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WATER RESOURCES OF THE MARINE CORPS SUPPLY CENTER AREA BARSTOW, CALIFORNIA

By

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WATER RESOURCES OF THE MARINE CORPS SUPPLY CENTER AREA, BARSTOW, CALIFORNIA

By G. A. Miller

SUMMARY AND CONCLUSIONS

Ground water in storage is presently the only dependable source of water for the Marine Corps Supply Center, Barstow, Calif. The stored water is a firm supply that is readily available to wells. The present water supply is pumped from the Barstow and Yermo subunits of the Mojave River system. These subunits supply water for all irrigation, industrial, public supply, military, and domestic uses in the area. Two million acre-feet or more of usable ground water is in storage in the two subunits. The historically slow rate of water-level decline in wells in the subunits suggests that the water in storage is adequate to meet demands for many years. The supply center has pumped about 1,550 acre-feet annually for several years.

Recharge to the ground-water basins is largely by seepage losses from the Mojave River during infrequent floods. During the period of record, 1931-66, about 580,000 acre-feet of floodwater passed the gage at Barstow. Almost one-fourth of this total occurred during 1 year (1938) and three-fourths of the total occurred as a result of large storms during only 4 years of the 36-year period. The potential recharge to the Barstow and Yermo subunits in this period averaged about 12,000 acre-feet annually.

In general, an obvious direct relation exists between the size of individual floods and the available recharge to the Barstow and Yermo subunits. Past records indicate that the character of floodflow in the Mojave is changing. The records show that in recent years less water flowed in the river at Barstow after storms upstream than flowed after similar storms in the past. This diminished flow is primarily due to the post-1946 dry period and to development and utilization of ground-water supplies upstream from Barstow. These conditions have resulted in a decline in ground-water level upstream that has increased the storage capacity of the aquifer system and allowed more floodwater to infiltrate in the reaches above Barstow. Thus, a smaller percentage of water that enters the Mojave River system in a storm now reaches the Barstow and Yermo subunits to provide recharge than did prior to the change in the upstream conditions outlined above. The operation of a proposed flood-control structure at The Forks of the Mojave River will probably further reduce the proportion of flow past Barstow.

The chemical quality of the ground water is suitable for most uses, including agriculture and public supply. The quality of ground water in the Barstow subunit at Nebo deteriorated steadily during the period 1943-66, except following floods on the Mojave River, which significantly enhanced the quality of the ground water. At the supply center at Nebo, the average concentration of dissolved solids in water from wells increased from about 300 mg/l (milligrams per liter) in 1943 to almost 600 mg/l in 1966. The concentration of dissolved solids in water from wells in the Yermo Annex of the supply center remained about 300-400 mg/l during this period. Water of degraded quality is presently moving downstream toward the supply center's wells at Nebo. This degraded water will probably reach the well field about 1971.

The trends of decline in ground-water levels and of increase in dissolved solids in the Barstow subunit strongly suggest that the chemical quality of the ground-water supply will concern users in the area long before a diminished quantity of water becomes a problem.

INTRODUCTION

An investigation of the water resources of the Marine Corps Supply Center, Barstow, Calif., was started in 1964 by the U.S. Geological Survey, Water Resources Division, at the request of the Department of the Navy. The supply center is in the lower Mojave Valley area of the Mojave Desert, about 140 miles northeast of Los Angeles, Calif. (fig. 1). The supply center area (fig. 2) includes three separate depots: Nebo, Yermo, and Daggett (now inactive). The entire water supply for each depot and for other users in the area is obtained from wells.

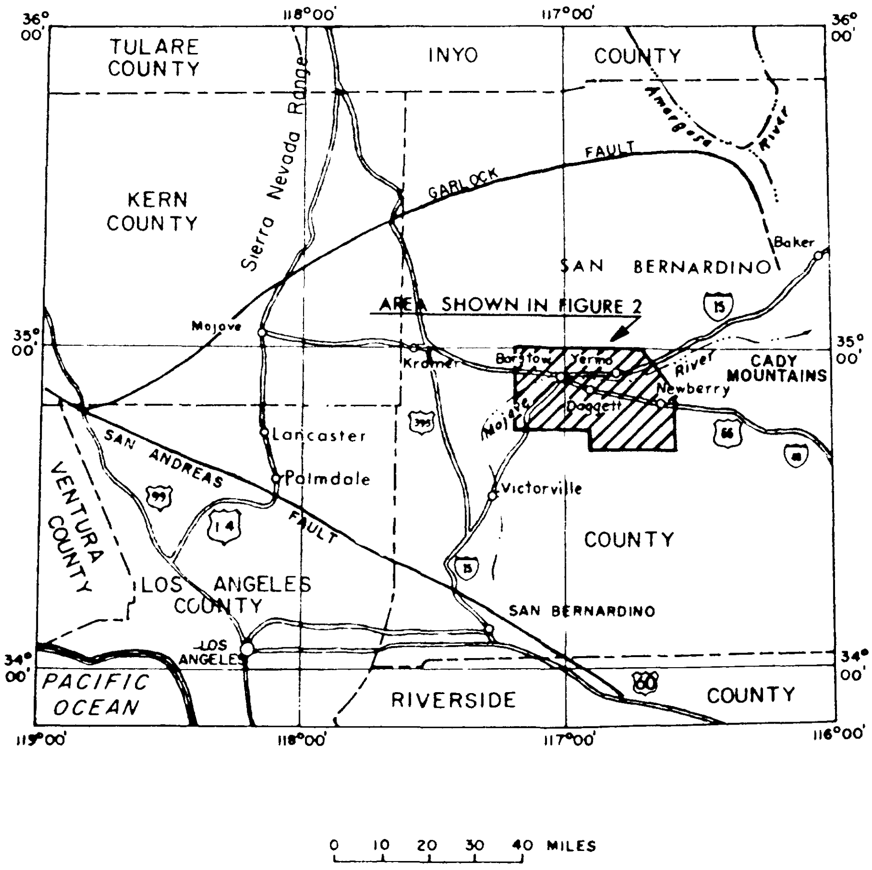


FIGURE 1.--Area described in this report.

Purpose and Scope of the Investigation

The purpose of this investigation is to identify, insofar as the data permit, the factors that affect the ground-water resources available to the supply center and to determine the long-term adequacy of the supply.

The scope of the investigation includes:

1. Study of the geology and ground-water hydrology of the area to determine the extent and character of the water-bearing deposits.

2. Location of geologic barriers to the movement of ground-water or conditions that might relate to the occurrence, source, and adequacy of the ground-water supply.

3. Evaluation of the effect on the water resources of the supply center caused by the use and development of ground water in other parts of the Mojave River valley.

4. Estimation of the ground-water storage capacity in the supply center area and the quantity of ground water available for use at the Marine Corps Supply Center, Barstow, during the next several years.

5. Study of the chemical quality of ground water and surface water, the possibility of changes in water quality, and the related effect on the water supply.

6. Description of the general extent of the Mojave River system and its relation to the geohydrology of the Marine Corps Supply Center area.

7. Description of the results of a test-drilling program.

The report was prepared by the U.S. Geological Survey, Water Resources Division, under the supervision of L. C. Dutcher, chief of the Garden Grove subdistrict, and under the general direction of Walter Hofmann and R. Stanley Lord, successive chiefs of the California district.

Previous Work and Acknowledgments

The collection of hydrologic data in the Mojave River area prior to the turn of the century consisted primarily of the intermittent operation of a few rain-gage stations (Thompson, 1929, p. 77-82) and a stream-gaging station on the Mojave River at Victorville. In 1904 the Geological Survey and the State of California began a cooperative program of measuring streamflow on the Mojave River. Records of those measurements are published in water-supply papers of the Geological Survey. Slichter (1905) studied the underflow of the Mojave River near Victorville. The earliest comprehensive hydrologic investigation was made by the Geological Survey in 1917 when Thompson (1929) studied the area as part of a regional reconnaissance of the geography, geology, and hydrology of the Mojave Desert region. The California Department of Public Works (1934) later studied in detail the hydrologic features of the area as part of an investigation of the Mojave River valley.

The U.S. Bureau of Reclamation (Moritz, 1952) studied the irrigation possibilities of the Mojave River area. Troxell (1954) studied the relation of recoverable water to precipitation in the San Bernardino Mountains and the distribution of mean annual streamflow on the Mojave River.

Several reports containing data on wells in the Mojave River basin and the adjoining basins north and east of the San Bernardino Mountains have been prepared by the Geological Survey, in cooperation with the California Department of Water Resources (Burnham, 1955; Riley, 1956; Kunkel, 1956; Bader, Page, and Dutcher, 1958; Bader and Moyle, 1958; Bader and Moyle, 1960; Page, Moyle, and Dutcher, 1960; Page and Moyle, 1960; Dyer, Bader, Giessner, and others, 1963). Those reports contained detailed data about water wells, records of water levels, drillers' logs of wells, and chemical analyses of water from wells throughout the area.

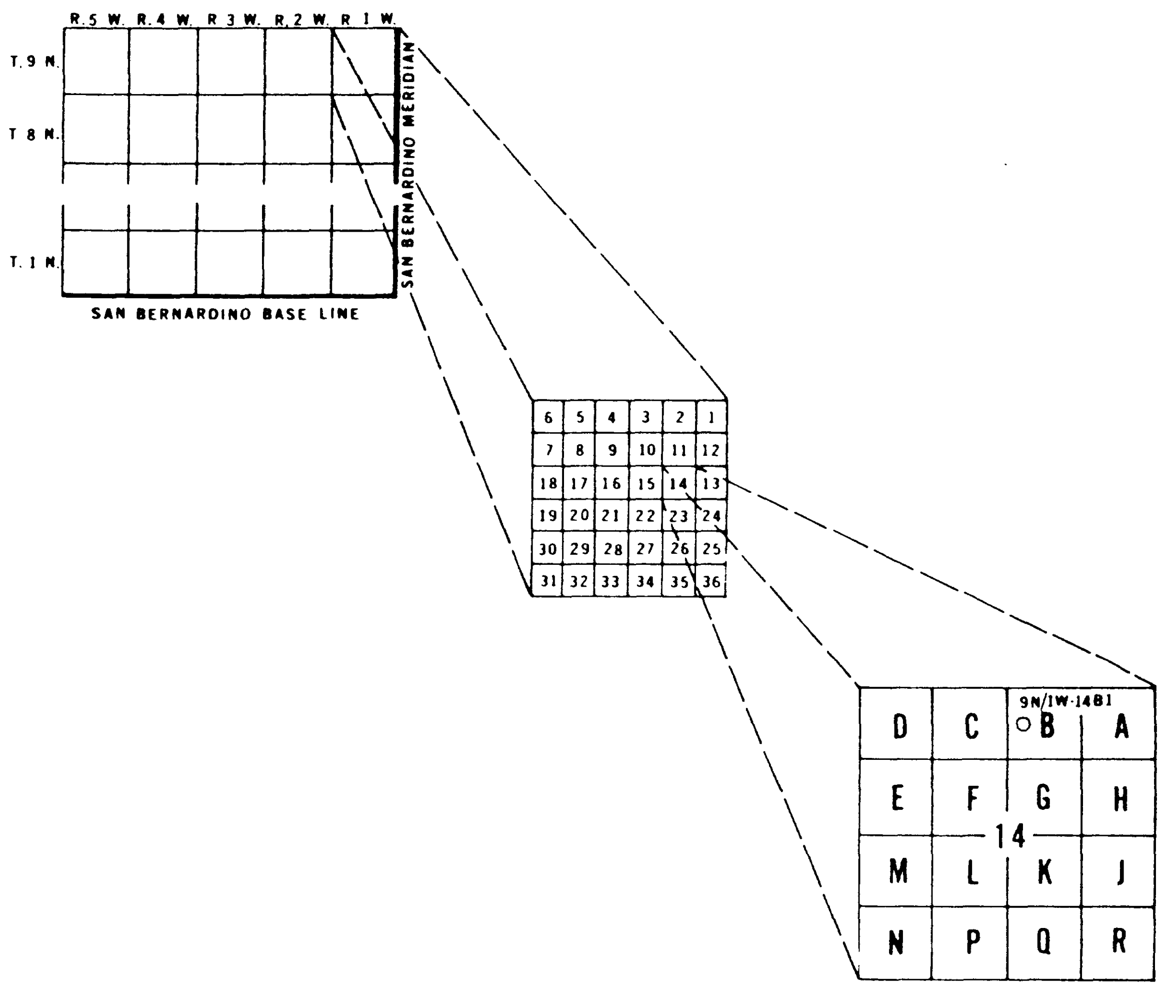
Geologic mapping in the area by Byers (1960), Dibblee (1960), Bassett and Kupfer (1964), and McCulloh (1965) has been particularly useful to the present study.

