A GROUND-WATER-QUALITY MONITORING NETWORK FOR THE LOWER MOJAVE RIVER VALLEY, CALIFORNIA

By Linda R. Woolfenden

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 83-4148

Prepared in cooperation with the

CALIFORNIA STATE WATER RESOURCES CONTROL BOARD

June 1984

UNITED STATES DEPARTMENT OF THE INTERIOR

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[Plates are in pocket]

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CONVERSION FACTORS

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

Multiply	By	To obtain
acres	0.4047	km^2 (square kilometers)
acre-ft (acre-feet)	1233	m^3 (cubic meters)
acre-ft/yr (acre-feet per year)	1233	m^3/a (cubic meters per annum)
ft (feet)	0.3048	m (meters)
ft/d (feet per day)	0.3048	m/d (meters per day)
ft^2/d (feet squared per day)	0.0929	m^2/d (meters squared per day)
ft/mi (feet per mile)	0.1894	m/km (meters per kilometer)
ft/yr (feet per year)	0.3048	m/a (meters per annum)
ft^3/s (cubic feet per second)	0.02832	m^3/s (cubic meters per second)
(gal/min)/ft (gallons per minute per foot)	0.01242	m^2/min (meters squared per minute)
gal/min (gallons per minute)	0.003785	m^3/min (cubic meters per minute)
(gal/d)/ft (gallons per day per foot)	0.01242	m^2/d (meters squared per day)
inches	25.4	mm (millimeters)
Mgal/d (million gallons per day)	3785	m^3/d (cubic meters per day)
mi (miles)	1.609	km (kilometers)
mi^2 (square miles)	2.590	km^2 (square kilometers)
µmho/cm at 25°C (micromhos per centimeter at 25° Celsius)	1.000	µS/cm at 25°C (microsiemens per centimeter at 25° Celsius)

Degrees Fahrenheit (°F) is converted to degrees Celsius (°C) by using the formula: Temp °C = (temp °F - 32)/1.8.

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

Water Year: The water year starts October 1 and ends September 30; it is designated by the calendar year in which it ends.

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ABSTRACT

A ground-water-quality monitoring network was developed for the Lower Mojave River valley to define and monitor the ground-water quality of the entire valley. The network was designed by the U.S. Geological Survey in cooperation with the California State Water Resources Control Board.

This report describes factors influencing water quality of the Lower Mojave River valley such as basin geohydrology, geology, water quality, and land use. Based on these factors, ground-water-quality monitoring objectives were developed and used in selecting well locations for a conceptual ground-water-quality monitoring network. The conceptual network was used as a guide in the design of the ground-water-quality monitoring network. Active monitoring sites, wells that are currently being monitored, were selected whenever possible because of budgetary constraints. Thirty-three active monitoring sites are included in the network. In areas where there are no wells being monitored, new well locations were selected where there may or may not be existing suitable wells. These new locations are considered proposed monitoring sites. Wells at one time were known to exist at 65 of these proposed locations (and still may), however, three of the locations have never had a well. Drilling is suggested at the proposed locations where there are no wells.

A review of the objectives after the initial water-quality samples are collected for the 68 proposed sites would aid in evaluating the feasibility of the network design. Subsequent reviews could be made when new water-quality problems arise.

INTRODUCTION

The Porter-Cologne Water Quality Act delegates the responsibility of protecting ground-water quality in the State of California to the State Water Resources Control Board and the Regional Water Quality Control Boards. Ground-water-quality monitoring networks for specific ground-water basins (designated as Priority I basins by the State) would be helpful to determine existing ground-water quality and to detect changes in ground-water quality. The Lower Mojave River valley is designated as one such basin. This report describes a ground-water-quality monitoring network, including active and proposed sites, for the Lower Mojave River valley, and the methodology used and factors considered in the development of the network.

The Lower Mojave River valley is in San Bernardino County about 100 miles northeast of Los Angeles (fig. 1). The valley is a large, sparsely populated area undergoing growth. Residential and industrial areas are concentrated in the western part; agriculture is concentrated in the eastern part of the valley. Ground-water quality is diverse, ranging from very poor to very good.

Purpose and Scope

This report summarizes the third phase of a three-phase study by the U.S. Geological Survey in cooperation with the California State Water Resources Control Board. Phase 1 was a reconnaissance survey of active ground-water-quality monitoring networks in selected basins. Phase 2 was a detailed inventory of operating ground-water-quality networks and individual monitoring sites for each basin. Phase 3, which is described in this report, is the design for the basinwide ground-water-quality monitoring networks. The data collected in phase 2 were used where possible in selecting the monitoring sites for the proposed network. The purposes of the network are to determine background water-quality conditions, extent and degree of water-quality change with time, and impact of land use (pollution sources) on ground water in the Lower Mojave River valley.

A major part of phase 3 was to collect background data and information from published reports. Basin geology, hydrology, land use, water quality, and pollution sources were studied in order to design the ground-water-quality monitoring network effectively. This background information is presented in the report and may be useful for subsequent revisions of the network.

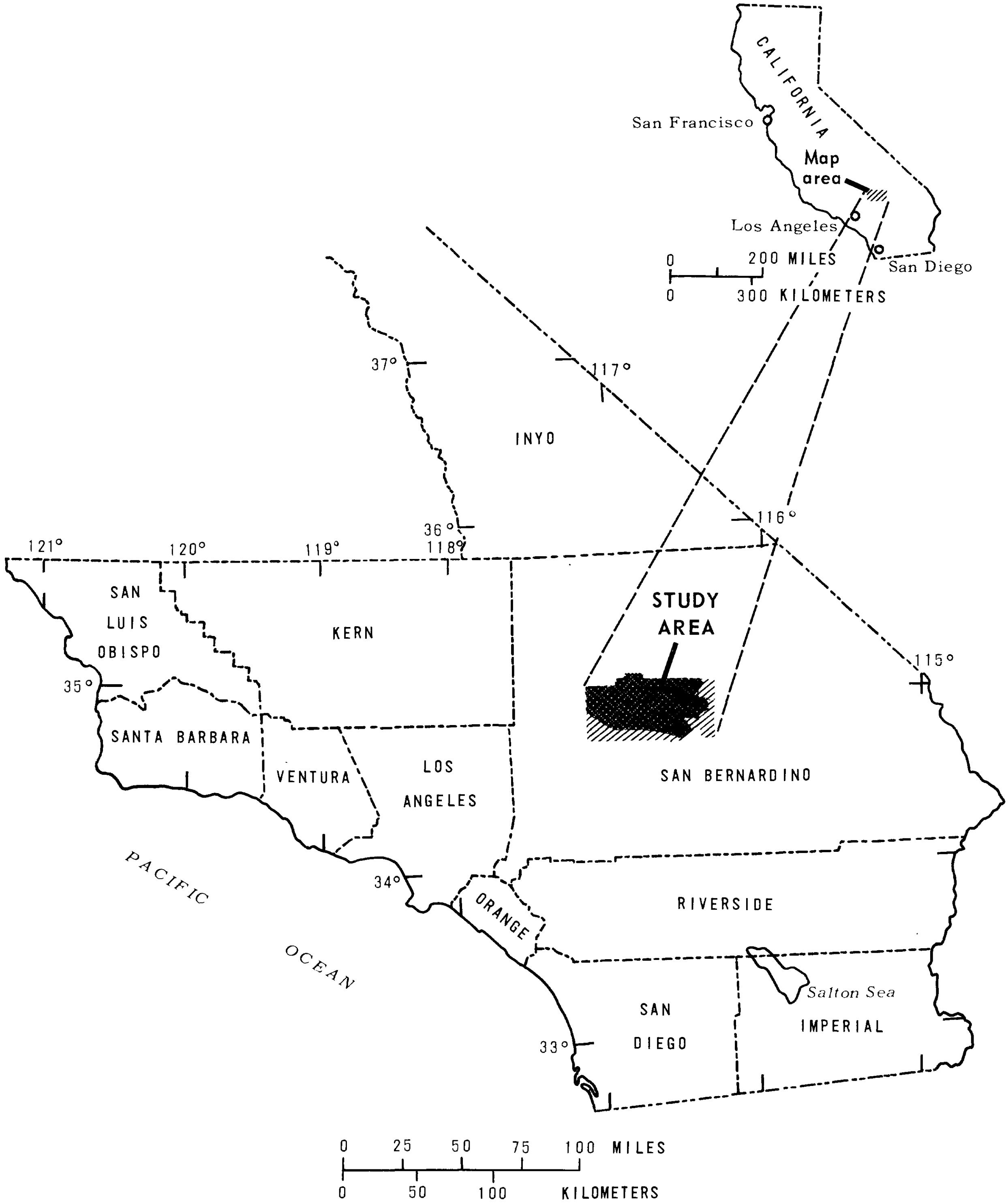


FIGURE 1.--Location of study area.

Approach

Hydrologic conditions, geologic characteristics, water quality, and land use in the Lower Mojave River valley were reviewed from previous reports. A conceptual network of wells or sites that should be monitored was designed without consideration of whether the wells were active or even existed at the chosen monitoring sites. Budgetary constraints were not considered. Development of the conceptual network was based on land use, hydrologic conditions, existing water-quality and water-level data, and extent and location of ground-water degradation. Data and information for most of the valley are as old as 25 years. For the Barstow area, however, current data and information are available.

The conceptual network was used as a guide in selecting monitoring sites that comprise the network to be implemented. Stringent budgetary constraints require that only active sites, currently being monitored by some agency, be used in the network. Few existing sites fit the conceptual network criteria; hence, other monitoring sites were proposed. A suite of water-quality constituents for analysis was also developed based on the factors affecting ground-water quality. A sampling frequency was also suggested.

A computer search was made for data useful in defining ground-water quality in the Lower Mojave River valley. One data base searched was WATSTORE, which contains water-resource data collected by the U.S. Geological Survey. One retrieval was made listing all wells in the area having values for specified constituents. A second retrieval was made screening for those chemical constituents that exceed U.S. Environmental Protection Agency recommended criteria (National Academy of Sciences, National Academy of Engineering, 1973). Another search was made in the U.S. Environmental Protection Agency's STORET data base for information collected by agencies other than the U.S. Geological Survey. No data for the Lower Mojave River valley were stored in STORET.

The emphasis of this report was placed on the Lower Mojave River valley, shown as the phase 2 study area on plate 1. However, Coyote Lake Valley and Caves Canyon Valley were included (pl. 1) because of two conditions. First, pumping in the Coyote Lake Valley has created a gradient toward the lake. Second, Afton Canyon in Caves Canyon Valley is the only point of outflow from the area, and the ground-water quality there reflects all influences from upstream conditions.

Project Limitations

The major project limitation was the absence of current water-quality data, hydrologic information, land uses, and possible sources of pollution for much of the area. As a result, the basis for the network well selection was varied. Numerous water-quality analyses have been made of water in the Barstow area and several reports that include the water-quality problems, hydrology, and pollution sources in the area have been written. The network for the rest of the area was based mainly on well locations published in California Department of Water Resources Bulletin 91-10 (Dyer and others, 1963), and sparse hydrologic, water-quality, and land-use information from other sources.

No field work was budgeted for this study. One set of chemical water-quality analyses and water-level measurements at the beginning of the project would have been of great help in well selection. Although such data cannot substitute for years of water-quality and water-level records, they could have aided in the design of the network.

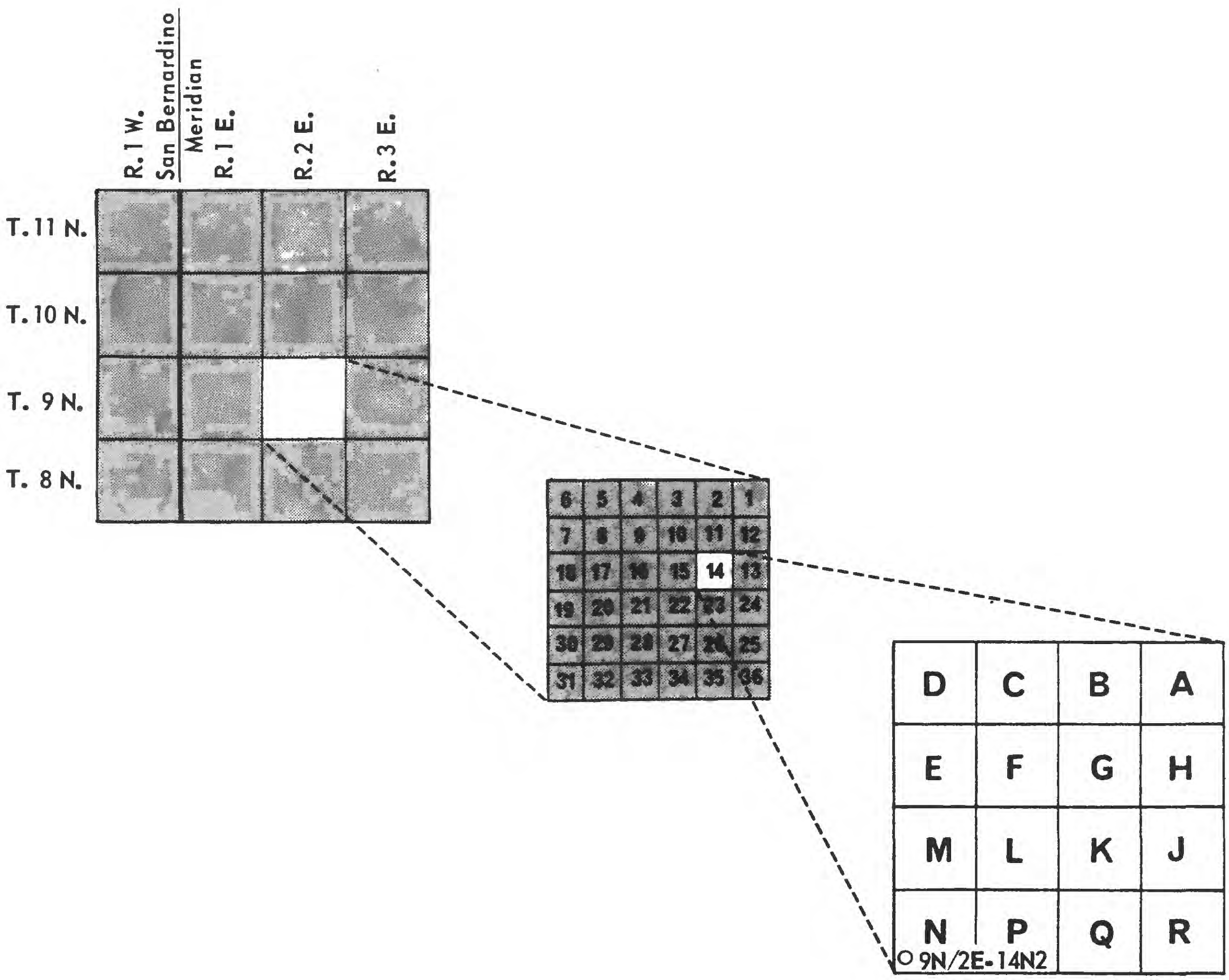
Other project limitations were an absence of well logs and well-construction data, such as depths and perforated intervals. A limited amount of current information was available for the Barstow, Yermo, and Daggett area (WATSTORE); California Department of Water Resources Bulletin 91-10 (Dyer and others, 1963) provided information for the rest of the area. Construction data were not available for many wells selected for the monitoring network.

Acknowledgments

The author appreciates the assistance from the staff of the California Water Quality Control Board--Lahontan Region, and, in particular, Robert Dodds and Michael B. Wochnick who provided information on permitted discharges; from Marvin Krieger of the San Bernardino County Planning Department for providing information on location of dairies in the study area; and from Wolfgang Koster of the Mojave Water Agency who provided general information about the Lower Mojave River valley.

Well-Numbering System

Wells are numbered according to their location in the rectangular system for the subdivision of public land. That part of the number preceding the slash, as in 9N/2E-14N2, indicates the township, north (T.9 N.); the part following the slash indicates the range, east (R. 2 E.); the number following the hyphen indicates the section (sec. 14); the letter following the section number indicates the 40-acre subdivision according to the lettered diagram below. The final digit is a serial number for wells in each 40-acre subdivision. The area covered by the report lies entirely north of the San Bernardino base line and both east and west of the San Bernardino meridian.



Location and General Features

The Lower Mojave River valley (including Coyote Lake Valley and Caves Canyon Valley) in the Mojave Desert region in the west-central part of San Bernardino County (pl. 1), is an east-west-trending alluvial basin covering about 1,200 mi^2. Altitudes range from 1,760 feet in the valley to more than 4,000 feet in the surrounding mountains.

