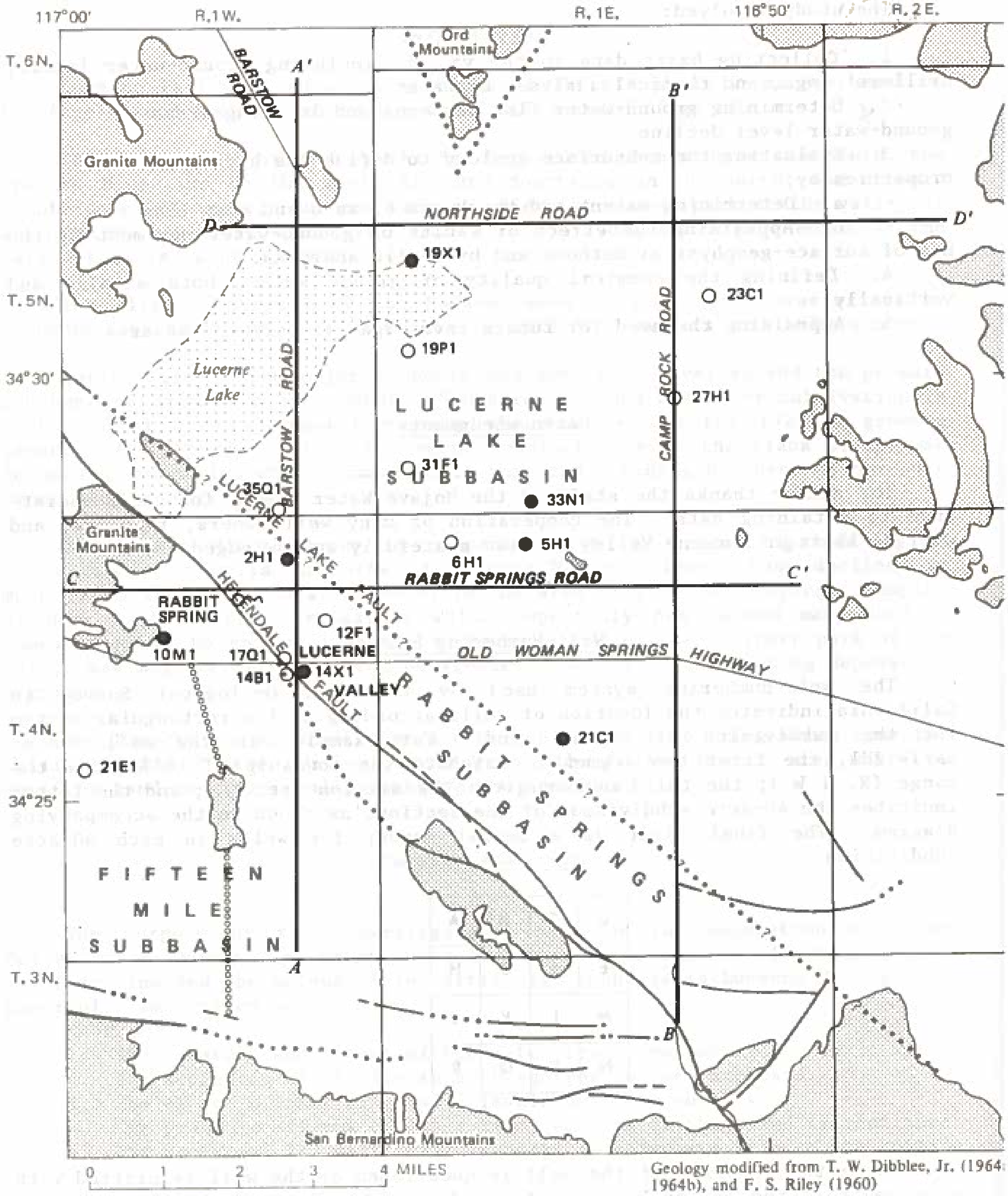


FIGURE 1.--Location and geology of area of investigation.

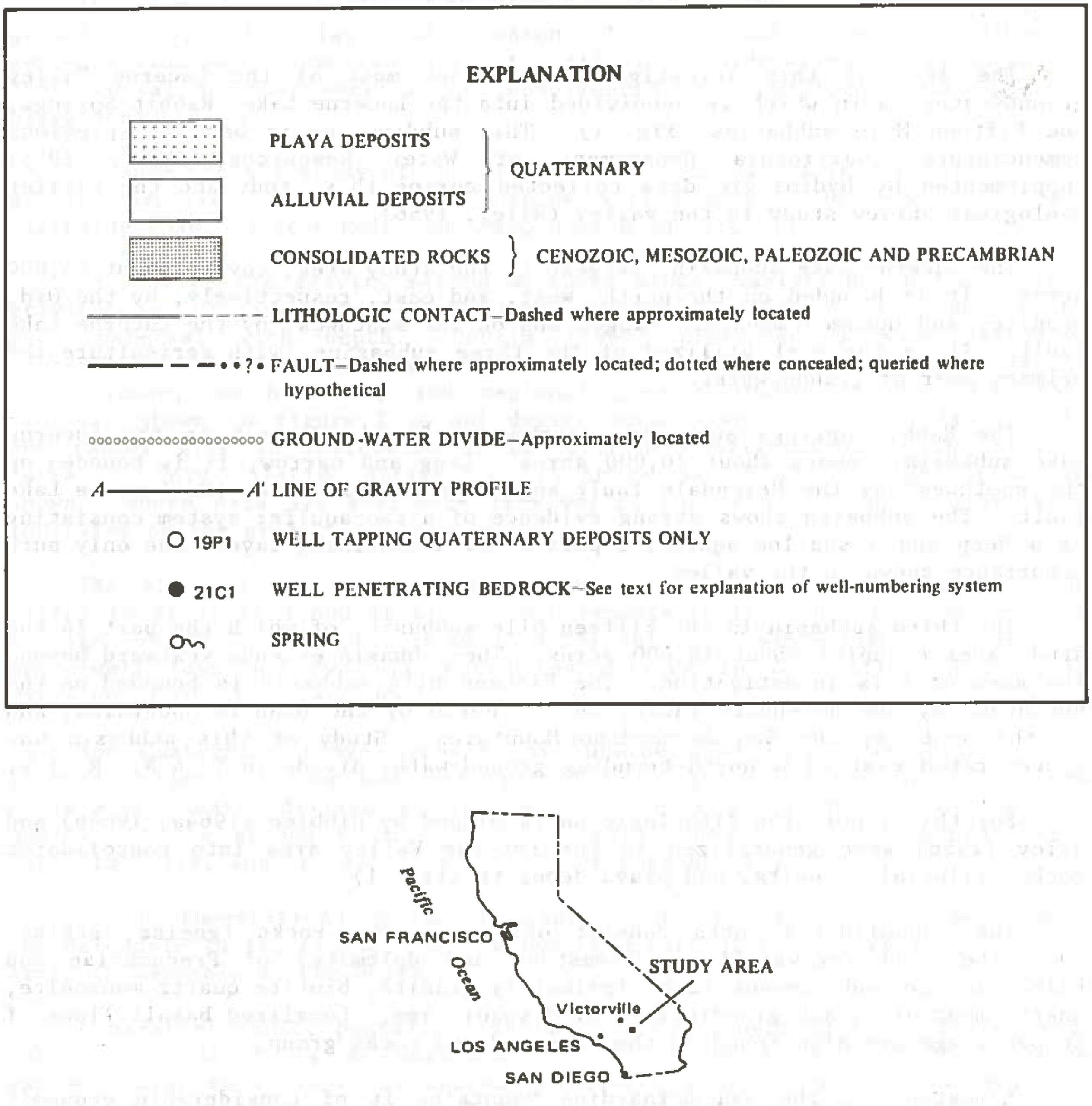


FIGURE 1.--Continued.

GROUND-WATER SUBBASINS AND GEOLOGY

The area of this investigation includes most of the Lucerne Valley ground-water basin which is subdivided into the Lucerne Lake, Rabbit Springs, and Fifteen Mile subbasins (fig. 1). This subdivision is based on previous nomenclature (California Department of Water Resources, 1967, 1975) supplemented by hydrologic data collected during this study and the earlier Geological Survey study in the valley (Riley, 1956).

The Lucerne Lake subbasin, largest in the study area, covers about 65,000 acres. It is bounded on the north, west, and east, respectively, by the Ord, Granite, and unnamed mountain ranges and on the southwest by the Lucerne Lake fault. It is the most utilized of the three subbasins, with agriculture the primary user of ground water.

The Rabbit Springs subbasin, southwest of and adjacent to the Lucerne Lake subbasin, covers about 10,000 acres. Long and narrow, it is bounded on the southwest by the Helendale fault and on the northeast by the Lucerne Lake fault. The subbasin shows strong evidence of a two-aquifer system consisting of a deep and a shallow aquifer separated by a confining layer, the only such occurrence known in the valley.

The third subbasin is the Fifteen Mile subbasin, of which the part in the study area occupies about 18,000 acres. The subbasin extends westward beyond the area of this investigation. The Fifteen Mile subbasin is bounded on the northeast by the Helendale fault, on the north by the Granite Mountains, and on the south by the San Bernardino Mountains. Study of this subbasin was concentrated east of a north-trending ground-water divide in T. 4 N., R. 1 W.

For this report the lithologic units mapped by Dibblee (1964a, 1964b) and Riley (1956) were generalized in the Lucerne Valley area into consolidated rocks, alluvial deposits, and playa deposits (fig. 1).

The consolidated rocks consist of metamorphic rocks (gneiss, schist, quartzite, and recrystallized limestone and dolomite) of Precambrian and Paleozoic age and igneous rocks (primarily granite, biotite quartz monzonite, quartz monzonite, and grandiorite) of Mesozoic age. Localized basalt flows of Cenozoic age are also found in the consolidated rocks group.

Limestone in the San Bernardino Mountains is of considerable economic importance to the valley. Companies annually extract about 2.5 million tons for the manufacture of cement (South Coast Geological Society, 1976).

Consolidated rocks underlie the alluvial and playa deposits in the valley and compose the surrounding hills and mountains. They are nearly impermeable except where fractured or weathered and are generally not an important source of ground water. For this study, the consolidated rocks are considered to be non-water-bearing.

The alluvial deposits of Quaternary age, as used herein, include stream alluvium, landslide deposits, and dune sand. These deposits are composed of gravel, sand, silt, clay, and occasional boulders and are unconsolidated or semiconsolidated. Where saturated, the alluvium yields water freely to wells. The alluvial deposits overlie the consolidated rocks and locally underlie the playa deposits.

Because the thickness of the alluvial deposits varies in the valley, four gravity profiles were made for Lucerne Valley along Rabbit Springs Road, Northside Road, Barstow Road, and Camp Rock Road (fig. 1).

Basically, the gravity method measures minute variations in the earth's gravitational field. These variations are due to differences in density of rock material with depth. Dobrin (1960) presented a more extensive explanation. Data from the gravity surveys were corrected to remove effects of latitude, earth tides, and regional gravity (Mabey, 1960). The four profiles shown in figure 2 do not depict actual depth to consolidated rocks but rather give an indication of the general configuration of the bedrock surface. Only relative differences in thickness of alluvial materials are shown. Where data are available from wells, the actual depth to bedrock is indicated on the profile for comparison.