Organizations studying specific phases of the hydrology of the Mojave River are the State of California Department of Water Resources, the U.S. Bureau of Reclamation, the U.S. Army Corps of Engineers, the San Bernardino County Flood Control District, and the Mojave Water Agency. The Geological Survey conducts a stream-gaging program on the Mojave River, measures a network of observation wells in the area, and in 1966 began construction of an analog model of part of the hydrologic system, in cooperation with the Mojave Water Agency.

The writer acknowledges the cooperation of the many well owners and drillers in the area who expedited the collection of much of the hydrologic information necessary for this report. Grateful acknowledgment also is made to the Commanding Officer of the supply center, General J. H. Masters, and his staff for their generous cooperation during the course of the study.

Well-Numbering System

The well-numbering system used by the U.S. Geological Survey in California indicates the location of wells according to the rectangular system for the subdivision of public land. For example, in the well number 9N/1W-14B1 the first two segments designate the township (T. 9 N.) and the range (R. 1 W.); the third number gives the section (sec. 14); and the letter indicates the 40-acre subdivision of the section, as shown in the accompanying diagram. The final digit is a serial number for wells in each 40-acre subdivision. The letter Z indicates the well was plotted from an unverified location description.



Geography

The Marine Corps Supply Center, Barstow, is in the western part of the lower Mojave Valley as described by Thompson (1929, p. 385). The lower Mojave Valley extends from Barstow eastward to the Cady Mountains. The valley near the supply center is bounded on the south by the Newberry Mountains and Daggett Ridge and on the north by the Calico Mountains (fig. 2). The supply center headquarters is near Nebo, 4 miles east of Barstow, south of the Mojave River. An annex is about 3 miles southwest of Yermo north of the river. Another annex (presently inactive) is about 5 miles east of Daggett.

The Mojave River has its headwaters in the San Bernardino Mountains about 50 miles southwest of Barstow and empties into the Soda Lake and East Cronese Lake playas about 60 miles east of Barstow (fig. 3).

The Atchison Topeka and Santa Fe Railway and the Union Pacific Railroad serve the area. U.S. Interstate Highways 15 and 40 cross the area from east to west.

Barstow is the largest city in the area. Other communities include Yermo, Daggett, and Newberry.

Important elements contributing to the economy of the area are the Marine Corps Supply Center, the railroad repair shops at Barstow, Camp Irwin and the Mojave Test Station Goldstone of the National Aeronautics and Space Administration (35 miles northeast of Barstow), agriculture, and the transient tourist trade. The mining industry was formerly of local importance but has declined during recent years.

Climate

The average annual precipitation in the lowland area of the Mojave River basin is less than 5 inches, but the potential evaporation is probably greater than 70 inches. However, at higher altitudes in the San Bernardino Mountains, in the headwater area of the Mojave River, annual precipitation is greater than in any other area in southern California, at times exceeding 75 inches. At Squirrel Inn (fig. 3) in the San Bernardino Mountains, at an altitude of about 5,200 feet, the average annual precipitation is more than 40 inches. This high area is the primary source of the water supply in the Mojave River system.

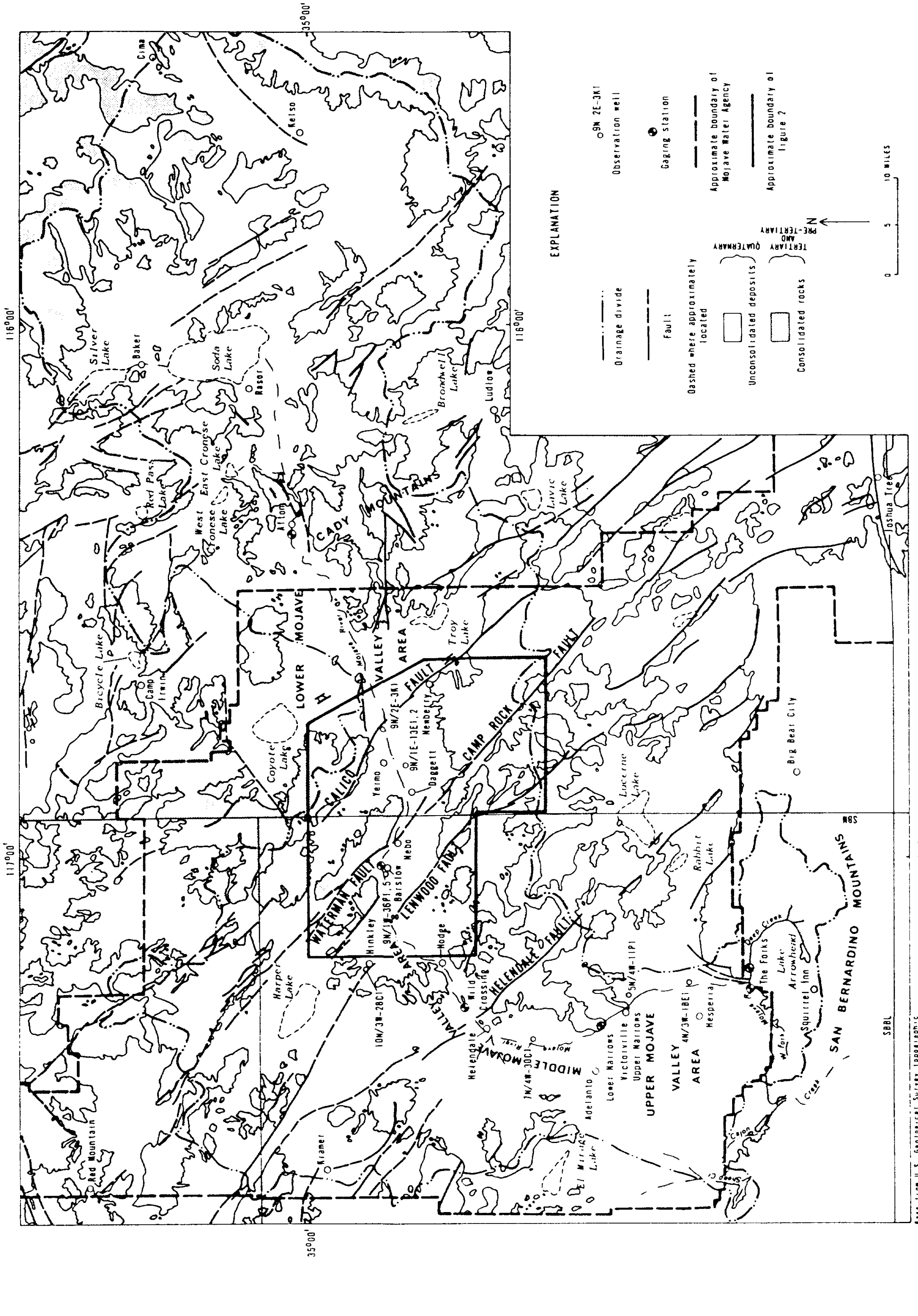


FIGURE 3.--The Mojave River area showing generalized geology, drainage boundary, gaging stations, selected wells, and approximate boundary of Mojave Water Agency.

The cumulative departure from average precipitation at Squirrel Inn, which is probably representative of the headwaters area where most of the water supply for the lower Mojave Valley originates, shows that a drought prevailed almost continuously during the period 1947-66 (fig. 4).

About three-fourths of the rainfall in the supply center area occurs during winter storms; the rest occurs during summer thunderstorms. The average annual precipitation at Barstow is about 4.2 inches.

The growing season is about 250 days. Temperatures below freezing often occur between November and March. Midafternoon temperatures during July and August are frequently above 100°F. in lower areas of the valley. High winds are common in the spring.

The low annual precipitation and high evaporation rate in the area preclude widespread perennial streamflow, except locally where ground water discharges to the surface in short reaches along the Mojave River. Flash floods are the most prevalent type of streamflow in the supply center area. Summer thundershowers cause local floods which are, for the most part, restricted to washes tributary to the river. General floods on the river originate in the San Bernardino Mountains as the result of widespread winter storms. The general storms cause most of the floodflow in the Mojave River and are the source of almost all of the recharge to the ground-water basins.

Water Use and Development

The water in the Mojave River system has been of beneficial use to man since prehistoric time when Indians used the river as a main route of travel from the interior desert to the coast. An account of the early development and use of water in the system has been given by Thompson (1929).

For many years irrigation has accounted for most of the water used by man. The high rate of evaporation and high temperatures during the growing season require that large quantities of water be applied to crops. Alfalfa, a plant that consumes as much as 5 acre-feet per acre annually, is the most common crop. Industry and public supply are also important users of water in the area. The Mojave Water Agency (written commun., 1967) estimated that 180,000 acre-feet of water has been pumped annually in the past few years from the Mojave River system. Probably no more than 40 to 50 percent of this was consumed, the remainder returning to the ground-water system.

Most of the water used for irrigation is pumped from wells, as is the water supply used for public, industrial, domestic, and other purposes. The Geological Survey has data on more than 4,000 wells in the general area, most of which are in ground-water subunits that are part of the Mojave River system.

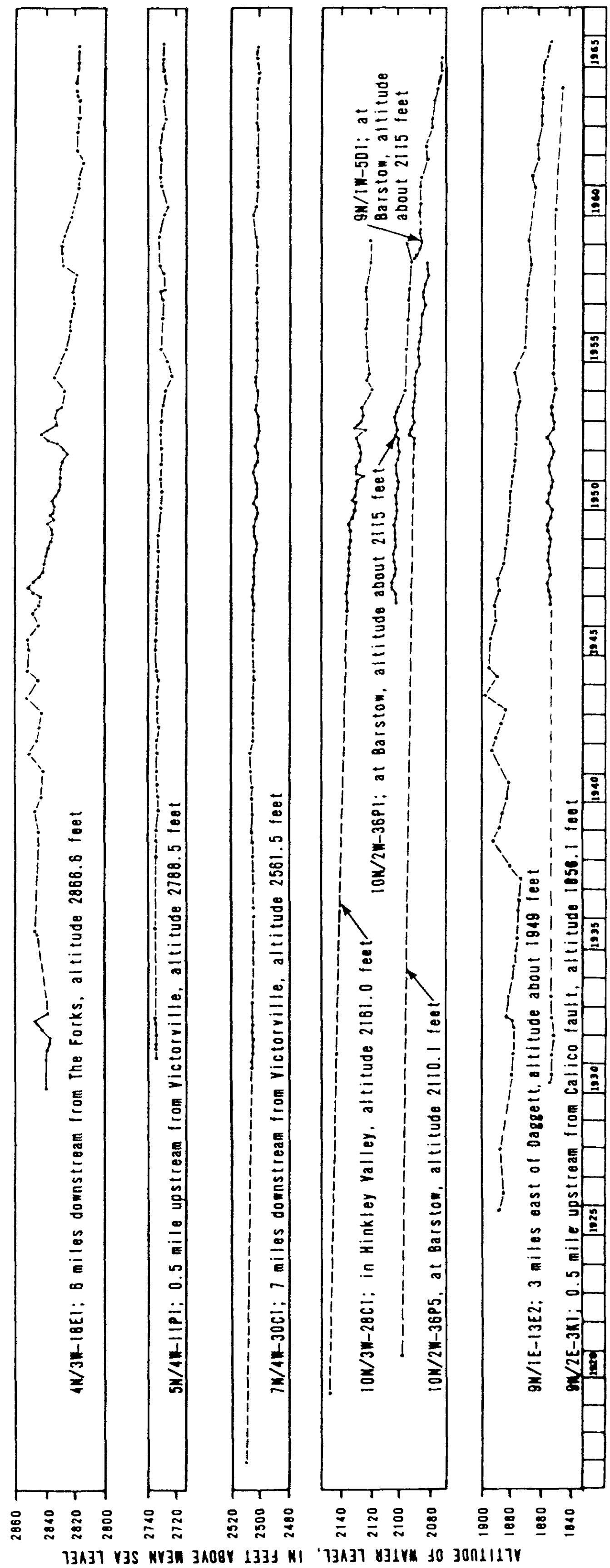


FIGURE 4.--Water-level fluctuations in selected wells, cumulative departure from average precipitation at Squirrel Inn, and annual streamflow at Barstow.