The study area is bounded on the east by the Cady Mountains and on the southeast by the Pisgah fault, a ground-water barrier. The southwest boundary is formed by the Lockhart fault which trends northwest and also forms a ground-water barrier. The northwest boundary is arbitrary and corresponds to the west edge of T. 10 N. and R. 2 W. The Newberry Mountains form the south boundary and the north boundary generally corresponds to the north edge of T. 11 N.

A dominant physical feature of the region is the Mojave River channel, the major source of recharge to aquifers in the study area. The river channel originates in the San Bernardino Mountains about 50 miles southwest of Barstow and ends at Silver Dry Lake, about 60 miles east of Barstow. Surface-water outflow from the study area is measured at Afton Canyon in the Cady Mountains.

The main population center in the study area is the city of Barstow; other communities include Yermo, Daggett, Minneola, Newberry Springs, and Harvard. The U.S. Marine Corps operates a supply center at Nebo (near Barstow), with an annex at Yermo, and the U.S. Army has a flight training center in the Daggett area (formerly a U.S. Marine Corps supply center). A large railway maintenance yard for the Atchison, Topeka and Santa Fe is located in the Barstow area. There are numerous manmade recreational lakes, and agricultural development is scattered throughout the study area but occurs mostly in the east part. Also, there is a small airport near Daggett.

The Newberry area is defined as a 130-mi^2 area bounded by the Calico Mountains on the north, the west edge of T. 9 and 10 N., R. 2 E. on the west, the Newberry Mountains on the south, and the Cady Mountains on the east. This area includes the communities of Daggett, Minneola, and Newberry Springs. Other locations, such as the Barstow area, refer to the named community and its immediate vicinity.

HYDROLOGY

Surface Water

The main source of surface-water flow in the Mojave River is runoff from the San Bernardino Mountains. Surface-flow contributions from other stream drainages are inconsequential. Surface-water flow in the study area is ephemeral except at two points along the Mojave River: at Camp Cady in T. 10 N., R. 3 E, and Afton Canyon at the extreme northeast boundary of the study area (pl. 1). At Camp Cady, clay deposits cause ground water to rise to the surface. Mean annual surface-water flow was estimated from data obtained from gaging stations at Barstow and Afton. For the water years 1931 through 1961, mean annual flow at Camp Cady was determined to be 12,200 acre-ft; 11,300 acre-ft was due to stormflow and 900 acre-ft was because of baseflow which is discharge of ground water into the river channel (California Department of Water Resources, 1967).

At Afton, a rather thin layer of alluvium overlies bedrock and constrictions in the cross-sectional area of the water-bearing materials result in perennial streamflow (California Department of Water Resources, 1967). At Afton, extremes in yearly streamflow ranged from 93 acre-ft in 1979 to 72,730 acre-ft in 1969. Mean annual outflow for the period was 6,970 acre-ft, and baseflow was 198 acre-ft (U.S. Geological Survey, 1970, 1971-74, 1974, 1975-80). Table 1 shows the yearly flow, in acre-feet, for water years 1961 through 1980 at gaging stations at Barstow and Afton.

Streamflow gaged at Barstow (table 1) consists entirely of storm runoff from the San Bernardino Mountains. November through March is generally the wet period and streamflow usually occurs at this time. At other times of the year the channel is dry. Data from table 1 show that no flow or minimal flow conditions prevailed for several years at Barstow. Extremes in annual streamflow ranged from no flow to 146,600 acre-ft, averaging 17,757 acre-ft for the 20-year period.

In the 1969 and 1978 water years, the Mojave River drainage area received 2.3 times the mean annual precipitation which resulted in flooding along the Mojave River. Maximum peak flow at Barstow was 30,000 ft^3/s in 1969, and 11,600 ft^3/s in 1978. At Afton, maximum peak flows were 18,000 ft^3/s in 1969, and 6,970 ft^3/s in 1978 (Buono and Lang, 1980).

Considering data from the period 1932-78, average intervals between discharge peaks were 9 years at Barstow and 15 years at Afton. Maximum surface-water discharge for the 1969 water year was 71,480 acre-ft at Barstow, and 31,180 acre-ft at Afton in February 1969. For the 1978 water year, maximum surface-water discharge was 69,950 acre-ft at Barstow and 26,820 acre-ft at Afton, in March 1978 (Buono and Lang, 1980).

TABLE 1. - *Streamflow in the Mojave River at Barstow and Afton, 1961-80*

Water year	Streamflow[1] (acre-feet)	
	Barstow	Afton
1961	No flow	566
1962	733	539
1963	0.2	751
1964	.8	563
1965	6	668
1966	6,350	4,780
1967	7,690	1,470
1968	1	357
1969	146,600	72,730
1970	No flow	543
1971	do.	360
1972	44	597
1973	.3	310
1974	.42	436
1975	.3	158
1976	1	296
1977	2	898
1978	50,460	46,740
1979	5,560	[2]93
1980	137,700	[2]6,550
Average 1961-80	17,757	6,970

[1]Total of daily means.
[2]Estimated; gaging station destroyed in 1978 flood.

Surface-Water Quality

Stormflow of the Mojave River is primarily of a calcium bicarbonate type and has a dissolved-solids concentration about 400 mg/L (milligrams per liter), as compared with most of the ground water. The perennial streamflow at Afton Canyon is primarily of a sodium bicarbonate chloride type and is poorer in quality than at upstream locations. Dissolved-solids concentration was about 900 mg/L in 1962 (California Department of Water Resources, 1967); the rate of discharge and whether or not the sample represents only a single sample is not known.

High surface-water discharges along the Mojave River result in large volumes of ground-water recharge because of the highly permeable river-channel deposits and large area for recharge. These conditions could dilute degraded ground water in storage, contribute to better water quality downstream, and contribute to the downgradient movement of degraded water whether or not dilution occurs.

Geohydrology

The geology of the study area has been described in previous reports by Dyer and others (1963), California Department of Water Resources (1967), Miller (1969), and Hardt (1971). Generally, the basin consists of consolidated rocks that compose the surrounding mountain ranges and underlie unconsolidated deposits that compose the lower parts of the basin. Faults are generally northwest trending and some act as barriers to ground-water movement (pl. 1). Names for the faults were taken from a fault map of California published by the California Division of Mines and Geology (Jennings and others, 1975).

Geologic Formations and their Water-Bearing Characteristics

The consolidated rocks in the study area comprise three groups--the pre-Tertiary basement complex, Tertiary continental and volcanic deposits, and Quaternary basalts. The basement complex is composed of granite, quartz diorite, granodiorite, quartz monzonite, and metamorphosed sedimentary and volcanic rocks (Dyer and others, 1963). These rocks yield small amounts (generally less than 5 gal/min) of water to wells where weathered or fractured.

The Tertiary continental sedimentary deposits are mostly poorly sorted and impermeable. These deposits consist of conglomerate, sandstone, siltstone, mudstone, shale, and limestone (Miller, 1969). Soluble materials such as gypsum and borates occur locally in these rocks and may contribute to poor chemical quality of ground water. These rocks are virtually dry, but where fractured may yield small amounts of water to wells.

The Tertiary volcanic rocks and Quaternary basalts are generally impermeable, but may yield small quantities of water where highly fractured.

The unconsolidated deposits overlie the consolidated rocks and consist of older alluvium, older fan deposits, river-channel deposits, younger alluvium, younger fan deposits, playa deposits, lacustrine deposits, and dune sand. All were deposited during the Quaternary Period.

The most important aquifers are the older alluvium, river-channel deposits, and, in some areas, older fan deposits. The older alluvium is of Pleistocene age and underlies most of the valley. This deposit is formed mainly of interbedded lenses of clay, silt, sand, and gravel, and is cemented with caliche in places. Thicknesses range from a few inches to 1,000 feet (Hardt, 1971). The older alluvium is permeable, extends below the water table, and yields moderate to large quantities, commonly 200 to 1,000 gal/min, of water to wells. However, wells in the older alluvium in the Daggett area yield as much as 2,000 gal/min (Hardt, 1971). This alluvium contains most of the ground water in storage (Hardt, 1971). Water in these deposits is generally suitable for most purposes, but in places has high concentrations of dissolved solids, boron, and fluoride.

River-channel deposits of Holocene age consist of fine sand in the channel and coarse sand on the flood plain, and contain occasional lenses of clay, gravel, and boulders. River-channel deposits are 0.25 to 1.50 miles wide, as much as 100 feet thick, and are highly permeable (Hardt, 1971). They yield moderate to large quantities of water, from a few hundred to more than 1,000 gal/min to wells (Hughes, 1975), and transmit water to older deposits. River-channel deposits yield most of the water that is pumped in the Barstow area for municipal and domestic purposes.

Older fan deposits of Pleistocene age commonly are near the mountain ranges and consist of gravel with boulders, cobbles, sand, silt, and clay (Dyer and others, 1963). In some places these deposits are cemented with caliche (Hardt, 1971). They range from a few inches to more than 800 feet in thickness (Miller, 1969). Where saturated, they yield small to moderate quantities (5 to 50 gal/min) of water to wells. Older fan deposits are localized (Barstow area) and contain water that is generally of poor quality.

Younger alluvium and younger fan deposits of Holocene age consist of clay, silt, sand, and gravel; the younger fan deposits also contain abundant boulders. Both deposits are permeable and where saturated, yield water freely to wells; however, they are mostly above the water table. Where saturated, younger alluvium generally yields less than 300 gal/min, and younger fan deposits yield from a few to about 1,200 gal/min (California Department of Water Resources, 1967). Younger alluvium ranges from a few inches to 100 feet in thickness; younger fan deposits range from a few inches to about 75 feet in thickness (California Department of Water Resources, 1967). Both deposits transmit water to deeper units.

Playa deposits of Holocene age are located in the lowest parts of the basin. They are as much as 25 feet thick and have low permeability (California Department of Water Resources, 1967). If saturated, they may yield small amounts of water that commonly contain high concentrations of dissolved solids.

Lacustrine deposits of Pleistocene age, consisting of clay, silt, and sand, are exposed in the Caves Canyon Valley just northeast of Harvard. These deposits are intermittent throughout the Newberry area and may result in localized perched ground-water conditions. However, these deposits are generally below the water table.

Holocene dune sand, generally located near playas and the Mojave River is porous and permeable, but generally is above the water table and is not a significant source of ground water.

Geologic sections of consolidated rocks and unconsolidated deposits are shown on plate 1. Section *A-A'* is for the Barstow and Yermo areas and also shows the spring 1966 water table; section *B-B'* is for the Newberry area.

Faults

Three major northwest-trending faults and one east-trending fault (pl. 1) in the study area act as ground-water barriers. The Harper fault can be traced for several miles north of the Mojave River. South of the river, however, it is concealed by sediments. The fault acts as a ground-water barrier in the vicinity of the U.S. Marine Corps Supply Center at Nebo. In 1965, at the south end of the fault, water levels were about 50 feet higher on the west side than on the east side of the fault (Miller, 1969); in 1977 and 1979 (after the 1978 flood) the differences were 40 feet and 15 feet, respectively (Eccles, 1981).

The Camp Rock fault may also act as a ground-water barrier (Miller, 1969). It trends northwest through the Newberry Mountains to a point about 4 miles south of Daggett where it is buried by fan deposits. The fault probably extends farther northwest as indicated by the older fan deposits which have been uplifted west of the U.S. Marine Corps firing range.

The Calico fault trends northwest and extends from the Newberry Mountains to the Calico Mountains. This fault is a barrier to ground-water movement except along the northwest section from the Mojave River to a point just east of Yermo. Differences in water levels across the fault have been as much as 60 feet (Miller, 1969).

The Manix fault trends eastward and acts as a ground-water barrier near Harvard Hill (pl. 1). Differences in water levels across the fault have been as much as 60 feet (Dyer and others, 1963).

Ground Water

The occurrence and direction of ground-water movement controls to a large degree the choice of monitoring-site locations. Recharge can improve or degrade the quality of ground water in storage. Discharge through evaporation and transpiration may have a negative effect on ground-water quality.

Occurrence and Movement

Ground water in the Lower Mojave River valley generally moves in a northeast direction, roughly parallel to the Mojave River. There is no known ground-water outflow from the study area; however, outflow does occur from the Lower Mojave River valley to Coyote Lake and Caves Canyon Valleys. Ground-water inflow from valleys west of the Lower Mojave River valley occurs near Barstow and in the northwest into Coyote Lake Valley.

The altitude of water levels in wells and the direction of ground-water movement as of about 1960 are shown in figure 2. There is an absence of current water-level data for the Lower Mojave River valley; hence, measurements taken from 1958-81 were used; the contours are indicative only of the general direction of ground-water movement. A few pumping depressions in the study area, notably at the U.S. Marine Corps Supply Center at Nebo and southeast of Coyote Lake, may impede ground-water movement in the northeast direction. These depressions are shallow and cannot be seen in figure 2 because their depth is less than the 20- and 50-foot contour intervals.

Ground-water levels range from land surface to depths of more than 300 feet but commonly are less than 100 feet below land surface. Water levels are near the land surface at the community of Newberry Springs, where the Calico fault acts as a ground-water barrier and causes the ground water to rise to the surface. Another area where water levels are at the surface is at Camp Cady, where impermeable layers force ground water to the surface. Some wells flow at the northwest end of Coyote Lake, where a confining layer results in artesian pressure. However, most of the aquifers in the study area are unconfined.

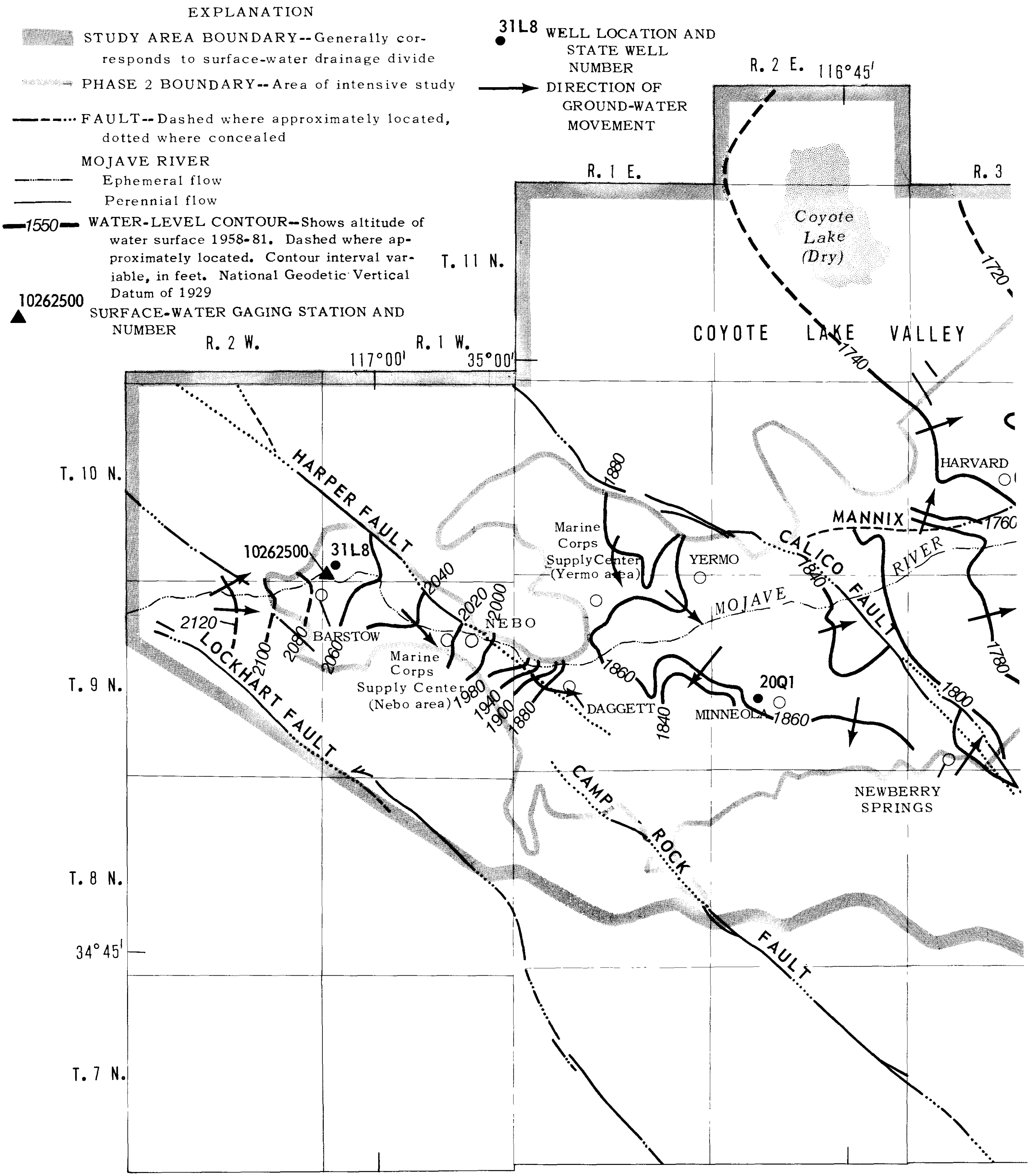


FIGURE 2.--Water-level contours and direction of ground-water movement.