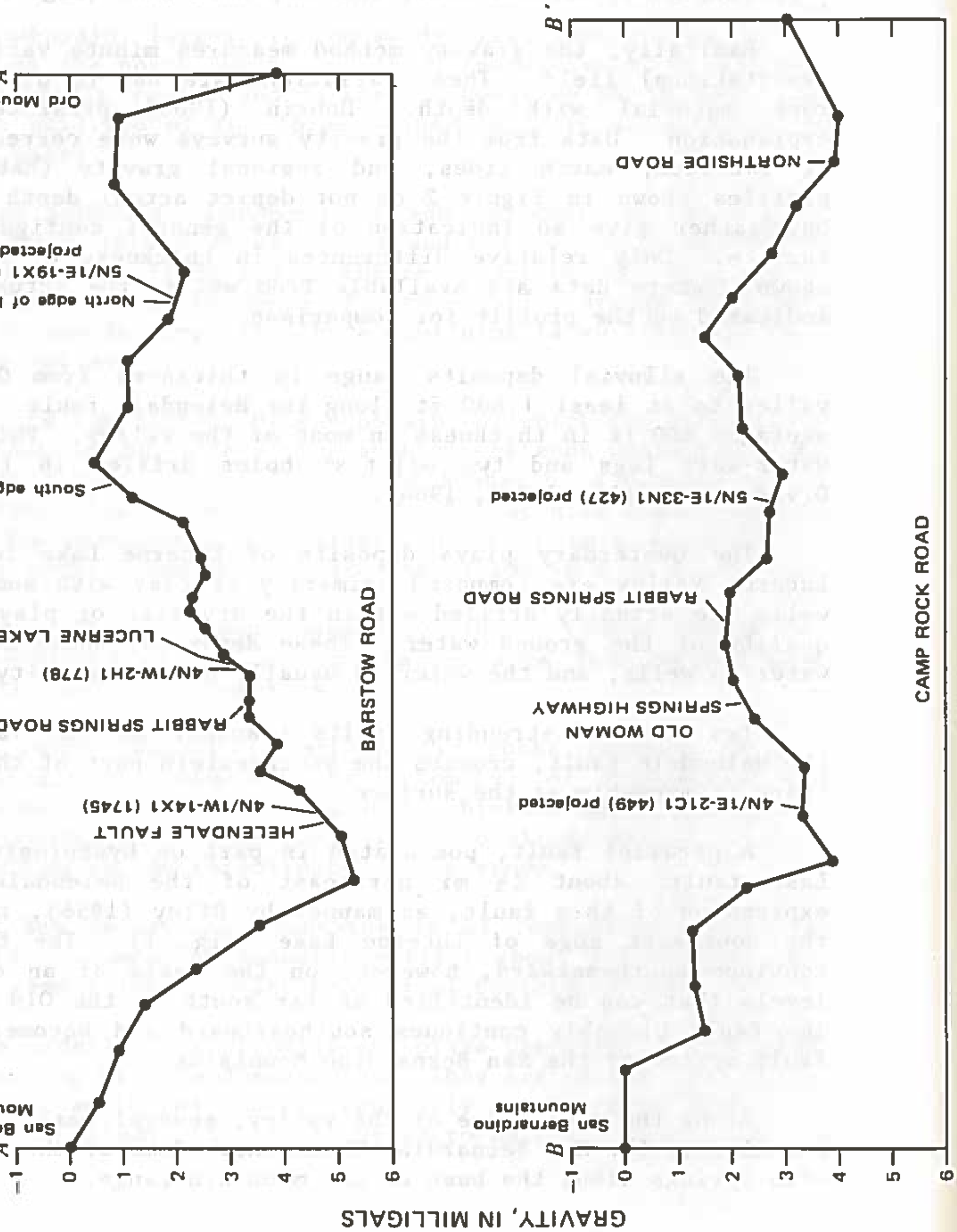
The alluvial deposits range in thickness from 0 at the edges of the valley to at least 1,800 ft along the Helendale fault. The alluvium probably averages 600 ft in thickness in most of the valley. This estimate is based on water-well logs and two oil-test holes drilled in the valley (California Division of Oil and Gas, 1964).

The Quaternary playa deposits of Lucerne Lake in the western part of Lucerne Valley are composed primarily of clay with some sand and silt. Few wells are actually drilled within the dry lake or playa, because of the poor quality of the ground water. These deposits, where saturated, yield little water to wells, and the water is usually of poor quality.

Two northwest-trending faults transect Lucerne Valley. The major one, the Helendale fault, crosses the southwestern part of the valley (fig. 1); its trace is mappable at the surface.

A parallel fault, postulated in part on hydrologic data, is the Lucerne Lake fault, about 1½ mi northeast of the Helendale fault. The surface expression of this fault, as mapped by Riley (1956), terminates southward at the southeast edge of Lucerne Lake (fig. 1). The fault is postulated to continue southeastward, however, on the basis of an offset in ground-water levels that can be identified as far south as the Old Woman Springs Highway. The fault probably continues southeastward and becomes part of the frontal fault system of the San Bernardino Mountains.

Along the south edge of the valley, several small faults trend east-west, parallel to the San Bernardino Mountains. Some of these faults are associated with springs along the base of the mountain range.


GRAVITY, IN MILLIGALS
BARSTOW ROAD
A
A'
San Bernardino Mountains
Ord Mountains
HELENDALE FAULT
4N/1W-14X1 (1745)
RABBIT SPRINGS ROAD
4N/1W-2H1 (778)
LUCERNE LAKE FAULT
South edge of lake
North edge of lake
5N/1E-19X1 (657) projected
CAMP ROCK ROAD
B
B'
San Bernardino Mountains
4N/1E-21C1 (449) projected
OLD WOMAN SPRINGS HIGHWAY
RABBIT SPRINGS ROAD
5N/1E-33N1 (427) projected
NORTHSIDE ROAD
-1
0
1
2
3
4
5
6

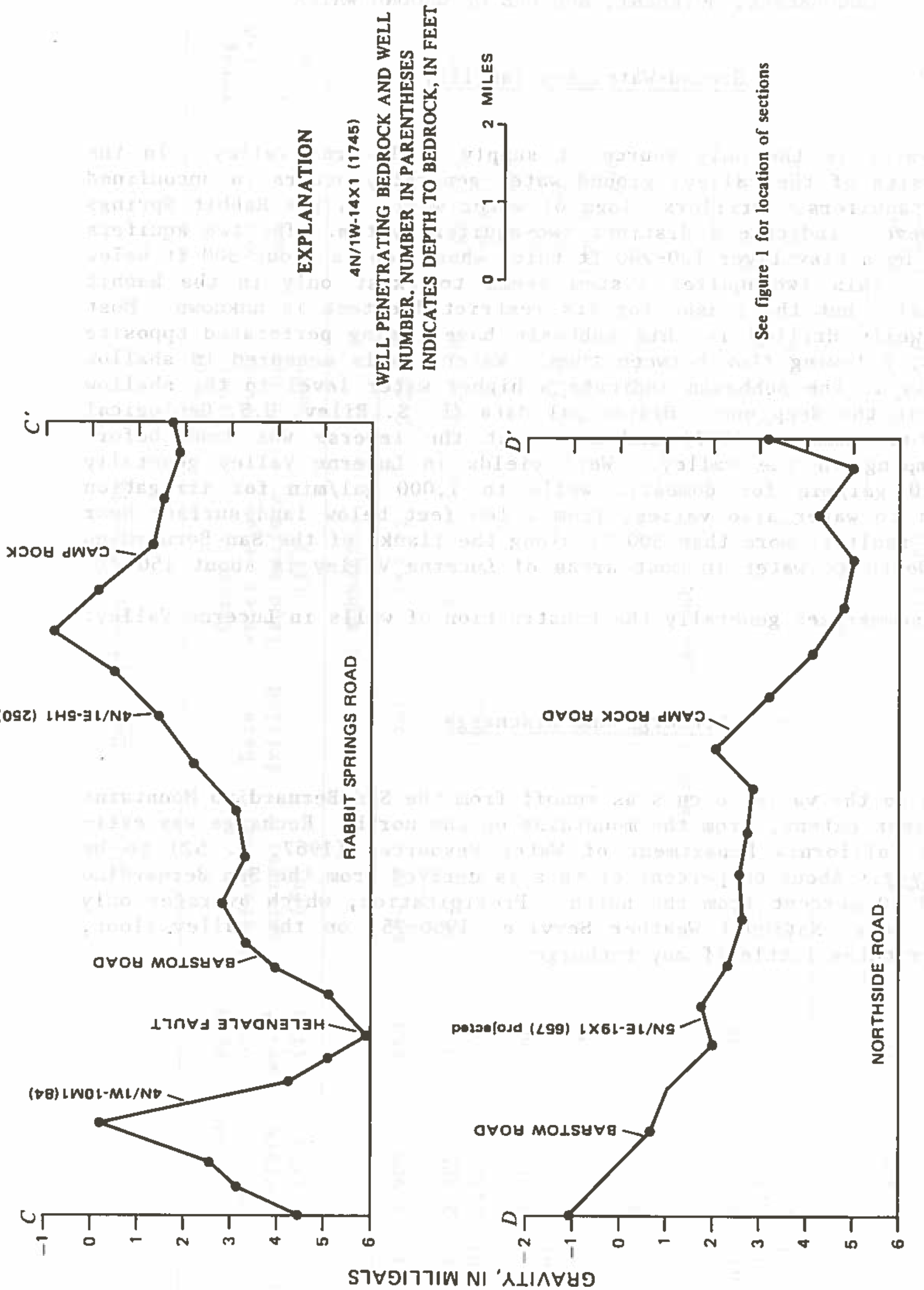


FIGURE 2.--Gravity profiles and bedrock data.

OCCURRENCE, MOVEMENT, AND USE OF GROUND WATER

Ground-Water Availability

Ground water is the only source of supply in Lucerne Valley. In the alluvial deposits of the valley, ground water generally occurs in unconfined (water-table) aquifers. Drillers' logs of water wells in the Rabbit Springs subbasin, however, indicate a distinct two-aquifer system. The two aquifers are separated by a clay layer 100-200 ft thick whose top is about 300 ft below land surface. This two-aquifer system seems to exist only in the Rabbit Springs subbasin, but the reason for its restricted extent is unknown. Most of the deep wells drilled in this subbasin have casing perforated opposite both aquifers, allowing flow between them. Water levels measured in shallow and deep wells in the subbasin indicate a higher water level in the shallow aquifer than in the deep one. Historical data (F. S. Riley, U.S. Geological Survey, written commun., 1977) indicate that the reverse was true before extensive pumping in the valley. Well yields in Lucerne Valley generally range from 10 gal/min for domestic wells to 1,000 gal/min for irrigation wells. Depth to water also varies, from a few feet below land surface near the Helendale fault to more than 300 ft along the flanks of the San Bernardino Mountains. Depth to water in most areas of Lucerne Valley is about 150 ft.

Table 1 summarizes generally the construction of wells in Lucerne Valley.

Recharge and Discharge

Recharge to the valley occurs as runoff from the San Bernardino Mountains and, to a lesser extent, from the mountains on the north. Recharge was estimated by the California Department of Water Resources (1967, p. 52) to be 1,000 acre-ft/yr. About 60 percent of this is derived from the San Bernardino Mountains and 40 percent from the north. Precipitation, which averages only 4 inches per year (National Weather Service, 1950-75) on the valley floor, probably contributes little if any recharge.