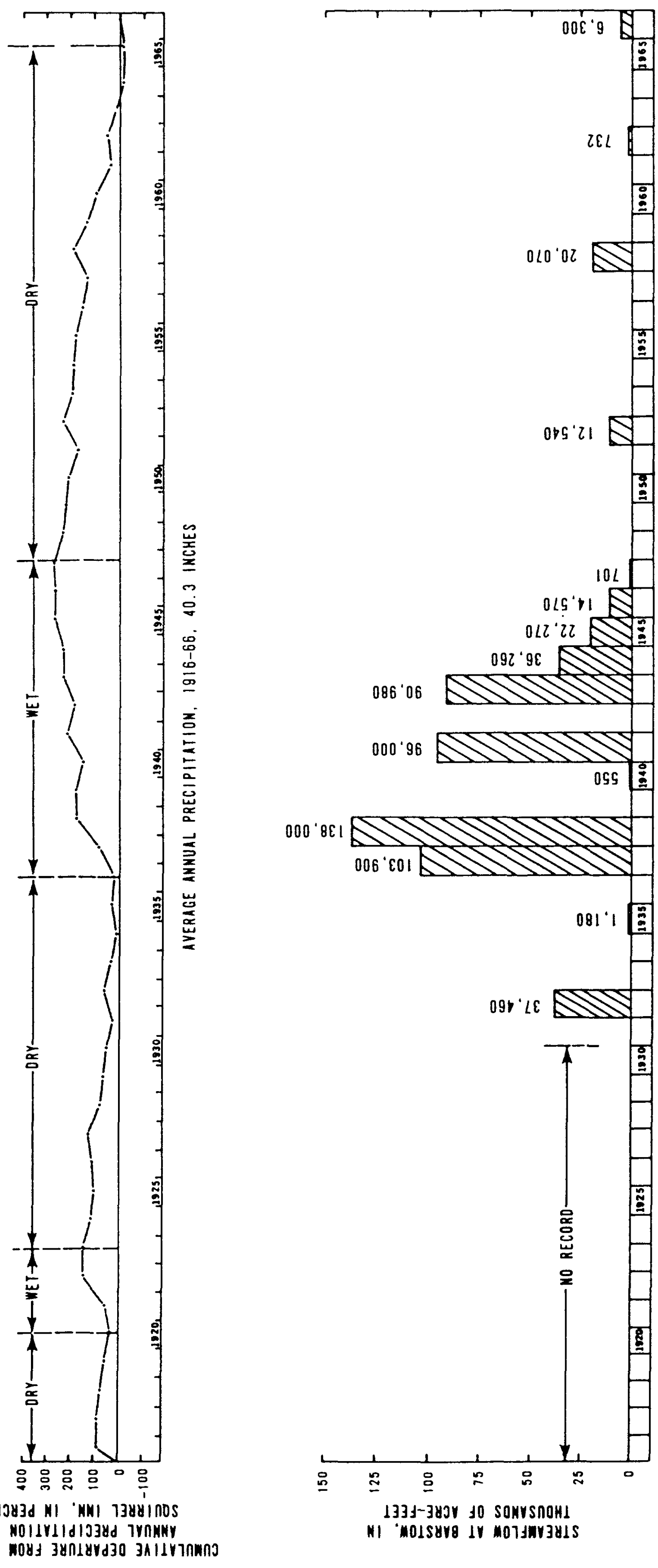


FIGURE 4.--Continued.

The Mojave Water Agency, created by legislative act of the State of California in 1959, is currently studying the present and projected need for water in the general area. The Marine Corps Supply Center, Barstow, is within the boundary of the agency. The agency has contracted with the State of California to participate in the plan to bring additional water from northern California to southern California.

The Mojave Water Agency has been given broad powers by the State to manage water in the area. Chapter 2146, California Statutes of 1959, sec. 15, states: "The Agency may do any and every act necessary to be done so that sufficient water may be available for any present or future beneficial use or uses of the lands or inhabitants of the Agency, including without limiting the generality of the foregoing, irrigation, domestic, fire protection, municipal, commercial, industrial, and recreational uses." Within these powers, the agency presumably plans to manage, to some degree, the bulk of the entire water resources of the Mojave River system inside its boundaries. Such action will reportedly include the addition of more than 50,000 acre-feet annually of imported water. In cooperation with the agency, the Geological Survey is constructing an analog model of part of the Mojave River ground-water system. This model will aid in the management of water resources in the area.

THE MOJAVE RIVER SYSTEM

The water resources of the supply center, especially the water-quality aspect at Nebo, are an integral part of the Mojave River system. Therefore, a brief description of the principal elements of the entire river system is in order.

The two principal components of the drainage system are (1) a headwaters area in the San Bernardino Mountains that encompasses all drainage upstream from the confluence of West Fork Mojave River and Deep Creek, and (2) a main channel and tributary system in the lowland desert area downstream from the confluence (fig. 3).

The boundary of the Mojave River drainage basin is shown in figure 3. This boundary is not marked everywhere by a simple topographic divide. For example, Sheep Creek, which has its headwaters in the San Gabriel Mountains near Wrightwood, flows northward onto a large alluvial fan where the stream forks; one channel leads into the Mojave drainage system and the other into Antelope Valley. Thompson (1929, p. 387) noted this feature and stated, "At one time or another whenever there has been any surface flow, the creek discharges first into one basin and then into another."

Northeast of the community of Hinkley a low topographic divide separates the Mojave River and Harper Valley; nevertheless, Harper Lake is included within the boundaries of the Mojave River drainage because some of the floodwaters of March 2 and 3, 1938, flowed across the divide into the lake. Other large floods in the recent past have probably flowed into Harper Lake. West and East Cronese Lakes and Silver Lake are shown within the drainage boundary of the river because downstream from Afton the Mojave River discharges onto a broad alluvial fan where it flows at times into Soda Lake and at times into East Cronese Lake. Several times in the past East Cronese Lake has filled and overflowed into West Cronese Lake. In a similar manner (during floods on the river) flow has crossed Soda Lake into Silver Lake. A low divide at the north end of Silver Lake separates it from the Amargosa River drainage, which flows into Death Valley. Hunt and others (1966, p. B27) concluded that drainage of the Mojave River into Death Valley by way of Silver Lake occurred during Pleistocene time, and possibly during the Holocene pluvial period. A narrow gorge, which has been cut into the crystalline bedrock at the north end of Silver Lake, attests to the past surface-drainage connection of the Mojave with Death Valley.

The area south and east of Soda Lake (fig. 3) near Kelso and Cima is part of the Mojave drainage. However, a combination of very low annual precipitation and very high evaporation potential results in little runoff water reaching the Mojave River from this area.

In summary, the drainage area of the Mojave River system has differed in the past with individual storms and with pluvial and dry periods.

Streamflow commonly is perennial in the headwaters area and is intermittent or ephemeral in most of the desert area. Perennial flow occurs locally in desert areas where the channel intersects the ground-water table. This effluent ground water originally entered the ground upstream from the perennial wash as channel seepage during infrequent floods. Except in small isolated areas of shallow ground water, vegetation is sparse in the lowland area and reflects the arid climate.

The following sketch of the ground-water regimen of the Mojave River system is by no means complete. Many important aspects of ground water in the system are not completely understood. For example, unknown quantities of ground water enter and leave the system as underflow in several areas. The general direction of ground-water movement in the Upper and Middle Mojave Valley is shown in U.S. Geological Survey Hydrologic Investigations Atlas 31 (Kunkel, 1962).

Ground water in the Mojave River system occurs in several ground-water subunits. The mountainous headwaters area may be considered as one subunit. Here, ground water that accumulates in soil and in cracks and fractures of consolidated rock during the winter months reappears as steadily diminishing base flow in some of the streams during the dry season.

The Upper Mojave Valley area, between The Forks and Victorville, is one of the largest subunits, in terms of both area and ground-water storage, of the Mojave River system. This subunit is recharged by large seepage losses during floods in the river. An unknown quantity of underflow probably enters the subunit from the Cajon Creek drainage (fig. 3). Part of the drainage in the upper reaches of Cajon Creek overlies permeable materials that apparently are in hydraulic continuity with and upgradient from part of the Upper Mojave subunit. An unknown but probably significant quantity of recharge to the subunit also occurs along the lower reaches of West Fork Mojave River, above the gaging station. Ground water from this subunit overflows near the Upper Narrows and maintains a perennial flow for several miles in the Mojave River. Some underflow leaves the subunit southwest of Victorville and enters the Middle Mojave area.

The Middle Mojave Valley area between Victorville and Barstow contains several ground-water subunits. The high water table beneath the river channel upstream from Hodge maintains flow in the river for several miles below Victorville, permitting only small seepage losses during floods. Dense phreatophytes in this reach consume large quantities of ground water. Downstream from Hodge the basin is wider, and the ground-water levels are low. Large seepage losses occur during floods and recharge the ground-water basins in the reach between Hodge and Barstow. The Harper Lake area (fig. 3) is herein included in the Mojave drainage basin because in the past, part of the flow of one or more large floods on the river has flowed into the basin. There is evidence (oral commun., W. F. Hardt, 1966) that west of Helendale some ground water moves through a narrow alluvial channel northward to Harper Lake.

The Lower Mojave Valley area between Barstow and Afton contains three or more ground-water subunits of the Mojave River system. The Barstow and Yermo subunits, from which the supply center obtains its water supply, are in this area. Most of the ground-water recharge by seepage losses from the river occurs in the western, or upstream, part of the valley. In the eastern half of the area, ground-water levels are high enough to cause local perennial flow in the Mojave River. Much of this flow is quickly lost by evapotranspiration or seeps back underground in areas where the water table is low.

Downstream from Afton is the East and West Cronese Lakes-Soda Lake-Silver Lake area of the Mojave River system (fig. 3). Several ground-water subunits are in this area, many of which are bounded by faults. Recharge to ground water in this area occurs chiefly by seepage from floodwater on the Mojave River along a reach of about 5 miles above West Cronese Lake and along about a 10-mile reach above Soda Lake. Floodwaters on the Mojave River flow into the lakes only during major floods. Most of the water that reaches the lakes probably evaporates; little seeps into the ground-water basins. Blaney (1957, p. 209) concluded that evaporation accounted for almost all the water that flowed into Silver Lake during the large flood on the Mojave River of March 1938.

Unpublished data (written commun., W. R. Moyle, Jr., 1967) on water wells in this area show that ground water moves from Soda Lake toward Silver Lake and from the south end of Silver Lake toward the north end. No apparent surface discharge occurs at Silver Lake, and there is little pumping in the area. This evidence strongly suggests that ground water moves from Silver Lake into the Amargosa River drainage and thus to Death Valley (fig. 1). Recent data gathered by Moyle are not conclusive; however, the ground-water hydraulic system between Silver Lake and the Death Valley drainage is probably not as simple as shown by Thompson (1929, p. 562) or Hunt and others (1966, p. B27).