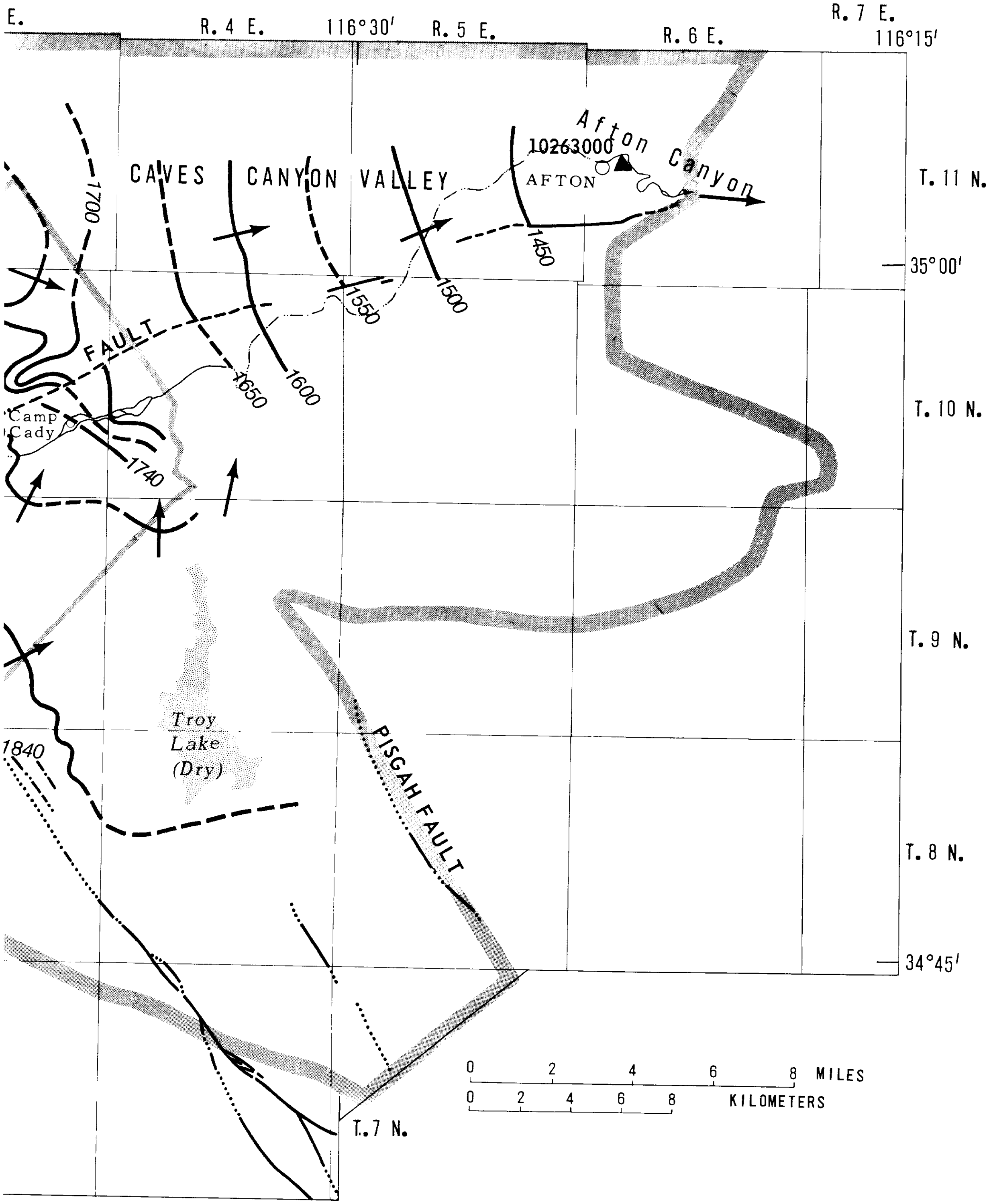


FIGURE 2.—Continued.

The Mojave River has an average gradient of 15 to 20 ft/mi throughout its length, from the base of the San Bernardino Mountains to Soda and Silver playa lakes 60 miles east of Barstow (San Bernardino County, 1982). In the Lower Mojave River valley the gradient varies. In general, along the Mojave River channel the ground-water gradient is fairly steep and ground-water moves at greater velocities than in areas away from the river where the gradient is flatter. Upstream from the Harper fault, along the Mojave River channel, the gradient is 10 to 15 ft/mi, whereas a steeper gradient prevails downstream from the fault (Hughes, 1975). In the Newberry area, away from the Mojave River channel, the water table slopes toward the northeast at a gradient of only about 6.8 ft/mi (San Bernardino County, 1982). From the Yermo area to the Calico fault, the ground-water gradient is similar to that of the Newberry area. From the Calico fault to the Cady Mountains along the river channel, the gradient again steepens, averaging 21 ft/mi (California Department of Water Resources, 1964).

The average velocity of ground-water flow in the river channel deposits, starting at the base of the San Bernardino Mountains 60 miles west of Barstow and ending 60 miles east of Barstow where the river terminates, is estimated (Thibeault and Saari, 1981) to be 1,000 to 1,500 ft/yr. In the Barstow area, the average velocity of ground-water flow is estimated to be 360 ft/yr (Hughes, 1975). The velocity is modified in locations where ground-water movement is affected by geologic conditions.

In general, transmissivities range from 3,350 ft^2/d (25,000 (gal/d)/ft) to more than 26,800 ft^2/d (200,000 (gal/d)/ft) (Hardt, 1971) in the river-channel deposits of the Mojave River. Away from the river channel, in the southern part of the basin between Daggett and Newberry Springs, transmissivities range from 13,400 ft^2/d (100,000 (gal/d)/ft) to 20,100 ft^2/d (150,000 (gal/d)/ft). Transmissivities in other areas, away from the river channel, range from 3,350 ft^2/d (25,000 (gal/d)/ft) to 6,700 ft^2/d (50,000 (gal/d)/ft) (Hardt, 1971).

Recharge

Sources of recharge for the Lower Mojave River valley are rainfall, intermittent streamflow from the surrounding mountains, underflow from the Middle Mojave River valley, and stormflow in the Mojave River. In the Barstow area, additional sources of recharge are sewage effluent and irrigation return.

Infiltration from rainfall and intermittent streams is minor. Mean annual precipitation for the valley ranges from 4 to 5 inches (Rantz, 1969). Storms are usually of short duration and the evaporation rate is high. Runoff from intermittent streams tends to accumulate on impermeable playa deposits and is evaporated.

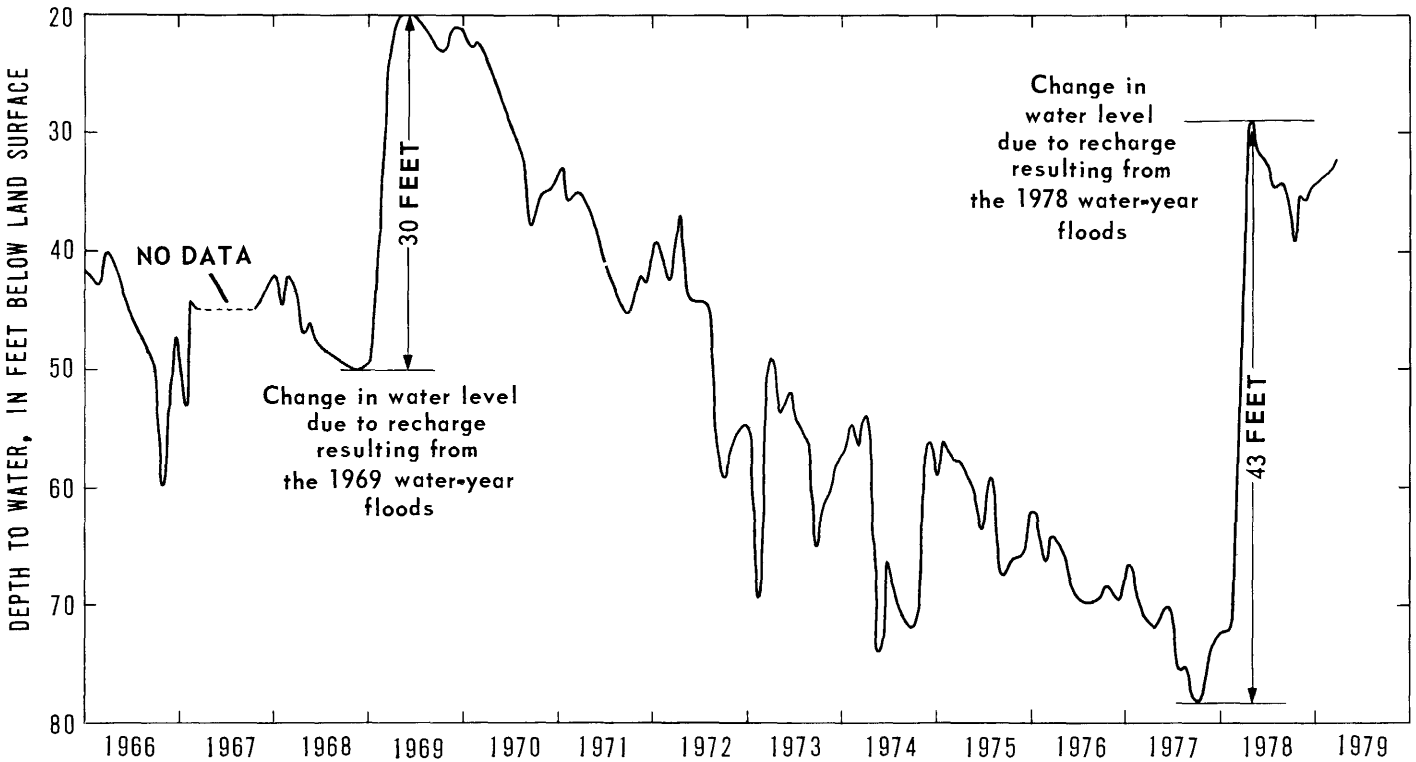
Recharge from underflow comes from basins upstream along the Mojave River. The Lower Mojave River valley receives approximately 3,000 acre-ft/yr from the Middle Mojave River valley at Barstow (Thibeault and Saari, 1981). Coyote Lake Valley receives an undetermined quantity of underflow from areas northeast and northwest of the basin.

The major source of recharge in the study area is stormflow in the Mojave River. The source of stormflow is runoff from precipitation in the San Bernardino Mountains. The headwaters of the Mojave River are at an altitude of about 5,200 feet. Average annual precipitation in the San Bernardino Mountains commonly ranges from 30 to 40 inches, but at times exceeds 75 inches. In 1969 and 1978, rainfall was much greater than normal in the San Bernardino Mountains. Ninety-eight inches were recorded for water year 1969 and 93 inches for 1978 (Buono and Lang, 1980). Peak flows occur between November and March.

Recharge from flow in the Mojave River is evident in two ways. First, is by the rise in water levels in wells adjacent to the river channel. This is illustrated by the flooding that occurred along the Mojave River in 1969 and 1978. In the Barstow area, recharge resulting from flooding increased water levels as much as 39 feet in one well (9N/2W-1F2) and 30 feet in another (10N/1W-31L8) during the 1969 water-year floods. During the 1978 water-year floods, the water levels increased 43 feet in well 10N/1W-31L8 (fig. 3) and 60 feet in well 9N/2W-1F2 (Buono and Lang, 1980). With distance from the river channel, effects on recharge from flooding decrease, and water levels in many areas are declining with pumpage (fig. 4). With the exception of the floodflows in 1969 and in 1978, relatively dry conditions have prevailed since 1948. Water levels have generally declined with development and increased pumping.

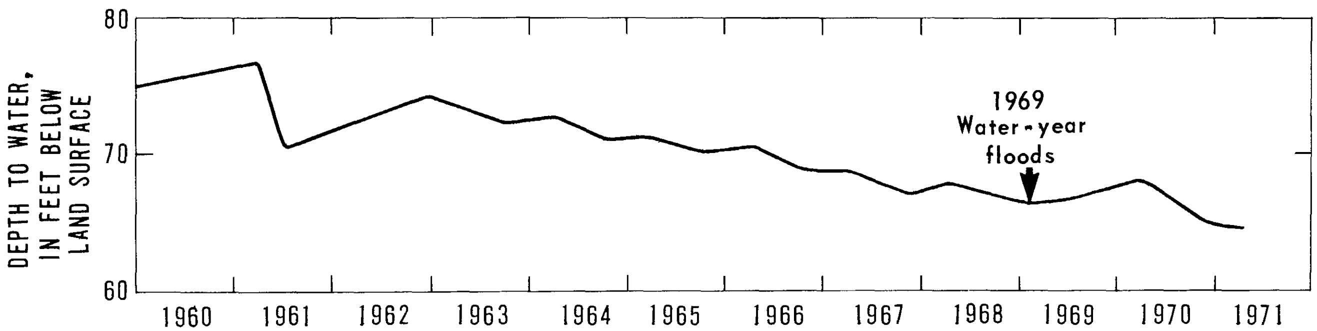
The second way is to determine water loss between the gaging stations at Barstow and Afton (fig. 2). For the 1969 floods, total discharge between December and April at Barstow was about 146,000 acre-ft, and at Afton was about 72,500 acre-ft, indicating that 73,500 acre-ft was lost between stations. In 1978, total discharge was about 91,300 acre-ft at Barstow, and 38,000 acre-ft at Afton, indicating a loss of about 53,300 acre-ft (Buono and Lang, 1980).

In the Barstow area, recharge occurs from deep percolation of sewage effluent water (Hughes, 1975, p. 7 and 8). The main sources of effluent are the sewage-treatment facilities of the city of Barstow, the Atchison, Topeka and Santa Fe Railway and the U.S. Marine Corps facilities at Nebo. Increases in recharge from effluent have been substantial since 1952. The amount of recharge from the city and railroad facilities ranged from 640 acre-ft in 1952 to 3,700 acre-ft for the 2-year period 1970-71. The total for the period 1952-71 was 22,840 acre-ft. Effluent from the U.S. Marine Corps Supply Center ranged from 410 acre-ft in 1952 to 960 acre-ft for the 2-year period 1970-71. The total recharge for the 1952-71 year period was 8,160 acre-ft (Hughes, 1975).



Hydrograph from Buono and Lang (1980)

FIGURE 3.--Hydrograph of well 10N/1W-31L8 adjacent to the Mojave River in the Barstow area (See plate 1 for location).



Data from Hughes and Patridge (1973)

FIGURE 4.--Hydrograph of well 9N/2E-20Q1, an unused well at the U. S. Army flight training operations center (See plate 1 for location).

High volumes of irrigation return were estimated by Hughes (1975) in the Barstow area because of the large quantities of water applied to crops, most of which are planted on highly permeable river-channel deposits. His estimates for irrigation return for 1952-71 ranged from 320 acre-ft to 2,840 acre-ft annually. The total return for the period was about 22,940 acre-ft. Dissolved-solids concentrations could be at least doubled with irrigation return because of leached minerals, dissolution of fertilizers, and evapotranspiration (Hughes, 1975).

Discharge

Sources of discharge in the study area are evaporation, transpiration, surface-water outflow, and pumping. Evaporation occurs in places where ground water is near or at land surface, such as at Coyote and Troy Lakes, Camp Cady, and Afton. Evaporation also occurs during times of surface-water flow. Annual evaporation from the Mojave River surface is about 5 ft/yr because of high air temperatures, low humidity, and wind action (Hardt, 1971). The total consumptive use by riparian native vegetation was 11,320 acre-ft/yr for the period 1930 through 1961 (California Department of Water Resources, 1967). The average annual consumptive use of precipitation by vegetation was 684 acre-ft; average annual consumptive use of ground water was 10,636 acre-ft/yr (California Department of Water Resources, 1967).

Surface-water outflow is measured at Afton Canyon, the only point of outflow from the study area, as discussed earlier in the section on surface water. Ground water is forced to the surface at Afton Canyon because the alluvium is only about 50 feet thick and overlies bedrock. Outflow at Afton for the 1937-46 period was about 26,200 acre-ft/yr, and for 1947-64 was estimated at 1,000 acre-ft/yr. Data for the 1936-46 period represent a wetter-than-normal period, whereas the data from 1947-64 represent a dry period. Average outflow for 1931-68 was about 8,300 acre-ft/yr (Hardt, 1971).