TABLE 1.--Descriptions of wells

Well no. (fig. 1)	Altitude of land surface (ft)	Depth of well[1] (ft)	Perforated interval (ft)	Date drilled	Depth to water below land surface (ft)	Date of water-level measurement	Well use	Average reported yield (gal/min)
				Lucerne Lake subbasin				
4N/1E-5H1	2,905	253	80-110 145-253	1947	153.77	12-28-76	Unused	240
4N/1E-6H1	2,885	336	70-336	1952	[2]168.32	12-28-76	Irrigation	700
5N/1E-19P1	2,853	209	154-209	1934			Domestic, Irrigation	1,000
5N/1E-23C1	2,980	200	--	1953			Domestic	--
5N/1E-27H1	2,930	--	--	--	109.35	12-27-76	Unused	--
5N/1E-31F1	2,860	267	--	1949	107.35	1-26-77	Domestic, Irrigation	800
5N/1W-35Q1	2,855	300	--	1947	44.26	12-27-76	Unused	--
				Rabbit Springs subbasin				
4N/1W-2H1	2,865	778	--	1913			Irrigation	800
4N/1W-11Q1	2,933	85	--	--	75.17	12-27-76	Domestic	--
4N/1W-12F1	2,915	542	300-542	1953	148.53	12-27-76	Irrigation	--
				Fifteen Mile subbasin				
4N/1W-14B1	2,945	148	140-148	1951	7.46	12-27-76	Domestic	--
4N/1W-21E1	3,083	314	145-314	1953	139.80	12-27-76	Domestic	--

[1]Depth to bottom of perforations. Measured depth, if perforated interval is unknown, may be greater or less than depth of perforations.

[2]Well pumped recently.

Around the turn of the century, before extensive development in the valley, discharge from the ground-water system occurred as evaporation from the soil by capillary action and transpiration by phreatophytes (plants that send their roots down to the water table or capillary fringe). Most of the evaporation was concentrated at the lowest part of the lakebed along the northwest side of the playa (fig. 3) (F. S. Riley, written commun., 1977). In this area, 2 mi long by ½ to 1 mi wide, the water table was probably 5 to 8 ft below the surface of the lake. Under these conditions the water rose nearly to the surface by capillary action and evaporated, much in the manner of a free-water surface. Depth to water under the rest of the dry lake was probably less than 12 ft. The water requirements of pickleweed and other phreatophytes that continue to grow along the edge of Lucerne Lake probably are met by moisture retained in the playa clays by capillary forces, inasmuch as the water table in the area has been lowered to about 50 ft beneath the lakebed.

When Thompson (1929) investigated the water resources of the valley in 1917, he noticed 40 to 50 wells supplying established agricultural activities. The areas of natural discharge were not observed by him, presumably because irrigation demands had lowered water levels in the lowest part of the valley sufficiently to reduce evapotranspiration.

Ground-Water Movement

Ground-water flow patterns have changed little since the first available data in 1916-17 and are probably similar to those that existed prior to man's influence. Ground water generally flows from areas of recharge adjacent to the mountains inward toward Lucerne Lake. Figure 3 shows the configuration of the potentiometric surface in 1916-17. Rather steep gradients are indicated in the vicinity of Old Woman Springs Highway, flattening toward the lakebed. The area of historical natural discharge is also shown on the map. Contours on the southwest side of Helendale fault indicate ground-water movement northward toward Lucerne Lake.

Figures 4 and 5 show the water-level contours in 1954 and 1976 respectively. Flow patterns for these periods and the earlier one are generally similar, but certain changes have occurred. The ground-water gradient has steepened toward the potentiometric low area. As heavy pumping for irrigation removes large quantities of ground water from storage, the slope of the water table into the pumping depression steepens. From 1916 to 1976 the depression shifted southeastward in response to pumping.

The Helendale and Lucerne Lake faults act as barriers to ground-water flow in the study area. Although the cause and nature of the barrier effects of faults are not completely understood, ground-water movement across the faults may be impeded because of one or more of the following conditions: (1) Permeable beds offset against less permeable beds; (2) presence of clay fault gouge, which is less permeable than the aquifer; (3) local deformation of beds near the fault, resulting in reduced permeability in the deformed beds; and (4) cementation of the fault zone and material immediately adjacent to the fault by deposition of minerals from ground water.

The Helendale fault is effective as a ground-water barrier with water-level differences ranging from 60 to 100 ft. Northwest of the town of Lucerne Valley, ground water crossing the Helendale fault is forced to the surface where it forms Rabbit Springs (fig. 1), a long-used desert watering place (Thompson, 1929).

The Lucerne Lake fault impedes movement of ground water from the Rabbit Springs subbasin into the Lucerne Lake subbasin directly south of the lake (fig. 4). The 1954 water-level contours, which are based on abundant data, show the barrier effects. These water-level differences are due also, in part, to head differences between the shallow and deep aquifers. In 1954, water levels in wells tapping the deep aquifer (not shown) were at a lower altitude than water levels in the Lucerne Lake subbasin. Whether this had any effect on ground-water movement between the two subbasins is not determinable from the data.

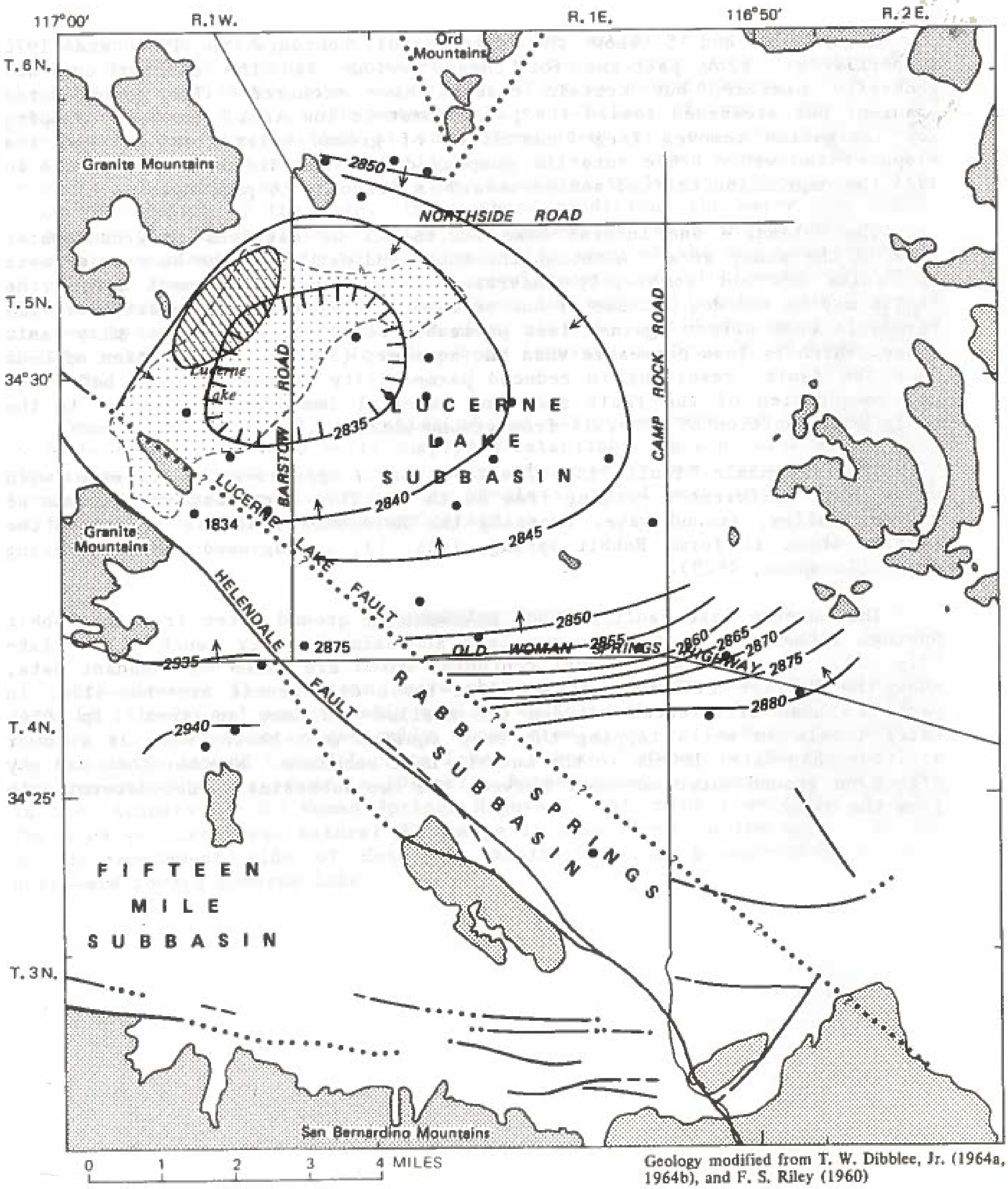


FIGURE 3.--Water-level contours, 1916-17, and area of historical natural discharge.

EXPLANATION

Geology as in figure 1

AREA OF HISTORICAL NATURAL DISCHARGE (Data from F. S. Riley, U.S. Geological Survey, written commun., 1977)

—— 2835 —— WATER-LEVEL CONTOUR—Shows altitude of water level in wells. Contour interval 5 feet. Datum is mean sea level.

• 2875 ALTITUDE OF WATER LEVEL, IN FEET, AT DATA POINT WHERE CONTOUR NOT DRAWN BECAUSE OF INADEQUATE CONTROL (Data from Thompson, 1929)