Most of the highland areas in the desert are characterized by outcrops of consolidated rock of Tertiary age or older. The rock generally does not contain large quantities of good quality ground water and for the most part yields only small quantities of water to wells. Typically, the desert lowland areas are underlain by unconsolidated sand and gravel deposits of Quaternary age (fig. 3). The deposits fill the most important ground-water basins and contain the bulk of the usable ground water in the area. The California Department of Water Resources (1967, p. 96) estimated that in 1961 the Upper, Middle, and Lower Mojave basins contained 29 million acre-feet of ground water in storage.

Several faults trend about N. 50° W. across the ground-water basins. Locally, these act as hydrologic barriers to ground-water movement.

The primary source of flow in the Mojave River is precipitation in the San Bernardino Mountains. The mountains constitute only about 4.5 percent of the 4,700-square-mile drainage basin of the river, but probably more than 80 percent of the water in the system originates there. Streamflow from the mountainous area is gaged by the Geological Survey at sites on the two main tributaries, Deep Creek and West Fork Mojave River. The gages are about half a mile upstream from The Forks, the local name applied to the confluence of the two tributaries. Streamflow is perennial at the Deep Creek gage. Little tributary inflow enters the river downstream from The Forks. The river is gaged near Victorville, in a reach where discharging ground water maintains perennial flow. Most of the ground water originated as seepage losses in a 9-mile reach below The Forks where the water table is generally several tens of feet below the channel. The river is gaged near Helendale, at Barstow, and at Afton (fig. 3), in reaches of ephemeral flow. Except during very large, rare floods, or in periods when the ground-water basins are nearly full, most of the water that passes the gaging station near Victorville seeps into the river channel above Barstow, principally in the 12-mile reach below Hodge. Only during large floods does the channel at Barstow carry water, and it is the floodflow passing Barstow that furnishes most of the recharge to the downstream ground-water subunits of the Mojave River system. The water table is low along a 25-mile reach of channel downstream from Barstow, and most of the channel seepage between the Barstow and Afton gages occurs in that reach. The supply center area lies within that 25-mile reach and taps the underlying Barstow and Yermo ground-water subunits (fig. 2) of the river system for its water supply.

Chemical quality of the water in the Mojave River system in general becomes progressively worse downstream. This decline in quality is caused by recycling of ground water through progressive use and reuse, by the availability of smaller quantities of fresh floodwaters in downstream areas to provide dilution by ground-water seepage, by inflow of poor-quality water from local sources within the basin, by the progressively longer period of contact of ground water with rock materials, and by natural evapotranspiration from free water surfaces and phreatophytes. Ground water use by phreatophytes is probably a major cause of the degradation in water quality in the reach from Victorville to near Hodge.

Ionic-concentration diagrams (fig. 5) show changes in quality as water moves through the Mojave River system. The diagrams are based on the concentration, in milliequivalents per liter, of the main dissolved constituents in water. Figure 5 shows three broad areas of distinctly different water quality in ground water along the Mojave River: (1) The Upper Mojave area, where ground water typically is of good to excellent quality, (2) the Middle and Lower Mojave areas, where most ground water is of good to fair quality, and (3) the Soda Lake area, where most of the ground water is of poor quality.

The concentration of dissolved material has also increased with time. The increase with time is somewhat more pronounced in the downstream areas than in the upstream areas.

Figure 5 also outlines the more uniform trend of the chemical quality of floodwaters in the Mojave River system. The diagrams are based on analyses of samples taken shortly after the flood crest in December 1966. Floodwaters, which are the major source of ground-water recharge, show a progressive increase in concentration of dissolved material during the course of their flow downstream; the change generally is from excellent quality in the headwaters area to good quality in the downstream areas. An examination of a limited number of analyses of spot samples taken during earlier floods on the river shows similar trends in quality of floodwater to that shown in figure 5.

To summarize the water situation in the Mojave River system, the total quantity of water--both surface and ground water--available to man on a long-term basis, usually decreases progressively downstream from the mountainous source area. This decrease in quantity is accompanied by a general decline in chemical quality of the water. These two related conditions are the essence of the present and potential water problems of the Mojave River.

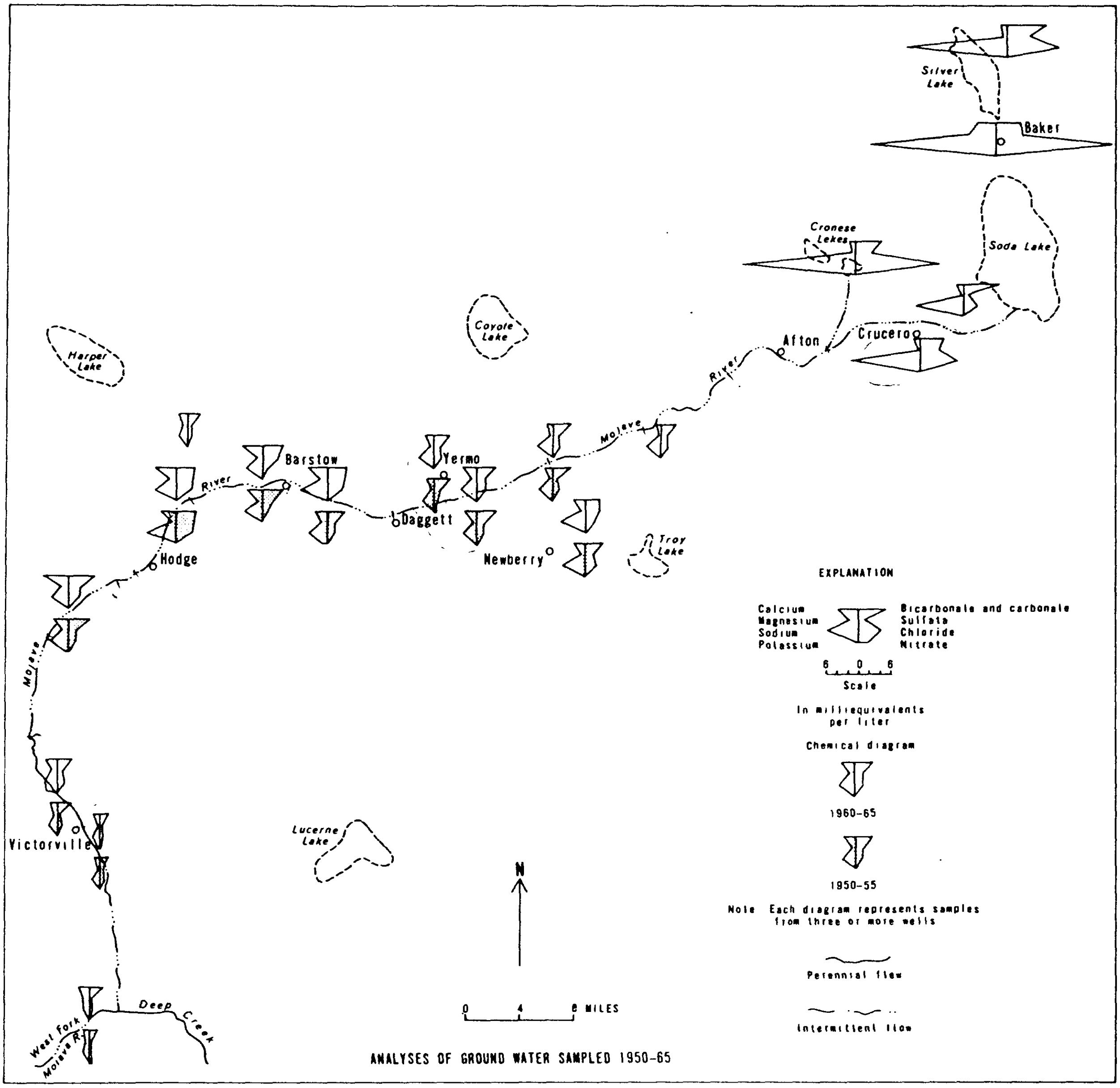


FIGURE 5.--General chemical nature of water in the Mojave River valley.

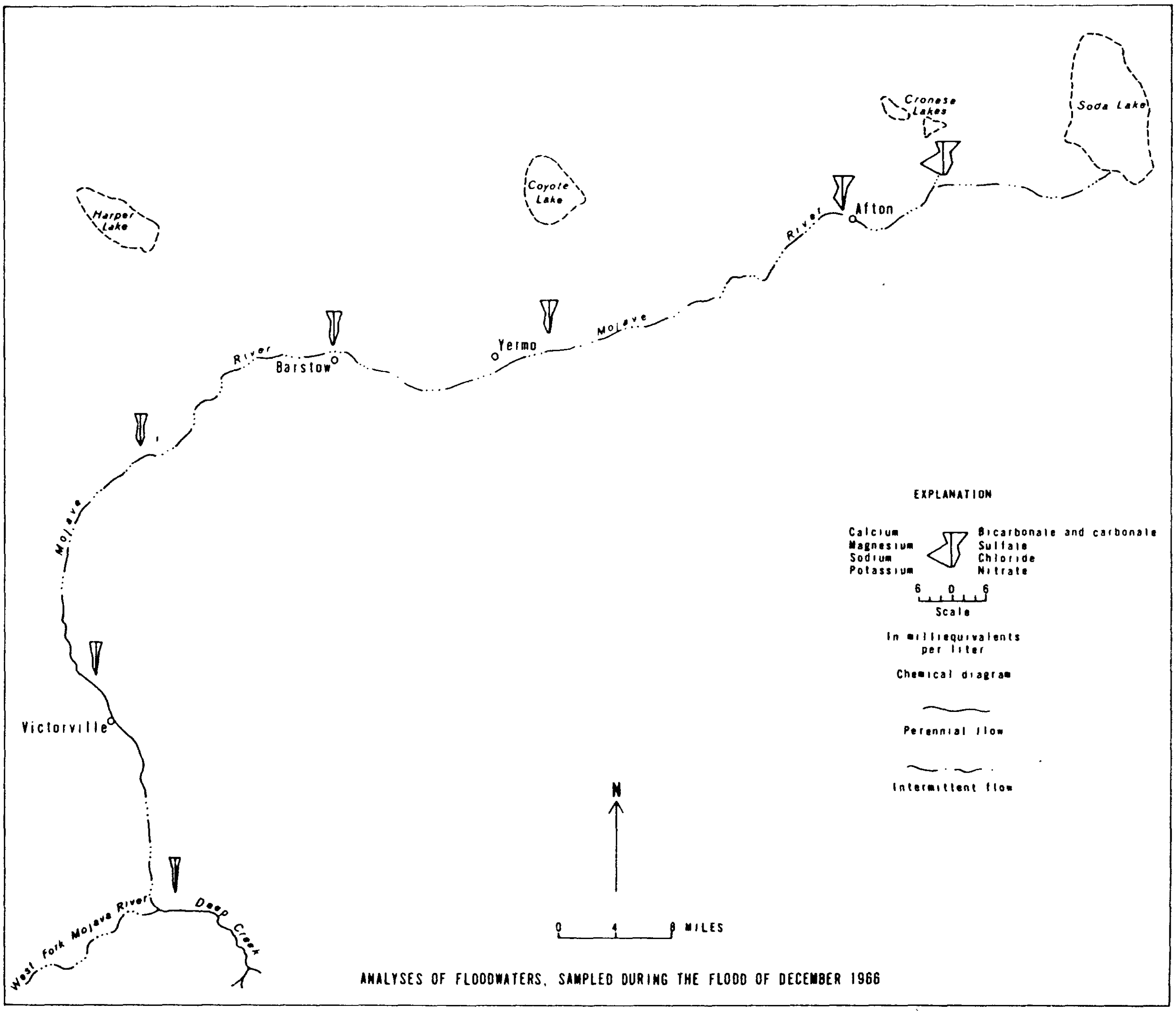


FIGURE 5.--Continued.

GROUND-WATER RESOURCES OF THE MARINE CORPS SUPPLY CENTER

Ground water stored in the Barstow and Yermo ground-water subunits of the Mojave River system (fig. 2) is the only present reliable source of water for the supply center. These subunits are only two of the many subunits along the Mojave River between the San Bernardino Mountains and Silver Lake. The quantity of water in storage in the two subunits is large, and the chemical quality of the water is such that it is usable for most purposes. The ground water in these subunits moves slowly in directions indicated by arrows across water-level contours in figure 2. These subunits receive recharge by seepage from surface flow in the Mojave River during infrequent floods and from adjacent upgradient subunits by underflow.