Ground-water pumpage for the Lower Mojave River valley is estimated from municipal, military, and industrial data and by indirect methods for domestic and agricultural uses (Hardt, 1971). The period of record used was 1951-63 (Hardt, 1971) because recent pumpage was not available. Pumpage for the period of record ranged from 18,500 acre-ft in 1951, to 46,400 acre-ft in 1963, and averaged about 31,700 acre-ft.

Consumptive use ranged from 8,300 acre-ft in 1951 to 20,600 acre-ft in 1963, averaging about 14,500 acre-ft (California Department of Water Resources, 1967). Approximately 46 percent of the water pumped was consumptively used. Since 1968, the amount of water pumped has probably increased because of additional development and population.

For the Barstow area, the net consumptive use of water was calculated by subtracting the water that returns to the aquifer from the total amount of water pumped (Hughes, 1975); values for the period 1952 to 1971 ranged from 3,140 acre-ft in 1952 to 13,960 acre-ft in 1970-71. The period total was 108,760 acre-ft and the average value was 5,180 acre-ft.

Ground-water pumpage in Coyote Lake Valley was about 5,600 acre-ft, and in Caves Canyon Valley was about 2,860 acre-ft in 1961 (California Department of Water Resources, 1967).

Storage

The Lower Mojave River valley has a large ground-water storage capacity, much greater than the average annual water supply. Ground water in storage is the main water resource in the study area. Storage capacity refers to the volume of space in water-bearing materials available for storing ground water, whereas storage refers to the amount of recoverable water contained in these materials. The following values for storage capacity and ground water in storage are related to 1961 water levels, and are based on average saturated thicknesses ranging from 230 to 275 feet (California Department of Water Resources, 1967). Total storage capacity for the Lower Mojave River valley was 8,702,000 acre-ft. The total ground-water storage was 5,636,000 acre-ft (California Department of Water Resources, 1967).

The change in ground water in storage is based on changes in water levels over a specific period in time. For the 33-year period 1930-63, the change in ground water in storage was estimated to be a decrease of 140,000 acre-ft (Hardt, 1971). From 1967 through 1969, ground water in storage increased by about 25,000 acre-ft (Hardt, 1971). This was primarily because of the large floods in January and February of 1969. In general, the amount of ground water in storage increased from 1936-45; however, in 1945, storage began to decrease (California Department of Water Resources, 1967).

In the Barstow and Yermo areas, water is stored mainly in the older alluvium and fan deposits. Development in these areas has reduced the amount of water in storage. In 1965, the Barstow area had about 300,000 acre-ft of water in storage, and the Yermo area had about 1,600,000 acre-ft in storage (Miller, 1969). In the Barstow area, between 1946-71, water in storage had declined by about 13,000 acre-ft (Hughes, 1975). The 1969 flood greatly reduced the rate of decline during that period.

The storage capacity for the Newberry area is estimated to be 4,035,000 acre-ft and in 1961, ground water in storage was about 76 percent of total capacity (California Department of Water Resources, 1967).

Coyote Lake Valley has an estimated 5,913,000 acre-ft of ground water in storage. Storage capacity in 1961 was estimated to be 7,530,000 acre-ft (California Department of Water Resources, 1967). Most wells in the valley are abandoned, probably because of high concentrations of boron and sodium, but a few of these wells are used for irrigation of alfalfa.

In Caves Canyon Valley, there is about 2,000,000 acre-ft of ground water in storage. Well yields range between 990 gal/min and 1,900 gal/min (Koehler and Ballog, 1979). Total storage capacity in 1961 was estimated to be 4,152,000 acre-ft (California Department of Water Resources, 1967). Only a few wells along the railroad in the southwestern part of the valley are being used.

Ground-Water Quality

Ground-water quality in the Lower Mojave River valley is variable. Dissolved-solids concentrations in wells less than 500 feet deep range from 196 mg/L near the U.S. Marine Corps Supply Center at Yermo, to 3,310 mg/L near Troy Lake (Page and Moyle, 1960; Dyer and others, 1963; Hughes and Patridge, 1973). There does not seem to be much water-quality change with depth. Figure 5 shows distribution of dissolved-solids concentrations. Data for the Barstow area are recent (December 1981), and reflect the current ground-water conditions in the area. Data for most of the basin are from California Department of Water Resources Bulletin 91-10 (Dyer and others, 1963) and may or may not represent current conditions. Dissolved-solids concentrations greater than 1,500 mg/L are shown individually at the sampled sites.

Chemical Characteristics

Four general types of ground water occur in the study area. The first type is predominantly sodium bicarbonate or calcium bicarbonate. Water of this type is common in a large part of the study area, including the city of Yermo and vicinity, most of the Newberry area, southeast of Newberry Springs, and in Caves Canyon Valley. The primary source of recharge to the Newberry and Yermo areas is stormflow in the Mojave River (predominantly calcium bicarbonate), and the mineral constituents are derived from the granitic rocks in the San Bernardino Mountains (California Department of Water Resources, 1967). As the water from the river moves underground the amount of sodium increases because of an ion exchange with clay in the water-bearing sediments (California Department of Water Resources, 1967). Concentrations of sodium range from 35 mg/L to 488 mg/L; bicarbonate concentrations range from 105 mg/L to 710 mg/L. Dissolved-solids concentrations average 300 mg/L (fig. 5). Caves Canyon Valley has water of sodium calcium bicarbonate type and generally contains a high concentration of sodium owing to evaporation of perennial surface-water flow at Camp Cady and Afton. Dissolved-solids concentrations are as high as 1,200 mg/L and average 904 mg/L (California Department of Water Resources, 1964).

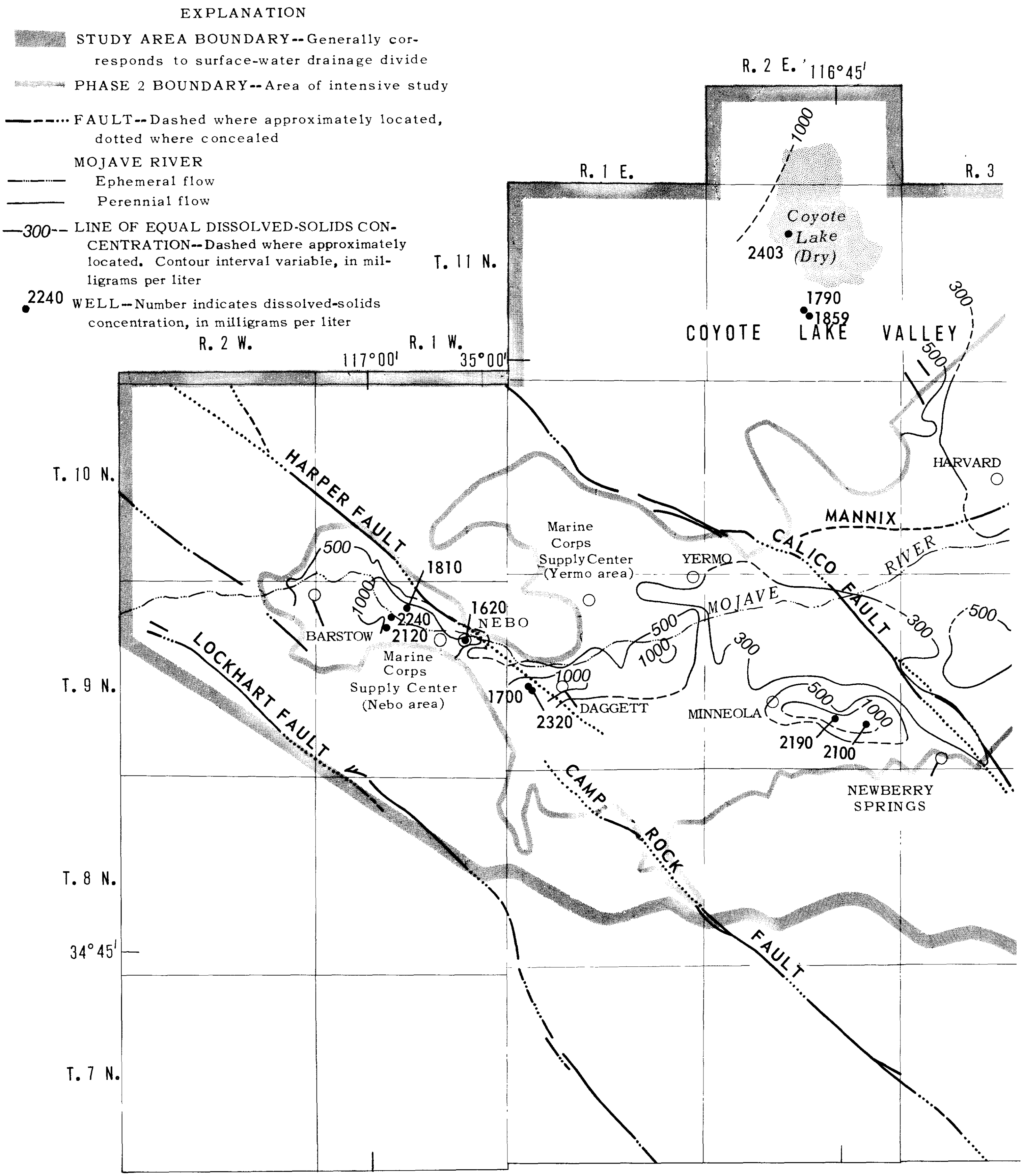


FIGURE 5.--Dissolved-solids concentration based on data from 1953 - 1981.

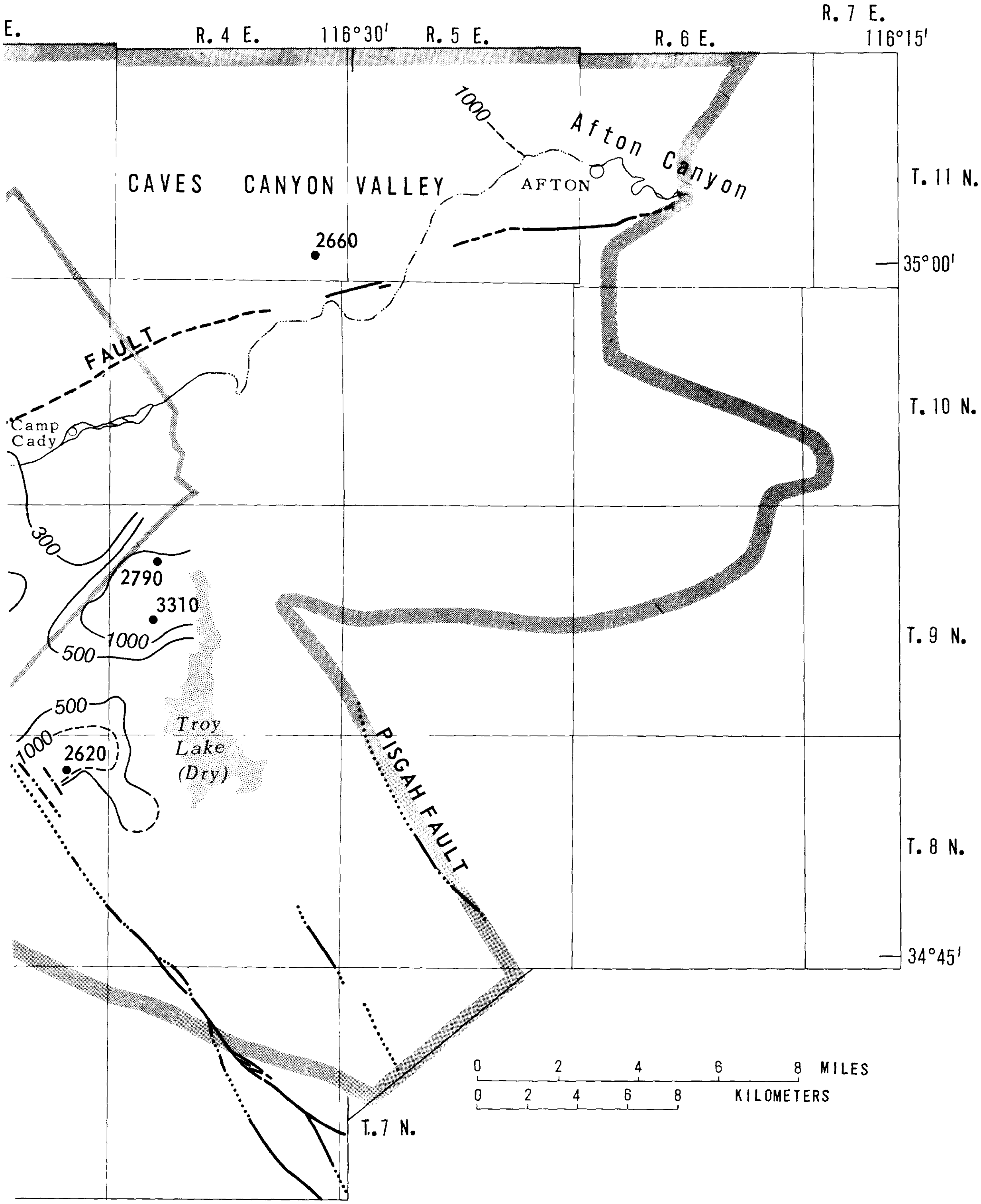


FIGURE 5.--Continued.

The second type of water is characterized by sodium as the major cation and sulfate as the major anion. This water is typical at the community of Daggett and vicinity and east of Minneola. Sodium sulfate type water with some high concentrations of calcium is typical at Coyote Lake (California Department of Water Resources, 1967). The sulfate ion generally occurs where there is little recharge or ground-water movement, or where there is a predominance of older alluvium having source rocks that include Tertiary sediments (California Department of Water Resources, 1967), as at Daggett and east of Minneola. Sodium concentrations in this water range from 106 to 522 mg/L, and sulfate concentrations range from 200 to more than 300 mg/L. The average dissolved-solids concentration is relatively high, about 700 mg/L (fig. 5), and several wells in these areas have dissolved-solids concentrations that exceed 1,500 mg/L. Dissolved-solids concentrations increase toward the south and east sides of Coyote Lake to values exceeding 2,000 mg/L. Near the Coyote Lake Valley and Lower Mojave River valley boundary, dissolved-solids concentrations range from 300 to 500 mg/L (fig. 5), and water becomes more sodium sulfate in type (California Department of Water Resources, 1967).

The third type of water is sodium calcium chloride and occurs in the fine-grained playa deposits of Troy Lake (California Department of Water Resources, 1967). Sodium concentrations in this water type range from 66 to 502 mg/L and calcium from 3 to 553 mg/L. Chloride concentrations range from 44 to 990 mg/L. Dissolved-solids concentrations range from 300 to more than 3,000 mg/L (fig. 5).

The fourth type of water is mixed in composition; major cations are sodium and calcium; major anions are bicarbonate and sulfate. All are of fairly equivalent concentrations. Water of this type is common in the Barstow area and at the U.S. Marine Corps Supply Center at Nebo. The mixed composition of the ground water is caused by the sources of recharge, which is of variable chemical composition. Dissolved-solids concentrations range from 279 to 2,240 mg/L (fig. 5). Water in this area was a sodium bicarbonate type in 1967 (California Department of Water Resources, 1967); however, development of the area probably increased the diversity of the chemical composition of the ground water. Typical analyses of water from selected areas according to type of water are given in table 2.

Ground-Water Degradation

Locations of selected wells yielding water having constituents that exceed U.S. Environmental Protection Agency recommended criteria for drinking and irrigation waters (National Academy of Sciences, National Academy of Engineering, 1973). The water quality in area A (fig. 6), which includes the city of Barstow and the U.S. Marine Corps Supply Center at Nebo, is represented by the quality of water in the wells shown. Table 3 shows the chemical constituents that exceed U.S. Environmental Protection Agency recommended criteria for each well located in figure 6. Because there are no current, consistent water-quality data for the entire study area, analyses made from 1952 to 1981 were used.

In general, poor quality water is localized in the Barstow area, at Daggett and Minneola, and east of Newberry Springs. However, the water in several isolated wells throughout the rest of the area has constituent concentrations greater than U.S. Environmental Protection Agency criteria.

Ground water in the Barstow area has been subjected to degradation from wastewater discharge and irrigation return for the past 60 years. Problems have included high dissolved-solids concentrations, odor, and dissolved organic carbon (DOC) which indicates the presence of various organic compounds. Other problem constituents include chloride, phenols, and methylene blue active substances (MBAS) which indicate foaming agents in ground water (Hughes, 1975). In places, ground water in the Barstow area contains excessive boron, nitrate, chloride, sodium, manganese, and iron (table 3).