• DATA POINT USED FOR WATER-LEVEL CONTOUR

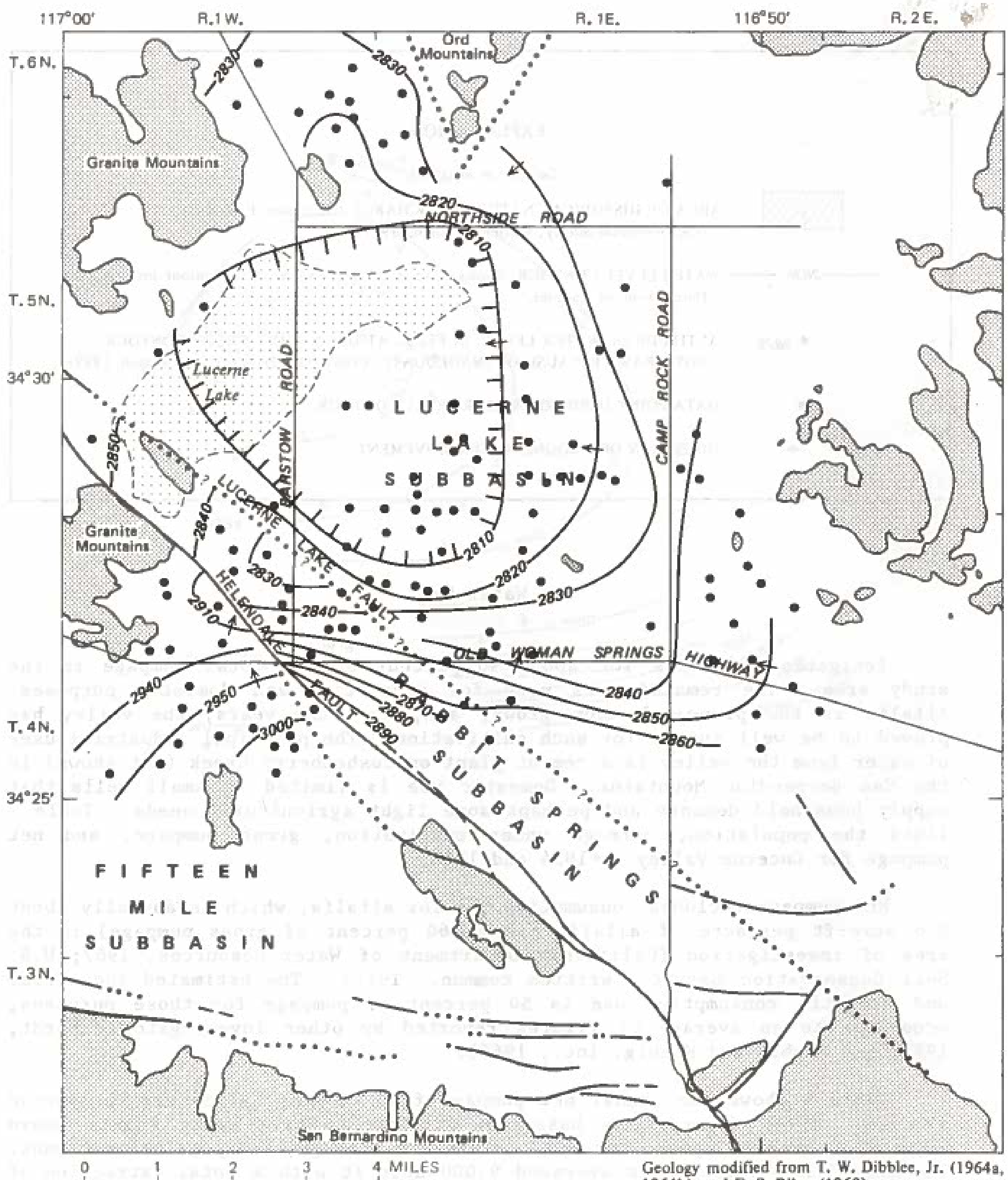
→ DIRECTION OF GROUND-WATER MOVEMENT

Water Use

Irrigation accounts for about 90 percent of the total pumpage in the study area. The remainder is used for industrial and domestic purposes. Alfalfa is the principal crop grown, and, over the years, the valley has proved to be well suited for such cultivation. The principal industrial user of water from the valley is a cement plant on Cushenberry Creek (not shown) in the San Bernardino Mountains. Domestic use is limited to small wells that supply household demands and perhaps some light agricultural needs. Table 2 lists the population, acreage under cultivation, gross pumpage, and net pumpage for Lucerne Valley in 1954 and 1976.

Net pumpage includes consumptive use for alfalfa, which is annually about 3.6 acre-ft per/acre of alfalfa (about 60 percent of gross pumpage) in the area of investigation (California Department of Water Resources, 1967; U.S. Soil Conservation Service, written commun., 1977). The estimated industrial and domestic consumptive use is 50 percent of pumpage for those purposes, according to an average of figures reported by other investigators (Hardt, 1971, and Koebig and Koebig, Inc., 1966).

Table 3 shows the annual net pumpage from Lucerne Valley for the period 1950-76. These figures are based on California State Water Rights Board extraction notices, power records, cultivated acreage, and population trends. The annual net pumpage has averaged 9,000 acre-ft with a total extraction of about 240,000 acre-ft since 1950.



Geology modified from T. W. Dibblee, Jr. (1964a, 1964b), and F. S. Riley (1960)

FIGURE 4.--Water-level contours, spring 1954.

EXPLANATION

Geology as in figure 1

——2820—— WATER-LEVEL CONTOUR—Shows altitude, in feet, of water level in wells. Contour interval variable. Datum is mean sea level. Contours in Rabbit Springs subbasin are for the confined (deep) aquifer only. Elsewhere, they define a single, unconfined system

• DATA POINT (1956) from Riley

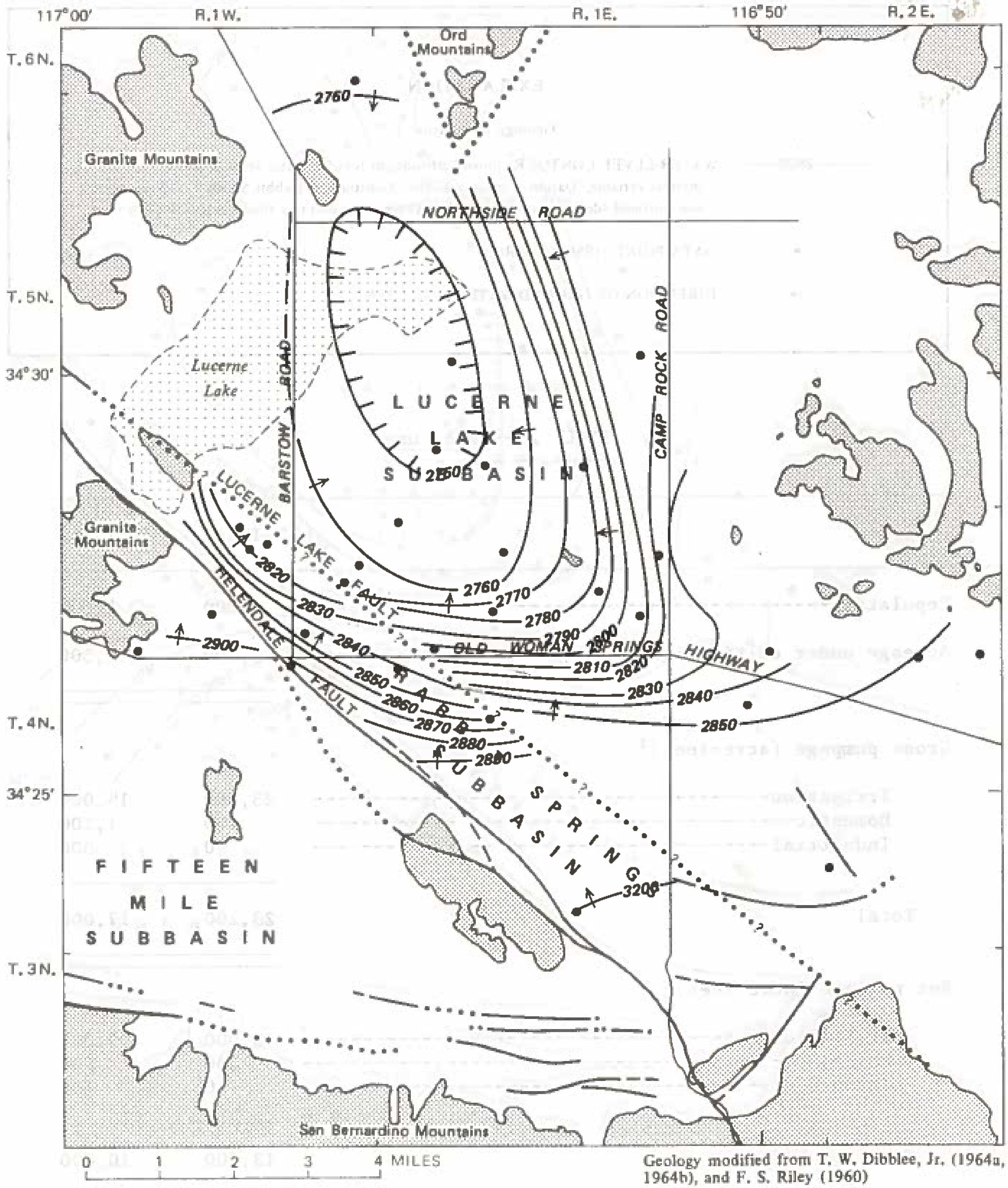
→ DIRECTION OF GROUND-WATER MOVEMENT

TABLE 2.--Water use

	1954	1976
Population	1,000	4,000
Acreage under cultivation (acres)	3,500	2,500
Gross pumpage (acre-feet)[1]		
Irrigation	23,000	15,000
Domestic	200	1,200
Industrial	0	800
Total	23,200	17,000
Net pumpage (acre-feet)[2]		
Irrigation	13,000	9,000
Domestic	100	600
Industrial	0	400
Total	13,100	10,000

[1]Amount of ground water pumped from the system.

[2]Amount of water lost from the system after irrigation and domestic returns, also known as consumptive use.



Geology modified from T. W. Dibblee, Jr. (1964a, 1964b), and F. S. Riley (1960)

FIGURE 5.--Water-level contours, winter 1976.

EXPLANATION

Geology as in figure 1

—— 2750 —— — WATER-LEVEL CONTOUR—Shows altitude, in feet, of water level in wells. Dashed where approximately located. Contour interval variable. Datum is mean sea level. Contours in Rabbit Springs subbasin are for the confined (deep) aquifer only. Elsewhere, they define a single, unconfined system

● DATA POINT

→ DIRECTION OF GROUND-WATER MOVEMENT

TABLE 3.--Annual net pumpage, in acre-feet

Year	Pumpage	Year	Pumpage	Year	Pumpage
1950	4,000	1959	6,000	1968	9,000
1951	4,000	1960	5,000	1969	11,000
1952	6,000	1961	9,000	1970	11,000
1953	8,000	1962	9,000	1971	10,000
1954	13,000	1963	9,000	1972	9,000
1955	12,000	1964	9,000	1973	8,000
1956	13,000	1965	9,000	1974	8,000
1957	12,000	1966	9,000	1975	10,000
1958	12,000	1967	8,000	1976	10,000
				Total	243,000

Water in Storage

Storage capacity is equivalent to the volume of ground water in the pore spaces of the saturated alluvial deposits that could be withdrawn for use. The quantity of water in storage in the unconfined alluvial aquifer is calculated by multiplying the surface area of the basin or subbasin by the average saturated thickness of the aquifer and this, in turn, by the specific yield.

The saturated aquifer thickness in Lucerne Valley was estimated to average 200 ft. In most areas of the valley it is appreciably greater, but it probably would not be economically practical to draw down water levels more than 200 ft below the current static level of about 150 ft below land surface.

Specific yield is the ratio of the volume of water the rock or soil will yield by gravity to the saturated volume of the deposit, expressed as a percentage of the saturated volume of the deposits. It is estimated on the basis of the lithologic information in drillers' logs. From a qualitative appraisal of about 50 logs, it was concluded that specific yields in the valley range from 6 to 15 percent. A value of 11 percent was chosen as representative for computing the quantity of water in storage.

Table 4 lists the water in storage for each subbasin before manmade influences (prior to 1917), using an average saturated thickness of 200 ft and an average specific yield of 11 percent. Subtracting the quantity of water removed from storage since 1950, and accounting for the annual recharge, about 1,750,000 acre-ft remains in storage.