Barstow subunit.--The supply center at Nebo obtains its water supply from the Barstow subunit. The geologic map in figure 2 shows features that define the subunit, and the geologic section A-A' across the area shows the general geologic conditions within the subunit.

In general the boundaries of the subunit are geologic features that act as hydrologic barriers, but, inasmuch as ground water enters the subunit through alluvial fill beneath the river, in places the boundaries are somewhat arbitrary. The western boundary is at Barstow, where consolidated, almost impermeable, rocks crop out on each side of the Mojave River. The eastern boundary is the projected trace of the Waterman fault (fig. 2). The bottom and the northern and southern boundaries of the subunit (fig. 2, geologic section A-A') are the base of the permeable, unconsolidated, water-bearing deposits of Quaternary age where they rest on older, less permeable rocks. The area of the subunit is about 20 square miles.

Yermo subunit.--The supply center annex near Yermo obtains its water supply from the Yermo ground-water subunit. The boundaries of the subunit, like those of the Barstow subunit, are geologic features which generally act as hydrologic barriers. Most of the bottom of the subunit and of the western, northern, and southern boundaries are the base of the permeable, unconsolidated, water-bearing deposits of Quaternary age where they rest on older less permeable rocks. The Yermo subunit shares a common boundary, the Waterman fault, with the Barstow subunit near Daggett (fig. 2). The eastern boundary of the subunit is the Calico fault. In the lowland area northwest of Yermo and in much of the area south of the valley floor west of Newberry, the edge of the basin is indefinitely known because there are few wells in these areas. The area of the subunit is about 65 square miles.

Ground-Water Geology

The surface geology (fig. 2) of the area is characterized by outcrops in the highland areas of consolidated rocks consisting of a basement complex of pre-Tertiary age, continental rocks of Tertiary age, and basalt of Quaternary age. The lowland areas are characterized by outcrops of unconsolidated deposits of Quaternary age that consist of older fan deposits, older alluvium, and older lacustrine deposits, of Pleistocene age, and younger fan deposits, younger alluvium, playa deposits, river-channel deposits, and wind-deposited sand, of Holocene age (fig. 2). The most important aquifers in the area are the older fan deposits and the older alluvium; the other unconsolidated deposits are, for the most part, above the water table.

The dominant trend of geologic structure is northwest (fig. 2). This is reflected in the trend of major faults. The complex basinlike structure that lies between the Newberry Mountains-Daggett Ridge area and the Calico Mountains contains most of the important water-bearing deposits (fig. 2, sections A-A' and B-B').

Consolidated Rocks

The basement complex, an assemblage of crystalline rocks that underlie the sedimentary deposits, consists chiefly of quartz monzonite, granite, granodiorite, hornblende diorite, gneiss, schist, and metavolcanic rocks (Bowen, 1954; Dibblee, 1960; Dibblee (written commun., 1966); and McCulloh, 1965). Most of the producible ground water in these rocks is contained in fractures. The few water wells that tap the basement complex have low yields.

The continental rocks of Tertiary age consist largely of conglomerate, sandstone, siltstone, mudstone, shale, volcanic rocks, and limestone. The volcanic rocks contain small quantities of ground water in fractures. The sediments that make up the bulk of the continental rocks are for the most part poorly sorted and have low permeability. A few wells with low yield tap these rocks. Soluble minerals, notably sulfates and borates, occur locally in these rocks and cause local high concentrations of dissolved material in the ground water.

The basalt of Quaternary age occurs as a lava flow about 5 miles south of Newberry (fig. 2). This flow is above the water table in this area.

Unconsolidated Deposits

The older fan deposits are composed of poorly sorted to moderately well-sorted boulders, gravel, sand, silt, and some clay. Locally, these deposits may be more than 800 feet thick (Dibblee, 1960, section B-B'). These deposits generally have a gentle initial dip from the highland areas toward the valley floor except where they have subsequently been folded. The older fan deposits are locally cemented and yield small to moderate quantities of water to wells. Locally, the water is of poor quality; test well 9N/1E-19J1 yielded about 50 gpm (gallons per minute) of poor quality water from the lower part of these deposits.

The older alluvium consists of well-sorted to poorly sorted gravel, sand, silt, and clay. This unit is, at least in part, the same age as the older fan deposits, and the two units probably intertongue (fig. 2, sections A-A' and B-B'). The older alluvium underlies most of the valley floor in the two ground-water subunits. It is the most important aquifer in the area and reportedly yields several thousand gallons of water per minute to some wells.

The older lacustrine deposits consist largely of moderately consolidated marl, silt, and sand. These deposits, which are above the water table, are in the highland area north of Nebo (fig. 2).

The younger fan deposits consist of loose boulders, gravel, sand, and silt overlying older deposits from which they were largely derived. The deposits, for the most part, occur above the water table. However, they are permeable and are thus able to absorb some flash-flood runoff and transmit recharge to the deeper deposits in the ground-water basin. Where the younger fan deposits are below the water table, they yield large quantities of water to wells.

Younger alluvium consists of loose gravel, sand, silt, and clay. These deposits cover most of the valley floor east of Daggett (fig. 2). The material is moderately to highly permeable but, for the most part, lies above the water table. Where saturated, these deposits yield large quantities of water to wells. Excess irrigation water may infiltrate through them and return to the ground-water reservoir. In irrigated areas, probably some precipitation infiltrates through the younger alluvium to the deeper deposits in the ground-water basin.

Playa deposits consist largely of clay, silt, and some sand, and are almost impermeable. These deposits occupy a large flat area 2 miles northwest of Yermo and a small closed depression about 5 miles south of Nebo (fig. 2).

River-channel deposits in the Mojave River bed consist of moderately sorted to well-sorted sand and gravel. Large seepage losses from the river occur during periods of flood through this highly permeable material. In the few areas where these deposits are saturated, they yield water readily to wells.

Wind-deposited sand covers a large area of the valley floor west of the Calico fault and a small area along the river west of Barstow (fig. 2). The water table is shallow and locally supports plant growth that holds the sand in place.

Geologic Structure

A large northwestward-trending depositional basin developed in the area during the Tertiary Period (Bassett and Kupfer, 1964, p. 15, 16), and the rocks of Tertiary age were deposited as the basin formed. The structure was subsequently folded and faulted, but sand, gravel, and boulders continued to be deposited in the synclinal trough during the Quaternary Period. The present highland area between Nebo and Yermo, where a thick sequence of rocks of Tertiary age and Mesozoic age are exposed (Dibblee, 1960), has been uplifted into a complex anticline (fig. 2).

Major faults, some with significant horizontal displacement, trend northwestward across the area. The Waterman fault extends several miles north of the Mojave River (fig. 2) and is readily traced on the land surface. South of the river this fault is buried by unfaulted surficial sediments, but it acts as a barrier to the movement of ground water from near Nebo to somewhere east of the supply center firing range. The water level in well 9N/1E-19J1, southwest of the fault, is about 50 feet higher than the water level in adjacent well 9N/1E-20R1, northeast of the inferred fault trace (fig. 2). A constant-discharge pumping test of 13-hours duration on well 9N/1E-19J1 shows a sharp increase in drawdown about 8 hours after pumping began, which probably indicates a hydrologic barrier near the well. The change in water level across this fault at Nebo is about 45 feet.

The Camp Rock fault (fig. 2) trends northwestward from the Newberry Mountains and Daggett Ridge to about 4 miles south of Daggett, where its surface trace is covered by alluvial-fan deposits. This fault parallels the Waterman fault. Older fan deposits exposed in a northwestward-trending hill west of the rifle range butts have been uplifted on the north side of the fault (section B-B'). The structure underlying this hill probably was formed by movement along the Camp Rock fault or along a related fault. The Camp Rock fault probably extends beneath the alluvial-fan deposits to the northwest and may act as a barrier to the movement of ground water in the Barstow subunit.

The Calico fault trends northwestward across the Mojave River valley from near Newberry on the south to the Calico Mountains on the north (fig. 2). It forms an effective barrier to the movement of ground water. The difference in water levels in wells across the fault is as much as 60 feet.

Ground-Water Hydrology

Ground water occurs beneath the land surface of the entire area shown in figure 2. However, only a part of the area is underlain by saturated material that is permeable enough to yield water readily to wells. This permeable water-bearing material consists chiefly of the unconsolidated sand and gravel in the older alluvium and older fan deposits. Ground water occurs below the water table in the interstices, or so-called pore spaces between individual particles of sand and gravel.

Ground water moves downgradient under the influence of gravity in much the same manner as surface water flows in a stream channel, but at a much slower rate because of friction with the granular material through which it moves. For example, Slichter (1905, p. 63) estimated that the rate of flow of ground water in the alluvium beneath the Upper Narrows near Victorville was about 2 feet per hour. This is extremely rapid compared with most ground water. The chemically degraded ground water downstream from Barstow (California Department of Public Health, 1966), discussed later in this report, has moved at a rate of less than 2 feet per day. In contrast, a typical rate of flow of surface water in the Mojave River during floods may be as high as 10,000 feet per hour for the advancing toe of the flood, and more than 50,000 feet per hour locally near the flood crest.

The approximate direction of movement of ground water can be determined by constructing a water-level contour map using the elevation of water levels in wells. Such a map, based on water levels during spring 1964, is shown for the supply center area in figure 2. Arrows at right angles to the contours show the general direction of ground-water movement. The pattern of movement is generally in the downstream direction of the Mojave River, from areas of recharge toward areas of discharge. Locally, the contours show ground water moving from the highland areas to the central lowland areas; this is in response to lowered water levels in the lowlands and does not indicate appreciable recharge from the direction of the highlands.

Fluctuation of Water Level in Wells

Significant changes of water level in wells are commonly a manifestation of recharge to, or discharge from, the aquifer. A rise of water levels in wells reflects an increase in the quantity of ground water in storage; a decline of water level indicates a decrease in the quantity of stored water.

Since 1945 the water level in well 9N/1E-13E2, 3 miles east of Daggett, has declined about 2 feet per year (fig. 4). A similar rate of decline occurred during the dry period 1926-36, when the pumping draft presumably was less. The well is near the center of the Yermo subunit, which contains highly permeable aquifers and generally exhibits a relatively flat water-table configuration with no pronounced depressions due to pumping. Therefore, the water-level changes in the well are probably representative of the entire subunit. This suggests that the post-1946 drought and accompanying reduced recharge have exerted more influence on the water level in that well than have the withdrawals of water by man.

During the period 1941-64 water levels in the supply center wells near Yermo declined about 25 feet. The water level in wells at Nebo declined about 15 feet. Records for other wells throughout the two ground-water subunits also indicate a similar net decline of water levels. The water-level decline has been small on the upgradient side of the Calico fault (fig. 4, well 9N/2E-3K1).

Recharge

Underflow from ground-water basins upstream, flow in tributaries as a result of local storms, and flow in the Mojave River during regional floods are the sources of recharge to the Barstow and Yermo ground-water subunits. Direct penetration of rain to the ground-water basin probably is rare in this area because of the short duration of the storms, the usually high soil-moisture deficiency, the high evapotranspiration rate, and the depth to the water table in most areas. Some infiltration may take place infrequently when rain falls on irrigated areas. Large floods on the river, which occur during the winter months, are the most important source of recharge. These flows are generally larger, of longer duration, and less subject to losses by evaporation than flows caused by summer thundershowers.

The most important effect of the recharge is to enhance the chemical quality of the upper part of the stored ground-water body that is utilized by man.

Annual underflow into the Barstow subunit at Barstow was estimated to be 9,000 acre-feet by the California Department of Public Works (1952, p. 12). Test borings and water-level measurements at Barstow by the Geological Survey in 1965 and 1966 indicate lower permeability values and deeper water levels than those used in the Department of Public Works computations. Therefore, the annual underflow at Barstow has been reestimated to be 1,100 acre-feet. This estimate was calculated by using the following formula for saturated flow through porous media:

$$Q = PIA$$

where Q = underflow, in gallons per day
P = permeability, in gallons per day per square foot at unit gradient
I = hydraulic gradient, in feet per foot
A = cross-sectional area of saturated flow, in square feet.