There are two major plumes of degraded water in the alluvial aquifer near Barstow. Figure 7 shows the distribution of DOC concentrations greater than 2.0 mg/L in ground water in 1977. This gives an indication of the areal extent of degradation from the plumes. The older plume resulted from percolation of wastewater from the old waste-treatment ponds shown on plate 2. The more recent plume, which overlies the older one, was caused by city and railroad waste disposal since 1968 (pl. 2). Recharge from the flood of 1978 contributed to a minor decrease in odor and the concentration of dissolved constituents in the ground water; however, during 1977-78 the degraded water spread (Eccles, 1981). Both plumes of degraded water have moved downgradient since 1912, shortly after the Santa Fe railway first began discharging waste. By 1972 the leading edge of the older plume had moved approximately 4.5 miles downgradient (Hughes, 1975). The original point of waste disposal in 1912 was at the site of the first waste-treatment plant for Barstow (abandoned in 1953) shown on plate 2. Using the velocity of about 1.0 ft/d (Hughes determined this velocity by comparing the location of the plume in 1972 with past records), the leading edge of the plume should presently be located approximately 0.7 mile farther downgradient. Pumping from the five wells that supplied the U.S. Marine Corps Supply Center at Nebo (pl. 2) was greatly curtailed in 1977 because of deteriorating water quality (Eccles, 1981).

TABLE 2. - *Typical analyses of ground water from*

[All constituents in milligrams per liter except

Type of water	Location	Specific conductance	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)
Sodium bicarbonate.	Marine Corps supply center, Yermo.	--	39	7	55
Do.	Newberry area	--	41	4	84
Do.	Southeast of Newberry Springs.	653	12	6	126
Sodium sulfate.	Daggett area	1,230	58	6	190
Do.	East of Minneola	1,680	125	29	208
Do.	Coyote Lake	1,180	23	15	219
Sodium, calcium, chloride.	Troy Lake	1,360	63	6	210
Mixed	Barstow area	1,340	160	29	110
Do.	Marine Corps supply center, Nebo.	1,520	110	24	190

[1]Detection level of dissolved nitrate.
[2]Sum of constituents.

selected areas in the Lower Mojave River valley

specific conductance in micromhos per centimeter at 25°C]

Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Nitrate (NO_3)	Dissolved solids	Boron (B)
2.5	171	45	42	3.50	351	0.23
1.6	163	70	62	4.00	380	--
2.5	184	99	56	[1]<.05	426	1.0
5.4	111	360	77	5.70	818	3.2
5.8	200	410	178	4.50	1,140	.8
.7	143	211	166	2.50	691	.72
1.0	172	122	254	1.00	802	.48
4.7	300	360	85	--	846	.37
3.7	300	240	170	4.10	[2]931	.9

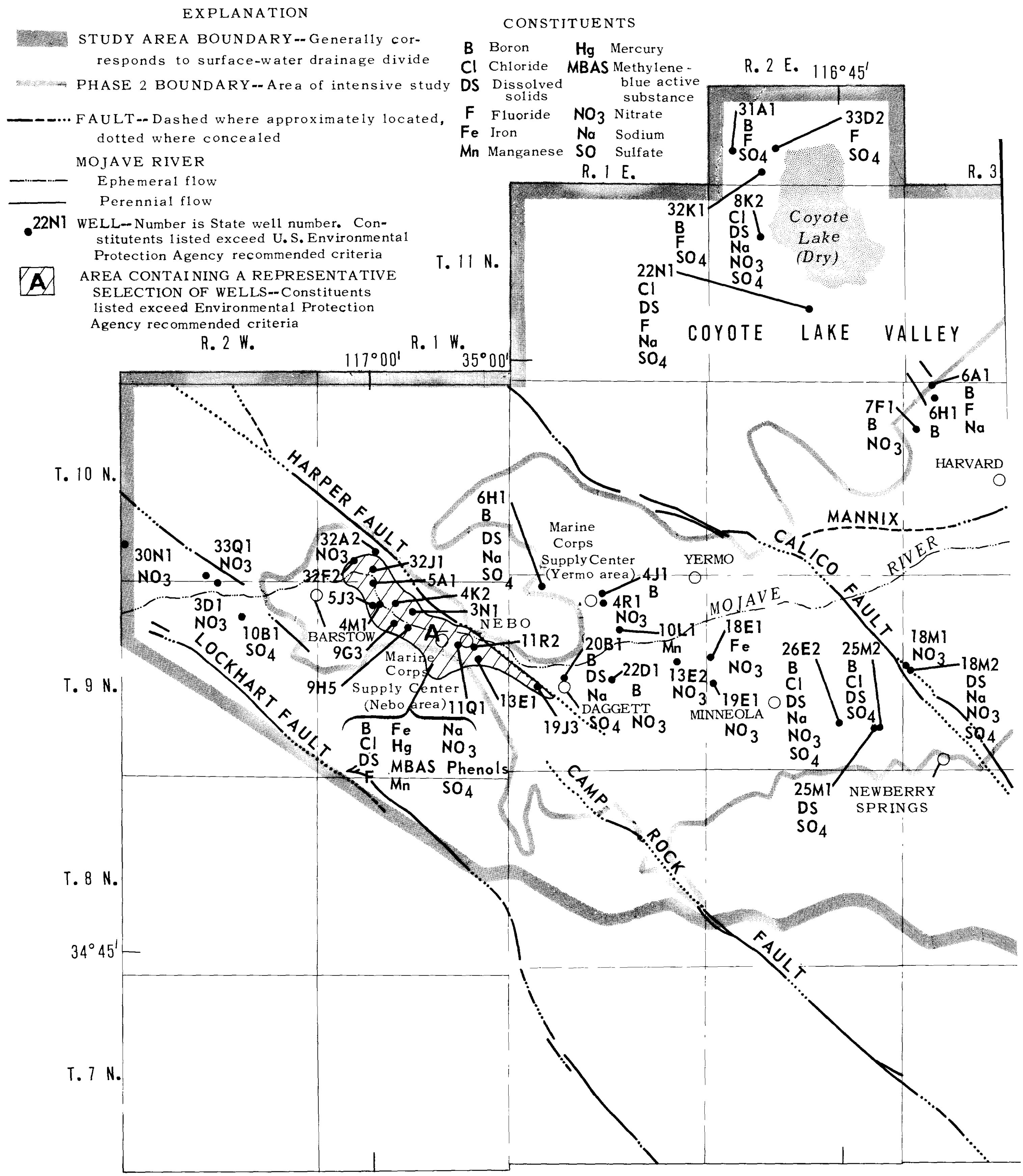
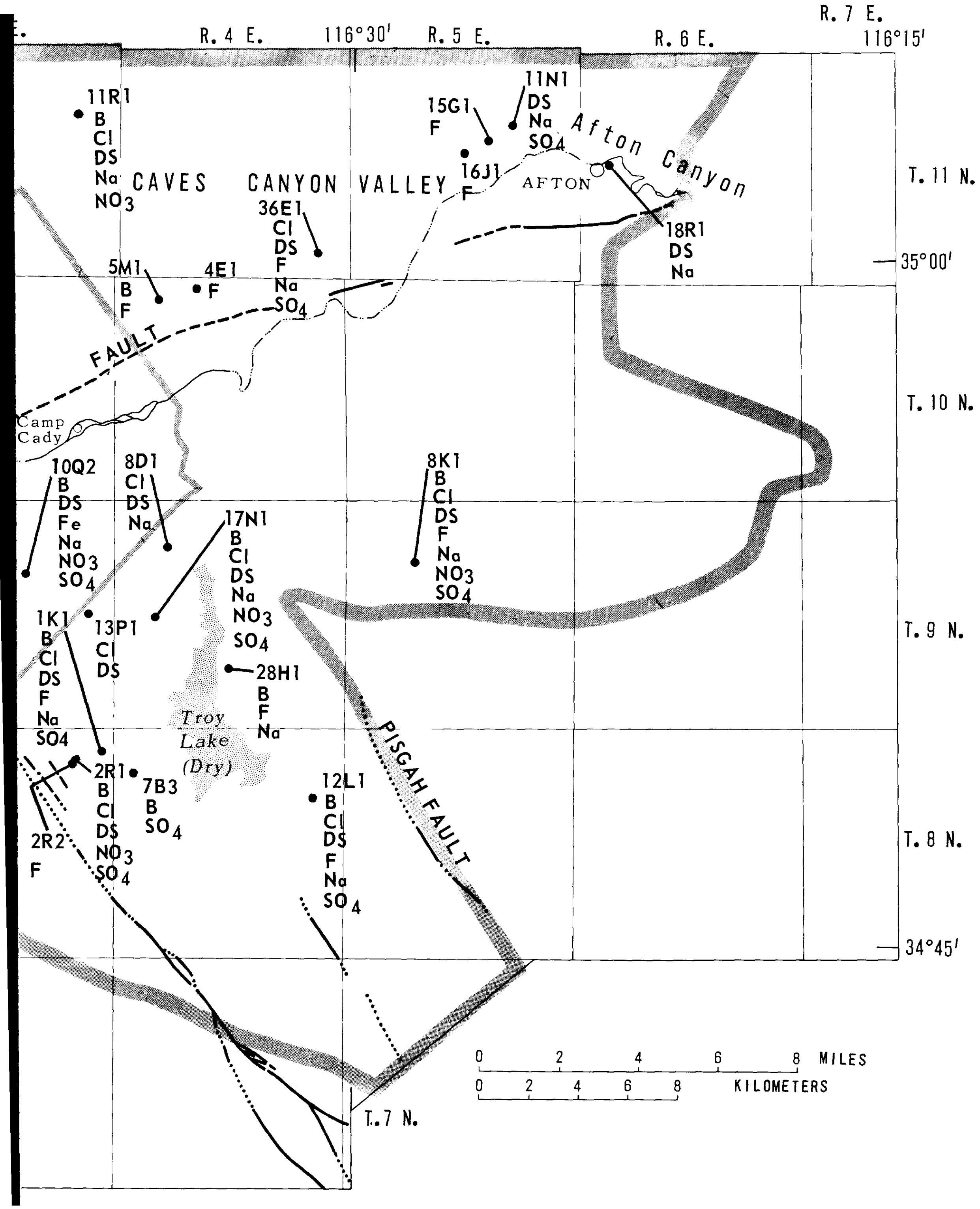


FIGURE 6.--Wells with chemical constituents exceeding U. S. Environmental Protection Agency



recommended criteria for drinking and irrigation waters based on data from 1953 – 1981.

TABLE 3. - *Constituents in water from selected wells that*
drinking and

[All constituents in

Site No. (fig. 6)	State well No.	Sodium (Na)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)
U.S. Environmental Protection Agency recommended limits[1]		[2]250	250	250	[3]1.8
1	9N/2W-3D1	--	--	--	--
2	9N/2W-10B1	--	311	--	4.0
3	10N/2W-30N1	--	--	--	--
4	10N/2W-33Q1	--	--	--	--
5[5]	9N/1W-3N1	300	770	--	--
6[5]	9N/1W-4K2	--	440	--	--
7[5]	9N/1W-4M1	--	320	--	--
8[5]	9N/1W-5A1	--	--	--	--
9[5]	9N/1W-5J3	317	423	261	3.4
10[5]	9N/1W-9G3	390	820	310	--
11[5]	9N/1W-9H5	--	300	330	--
12[5]	9N/1W-11Q1	--	260	280	--
13[5]	9N/1W-11R2	--	--	--	--
14[5]	9N/1W-13E1	--	278	--	--
15	10N/1W-32A2	--	--	--	--
16[5]	10N/1W-32F2	330	746	--	3.0
17[5]	10N/1W-32J1	--	340	--	--
18	9N/1E-4J1	--	--	--	--
19	9N/1E-4R1	--	--	--	--
20	9N/1E-10L1	--	--	--	--
21	9N/1E-6H1	380	424	--	--
22[7]	9N/1E-13E2	--	--	--	--
23[5]	9N/1E-19J3	260	420	--	2.5
24[7]	9N/1E-20B1	522	1,080	--	--
25[7]	9N/1E-22D1	--	--	--	--
26	9N/2E-18E1	--	--	--	--
27	9N/2E-19E1	--	--	--	--
28	9N/2E-25M1	--	410	--	--
29	9N/2E-25M2	405	840	312	--
30	9N/2E-26E2	410	822	392	--
31	9N/3E-10Q2	255	372	--	--
32	9N/3E-13P1	--	--	289	--
33	9N/3E-18M1	--	--	--	--
34	9N/3E-18M2	339	261	--	--
35	8N/3E-1K1	488	432	400	4.0

See footnotes at end of table.

exceed U.S. Environmental Protection Agency recommended criteria for irrigation waters

milligrams per liter]

Dissolved solids residue at 180°C	Nitrate (NO_3 as N)	Boron (B)	Iron (Fe)	Manganese (Mn)	Mercury (Hg)	Phenols	Methylene blue active substance
1,000	10	[4]1.0	0.3	0.05	0.002	0.001	0.5
--	11	--	--	--	--	--	--
--	--	--	--	--	--	--	--
--	33	--	--	--	--	--	--
--	16	--	--	--	--	--	--
1,810	14	--	--	0.07	--	--	--
1,280	--	--	--	--	--	--	--
--	--	1.2	1.1	--	--	0.002	--
--	--	1.6	--	.29	--	.005	--
1,280	12	2.5	--	--	--	.02	--
2,120	11	3.0	1.2	.05	--	--	1.0
1,140	--	1.0	.83	--	[6]0.02	.005	.58
1,180	--	1.0	--	--	--	.001	--
--	--	--	2.0	.091	--	.001	.50
--	17	1.1	3.2	--	--	--	--
--	21	--	--	--	--	--	--
1,710	--	--	--	--	--	--	--
--	15	--	--	--	--	--	--
--	--	1.0	--	--	--	--	--
--	12	--	--	--	--	--	--
--	--	--	--	.07	--	--	--
1,230	--	6.6	--	--	--	--	--
--	22	--	--	--	--	--	--
1,110	16	6.5	--	--	--	.2	--
2,010	--	27	--	--	--	--	--
--	28	1.0	--	--	--	--	--
--	12	--	1.0	--	--	--	--
--	16	--	--	--	--	--	--
1,140	--	--	--	--	--	--	--
2,100	--	4.5	--	--	--	--	--
2,190	17	4.2	--	--	--	--	--
1,240	30	1.3	2.9	--	--	--	--
1,030	--	--	--	--	--	--	--
--	17	--	--	--	--	--	--
1,220	11	--	--	--	--	--	--
1,630	--	5.6	--	--	--	--	--

TABLE 3. - *Constituents in water from selected wells that drinking and*

Site No. (fig. 6)	State well No.	Sodium (Na)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)
U.S. Environmental Protection Agency recommended limits[1]-------		[2]250	250	250	[3]1.8
36	8N/3E-2R1	--	544	705	--
37	8N/3E-2R2	--	--	--	2.2
38	8N/4E-7B3	--	454	--	--
39	8N/4E-12L1	341	369	289	8.0
40	9N/4E-8D1	396	--	254	--
41	9N/4E-17N1	484	1,370	565	--
42	9N/4E-28H1	346	--	--	11
43	9N/5E-8K1	480	405	320	4.2
44	10N/3E-6A1	282	--	--	3.5
45	10N/3E-6H1	--	--	--	--
46	10N/3E-7F1	--	--	--	--
47	10N/4E-4E1	--	--	--	8.1
48	10N/4E-5M1	290	--	--	4.4
49	11N/2E-8K2	272	267	276	--
50	11N/2E-22N1	650	698	266	7.8
51	11N/3E-11R1	500	--	267	--
52	11N/4E-36E1	930	710	790	11
53	11N/5E-11N1	391	518	--	--
54	11N/5E-15G1	--	--	--	2.7
55	11N/5E-16J1	--	--	--	4.0
56	11N/6E-18R1	359	--	--	--
57	12N/2E-31A1	--	296	--	3.2
58	12N/2E-32K1	--	310	--	4.5
59	12N/2E-33D2	--	291	--	4.0

[1]Recommended limits given in National Academy of Sciences, National Academy of Engineering, (1973).

[2]Recommended limit for individuals with moderate sodium-restricted diets.

[3]Based on an average air temperature of 68.5°F for the period 1971-81.