TABLE 4.--Ground water in storage prior to 1917

Subbasin	Surface area (acres)	Water in storage (acre-ft)
Lucerne Lake	65,000	1,400,000
Rabbit Springs	10,000	200,000
Fifteen Mile (in study area)	18,000	400,000
Total		2,000,000

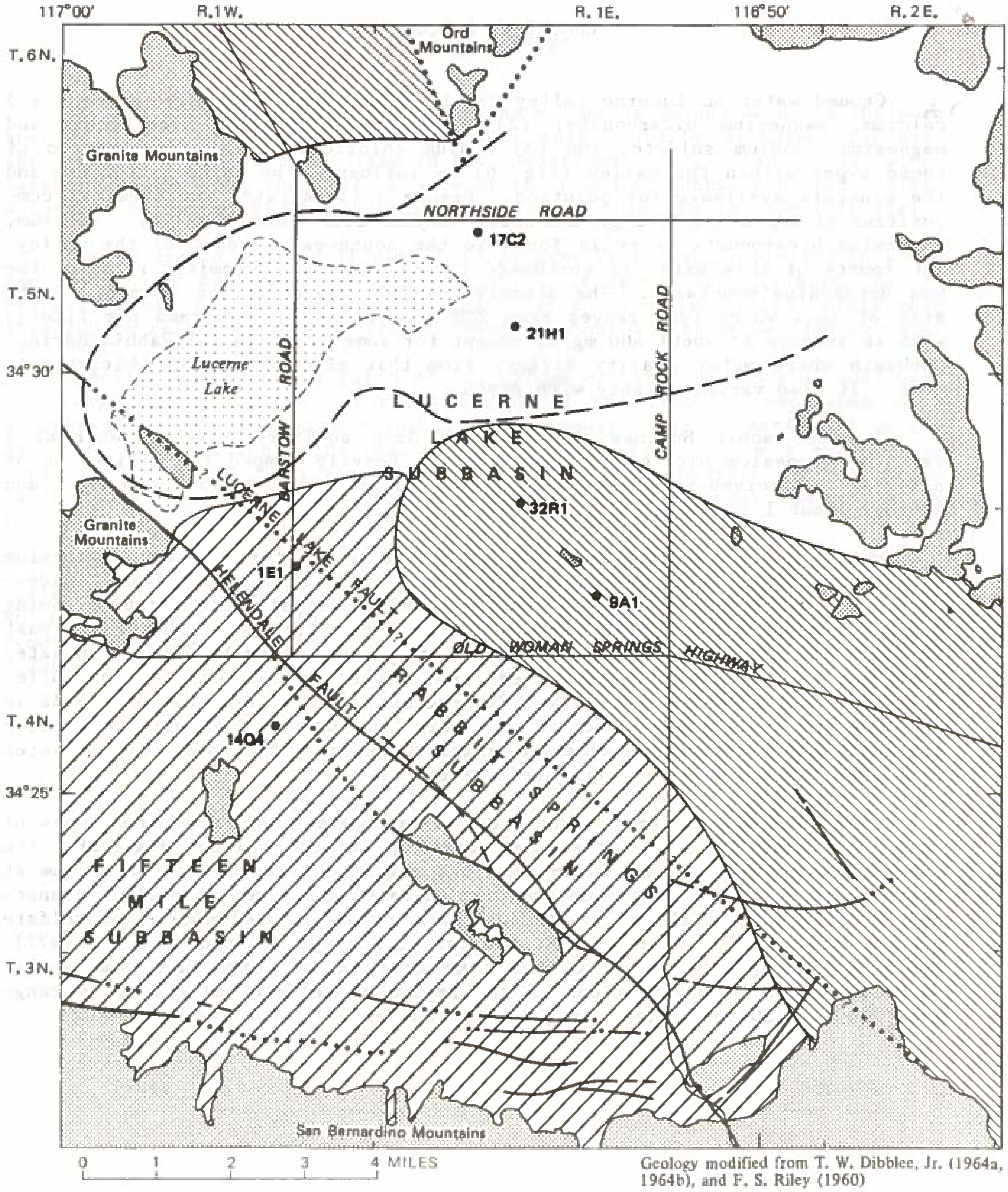
GROUND-WATER QUALITY

Ground water in Lucerne Valley can be classified into three types: (1) calcium, magnesium bicarbonate; (2) a mixture of calcium bicarbonate and magnesium, sodium sulfate; and (3) sodium chloride. Areal distribution of these types within the valley (fig. 6) is influenced by recharge sources and the minerals available for solution. Figure 7 illustrates the chemical composition of representative ground-water samples from Lucerne Valley. Calcium, magnesium bicarbonate water is found in the southwestern part of the valley. The source of this water is northward runoff from the dolomitic rocks of the San Bernardino Mountains. The dissolved-solids concentration in most of the area of this water type ranges from 200 to 500 mg/L (milligrams per liter), with an average of about 400 mg/L, except for some areas in the Rabbit Springs subbasin where water quality differs from that elsewhere in the bicarbonate area. It also varies notably with depth.

In the Rabbit Springs subbasin the deep aquifer contains water of a calcium, magnesium bicarbonate type that is heavily pumped for irrigation of alfalfa. Dissolved-solids concentrations range from 500 to 2,000 mg/L and average about 1,300 mg/L.

Water in the shallow aquifer is primarily of the calcium, magnesium bicarbonate type, but sulfate is commonly present in appreciable concentrations. Water quality in this aquifer is progressively deteriorating, owing to infiltration of irrigation return water of poor quality. During the past 14 years the dissolved-solids concentration has increased 44 percent in water from one well in the irrigated area. Concentrations in the shallow aquifer averaged about 2,700 mg/L in 1976. Consequently, the water from some wells is too poor in quality for domestic or irrigation uses. High nitrate concentrations, which commonly indicate irrigation return water, occur in the water from some shallow wells in irrigated areas.

A mixture of calcium bicarbonate and magnesium, sodium sulfate types of water is found in the southeastern part of Lucerne Valley (fig. 6). Its source is probably ground water that has migrated through older alluvium at depth where it dissolved gypsum (calcium sulfate) and other minerals. Johnson and Fry Valleys (not shown) to the east have a similar predominance of sulfate ground water (J. J. French, U.S. Geological Survey, written commun., 1977). Sodium is the predominant cation in the analyses of water from some wells. Dissolved-solids concentrations in the region of sulfate water usually range from 300 to 1,200 mg/L and average about 800 mg/L.



Geology modified from T. W. Dibblee, Jr. (1964a, 1964b), and F. S. Riley (1960)

FIGURE 6.--Areal distribution of ground-water quality types.

EXPLANATION

Geology as in figure 1

TYPE OF WATER

Calcium, Magnesium Bicarbonate—(Dissolved-solids concentration: 200-500 milligrams per liter; see text for exceptions in Rabbit Springs subbasin)

Mixture of Calcium Bicarbonate and Magnesium, Sodium Sulfate—(Dissolved-solids concentration: 300-1,200 milligrams per liter)

Sodium Chloride—(Dissolved-solids concentration: 1,200-7,000 milligrams per liter)

APPROXIMATE BOUNDARY OF WATER OF POOR QUALITY—(Dissolved-solids concentration greater than 2,000 milligrams per liter)

• 21H1 DATA POINT FOR FIGURE 7

The third type of water in the Lucerne Valley is the sodium chloride type, which occurs in the vicinity of Lucerne Lake and east of it (fig. 6). Dissolved-solids concentrations generally range from 1,200 mg/L to 7,000 mg/L, averaging about 5,000 mg/L. Where historical ground-water discharge occurred, water in the playa sediments was concentrated by evapotranspiration. The origin, however, of the sodium chloride water in the deeper sand and gravel east of the exposed dry lakebed is not known. A possible explanation is that the lake may have formerly occupied an area east of the present lakebed. No evidence of buried playa deposits that would have resulted appears in the limited well-log data from this area. Gravity data show a gravity low (fig. 2) about 6 mi east of Barstow Road on Northside Road (fig. 1). If the gravity low is the site of older buried lake deposits, dissolution of evaporites in the deposits would result in ground water of poor quality.

Alfalfa, which is the primary user of water in Lucerne Valley, requires water meeting certain quality standards. It has a medium tolerance for salinity (dissolved solids) (National Academy of Sciences, National Academy of Engineering, 1972), requiring irrigation water with a dissolved-solids concentration less than 2,000 mg/L. The use of water of poor quality for irrigation of alfalfa has caused many farming attempts to fail (F. S. Riley, written commun., 1977). The part of the valley where water is too saline for irrigation (dissolved-solids concentration greater than 2,000 mg/L) is outlined in figure 6.

A review of historical chemical data fails to demonstrate a significant migration of the boundaries of this area of water of poor quality during the past 20 years, despite the large water-level declines.

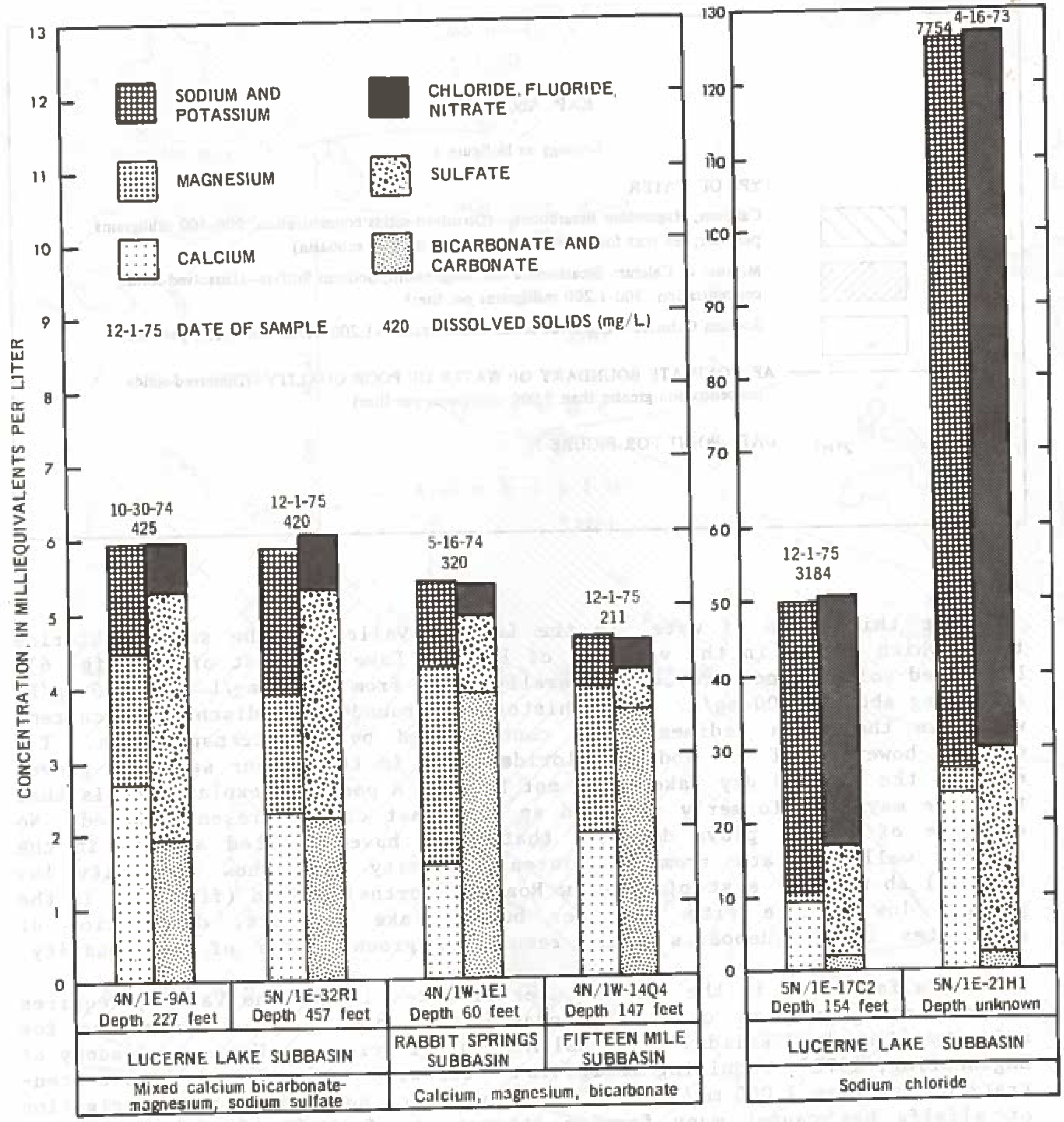


FIGURE 7.--Chemical composition of representative ground-water samples from Lucerne Valley.

WATER-LEVEL DECLINES AND ASSOCIATED PROBLEMS

Water levels in Lucerne Valley probably began to decline early in this century. Figure 8 shows water-level declines from 1917 to 1954. These declines are undoubtedly due to pumping for irrigation, although no data are available on the pumpage in this period. In 1954 about 3,500 acres was under cultivation (fig. 8).