The average permeability (*P*) of the saturated material overlying bedrock in the area of the railroad bridge across the Mojave River northwest of Barstow is estimated to be at least 1,000 gpd (gallons per day) per square foot. This estimate of permeability is based on the results of test drilling and on the specific capacity[1] of wells in the area, most of which penetrate the highly productive part of the alluvium. The gradient (*I*) was estimated from the water-level contours to be 10 feet per mile, or 0.002 feet per foot. Using the water level in wells as the top of the saturated zone, test holes bored through the unconsolidated deposits to the consolidated rock indicate the cross-sectional area (*A*) to be at least 500,000 square feet (equivalent to about 1 mile wide and 100 feet thick).

Thus, using the formula, $Q = PIA$

Q = 1,000 x 0.002 x 500,000

Q = 1,000,000 gallons per day or about 1,100 acre-feet per year.

The contribution as recharge to the ground-water subunits by runoff from local storms is not readily estimated, but the quantity is probably small. Weir and others (1965) estimated that the contribution to the ground-water basin in Antelope Valley from precipitation in areas with annual precipitation of less than 10 inches was 1 percent of the total local precipitation. Antelope Valley is about 60 miles west of Barstow and the climate, geology, and topography are in many respects similar to conditions at the supply center.

The average annual precipitation at Barstow is only about 4 inches; thus the part of precipitation that contributes to recharge may be even lower. Assuming that less than 0.5 percent of the average annual rate of precipitation at Barstow is added to the ground-water basins, the Barstow subunit would receive less than 100 acre-feet and the Yermo subunit would receive less than 250 acre-feet. These estimates of ground-water recharge from local precipitation are not presumed to be precise; they are included merely to point out that as a source of recharge to ground water, local precipitation is probably not important in this area.

Channel seepage during periods of floodflow on the Mojave River provides the great bulk of the recharge to the Barstow and Yermo subunits. This is evident from a comparison of the streamflow records for Barstow, upstream from the supply center, and Afton, downstream from the center. Further evidence is the rise of water levels in nearby wells following periods of floodflow on the Mojave River at Barstow (fig. 4).

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[1]Specific capacity: The yield of a well, in gallons per minute, divided by the drawdown, in feet.

The difference in flow between a gage at the upstream end of a ground-water basin and a gage at the downstream end includes seepage into the ground-water reservoir and evaporation losses from the water surface and the wetted channel, and water retained in material above the water table.

Seepage from the Mojave River into the ground-water reservoir between Barstow and Afton can be estimated by subtracting the floodflows gaged at Afton from related floodflows gaged at Barstow. During the wetter-than-average years 1932, 1958, 1962, and 1966, when the ground-water levels were low and large quantities of water infiltrated, the floodflow at Afton was about 20 percent of that at Barstow. About 80 percent of the flow, less evaporation, seeped into the ground between the two gages. This estimate is probably a reliable indication of the total recharge to the entire Lower Mojave Valley area. Recharge to the Barstow and Yermo subunits, which are crossed by the river within a distance of about 20 miles, is less, as the total distance between the two gages is about 48 miles.

In 1964 the water table was within 20 feet of the streambed along only about 1 mile of the river channel in the Barstow and Yermo subunits. Downstream from the Yermo subunit, between the Calico fault and the gage at Afton, the water table was about 10-20 feet below the riverbed for approximately 20-25 miles. Thus, the total reach between the two gages where the water table is appreciably below the streambed and where large seepage losses can readily occur is about 25 miles. If the seepage were distributed evenly across this distance, about 4 percent of the total seepage would occur along each mile of the channel.

Although the conditions in the channel that control seepage are similar throughout the 25 miles, the rate of seepage decreases downstream because floodflows diminish in a downstream direction, along with many of the factors controlling seepage that are a direct function of discharge such as depth of flow, scouring of the channel, and wetted area. This causes a higher rate of seepage in the upstream part of the area than in the downstream part. As a result, the 19 miles of riverbed in the Barstow and Yermo subunits where the water table is at appreciable depth probably received more than 4 percent of the total seepage per mile. No data are available to substantiate such an estimate, but it seems reasonable to assume that each mile in this reach might receive an average additional increment of at least 0.5 percent of the seepage. This would mean that about 85 percent of the seepage losses from the Mojave River between Barstow and Afton occur in the Barstow and Yermo subunits.

Total flow past the gage at Barstow in the 36-year period 1931-66 was about 580,000 acre-feet. Three-fourths of this occurred during only 4 years, 1937, 1938, 1941, and 1943. About 500,000 acre-feet of this total flow occurred in the wet period 1937-46, when the water table was at shallow depth below the streambed, and the capacity for receiving recharge was accordingly not great along several miles of the channel across the Barstow and Yermo subunits. The flow past Afton was not gaged during this wet period, but it probably amounted to a much larger percentage of the flow at Barstow than during the post-1946 dry period. This conclusion is based on studies of seepage in gaged reaches of the river upstream from Barstow. The studies show that much less seepage occurred between gages upstream from Barstow during individual floods in the wet period prior to 1946 than occurred during floods of similar magnitude in the drought period after 1946. The studies also show that little seepage occurred between Victorville and Helendale, a reach where the water level is at or very close to the streambed. If, however, it is assumed that the ground-water basins between the gages at Barstow and Afton had been depleted during the entire period 1931-66, and if the premise is accepted that 80 percent of the water available for recharging the basins actually did so in the Lower Mojave Valley area, the total recharge during the 36-year period would have been about 470,000 acre-feet, or an average of about 13,400 acre-feet annually. Assuming that 85 percent of this seepage occurred in the Barstow and Yermo subunits, the total recharge then would have been about 400,000 acre-feet, and the average annual recharge would have been about 11,400 acre-feet.

As much as 5 square miles of the river channel in the two subunits is wetted by a large flood; this wetted area is subject to subsequent evaporation losses. No data are available in this area to reliably estimate such losses; however, they are probably small, perhaps about 0.5 acre-foot per acre, or 1,600 acre-feet following seasonal floods. During the period 1932-66, most of this 1,600 acre-feet would have been lost only during the 17 years when flow occurred past Barstow, leaving about 370,000 acre-feet as the total recharge during the period, or an annual average of about 10,600 acre-feet.

Thus, the total average annual potential recharge to the Barstow and Yermo subunits may be about 350 acre-feet from local precipitation, 1,100 acre-feet from underflow, and 10,600 acre-feet by seepage from floods--a total of about 12,000 acre-feet.

The above estimate for recharge is based on records obtained during a period whose earlier years were wetter than average and whose later years were drier than average. Because of the recent dry years, the percentage of upstream floodflow that passes Barstow is now (1968) smaller than in former years, and thus the average recharge is declining.

The average annual flow past Barstow varies widely, compared with flow past upstream areas, with changing climatic conditions. Figure 6 shows the average flow past gages at The Forks, Victorville, and Barstow during the entire period of record, 1931-66, compared with the average flow during the wetter-than-average period, 1937-46, and the drier-than-average period, 1947-66. Average annual flow past Barstow during the dry period was about 4 percent of the flow during the wet period, while flow past the upstream stations during the dry period was close to 35 percent of the flow during the wet period. Figure 7 is a double-mass plot of annual floodflow past The Forks versus floodflow past downstream stations. This graph shows the slight decline in floodflow, beginning about 1947, at Victorville and the coincident abrupt decline at Barstow.

The present decline of ground-water levels at Barstow will cause a commensurate decrease in underflow to the Barstow subunit with continued dry conditions, and continued upstream development flow will decrease even further. In addition, a flood-control structure is planned at The Forks. This structure will reportedly have an ungated outlet whose design peak outflow is about 25,000 cfs (cubic feet per second) (oral commun., U.S. Army Corps of Engineers, 1967). The net effect of such a structure, or of any conventional flood-detaining scheme upstream from Barstow, would be to cause a general and significant redistribution of recharge whereby recharge would be increased in upstream areas and a smaller portion of the total flow past The Forks would pass Barstow.

The detailed effects of the planned flood-control structure on the area downstream from Barstow cannot be estimated quantitatively at this time. However, the major effects and their direction can be stated with reasonable certainty. A conventional flood-control structure at The Forks whose outflow would rarely exceed 25,000 cfs would have the following results:

1. Attenuation of flood crests passing through the detention reservoir and a greater duration of floodflow downstream from the reservoir.

2. A larger percentage of the total water available in each flood would enter the ground-water basins upstream from Barstow, because at reduced flow rates the seepage capacity of the channel would less frequently be exceeded. This would leave less floodwater available to recharge basins downstream from Barstow, which would result in more rapid decline in ground-water levels there. Retardation of floodwater by a flood-control structure would cause a great reduction in the suspended load of the water discharged to downstream areas; this comparatively clear water would tend to infiltrate more rapidly, resulting in less water for recharge in the downstream areas. It is conceivable, however, that during a long sequence of wet years the ground-water basins upstream from Barstow might fill, and greater proportions of subsequent floodflow would reach Barstow.

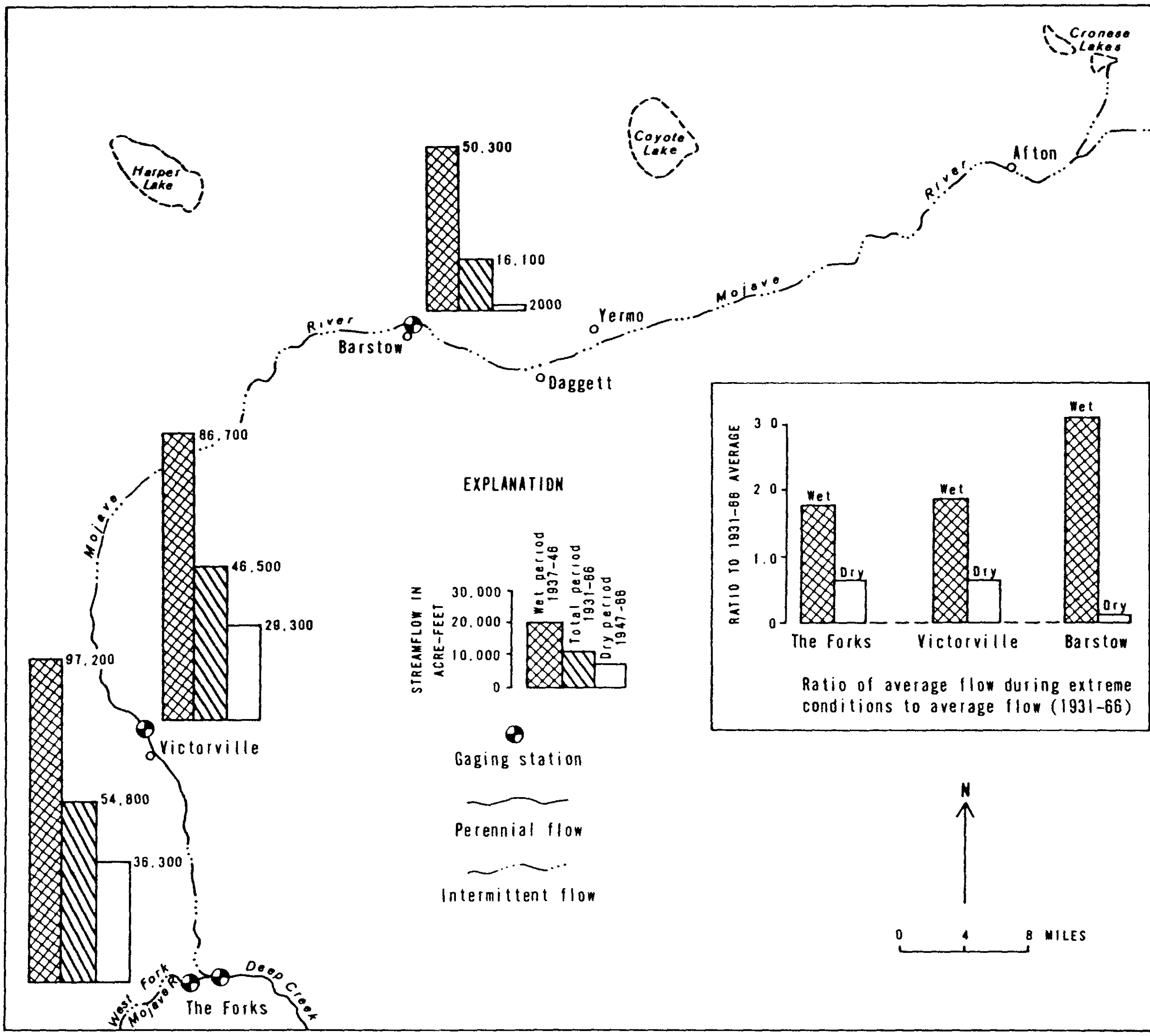

FIGURE 6.--Relation of extreme streamflow to mean annual streamflow on the Mojave River, 1931-66.