[4]Recommended limit for irrigation of semitolerant plants.

exceed U.S. Environmental Protection Agency recommended criteria for irrigation waters--Continued

Dissolved solids residue at 180°C	Nitrate (NO_3 as N)	Boron (B)	Iron (Fe)	Manganese (Mn)	Mercury (Hg)	Phenols	Methylene blue active substance
1,000	10	[4]1.0	0.3	0.05	0.002	0.001	0.5
2,620	17	9.5	--	--	--	--	--
--	--	--	--	--	--	--	--
--	--	4.2	--	--	--	--	--
1,200	--	3.2	--	--	--	--	--
1,130	--	--	--	--	--	--	--
3,310	18	5.0	--	--	--	--	--
--	--	3.2	--	--	--	--	--
1,470	25	4.5	--	--	--	--	--
--	--	4.0	--	--	--	--	--
--	--	1.6	--	--	--	--	--
--	18	1.6	--	--	--	--	--
--	--	--	--	--	--	--	--
--	--	2.4	--	--	--	--	--
1,040	17	--	--	--	--	--	--
1,790	--	--	--	--	--	--	--
1,350	10	2.3	--	--	--	--	--
2,660	--	--	--	--	--	--	--
1,270	--	--	--	--	--	--	--
--	--	--	--	--	--	--	--
--	--	--	--	--	--	--	--
1,050	--	1.6	--	--	--	--	--
--	--	1.5	--	--	--	--	--
--	--	2.1	--	--	--	--	--
--	--	--	--	--	--	--	--

[5]Representative of the numerous wells in area A with constituents exceeding U.S. Environmental Protection Agency recommended limits.

[6]Based on one sample taken October 7, 1971.

[7]Representative of nearby wells.

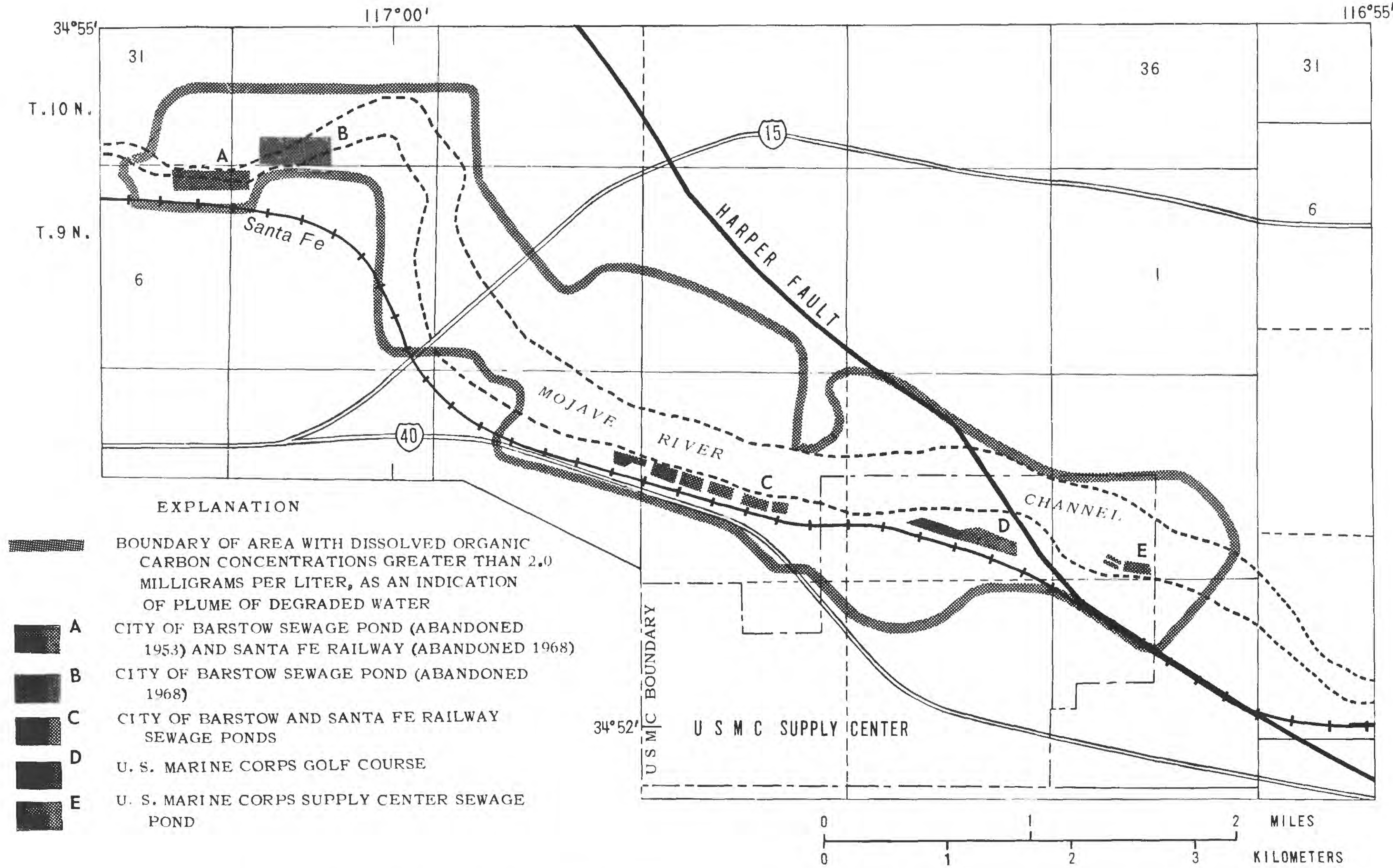


FIGURE 7.--Areal extent of dissolved organic carbon concentrations greater than 2.0 milligrams per liter in ground water at Barstow, 1977. (From Eccles, 1981).

Ground water at Daggett may have excessive concentrations of manganese, sodium, fluoride, sulfate, nitrate, boron, dissolved solids, and phenols (table 3). The Minneola area has the same problem constituents as Daggett, with the exception of fluoride and manganese, and the addition of chloride (table 3). In general, east of Newberry Springs, high concentrations of sodium, sulfate, chloride, fluoride, boron, and dissolved solids prevail. Constituents such as manganese, fluoride, boron, sulfate, and sodium may occur naturally in ground water in these areas because of the dissolution of minerals containing these constituents. Nitrate also can occur naturally from decomposition of plants native to the desert (Hem, 1970).

Fluoride-bearing minerals in the study area are generally associated with fault zones. Constituents such as nitrate, sulfate, boron, and phenols, may occur in ground water because of such manmade factors as domestic wastes and application of fertilizers, both of which occur at Daggett, near Minneola, and east of Newberry Springs.

Isolated wells with water having high concentrations of one or more chemical constituents are located throughout the study area (fig. 6). Playas may also be a source of contaminants, such as sulfate, chloride, and sodium.

LAND USE

Land use in the Lower Mojave River valley is diverse, including agriculture, residential, municipal, industrial, and military. There is a possibility of dairies locating in the valley at a future time. A study by the San Bernardino County Planning Department stated that increasing pressure from urban land uses in areas where dairies are currently located, resulted in a large number of requests by dairy farmers to relocate in various desert basins, including the Newberry and Barstow areas (San Bernardino County, 1982). All the above types of land use can be major contributors to ground-water degradation.

Plate 2 shows the generalized land use for the Lower Mojave River valley. Two broad categories are shown, agricultural land use and urban and built-up land use. Several specific types of land use are identified, some as known and potential pollution sources. The undefined area that includes a large part of the basin is virtually unused land with typical, high-desert vegetation.

Agriculture is located principally in the Newberry area, but some alfalfa is grown near Barstow and Coyote Lake. Hay and alfalfa are the major crops, with some fruit orchards. Agriculture has increased steadily from 1930 to 1977. Presently, the amount of agriculture in the area has more or less stabilized. Predictions for the next 20 years indicate that the amount of agricultural land will remain the same or decrease if industrial activities increase and if dairies move into the area (California Department of Water Resources, 1981).

Residential and industrial areas are concentrated mainly in the western part of the basin around Barstow, Yermo, Daggett, and the Mojave River. The population of the study area has been steadily increasing. Population increased from 1,100 in 1930 to 18,300 in 1960. The current population is about 25,000, of which 17,000 reside in Barstow. Estimates of future populations range from a low of about 32,500 to a high of about 36,000 by the year 2000 (California Department of Water Resources, 1981). As the population increases, the amount of residential waste and municipal sewage effluent will increase. The communities of Daggett and Yermo use individual septic tanks for waste disposal; the city of Barstow operates a sewage-treatment plant.

Industrial development includes a railroad maintenance yard in the Barstow area, a chemical company east of Newberry Springs, a power plant near Daggett, and gravel plants. The railroad maintenance yard is the only industrial site permitted to discharge industrial wastes. Waste from the maintenance yard is treated at the Barstow sewage-treatment facilities.

The U.S. Marine Corps operates a supply center at Nebo and an annex at Yermo. Both the Nebo and Yermo centers have their own facilities for domestic and industrial-waste treatment and disposal. Effluent produced from the Nebo center has been and is currently used to irrigate the base golf course. Both facilities handle toxic chemicals.

Other specific land uses shown on plate 2 include the Barstow-Daggett airport, mines, and manmade recreational lakes. The airport has a waste-discharge permit and discharges are below the maximum amount allowed. Mines in the surrounding mountains do not contribute significantly, if at all, to ground-water degradation. A large number of manmade ponds and recreational lakes located throughout the Newberry area are filled with ground water (San Bernardino County, 1982). The impact of these lakes on ground-water quality is not presently known. A few of the larger lakes are shown on plate 2.

Relocation of dairies into the study area could contribute to ground-water degradation. Wastes from dairies can contain high concentrations of nitrate, chloride, sulfate, dissolved solids, bacteria, and organic matter. Ground-water degradation caused by the inorganic chemicals and bacteria is a major concern (Todd and others, 1976). The establishment of dairies in the area will depend upon recommendations made by the San Bernardino County Planning Department presented to the County Board of Supervisors, and whether the dairies can comply with waste-discharge requirements imposed by the Lahontan Regional Water Quality Control Board. A variety of conditions were used to set standards, including methods of waste disposal, possibility of flood hazard, effects on ground-water quality, and availability of water. The prescribed methods of waste disposal would depend upon soils, slope, existing ground water, proximity to the river, availability of cropland, topographical features, subsurface geology, and herd size (San Bernardino County, 1982). The study made by the San Bernardino County Planning Department on the suitability of the areas for dairies, outlined recommendations based on the described elements of the study. In general, dairies were discouraged from moving to the Barstow area because of water limitations and pollution potential. Consideration of the Newberry area was deferred until a ground-water study and community plan is completed. The Harvard area was suggested as an alternative dairy site, but further study will be required to determine its suitability for dairy operations (San Bernardino County, 1982).

Sources of Pollution

Sources of known and potential pollution are industrial and domestic wastes, agriculture, and geologic formations. In the Lower Mojave River valley, ground-water degradation can be a result of any one or a combination of these factors.

Pollution problems can be caused by either point or nonpoint sources. Plate 2 shows known and possible point sources of pollution, all of which are manmade. It is evident from plate 2 that these known and possible point source pollution problems are concentrated in the more developed areas around Barstow and Yermo. Nonpoint sources of pollution are diffuse over an area and could be localized or regional in nature.

Tables 4 and 5 list known and possible sources of pollution and related information. The California Regional Water Quality Control Board--Lahontan Region is responsible for regulating wastewater discharges in the Lower Mojave River valley. The known and possible point sources of pollution shown are based on discharge permits issued and reports done by Hughes (1975), and Eccles (1981). The possible nonpoint sources of pollution listed are based on land use and available water-quality data.

TABLE 4. - *Known sources of pollution*

[Types of pollutants: Cl, chloride; Cr, total chromium; DOC, dissolved organic carbon; DS, dissolved solids; Fe, iron; Hg, mercury; Mn, manganese; MBAS, methylene blue active substances; Na, sodium; NO_3, nitrate; SO_4, sulfate]

Known source of pollution	Types of pollutants[1]	Area	Permitted discharge[2] (Mgal/d)	Type of discharge	Point or nonpoint source
Barstow waste-treatment facility.	Fe, NO_3, B, Na, SO_4, DS, phenols, MBAS, Cr, oil and grease.[3]	Barstow	--	Industrial, domestic	Point
Barstow waste-treatment facility (abandoned 1968); included Santa Fe industrial waste.	Fe, NO_3, DS, phenols, MBAS, oil and grease.	do.	--	do.	Do.
Barstow waste-treatment (current); includes Santa Fe industrial waste.	DS, B, phenols, MBAS, Cl, Cr, DOC, Na, oil and grease.[4]	do.	4.5	do.	Do.
Marine Corps supply center, Nebo waste-treatment.	Na, SO_4, B, DS, phenols, NO_3, MBAS, Mn, Hg, Fe, oil and grease.[5]	do.	0.6	do.	Do.
Marine Corps supply center golf course irrigation return, fertilizers.	NO_3, DS	do.	--	--	Nonpoint

[1]Taken from Hughes (1975).

[2]Written communication, California Regional Water Quality Control Board--Lahontan Region, 1982; all discharges equal design capacities.

[3]B, Na, SO_4, DS, phenols, MBAS, Cr, oil and grease from Santa Fe Railway waste discharged at same site.

[4]DOC and Cl based on Eccles, 1981.

[5]Mn, Hg, and Fe based on WATSTORE retrieval.

TABLE 5. - *Possible sources of pollution*

[Types of pollutants: Cl, chloride; DOC, dissolved organic carbon; DS, dissolved solids; Fe, iron; Mn, manganese; MBAS, methylene blue active substances; Na, sodium; NO_3, nitrate; SO_4, sulfate; trace elements include arsenic, barium, cadmium, chromium (total), chromium (hexavalent), copper, cyanide, iron, lead, manganese, mercury, selenium, silver, and zinc]

Possible source of pollution	Types of pollutants[1]	Area	Permitted discharge[2] (Mgal/d)	Type of discharge	Point or nonpoint source
Marine Corps supply center, Yermo waste-treatment.	Na, SO_4, Cl, NO_3, DS, phenols, Fe, Mn, MBAS, DOC	Yermo	0.2	Industrial, domestic	Point
Union Pacific waste-treatment.	NO_3, MBAS, DOC, Na, SO_4, Cl, phenols, DS	Yermo	.013	Domestic	Do.
Barstow-Daggett airport waste-disposal.	do.	Daggett	.15	Domestic, minor industrial.	Do.
Industrial clay processing plant.	Na, SO_4, Cl, NO_3, DS, trace elements	Newberry Springs	--	Industrial	Do.
Septic tanks	do.	Yermo and Daggett	--	Domestic	Nonpoint
Agriculture-irrigation return, fertilizers.	NO_3, SO_4, Na, Cl, DS	Basinwide	--	--	Do.
Geologic conditions--sediments from Tertiary rocks, faults, playas, various minerals contained in rocks.	Mn, Fe, DS, SO_4, F, Na, Cl, B	Troy Lake, Coyote Lake, Daggett, Minneola	--	--	Do.

[1]Constituents commonly associated with these possible sources of pollution from Todd, Tinlin, Schmidt, and Everett (1976).

[2]Written communication, California Regional Water Quality Control Board--Lahontan Region, 1982; all discharges equal design capacities except Union Pacific Railroad.

Known point sources of pollution are effluents produced by the city of Barstow and the U.S. Marine Corps Supply Center at Nebo waste-treatment facilities. Barstow has operated three waste-treatment facilities since 1938. The oldest plant, adjacent to the Mojave River (pl. 2), was used until 1953 when it was abandoned for a larger plant. This plant treated domestic effluent only, which was discharged directly into the highly permeable Mojave River channel. This point of discharge was also used by the Atchinson, Topeka and Santa Fe Railway (pl. 2) for disposal of industrial wastes from their railway maintenance yard between 1910 and 1968. From 1910 to 1915 these wastes were not treated. After 1915, oil was separated and after 1959 some flocculation and oxidation was done before discharge. Effluent from these sources contained high concentrations of iron, nitrate (probably from irrigation return upstream), boron, sodium, sulfate, dissolved solids, oil, grease, phenols, and MBAS (Hughes, 1975). This effluent formed the older plume of degraded water mentioned previously in this report.

In 1953, a new waste-treatment facility was built just east and downstream from the first one. This plant had increased capacity and additional stages of treatment. Most waste received secondary treatment, but some received only primary treatment. Disposal of effluent was largely by direct percolation into the Mojave River channel and by evaporation from oxidation ponds. However, some of the treated effluent was used for irrigation of alfalfa. This effluent consisted of treated domestic wastes (Hughes, 1975). Excessive concentrations of iron, nitrate, dissolved solids, phenols, oil, grease, and MBAS were found in this wastewater.