Maximum declines from 1917 to 1954 were more than 40 ft in the northern part of the valley, near Peterman Hill, and 40 ft in the central part, southeast of the lake. Some localized declines, such as that indicated northeast of the Lucerne Lake fault, are the result of fairly large agricultural pumpage.

From 1954 to 1976, population in the valley increased 400 percent, industrial activity increased substantially, agriculture decreased, and water levels declined further, as shown in figure 9. Maximum declines, exceeding an additional 60 ft, again occurred southeast of the lake and in the northern valley area.

For the period 1917-76 a total water-level decline of 100 ft occurred in the heavily pumped irrigated acreage near the lake and about 100 ft of decline occurred near Peterman Hill.

Decline in the Rabbit Springs subbasin for the period 1954-76 in the deep aquifer was as much as 25 ft. Irrigation wells in this subbasin tap the deep aquifer exclusively because its water is of better quality than that in the shallow aquifer. Another factor contributing to the decline in the deep aquifer is the lack, or at least scarcity, of irrigation return water. The confining layer retards downward movement. Water levels in the shallow aquifer declined 10-12 ft in the period 1954-76, even though the aquifer is used primarily for domestic purposes and the water quality is poor.

The Fifteen Mile subbasin has shown some localized decline in water levels owing to limited pumping in the area, but data are too sparse to permit the drawing of lines of decline.

The hydrologic budget of a ground-water system can be expressed as

$$\text{Recharge (R)} = \text{Discharge (D)} \pm \text{Change in storage } (\Delta S).$$

Using calculated and estimated figures for 1976 to substitute in the above equation

$$1{,}000 \text{ acre-ft (R)} = 10{,}000 \text{ acre-ft (D)} - 9{,}000 \text{ acre-ft } (\Delta S).$$

Thus, ground-water discharge from the valley is estimated to have exceeded recharge to the system by 9,000 acre-ft in 1976. This removal each year of ground water from storage in quantities that far exceed recharge explains the continuing decline in water levels.

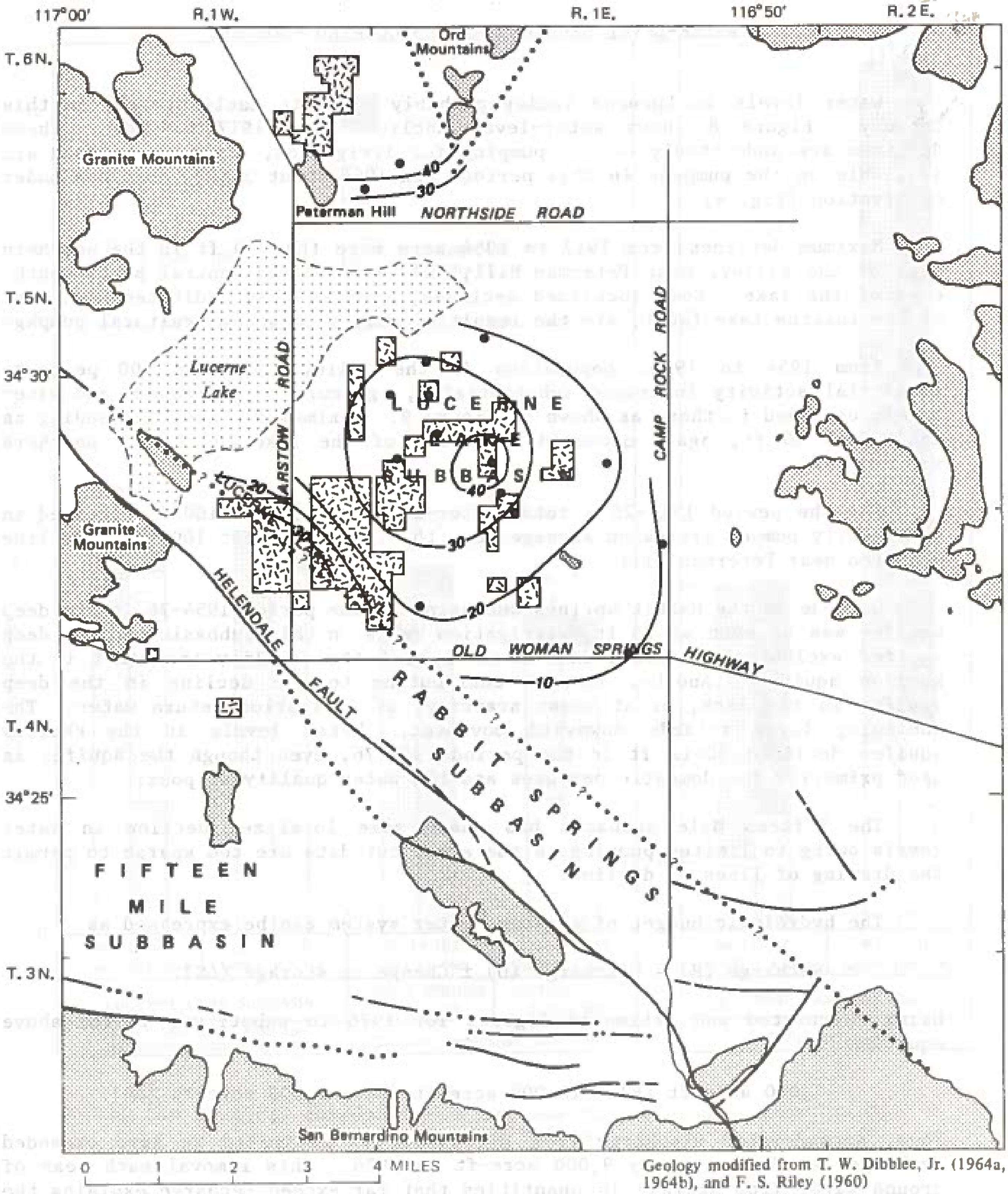


FIGURE 8.--Water-level decline, 1917-54, and irrigated area in 1954.

EXPLANATION

Geology as in figure 1

IRRIGATED AREA

—50— **LINE OF EQUAL WATER-LEVEL DECLINE–Interval 10 feet**

● **DATA POINT**

Figures 10-12 present hydrographs of six wells having long-term records. The measurements shown are mostly the spring measurements made before irrigation pumping begins. Four of the wells are in the Lucerne Lake subbasin; they had declines between 1954 and 1976 that ranged from 3.2 to 60 ft.

The water level in well 4N/1W-14P1 (Fifteen Mile subbasin) has declined 20 ft and well 4N/1W-12F1 (Rabbit Springs subbasin, tapping the deep aquifer) has declined 62 ft in the same period.

Two obvious problems associated with declining water levels are the rise in pumping costs and the drying up of shallow wells. Other problems have already been noted and more may occur in the future. One problem now developing is land subsidence. Subsidence occurs in many areas of large ground-water withdrawal. Water is stored in the pore spaces of subsurface material. When the water is removed, these spaces become smaller, owing to compaction, and the ground surface subsides. The large cracks that sometimes develop at the surface may result in damage to manmade structures. Subsidence has apparently been going on in the area for many years (Fife, 1977). The large-scale withdrawal of ground water may have caused subsidence and the resulting cracks on the valley floor and in the surface of the dry lakebed. Continued decline in water levels may cause the cracks to enlarge. These cracks, which are often many feet deep, can act as conduits permitting poor-quality surface water and irrigation return water to contaminate domestic ground-water supplies. The cracks can also be a hazard to vehicle use.

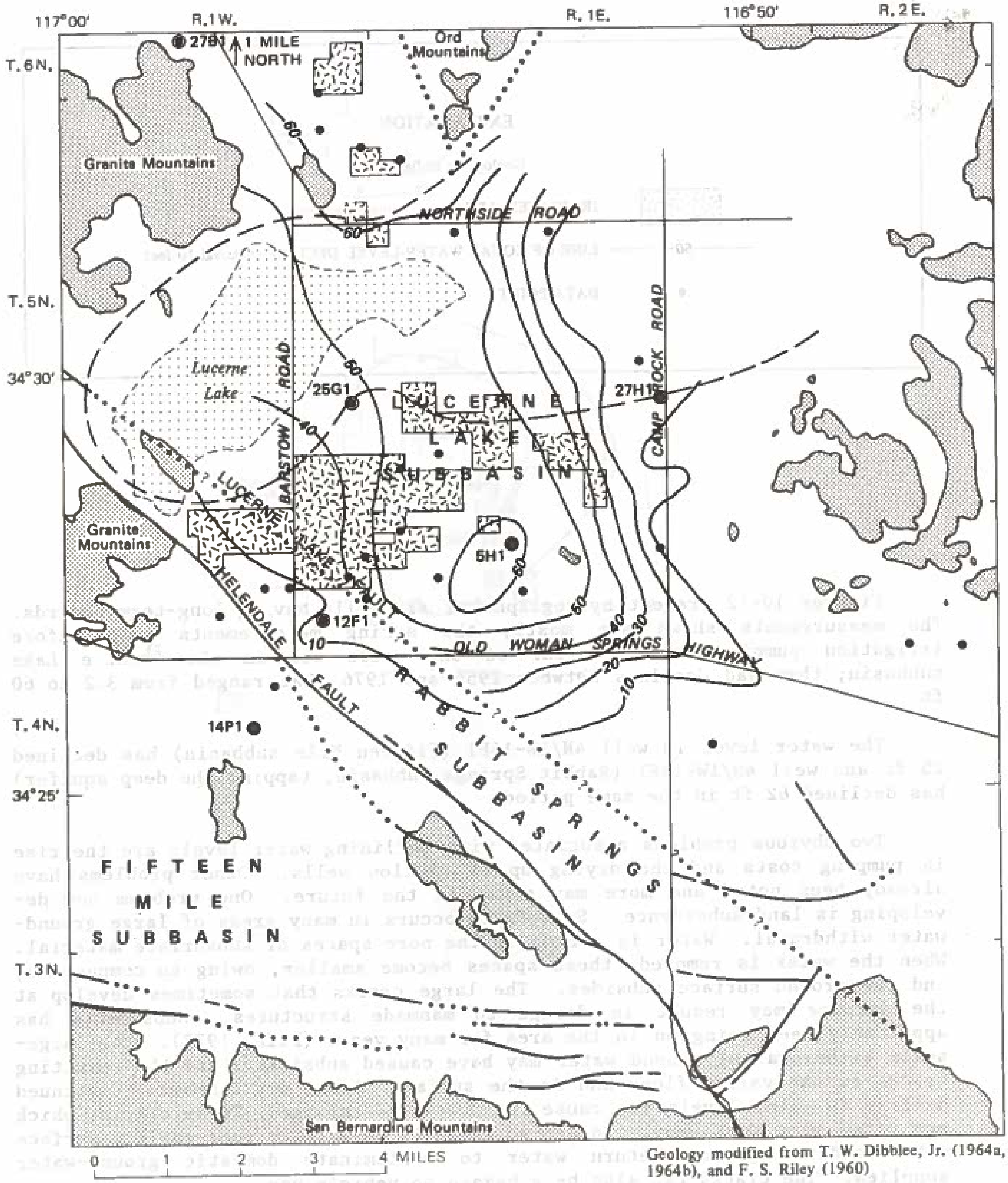


FIGURE 9.--Water-level decline, 1954-76, and irrigated area in 1976.