3. Less ground-water recharge by floodwater of good quality would accelerate the present trend toward deterioration of chemical quality in the basins below Barstow, because an ever-increasing percentage of the water pumped there would be recycled water.

4. Less frequent floodflows past Barstow would result in floodwater of higher salt content, because longer interflood periods would allow salt buildup along the channel.

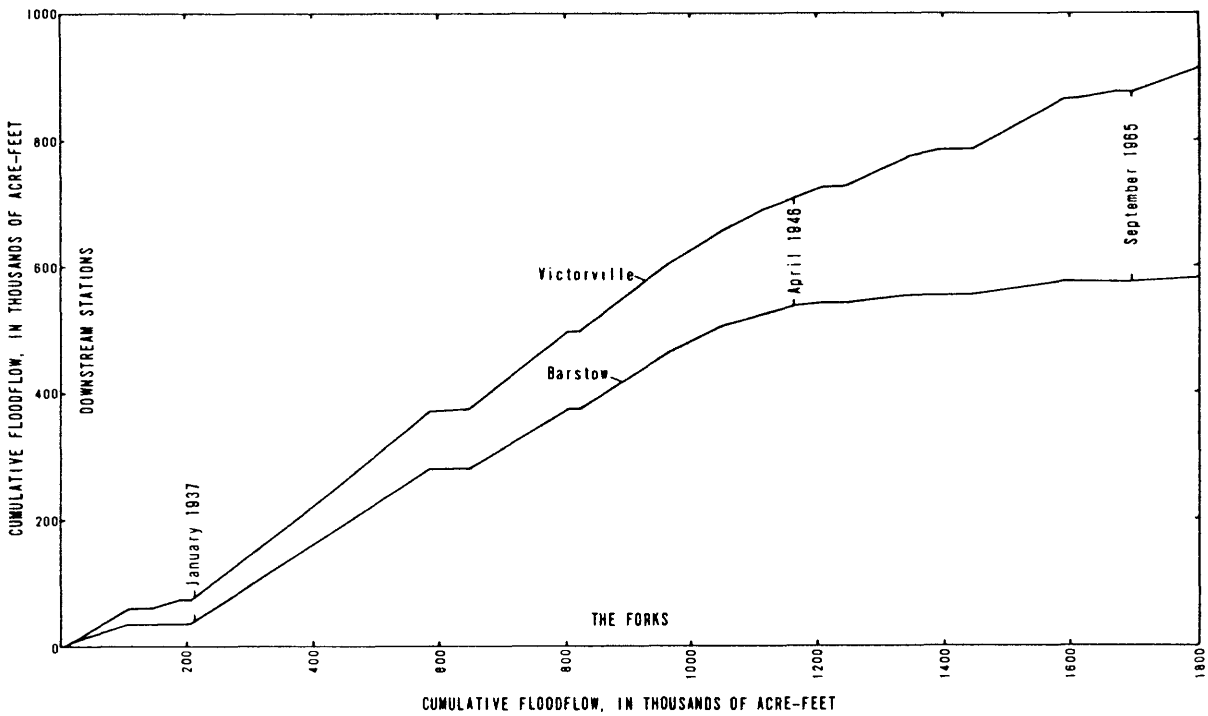

FIGURE 7.--Double-mass curves of annual floodflow, past The Forks versus flow past Victorville and Barstow on the Mojave River, 1931-66.

Discharge

Discharge from the Barstow and Yermo ground-water subunits occurs by underflow past the Calico fault, by pumping, and by consumptive use of native vegetation. Other than pumpage the individual elements of discharge are not readily measurable, and data are not available to permit a reliable estimate of the total discharge. Lowered water levels during the period 1947-66, caused chiefly by the drought and to some degree by increased pumpage, probably caused some decline in the quantity of natural discharge from the subunits. However, the average annual long-term recharge to the Barstow and Yermo subunits is approximately equal to the long-term average natural discharge. Thus, although about 12,000 acre-feet may have been available as average annual recharge to the subunits, the carryover storage is so large in relation to recharge that to date man's influence has had little effect on the discharge or on the total water resource available.

Quantity in Storage

Ground water has accumulated in storage principally in the older alluvium and older fan deposits over a long period and is the main source of water for the supply center. The water-bearing properties of the underlying consolidated rocks of Tertiary age and older are not well known. These rocks contain some ground water, although in part it is of poor chemical quality.

The physical limits and the water-bearing properties of the saturated part of the unconsolidated deposits are not known well enough to permit a precise estimate of the quantity of ground water in storage. The following estimates, however, are probably reasonably accurate.

The Barstow subunit contains about 14,000 acres that are underlain by about 150 feet, on the average, of saturated unconsolidated material. This volume of sediments, about 2,100,000 acre-feet, has a specific yield of about 15 percent and contains more than 300,000 acre-feet of usable ground water in storage.

The Yermo subunit contains more than 40,000 acres that are underlain by 200 feet or more of unconsolidated, saturated material. Most of this material is older alluvium, which has a specific yield of about 20 percent. This volume of sediments, 8 million acre-feet, contains about 1,600,000 acre-feet of ground water in storage.

Both subunits locally contain water-bearing material beneath the 150- and 200-foot-depth zones described above; however, few of the wells in these units penetrate more than 200 feet of saturated material. Therefore, information is scant about the deeper part of the ground-water basins. Surface geology and information from a few deeper wells suggest that the Barstow subunit might locally contain ground water of usable quality to a depth of more than 200 feet below the water table, and the Yermo subunit might locally contain usable ground water to a depth of more than 400 feet below the water table.

Chemical Quality

Wells in the Barstow subunit yield water that contains from less than 300 to more than 2,000 mg/l of dissolved solids, and ground water in the Yermo subunit generally contains from 200 to 500 mg/l of dissolved solids (Dyer and others, 1963).

Analyses from several wells in the Barstow and Yermo subunits are shown in table 1. The water from wells at the supply center at Nebo contains about 600 to 700 mg/l of dissolved solids. This is an increase from about 300 mg/l in 1943. Water from wells at Yermo Annex contains about 300 to 400 mg/l of dissolved solids. The concentration did not change significantly during the period 1943-66. The water in both subunits is of a calcium-sodium bicarbonate-sulfate type. The water from wells at Yermo is moderately hard to hard; the water from wells at Nebo is moderately hard to very hard.

The U.S. Public Health Service (1962) recommended that drinking water should not exceed 500 mg/l of dissolved solids if less mineralized supplies are available. The Service also recommended limits on the concentration of certain individual dissolved constituents in drinking water. As shown in table 1 the concentrations of the individual major constituents in ground water used at the supply center generally are within the recommended limits.

TABLE 1.--*Chemical analyses of water*

Values for dissolved solids indicate the residue on evaporation at 180°C.

Laboratory : USN: Sanitary Engineering Laboratory, Eleventh Naval District, San Diego, Calif.; USGS: U.S. Geological Survey, Sacramento, Calif.

Well number	Date of collection	Depth of well (feet)	Water temperature (°C)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids	Hardness as $CaCO_3$	Noncarbonate hardness as $CaCO_3$	Percent sodium	Specific conductance (micromhos at 25°C)	pH	Laboratory
				Results in milligrams per liter																			
U.S. Public Health Service drinking-water standards (1962)					0.3							250	250	0.8	45		500						
9N/1W-14B1 (Nebo 1)	11- 6-64	192		25	0.00	69	12	112	3.5	229		165	81	1.0	1.8	0.43	610	222	34	52	874	7.2	USN
14A2 (Nebo 2)	11- 6-64	408		26	.00	62	12	138	3.6	229		160	94	1.2	3.1	.30	510	204	16	59	810	7.5	USN
14B2 (Nebo 3)	11- 6-64	280		22	.00	59	13	108	3.1	210		150	74	1.3	1.8	.30	550	200	23	54		7.4	USN
13E1 (Nebo 4)	11- 6-64	348		26	.00	85	22	146	4.6	226		210	143	1.0	5.8	.40	740	300	112	51	1060	7.3	USN
13E2 (Nebo 5)	11- 6-64	450		28	.00	56	12	122	5.1	205		140	100	1.2	7.5	.38	640	188	10	58	918	7.5	USN
9N/1E-4J1 (Yermo 1)	11- 6-64	278		23	.00	35	4.9	62	3.2	176		38	40	.9	.1	.10	295	108		55	424	7.2	USN
4R1 (Yermo 2)	11- 6-64	174		21	.00	45	8.3	64	3.6	183		60	56	.9	3.5	.36	335	146		48	479	7.2	USN
10L1 (Yermo 3)	11- 6-64	214		21	.00	27	5.9	38	2.6	137		29	25	.3	1.8	.83	265	92		46	380	7.2	USN
4J2 (Yermo 4)	11- 6-64	350		20	.00	43	7.8	65	3.3	183		48	56	.8	2.0	.06	360	140		50	512	7.5	USN
9N/1W-11K3	6-27-66	105	20	21	.00	42	6.0	47	2.3	196	0	41	22	.6	.5	.0	279	136	0	43	458	7.6	USGS
9N/1E-19J1 (Test well 1) (deep)	6-24-66	680	29	20	.1	142	7.8	488	8.0	71	0	1150	122	4.8	6.1	18	2320	388	330	73		7.7	USN
(Test well 1) (shallow)	7- 6-66	250	28	27	.1	38	2.9	196	3.5	132		290	86	1.6	50	.1	836	106	2	80		7.8	USN
9N/1W-27D1 (Test well 2)	8-24-66	448		.2		9.6	.5	155	7.5	124	0	22	170	.2	.6	1.0	428	24	0	90	814	8.2	USGS
15Q1 (Test well 3) (deep)	6-30-66	475		19	1.5	34	4.2	210	4.5	126	0	266	122	1.1	16	5.0	745	110	7	81	1200	8.1	USGS
15Q2 (Test well 3) (shallow)	7- 1-66	275		22	.17	32	3.9	160	5.5	158	0	154	100	1.0	20	2.2	579	100	0	77	948	7.7	USGS

Data are available for only a few of the dissolved constituents present in minor or trace quantities in the center's water supply. Analyses of water samples taken from wells at Nebo in 1964 show that the concentration of fluoride, about 1.1 mg/l, is slightly more than the limit recommended by the Public Health Service. The recommended upper and lower limits of concentration of fluoride depend on the local annual average maximum daily air temperature, which is regarded as a measure of water intake by individuals. The maximum allowable concentration of fluoride may be twice the recommended optimum limit (U.S. Public Health Service, 1962, p. 8). The recommended fluoride concentration at Barstow (annual average maximum daily air temperature, 27° Celsius (centigrade) or 80.4°F) is 0.6 mg/l lower limit, 0.7 mg/l optimum limit, and 0.8 mg/l upper limit. The concentration of the fluoride ion in water from wells at the Yermo Annex in 1964 was about 0.8 mg/l. Some of the potential effects of the slightly above-optimum fluoride concentrations are probably offset because many supply center personnel spend most of the hotter days in an air-conditioned artificial climate of somewhat lower average maximum temperature than 27°C. Thus, the quantity of drinking water consumed might be lower than that suggested by the outside temperature. Military personnel and dependents living at the center normally are exposed to the above-optimum fluoride content for only a year or so, which would also tend to offset any deleterious effects.