In 1968 the second waste-treatment plant was abandoned for the one now in use. This plant is a short distance upstream from the U.S. Marine Corps Supply Center at Nebo (pl. 2). All wastes at this facility receive primary treatment. Between 1968 and 1973 only some wastes received secondary treatment. In 1973, the plant was expanded to include secondary treatment for all wastes. The Atchinson, Topeka and Santa Fe Railway modified its treatment of wastes to comply with the Lahontan Regional Water Quality Control Board and city of Barstow standards; most wastes are diverted to this plant for disposal. Treated industrial and municipal wastewaters percolate into the Mojave River bed and are the source of the more recent plume of water that overlies the older one. This effluent has high concentrations of MBAS, phenols, oil, grease, dissolved solids, DOC, chloride, boron, sodium, and total chromium (Hughes, 1975 and Eccles, 1981).

The second known source of pollution is the domestic and industrial effluent produced by the U.S. Marine Corps Supply Center waste-treatment facilities at Nebo. The original facilities were built in 1942 and expanded in 1957. They provide primary treatment and some secondary treatment. Disposal of treated effluent is by evaporation or direct percolation into the Mojave River channel (Hughes, 1975). The U.S. Marine Corps Supply Center waste contained high concentrations of sodium sulfate, boron, dissolved solids, phenols, oil and grease, and MBAS (Hughes, 1975).

In June 1976, the Marine Corps completed construction of a new domestic wastewater-treatment facility at Nebo. The facility provides for preaeration, grit removal, primary sedimentation, anaerobic solids digestion, lined sludge lagoons, oxidation ponds, ozonation, and chlorination. All domestic wastewater receives secondary treatment (Lahontan Regional Water Quality Control Board, written commun., 1983).

Potential point sources of pollution in the study area are the U.S. Marine Corps Supply Center annex at Yermo, Union Pacific Railroad (employee residences), the Barstow-Daggett Airport, and a clay-processing plant near Newberry Springs. The U.S. Marine Corps Supply Center annex at Yermo has waste-treatment facilities for domestic and industrial wastes. In June 1976, construction of new domestic wastewater facilities were completed. The facility provides for the same treatment as at Nebo except chlorination (Lahontan Regional Water Quality Control Board, written commun., 1983). Types of pollution commonly found in this type of effluent are shown in table 5. Concentrations of nitrate and boron are the only constituents found in excess there. Available data (1952-71) show that dissolved-solids concentrations ranged from 200 to 400 mg/L, and that there was no excessive mineralization or increasing trends (Hughes and Patridge, 1973).

The Union Pacific Railroad provides employee housing in the Yermo area and operates sewage-treatment ponds for domestic wastes. Data from 1952 through 1971 showed dissolved-solids concentrations in ground water ranging from 100 to 200 mg/L, with no established trends (Hughes and Patridge, 1973). All other constituents in the ground water there were less than U.S. Environmental Protection Agency criteria for drinking water.

The Barstow-Daggett airport near Minneola is permitted to discharge wastewater, mainly domestic, which could contain minor amounts of industrial wastes. Dissolved solids in ground water in this area between 1952 and 1971 ranged from 200 to 400 mg/L (Hughes and Patridge, 1973). There were no indications of ground-water degradation from other constituents at that time.

The clay-processing plant near Newberry Springs has wastewater ponds that are well sealed with the same clays that are processed. Wastewater contains residual clay and is high in nitrate and dissolved solids. Ground water in the area is relatively shallow and is of good quality (Robert Dodds, California Regional Water Quality Control Board--Lahontan Region, oral commun., 1983).

The known nonpoint source of pollution is the golf course at the U.S. Marine Corps Supply Center at Nebo. Some of the effluent treated at the supply center facilities is used to irrigate the golf course. This practice probably began in the early 1950's, was discontinued in 1972, and resumed in 1979 (Eccles, 1981). Chemical analyses of treated water indicated dissolved-solids concentrations of about 1,000 mg/L with occasionally high concentrations of phenols, oil, grease, fluoride, and MBAS. About half the water applied to the golf course reaches the aquifer through sandy soils. Dissolved-solids concentrations of the returned water was estimated to be about 2,000 mg/L (Hughes, 1975). Water high in nitrate exists in the upper 50 feet of ground water beneath the supply center, which results from the application of nitrogen fertilizers used on the golf course (Hughes, 1975).

The three possible nonpoint sources of pollution are septic tanks, agriculture, and geologic formations. Septic tanks are used throughout the communities of Yermo and Daggett. Possible types of pollutants associated with septic-tank use include MBAS, nitrate, sodium, sulfate, chloride, and dissolved solids. No high concentrations of constituents commonly associated with septic tanks, except nitrate, are found in the Yermo area.

Ground water in the Daggett area has dissolved-solids concentrations ranging from 370 mg/L to more than 2,000 mg/L. Data for 1951 through 1972 indicate that dissolved-solids concentrations have gradually increased over time (Hughes and Patridge, 1973). Constituents that show a corresponding gradual increase are sodium, chloride, and bicarbonate. Sulfate was also increasing, but more slowly. Elevated concentrations of sodium, chloride, and sulfate are common in ground water in areas using septic tanks. In this area, the sulfate may be in part from geologic formations.

The second possible nonpoint source of pollution is irrigation return and fertilizers associated with agriculture. Agricultural areas are located throughout the study area. In the Barstow area, effluent from the city waste-treatment facility was used until 1964 to irrigate an alfalfa field about 0.5 mile downstream from the second waste-treatment plant. The treatment of effluent effectively reduced the nitrate; hence, the presence of nitrate in irrigation-return water in the area is probably caused by plant decomposition, soils, and fertilizers (Hughes, 1975). In the autumn of 1982, the city of Barstow began using secondary effluent from the city's wastewater-treatment plant to irrigate fodder crops. A 72-acre site located adjacent to the Mojave River near the city's current percolation ponds (pl. 2) has been developed for wastewater irrigation. A 67-acre site located across the river from the 72-acre site will be developed when additional wastewater disposal capacity is needed. Each site will be capable of using up to 2.5 Mgal/d of reclaimed water (M. B. Wochnick, California Regional Water Quality Control Board--Lahontan Region, written commun., 1983).

Agriculture in the valley is most extensive in the Newberry area. Data for this area (Dyer and others, 1963) show high concentrations of sulfate, nitrate, boron, sodium, dissolved solids, chloride, and fluoride in the ground water. Of these, constituents associated with agriculture are nitrate, sulfate, sodium, chloride, boron, and dissolved solids. Dissolved sodium, chloride, nitrate, and boron "...can be concentrated by evapotranspiration and leaching of salts from the soil, and commonly are the most mobile in soil-ground-water systems" (Todd and others, 1976, p. 29). In arid areas, such as the Lower Mojave River valley, the residual salts can be dissolved from the soil by percolating irrigation waters (Todd and others, 1976).

Another potential source of pollution to ground water are fertilizers. Of particular concern related to ground-water degradation is pollution by nitrate and the related increase in salinity (Todd and others, 1976). The data indicate that nitrate is fairly widespread. Water from two wells in agricultural lands southwest of Coyote Lake contains a high concentration of sulfate, chloride, and sodium.

The third possible nonpoint source of pollution is the geologic formations in the Daggett and Minneola areas, and near Troy and Coyote Lakes. High concentrations of fluoride in ground water, primarily west of Daggett and east of Newberry Springs, may be dissolved from fluoride-bearing minerals associated with fault zones. Wells yielding water having high fluoride concentrations west of Daggett are near the Harper fault; those east of Newberry Springs are close to the Calico fault.

Ground water in the Daggett area and in the area east of Minneola typically has high concentrations of sulfate. The sulfate probably is from the sediments in the area that are derived from Tertiary source rocks that contain gypsum (W. R. Moyle, Jr., U.S. Geological Survey, oral commun., 1982).

Ground-water-quality data for Coyote and Troy Lakes area (Dyer and others, 1963) indicate high concentrations of sodium, sulfate, chloride, boron, dissolved solids, and fluoride. Sodium, sulfate, chloride, and boron are common evaporite constituents in the fine-grained playa sediments that can be dissolved and percolate into the ground-water system.

A possible pollution source not shown on tables 4 and 5 are mining and milling operations near Barstow. The mining and milling operations in Barstow were active until 1954. Wastes were disposed about 0.5 mile upstream from the first sewage-treatment facility. These wastes contained high concentrations of iron, aluminum, copper, lead, calcium, magnesium, sodium, and dissolved solids (Hughes, 1975). High concentrations of iron, sodium, and dissolved solids are currently found in the Barstow area, but may be attributable to other sources.

NETWORK DESIGN

Objectives

Conceptual ground-water-quality network objectives and the reasons for choosing each objective are listed in table 6. These objectives are ranked, giving highest priority to monitoring ambient water-quality and water-level conditions because of the general absence of recent hydrologic data for the basin. Highest priority is also given to the city of Barstow and Santa Fe Railway waste-treatment facilities and the U.S. Marine Corps Supply Center at Nebo waste-treatment facility, because they are the sources of the plume of degraded water in the Barstow area. The other objectives are rated according to known and potential pollution problems; the known problems are assigned a higher priority. Priorities were established in consultation with the California Water Quality Control Board--Lahontan Region. These objectives were also used as a guide in selecting monitoring locations for the ground-water-quality monitoring network to be implemented.

Changes in the existing objectives, and therefore the designed network, may be necessary with time because of increased development and different land uses, or as a result of the collection of the initial round of data. The objectives and network can be reviewed after the initial sampling and every 5 years thereafter in order to consider the possible changes.

The ground-water-quality monitoring networks for each objective are given in table 7. In general, the objectives with higher priorities contain the most monitoring sites.

Approach

Development of the conceptual network was based on available water-level and water-quality data, geohydrologic conditions, land uses, and sources of pollution, and was developed without regard to budgetary constraints or use of existing monitoring sites. The conceptual network was used in choosing the existing and new monitoring sites in the network to be implemented.

TABLE 6. - *Conceptual ground-water-quality monitoring objectives*

[Priority: 1, highest; 4, lowest]

Objective	Reason for choosing objective	Priority
1. Ambient		
a. Determine direction and rate of ground-water flow, effectiveness of faults as barriers to ground-water movement and location of pumping depressions.	Knowledge of direction and rate of ground-water flow is necessary to monitor movement of pollutants; determine if fault barriers will contain or slow movement of plumes of contaminants and if pumping depressions appreciably affect flow.	1
b. Establish ground-water quality and water-level bases.	Need for consistent, basinwide data base from which network updates may be made.	1
2. Point sources		
a. Monitor extent, location, and concentrations of constituents in plumes of degraded water from Barstow city and rail-road waste-treatment plants (past and present).	Determine changes in concentrations and effects of plumes on water supplies; determine if Harper fault curtails movement of plumes downgradient.	1
b. Monitor extent, location and concentration of constituents in degraded water from the Marine Corps Supply Center (Nebo) waste-treatment facilities and supply center golf course.	Determine effects of effluent disposal on water supplies; determine whether the Harper fault curtails the downgradient movement of degraded water; determine effect of treated effluent used for irrigation of golf course.	1
c. Monitor effects of Marine Corps Supply Center annex (Yermo) waste disposal.	Determine possible effects of pollutants related to this source on water supplies.	3
d. Monitor effects of Union Pacific Railroad waste disposal.	do.	4

TABLE 6. - *Conceptual ground-water-quality monitoring objectives*--Continued

Objective	Reason for choosing objective	Priority
2. Point sources		
e. Monitor effects of Barstow-Daggett Airport waste disposal.	Determine possible effects of pollutants related to this source on water supplies.	4
f. Monitor effects of clay-processing plant wastewater on ground water.	do.	4
3. Regional nonpoint sources		
a. Monitor impact of agriculture on ground-water quality.	Determine possible ground-water degradation from irrigation return, evaporation, leaching of salts, and use of fertilizers and pesticides; serve as base data for evaluation of effects from possible location of dairies into area.	3
b. Monitor effect of geologic formations on ground-water quality.	Determine whether possible ground-water degradation results from geologic formations.	4
4. Localized nonpoint sources		
a. Monitor effects of septic tanks used in Yermo and Daggett.	Determine possible effects of pollutants related to septic disposal on water supplies.	4

TABLE 7. - *Ground-water-quality monitoring networks by objective*

[Objectives are given in table 6]

Point-source network		Nonpoint-source network		Ambient-conditions network
Monitoring objective	Well No.	Monitoring objective	Well No.	Well No.
Railroad and city of Barstow, waste treatment.	9N/1W-3N1	Agriculture	9N/2E-3K1	8N/3E-1K1
	9N/1W-5J3		9N/2E-14N2	8N/3E-4B2
	9N/1W-9G3		9N/2E-18E1	8N/4E-7B3
	9N/1W-9H4		9N/2E-22E2	9N/2W-1F4
	9N/1W-10D2		9N/2E-25Q1	9N/1W-3N1
	9N/1W-10F7		9N/2E-27E1	9N/1W-5J3
	9N/1W-10H3		9N/3E-14D1	9N/1W-9G3
	9N/1W-10Q2		9N/3E-16D1	9N/1W-10D2
	9N/1W-10R2		9N/3E-19N1	9N/1W-10F7
	9N/1W-11K7		9N/3E-24K2	9N/1W-10H3
	9N/1W-11N2		9N/3E-26J2	9N/1W-10R2
	9N/1W-11P1		9N/3E-27Q1	9N/1W-11K7
	9N/1W-11P2		9N/3E-29G1	9N/1W-11N2
	9N/1W-12N1		9N/4E-6N1	9N/1W-11P1
	9N/1W-12N3		10N/3E-3G1	9N/1W-12N1
	9N/1W-13H1		10N/3E-14J1	9N/1W-12N3
	9N/1W-13H2		10N/3E-21A1	9N/1W-12P
	9N/1W-15A1		--	9N/1W-13E1
		Geologic formations	8N/3E-1K1	9N/1W-13E2
Marine Corps Supply Center, Nebo, waste treatment.	9N/1W-10H3		8N/3E-4B2	9N/1W-13H1
	9N/1W-11P1		8N/4E-7B3	9N/1W-13H2
	9N/1W-11P2		9N/1W-11K7	9N/1W-14A2
	9N/1W-12N1		9N/1W-11N2	9N/1W-15H1
	9N/1W-12N3		9N/1W-12P	9N/1E-1L1
	[1]9N/1W-12P		9N/1W-13H2	9N/1E-1N1
	9N/1W-13E1		9N/1E-18Q1	9N/1E-1P1
	9N/1W-13E2		9N/1E-20B1	9N/1E-2B3
	9N/1W-13H1		9N/1E-21H1	9N/1E-3H1
	9N/1W-13H2		9N/1E-22D1	9N/1E-5H3
	9N/1W-14A2		9N/2E-3K1	9N/1E-12D1
	9N/1E-18Q1		9N/3E-18Q1	9N/1E-14M1
	--		9N/3E-20J1	9N/1E-15N1
				9N/1E-15N2

See footnote at end of table.

TABLE 7. - *Ground-water-quality monitoring networks by objective*--Continued

Point-source network		Nonpoint-source network		Ambient-conditions network
Monitoring objective	Well No.	Monitoring objective	Well No.	Well No.
Marine Corps Supply Center, Yermo, waste treatment.	9N/1E-1N1		9N/3E-29G1	9N/1E-17H1
	[1]9N/1E-2N		9N/3E-34N1	9N/1E-18Q1
	9N/1E-3H1		9N/4E-17B1	9N/1E-20B1
	9N/1E-3P1		9N/4E-20L1	9N/1E-21H1
	9N/1E-3P2		10N/1W-33P3	9N/1E-21L1
	9N/1E-4J1		10N/3E-22M1	9N/2E-1C1
	9N/1E-4J2		10N/3E-30M1	9N/2E-3K1
	9N/1E-4R1		10N/4E-7P1	9N/2E-4D1
	9N/1E-10H1		11N/3E-30J2	9N/2E-8N2
	9N/1E-10L1		--	9N/2E-10D2
	9N/1E-12D1		--	--
Union Pacific Railroad, waste disposal.	9N/1E-1A1	Septic tanks	9N/1E-1A1	9N/2E-14N2
	9N/1E-1C1		9N/1E-1C1	9N/2E-18E1
	9N/1E-1C2		9N/1E-1C2	9N/2E-20Q1
	9N/1E-1L1		9N/1E-14M1	9N/2E-22E2
	9N/1E-1P1		9N/1E-15N1	9N/2E-25Q1
	9N/2E-4D1		9N/1E-15N2	9N/2E-27E1
	9N/2E-6D1		9N/1E-20B1	9N/3E-4J1
	--		9N/1E-21H1	--
Barstow-Daggett Airport waste disposal.	[1]9N/2E-16N		9N/1E-21L1	9N/3E-14D1
	9N/2E-20K1		9N/1E-22D1	9N/3E-15N1
	9N/2E-20Q1		9N/2E-6D1	9N/3E-16D1
	9N/2E-22E2		10N/2E-31R2	9N/3E-16D2
Industrial clay, processing plant.	8N/3E-4B2		10N/2E-32J1	9N/3E-18Q1
	9N/3E-27Q1		--	9N/3E-19N1
	9N/3E-29G1		--	9N/3E-20J1
	9N/3E-34N1		--	9N/3E-24K2
	--		--	9N/3E-27Q1
	--		--	9N/3E-29G1
	--		--	9N/3E-34N1
	--		--	9N/4E-6N1
	--		--	9N/4E-17B1
	--		--	9N/4E-20L1

See footnote at end of table.