EXPLANATION

Geology as in figure 1

IRRIGATED AREA

APPROXIMATE BOUNDARY OF WATER OF POOR QUALITY—(Dissolved-solids concentration greater than 2,000 milligrams per liter)

50 LINE OF EQUAL WATER-LEVEL DECLINE—Interval 10 feet. In Rabbit Springs subbasin the aquifers are separated by a confining bed. Most pumping is from the deeper aquifer which is hydraulically separate from the shallow one, and the water-level decline exceeds 40 feet. See also hydrograph for well 4N/1W-12F1 in figure 12

● DATA POINT

● 14P1 WELL SITE AND NUMBER FOR HYDROGRAPHS IN FIGURES 10-12

Degradation of water quality associated with the water-level decline is not a problem at present, but it may become one if decline continues. The area of water of poor quality (dissolved-solids concentration greater than 2,000 mg/L) shown in figure 6 borders both the northern and southern water-level depressions. These depressions, if they continue to expand and deepen, can cause changes in gradient and direction of movement that will induce water of poor quality to flow into the areas of depressed water levels. If this occurs, water quality in some areas could become degraded. The water quality around these depressions should be monitored periodically to detect changes that would indicate encroachment of the mineralized water.

POTENTIAL FOR ARTIFICIAL RECHARGE TO ALLEVIATE WATER-LEVEL DECLINES

Pumpage in the valley exceeded recharge by perhaps 9,000 acre-ft in 1976. Since 1950, about 240,000 acre-ft has been removed from storage. This overdraft is the cause of the continuing water-level decline. To halt the decline, discharge and recharge would have to be equalized. To reverse the decline, recharge would have to exceed discharge substantially. To halt all discharge from the valley is an unworkable solution. Increasing recharge by artificial means is a management alternative that might be considered.

Several methods are presently in use to recharge a ground-water system artificially. Most of the methods employ either wells or surface spreading.

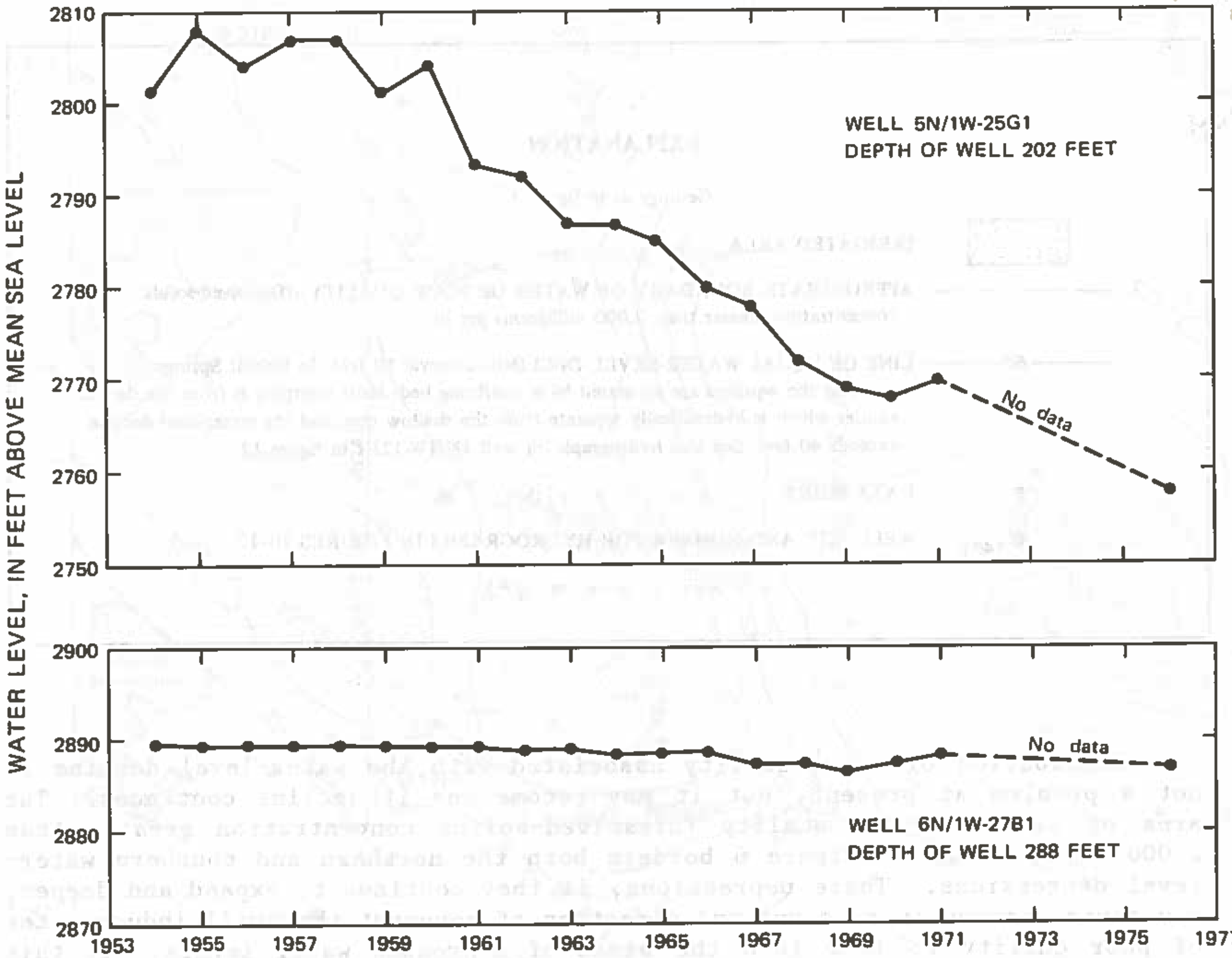


FIGURE 10.--Hydrographs of selected wells in the western part of the Lucerne Lake subbasin.

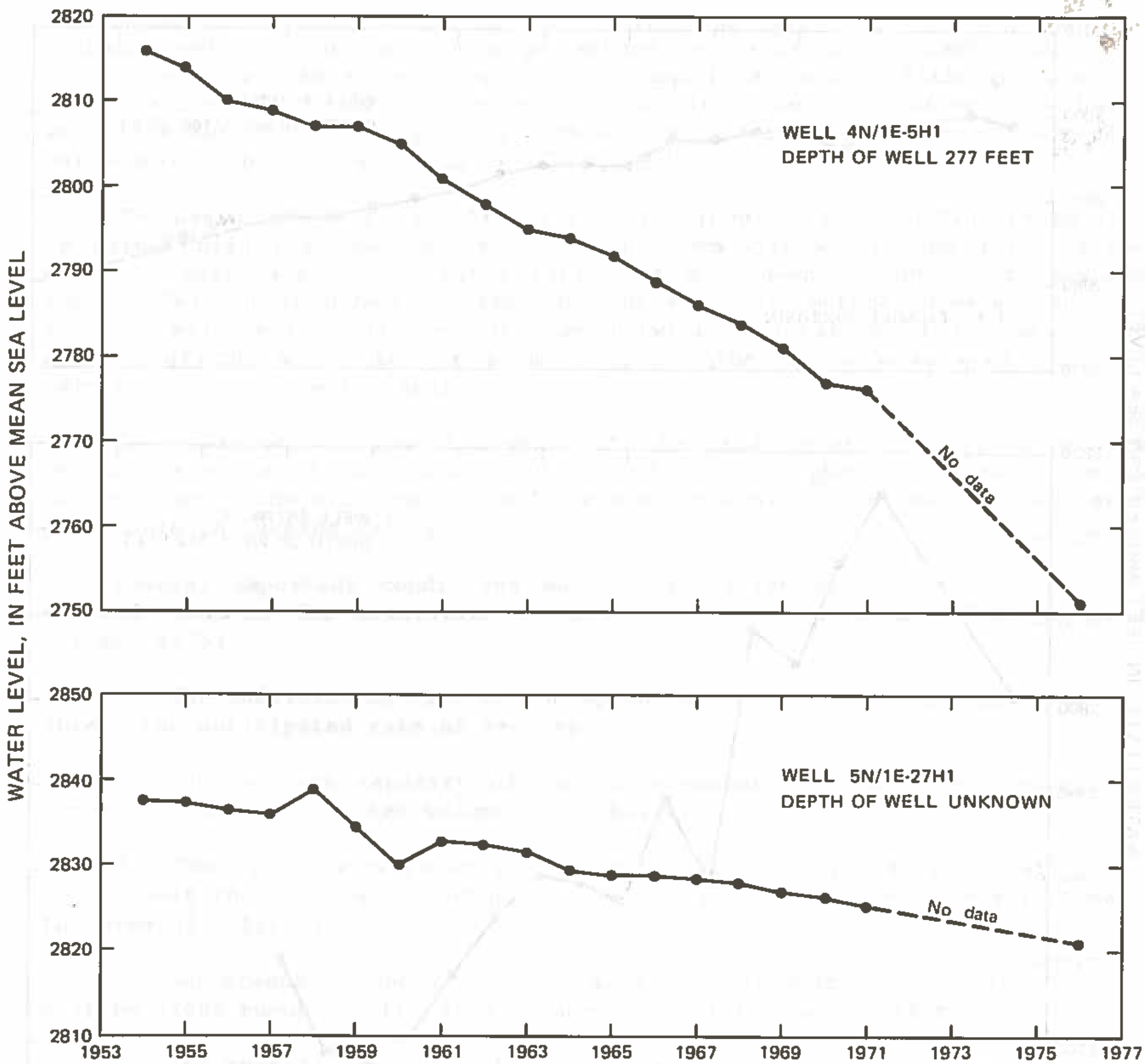


FIGURE 11.--Hydrographs of selected wells in the eastern part of the Lucerne Lake subbasin.

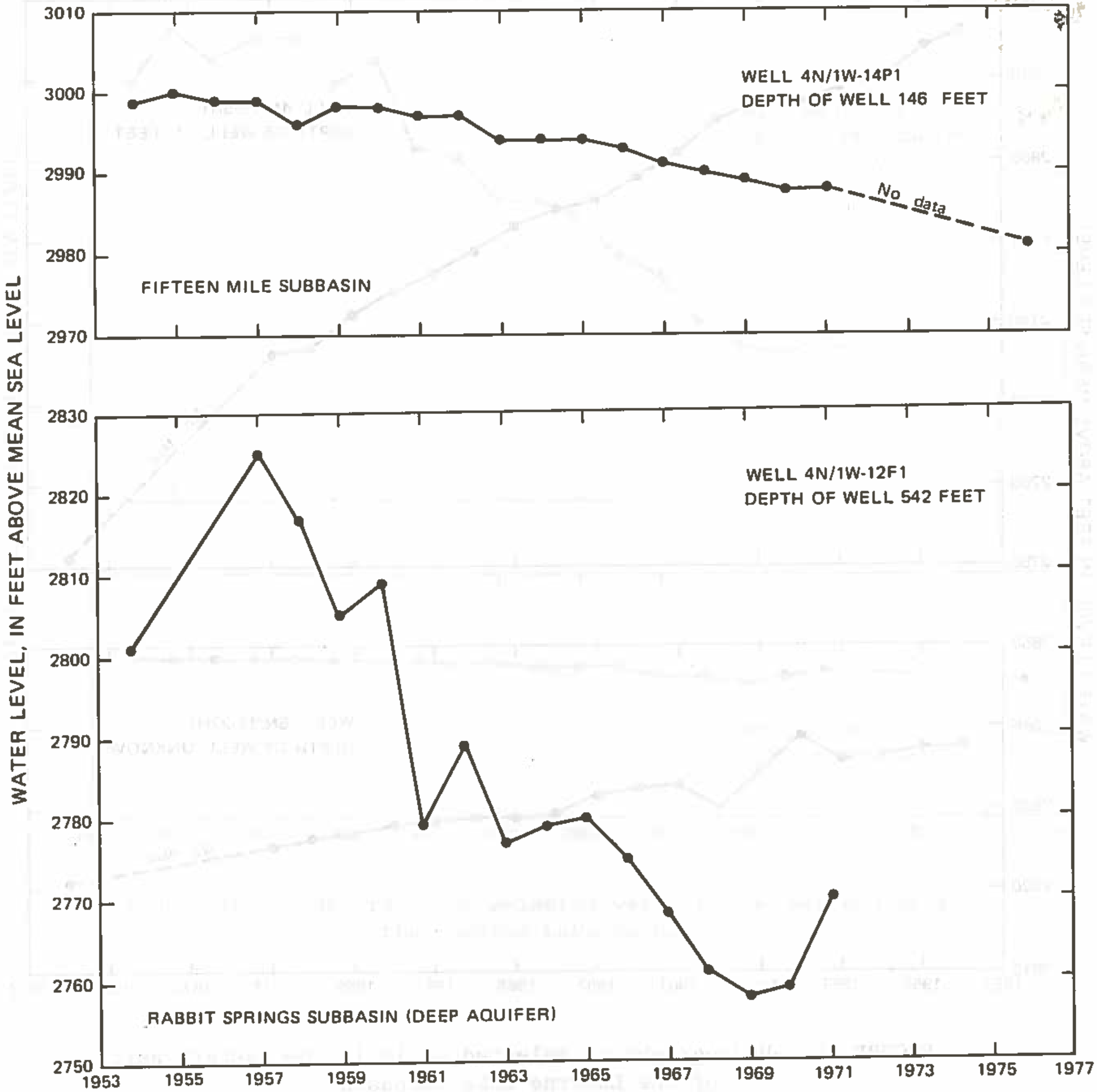


FIGURE 12.--Hydrographs of selected wells in the Fifteen Mile and Rabbit Springs subbasins.

Recharge through wells involves injecting the aquifer directly with recharge water. The well-recharge method is particularly useful in areas where space is limited or deep confined aquifers exist. Although such recharge allows the direct injection of water into the areas of need, recharge wells are subject to clogging by particulate matter in the water and are also vulnerable to biological clogging (Todd, 1959).

The basin method of artificial recharge involves constructing large pits or using unlined stream channels, filling them with water, and allowing the water to percolate to the water table and move downgradient toward pumping areas. Certain disadvantages are inherent with this method, however, such as loss by evaporation and the lag time between application of the water and arrival of the water to the area of need. The basins also need periodic maintenance to prevent clogging.

Selection of the specific method to be used is an engineering problem beyond the scope of this study, but, based on the higher inflow rates common to recharge by the basin method and the simpler design, the basin method seems preferable in Lucerne Valley.

Several important conditions must be satisfied for an area to be considered suitable for artificial recharge by the basin method (Schaefer and Warner, 1975).

1. The infiltration rate of the spreading grounds must be high enough to accept the anticipated rate of recharge.

2. The storage capacity of the ground-water basin must be adequate to accomodate the anticipated volume of recharge.

3. The transmissivity of the water-bearing material must be sufficient to transmit the water at an acceptable rate away from the recharge site toward the area of extraction.

4. An adequate supply of water must be available for recharge, and it must be close enough to the area of need to meet economic criteria.

5. The spreading grounds should be upgradient of the withdrawal areas or be so situated with respect to withdrawal areas that water moves as directly as possible from one area to the other.

6. Spreading basins should also be placed so that faults and other geohydrologic barriers do not impede the movement of recharge water.

7. The recharge water must be geochemically compatible with that in the aquifer, in order to minimize mineral precipitation and clogging of the aquifer with consequent reduction in rates of recharge.

An area in Lucerne Valley that might be suited for artificial recharge by the percolation method is shown in figure 13. The area outlined was chosen for several reasons. It is upgradient from the large pumping depression in the central part of the valley. Some well-log evidence shows that the clay confining bed is thinnest, or even missing, in that part of the Rabbit Springs subbasin, thus favoring the possibility of recharge to the shallow and deep zones. Because the Helendale fault is an effective ground-water barrier throughout its length across the valley, the Fifteen Mile subbasin would not benefit from spreading operations on the northeast side of the fault. If water-level declines in this subbasin become extensive, recharge pits on the southwest side of the Helendale fault could be considered.

The proposed spreading ground is close to the proposed alinement of the pipeline. Therefore, water will be readily available for recharge operations. The surface of the area is composed of coarse sand and gravel with little silt and clay. Although existing data are limited, a cursory examination suggests that the surface has good infiltration characteristics. To ascertain actual infiltration rates, further testing is necessary.

The storage capacity of the unsaturated zone in the area is probably large enough to accept sufficient recharge to meet needs. About 150 ft of unsaturated alluvium underlies the recharge area. Using an estimate of 2 mi^2 of infiltration area and a specific yield of 11 percent, about 20,000 acre-ft could be stored at any given time in the area. The maximum annual recharge to the ground-water system that would be possible depends on the rate the recharge water would infiltrate and move downgradient in the zone of saturation. Transmissivity values in the general area, based on limited specific-capacity-test data, average about 8,000 ft^2/d. This value is probably high enough to allow the recharge water to flow at an adequate rate toward the area of extraction.

FUTURE INVESTIGATIONS

A more detailed survey of the proposed recharge area is suggested before planning any recharge operations. The hydrologic and geologic conditions in the area are not well defined. Some possible approaches are:

1. Drill a few test holes in the area of the proposed recharge basins to better define the subsurface geology. Cores should be taken for laboratory determination of permeability and porosity for use in predicting recharge rates and effects.

2. Make infiltration tests to determine rates at which recharge water will enter the ground.

3. Make detailed surface geophysical surveys to determine depth to bedrock and its effect on the movement of recharge water.

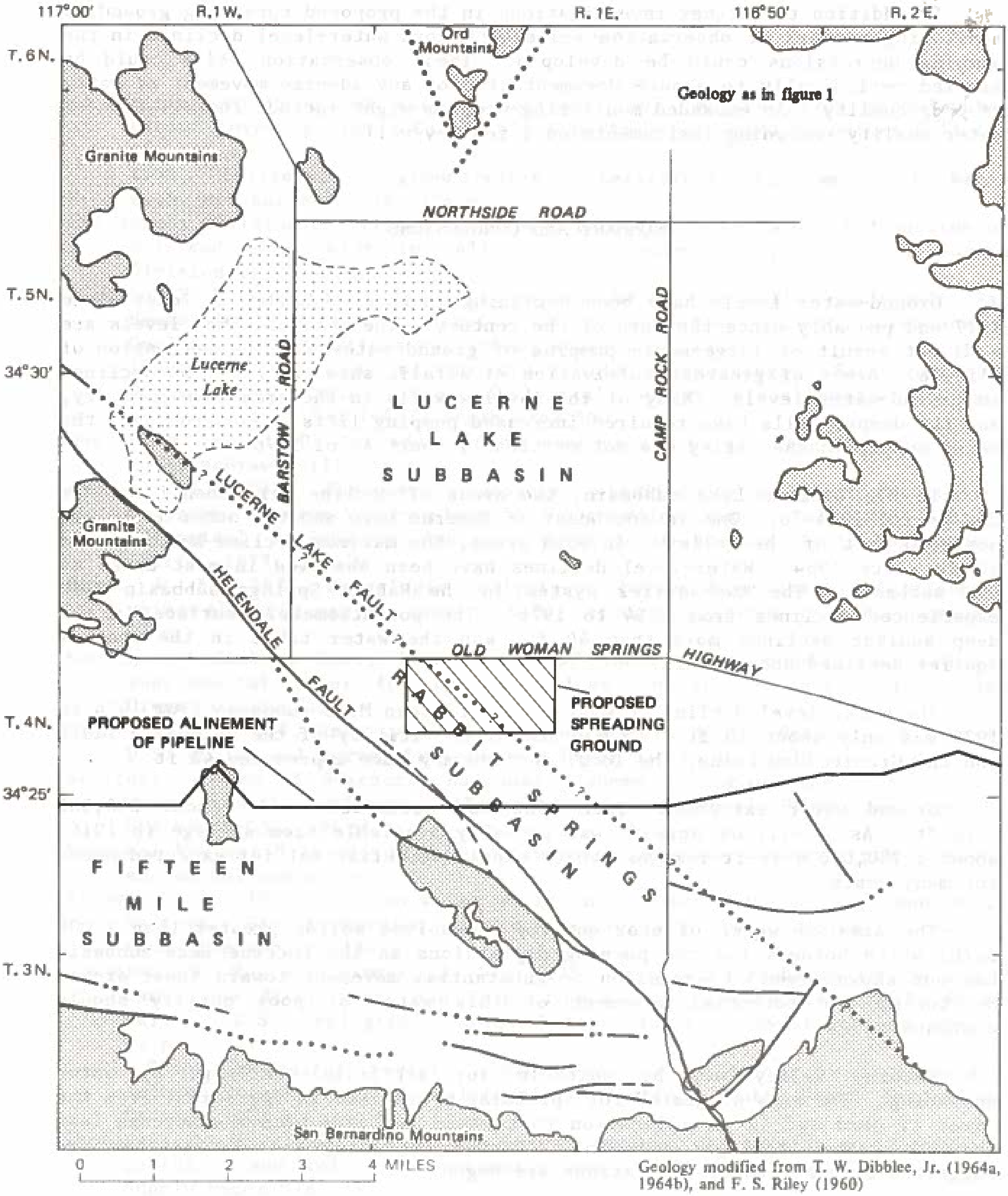


FIGURE 13.--Location of proposed spreading ground and pipeline.

In addition to further investigations in the proposed spreading ground, a monitoring network of observation wells to record water-level declines in the pumping depressions could be developed. These observation wells could be sampled periodically to assure documentation of any adverse movement of water of poor quality. An expanded monitoring program might include installation of water-quality recording instruments on a few key wells.

SUMMARY AND CONCLUSIONS

Ground-water levels have been declining in Lucerne Valley at least since 1917 and probably since the turn of the century. The lowered water levels are a direct result of large-scale pumping of ground water for the irrigation of alfalfa. Areas of greatest cultivation of alfalfa show the greatest declines in ground-water levels. Many of the shallow wells in the area have gone dry, and the deeper wells have required increased pumping lifts. Nevertheless, the water supply in the valley was not critically short as of 1976.

In the Lucerne Lake subbasin, two areas of decline were identified for the period 1954-76. One is southeast of Lucerne Lake and the other is in the northern part of the valley. In both areas, the maximum decline has exceeded 60 ft since 1954. Water-level declines have been observed in most areas of the subbasin. The two-aquifer system in the Rabbit Springs subbasin also experienced declines from 1954 to 1976. The potentiometric surface in the deep aquifer declined more than 40 ft, and the water table in the shallow aquifer declined about 10 ft.

The water-level decline in most of the Fifteen Mile subbasin from 1954 to 1976 was only about 20 ft. In the immediate vicinity of the Helendale fault and the Granite Mountains, the local decline may have approached 40 ft.

Ground water extracted since 1950 was estimated to be about 240,000 acre-ft. As 2 million acre-ft was probably available from storage in 1916, about 1,750,000 acre-ft remains, which should be sufficient for expected needs for many years.

The area of water of poor quality (dissolved solids greater than 2,000 mg/L) which borders the two pumping depressions in the Lucerne Lake subbasin has not shown signs of expansion or substantial movement toward these areas. Monitoring for potential movement of this water of poor quality should continue.

Lucerne Valley may be suitable for artificial recharge by water spreading. The area suggested for spreading operations is upgradient from the areas of need and is in a location that would recharge both the Lucerne Lake and the Rabbit Springs subbasins. Further hydrologic investigations are suggested before recharge operations are begun.

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