TABLE 7. - *Ground-water-quality monitoring networks by objective*--Continued

Point-source network		Nonpoint-source network		Ambient-conditions network
Monitoring objective	Well No.	Monitoring objective	Well No.	Well No.
	--		--	10N/1W-31L8
	--		--	10N/1W-33P3
	--		--	10N/1E-35P2
	--		--	10N/2E-32J1
	--		--	10N/3E-3G1
	--		--	10N/3E-7F1
	--		--	10N/3E-14J1
	--		--	10N/3E-21A1
	--		--	10N/3E-22M1
	--		--	10N/3E-25A1
	--		--	10N/3E-27B1
	--		--	10N/3E-28P4
	--		--	10N/3E-30M1
	--		--	10N/4E-7P1
	--		--	11N/3E-30J2
	--		--	11N/6E-18R1

[1]Locations with incomplete well number are sites with no known well, but where it is suggested that one be drilled.

The first step in designing the conceptual network was to develop the objectives for monitoring the Lower Mojave River valley (table 6). The second step was to develop a network for each objective. Well locations are selected both upstream and downstream from known and potential pollution sources, and from faults that are ground-water barriers. Other sites are located within the known pollution areas. The conceptual ground-water-quality monitoring network for the basin is an aggregation of the individual networks and satisfies all the objectives. The network was then scaled down using the priority ratings for each objective. The scaling-down process eliminated duplication of wells for different objectives and extra wells that could be represented by a single well. The highest priority is generally represented by the greatest number of monitoring locations.

The ground-water-quality monitoring network to be implemented is the resolution of the conceptual network within the constraints described under "Approach." The monitoring sites were catalogued in phase 2 of the project and were being monitored by some agency in 1981. Locations chosen for the ground-water-quality monitoring network are based on the proximity of the well currently being monitored to the locations selected for the conceptual network; the well numbers are given in table 8. Well qualifications such as well depth and perforated interval were also considered in selecting the monitoring locations when possible.

Where there is no active monitoring site located near a conceptual site, as is the case in a large part of the basin, a nearby well was selected from descriptions given in California Department of Water Resources Bulletin 91-10, (Dyer and others, 1963) and the well numbers are given in table 8. It is not known whether these wells still exist. If not, it is suggested that a well be drilled at the selected well site. Well sites with partial well numbers shown in table 8 are proposed drilling locations where wells have never been. New well sites and proposed drilling sites are defined as proposed monitoring sites.

Monitoring Locations

Active and proposed monitoring sites for the ground-water-quality monitoring network were based on factors that might influence the water quality of the Lower Mojave River valley. These factors included geology, water-level data, water-quality data, known and possible sources of pollution, and past, present, and future land uses. Previous reports and information from the Lahontan Regional Water Quality Control Board were also used in selecting monitoring sites.

TABLE 8. - *Ground-water-quality monitoring locations*

[Objectives are given in table 6. Objectives indicate monitoring criteria]

Well No.: Wells that are not currently monitored were identified from California Department of Water Resources Bulletin 91-10 (Dyer and others, 1963). A well may or may not currently exist at this site. If no well is at the proposed site, one could be drilled to meet the network objectives. Locations identified by partial well numbers are sites having no known well but where one could be drilled. These wells and sites comprise the proposed monitoring locations.

Well currently monitored: Wells currently being monitored indicated by "X"; proposed sites indicated by "*." Wells currently being monitored represent active monitoring locations.

Well class: The well-class number indicates the amount of well-qualification data available for the individual wells. Well-class criteria is based on the following key information items: (1) Opening records (perforated intervals); (2) depth of well; (3) casing record; (4) sealing record; and (5) well logs.

Class 1, all five key information items available.
Class 2, the perforated interval is available, but any or all of remaining items lacking.
Class 3, the perforated interval is lacking, but one or more of remaining items available.
Class 4, all key information items lacking.

Well No.	Depth of well (feet)	Perforated interval (feet)	Objectives	Currently monitored	Well class
8N/3E-1K1	66	--	1a, 1b, 3b	*	3
8N/3E-4B2	50	--	1a, 1b, 2f, 3b	*	3
8N/4E-7B3	135	--	1a, 1b, 3b	*	3
9N/2W-1F4	180	--	1a, 1b	X	3
9N/1W-3N1	25	--	1a, 2a	X	3
9N/1W-5J3	222	40-222	1a, 1b, 2a	*	2
9N/1W-9G3	72	10-72	1a, 2a	X	2
9N/1W-9H4	225	--	2a	X	4
9N/1W-10D2	132	--	1a, 1b, 2a	X	4
9N/1W-10F7	160	103-160	1a, 1b, 2a	X	1
9N/1W-10H3	80	78-80	1a, 1b, 2a, 2b	X	2
9N/1W-10Q2	48	--	2a	X	4
9N/1W-10R2	249	140-249	1a, 1b, 2a	*	2
9N/1W-11K7	102	100-102	1a, 2a, 3b	X	2
9N/1W-11N2	100	60-100	1a, 2a, 3b	X	2

TABLE 8. - *Ground-water-quality monitoring locations*--Continued

Well No.	Depth of well (feet)	Perforated interval (feet)	Objectives	Currently monitored	Well class
9N/1W-11P1	52	50-52	1a, 2a, 2b	X	2
9N/1W-11P2	115	113-115	2a, 2b	X	2
9N/1W-12N1	92	90-92	1a, 2a, 2b	X	2
9N/1W-12N3	136	134-136	1a, 1b, 2a, 2b	X	2
9N/1W-12P	100	50-100	1a, 2b, 3b	*	2
9N/1W-13E1	348	48-348	1a, 2b	X	2
9N/1W-13E2	440	65-440	1a, 2b	X	2
9N/1W-13H1	90	--	1a, 2a, 2b	X	3
9N/1W-13H2	108	65-108	1a, 1b, 2a, 2b, 3b	X	2
9N/1W-14A2	407	107-407	1a, 2b	X	2
9N/1W-15A1	129	110-129	2a	X	2
9N/1W-15H1	220	--	1a, 1b	X	3
9N/1E-1A1	250	90-114, 160-168, 180-187, 214-225, 232-245	2d, 4a	X	2
9N/1E-1C1	248	--	2d, 4a	X	3
9N/1E-1C2	240	--	2d, 4a	X	3
9N/1E-1L1	325	--	1a, 1b, 2d	*	3
9N/1E-1N1	202	--	1a, 1b, 2c	*	3
9N/1E-1P1	110	--	1b, 2d	*	3
9N/1E-2B3	200	100-200	1a, 1b	X	2
9N/1E-2N	200	100-200	2c	*	--
9N/1E-3H1	137	--	1a, 1b, 2c	*	3
9N/1E-3P1	504	494-504	2c	*	2
9N/1E-3P2	400	160-400	2c	*	2
9N/1E-4J1	260	142-260	2c	*	2
9N/1E-4J2	350	60-350	2c	*	2
9N/1E-4R1	174	--	2c	*	3
9N/1E-5H3	200	120-200	1a, 1b	X	2
9N/1E-10H1	441	431-441	2c	*	2
9N/1E-10L1	428	--	2c	*	3
9N/1E-12D1	180	--	1a, 1b, 2c	*	3
9N/1E-14M1	330	--	4a	*	3
9N/1E-15N1	134	93-134	1a, 1b, 4a	*	2
9N/1E-15N2	504	50-504	1a, 1b, 4a	*	2
9N/1E-17H1	135	70-135	1a, 1b	X	2
9N/1E-18Q1	101	--	1b, 2b, 3b	*	3

TABLE 8. - *Ground-water-quality monitoring locations*--Continued

Well No.	Depth of well (feet)	Perforated interval (feet)	Objectives	Currently monitored	Well class
9N/1E-20B1	242	--	1a, 1b, 3b, 4a	*	3
9N/1E-21H1	398	148-398	1a, 1b, 3b, 4a	*	2
9N/1E-21L1	426	225-?	1a, 1b, 4a	X	2
9N/1E-22D1	152	--	3b, 4a	*	3
9N/2E-1C1	250	--	1a, 1b	X	3
9N/2E-3K1	19	--	1a, 1b, 3a, 3b	*	3
9N/2E-4D1	284	--	1a, 1b, 2d	*	3
9N/2E-6D1	150	108-125, 132-142, 144-147, 148-150	2d, 4a	X	1
9N/2E-8N2	295	72-295	1a, 1b	*	2
9N/2E-10D2	110	--	1a, 1b	*	3
9N/2E-14N2	215	--	1a, 1b, 3a	*	3
9N/2E-16N	200	100-200	2e	*	--
9N/2E-18E1	159	--	1a, 1b, 3a	*	3
9N/2E-20K1	388	242-388	2e	*	2
9N/2E-20Q1	120	--	1a, 1b, 2e	X	3
9N/2E-22E2	280	--	1a, 1b, 2e, 3a	*	3
9N/2E-25Q1	147	--	1a, 1b, 3a	*	3
9N/2E-27E1	150	--	1a, 1b, 3a	*	3
9N/3E-4J1	144	--	1a, 1b	*	3
9N/3E-14D1	105	--	1a, 1b, 3a	*	3
9N/3E-15N1	75	--	1a, 1b	*	3
9N/3E-16D1	83	--	1a, 1b, 3a	*	3
9N/3E-16D2	325	--	1a, 1b	*	3
9N/3E-18Q1	274	--	1a, 1b, 3b	*	3
9N/3E-19N1	328	--	1a, 1b, 3a	*	3
9N/3E-20J1	100	50-56 73-96	1a, 1b, 3b	*	2
9N/3E-24K2	35	--	1a, 1b, 3a	*	3
9N/3E-26J2	256	--	3a	*	3
9N/3E-27Q1	150	--	1a, 1b, 2f, 3a	*	3
9N/3E-29G1	--	--	1a, 1b, 2f, 3a, 3b	*	3
9N/3E-34N1	99	--	1a, 1b, 2f, 3b	*	3
9N/4E-6N1	165	--	1a, 1b, 3a	*	3
9N/4E-17B1	77	--	1a, 1b, 3b	*	3
9N/4E-20L1	75	--	1a, 1b, 3b	*	3
10N/1W-31L7	--	--	1a, 1b	X	4

TABLE 8. - *Ground-water-quality monitoring locations*--Continued

Well No.	Depth of well (feet)	Perforated interval (feet)	Objectives	Currently monitored	Well class
10N/1W-33P3	150	40-150	1a, 1b, 3b	X	2
10N/1E-35P2	176	76-176	1a, 1b	X	2
10N/2E-31R2	80	--	4a	*	3
10N/2E-32J1	114	--	1a, 1b, 4a	*	3
10N/3E-3G1	165	--	1a, 1b, 3a	*	3
10N/3E-7F1	297	--	1a, 1b	*	3
10N/3E-14J1	130	--	1a, 1b, 3a	*	3
10N/3E-21A1	139	--	1a, 1b, 3a	X	3
10N/3E-22M1	121	--	1a, 1b, 3b	*	3
10N/3E-25A1	160	--	1a, 1b	*	3
10N/3E-27B1	10	--	1a, 1b	--	3
10N/3E-28P4	100	--	1a, 1b	--	3
10N/3E-30M1	1,287	--	1a, 1b, 3b	--	3
10N/4E-7P1	194	80-180	1a, 1b, 3b	--	2
11N/3E-30J2	141	47-141	1a, 1b, 3b	--	2
11N/6E-18R1	--	--	1a, 1b	--	4

Plate 1 shows ground-water-quality monitoring locations for the Lower Mojave River valley. Active and proposed monitoring sites are shown. It is evident from plate 1 that all the active monitoring sites are concentrated in the western, more developed part of the basin, particularly at Barstow and the U.S. Marine Corps Supply Center at Nebo. A few active monitoring sites are located near Yermo and the U.S. Marine Corps annex at Yermo. The rest of the basin is represented by proposed monitoring sites where it is suggested that wells be drilled if there are no wells at these sites. Availability of well-qualification data varies for these locations.

Ground-water-quality monitoring locations are listed in table 8. Available data on well depth, perforated interval, and monitoring status are also included as are the objectives satisfied by the individual well locations.

Surface-water quality can also be monitored at gaging station 10263000 near Afton, shown in plate 1. This is the only point of outflow from the study area because ground water is forced to the surface here resulting in perennial streamflow. Monitoring surface-water quality here would fall into objective category 1b. Surface-water-quality analyses should be made annually for bacteria and standard minerals.

Sampling Constituents and Frequencies

The sampling regimen for wells that satisfy the specified objectives are shown in table 9. Seven groups or types of constituents are suggested for sampling. Ground-water levels can be measured, if possible, whenever a well is sampled. Constituents other than standard minerals to be monitored for ambient conditions correspond to those that seem to be widespread in the Lower Mojave River basin.

Known and possible sources of pollution and land use were the main factors in determining other sampling constituents. Choice of constituents is based on types of pollution and constituents commonly associated with them. Constituents identified in ground water from existing data were also considered.

Constituents chosen for agricultural areas are commonly associated with pesticides. Pesticides are widely used in the Lower Mojave River valley, but there is no systematic program to identify them in the ground water. Analysis for pesticides could be done initially and every 5 years thereafter (Marvin Fretwell, U.S. Geological Survey, oral commun., 1983).

Sampling frequencies are mainly determined by pollution sources. Only wells monitoring the plume of degraded water in Barstow are sampled semiannually (spring and autumn). This is done to determine the location of the plume of degraded water before the rainy season (autumn sampling), and any effects from flooding on movement or areal extent of the plume (spring sampling).

Annual sampling should be sufficient to monitor any other water-quality changes in the ground water. Autumn, when pumping stress is greatest, is probably the best time to sample, although pumping occurs all year. Annual sampling, however, may not detect changes in ground-water quality, particularly for ambient conditions and the sampling frequency should be subject to revision.

Network Limitations

The major limitation of the network design is the absence of current hydrologic, land-use, water-level, and water-quality data. Most of the proposed monitoring sites are based on information and data from earlier reports. Therefore, selected wells based on this older information and data may not represent the best choices for present conditions.

Another network limitation is that depth was not considered in the overall network design because of the lack of information and data for different depths. Until more information and data are available, usefulness of the network design in this report may be limited.

TABLE 9. - *Suggested sampling for monitoring ground-water quality*

[Monitoring objective: Numbers correspond to table 6. Constituents: B, boron; DOC, dissolved organic carbon; DS, dissolved solids; MBAS, methylene blue active substance; NO_3 as N, nitrate as nitrogen; Standard constituents and properties include alkalinity, boron, calcium, chloride, dissolved solids, fluoride, hardness, magnesium, nitrate as N, silica, sodium, specific conductance, and sulfate; trace elements include arsenic, barium, cadmium, chromium (total), chromium (hexavalent), copper, cyanide, iron, lead, manganese, mercury, selenium, silver, and zinc]

Monitoring objective	Location	Constituents	Frequency
Background conditions (1a, 1b, 3b).	Basinwide	Water levels; DS, NO_3 as N, B; standard constituents and properties.	Whenever well is sampled; annually, autumn; initially and every 5 years thereafter.
Waste treatment, domestic and (2a, 2b).	Barstow area	DS, NO_3 as N, B, DOC, phenols, MBAS, trace elements.	Semiannually, spring and autumn.
Waste treatment, domestic and industrial (2c).	Yermo area	DS, NO_3 as N, B, DOC, phenols, trace elements.	Annually, autumn.
Waste treatment, domestic (2d, 2e).	Yermo area, Minneola area.	DS, NO_3 as N, DOC	Annually, autumn.
Golf course (2b).	Barstow area	DS, NO_3 as N	Semiannually, spring and autumn.
Septic tanks (4a).	Yermo, Daggett	DS, NO_3 as N, trace elements.	Annually, autumn.
Agriculture (3a).	Basinwide	DS, NO_3 as N; pesticides.	Annually, autumn; initially and every 5 years thereafter.
Industrial (2f).	Newberry Springs	DS, NO_3 as N, trace elements.	Annually.

The sampling frequencies for the network may also be a limitation. Monitoring sites that describe ambient conditions may identify only long-term changes; those in known areas of pollution will probably identify change over the short-term.

These limitations necessitate subsequent review and possible changes of the network and sampling regimen as more information and data become available.

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