The California Department of Public Health and the California Department of Water Resources reported (1960) that the chemical quality of ground water downstream from Barstow was degraded. The degradation was evidenced by tastes and odors, caused by phenolic compounds, and by an objectionable concentration of synthetic detergents. The source of these materials was attributed to waste discharged near Barstow. By 1960 the objectionable material had moved downstream from Barstow to the western edge of sec. 10, T. 9 N., R. 1 W. (fig. 2), about 1.4 miles upstream from the center's supply well 9N/1W-14B2 (Nebo 3). In 1966 (California Department of Public Health) the degraded water, still evidenced for the most part by objectionable tastes and odors, had advanced downstream to within about 0.6 mile of supply well 3. If its rate of movement of about 0.1 mile per year persists, the degraded ground water will reach supply well 3 by 1971-72. If an appreciable increase in gradient or pumping depression extends upstream from the center's wells at Nebo, the degraded water would, upon entering this area, move more rapidly than the historic rate.

Changes in Water Quality

In many ground-water basins in California, the concentration of dissolved solids increased as the basin was developed. Records of chemical analyses of ground water in the Barstow subunit show a significant increase in the concentration of dissolved solids in the period 1941-66. Figure 8 is a plot of the concentration of fluoride, chloride, sulfate, and dissolved solids in well 9N/1W-14B1 (Nebo 1) in the Barstow subunit and 9N/1E-4J1 (Yermo 1) in the Yermo subunit for the period 1943-66. A long record of chemical analyses is available for these wells, and they probably are representative of the chemical quality of ground water in the two subunits. The concentration of chloride in well 9N/1W-14B1 (Nebo) increased from about 35 mg/l in the early 1940's to about 80 mg/l in 1964. Dissolved solids in this well show an erratic increase from about 300 mg/l in the early 1940's to about 600 mg/l in 1966. The increase in concentration of chloride and of dissolved solids in well 9N/1E-4J1 (Yermo) is not great enough to be significant. Figure 8 shows a fairly slow steady increase in chloride, but the concentration of dissolved solids shows little net increase, from about 220 mg/l in 1949 to a high of about 380 mg/l in 1960, and decreasing to about 220 mg/l in 1964.

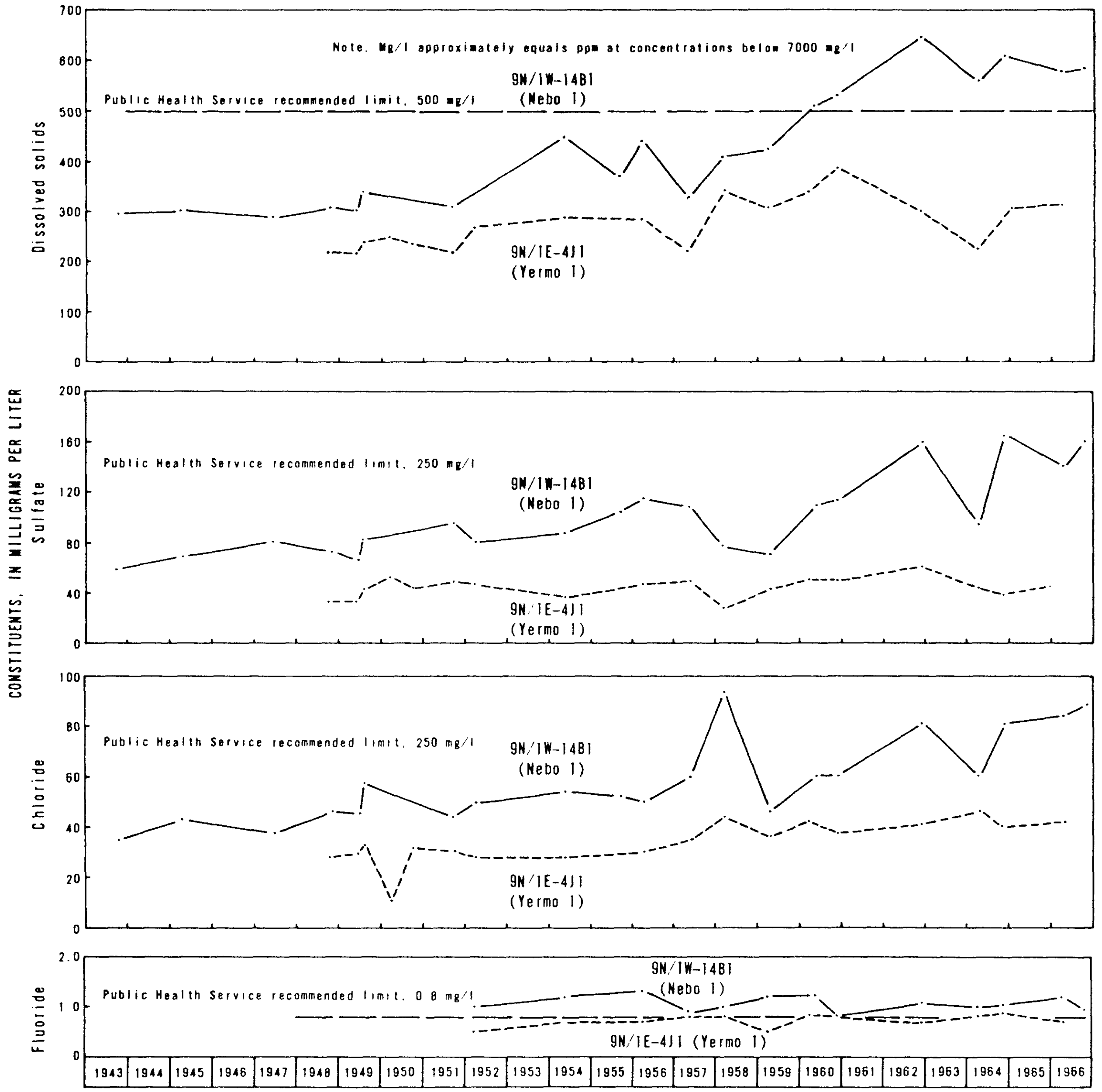

FIGURE 8.--Selected chemical constituents in ground water at Nebo and near Yermo, 1943-66.

The bar graphs in figure 9 are scaled in milliequivalents per liter, a term related to the combining weight of the ions. The graph of well 9N/1E-4J1 (Yermo 1) shows little change in either total or individual constituents during this period. The total of dissolved solids concentration in water from well 9N/1W-14B1 (Nebo 1) shows a slight, steady increase from 1943 to about 1960, followed by a rapid increase from 1961 to 1966. The concentration of individual ions shows an increase during 1943-66 of about 1.4 times for the carbonate and bicarbonate ions and about 2.8 times for calcium. The total concentration of all ions almost doubled during this period.

The deterioration in water quality at Nebo is probably related to two factors: (1) The recycling of ground water by upstream users coupled with the long dry period when little fresh floodwater was added to storage in the system. (2) This condition and the resultant decline in water levels have led to the withdrawal of a greater percentage of water from the lower part of the aquifer system, which probably contains poor quality water.

The general effect on water quality at Nebo of infiltration of flood waters of 1958 and 1966 is also shown in figure 9. About 20,000 acre-feet of floodflow passed Barstow in April 1958. Seepage to the local ground-water basin from this large flood caused a significant reduction in dissolved-mineral content of the sample of early 1959 compared with the sample preceding the flood. The illustration suggests that some beneficial effects of this flood on water quality lasted as late as 1960. Recharge from the small floods (about 6,300 acre-feet past Barstow) of late 1965 apparently prevented the concentration of dissolved material from increasing between late 1964 and early 1966.

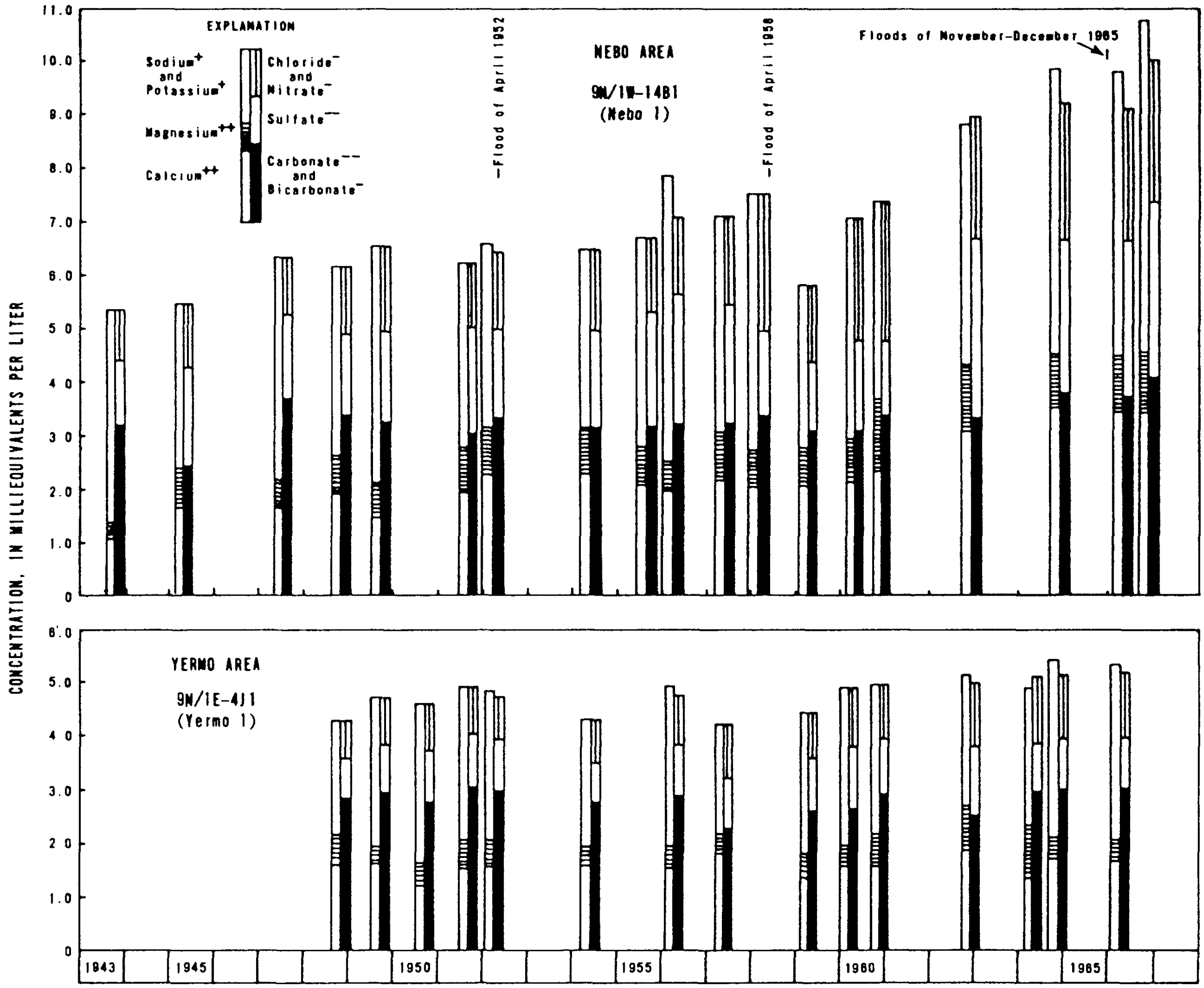

FIGURE 9.--Major chemical constituents in water from supply wells, 1943-66.

Chemical Quality and the Future Water Supply

The unabated trend of increase in dissolved solids at Nebo, if representative of the Barstow subunit, will result in a ground-water supply of significantly poorer quality within a few years. The quality of water could become more of a limiting factor in the water resources of the supply center than the quantity of water available. Figure 5 suggests that such a trend toward deteriorating quality exists in much of the Mojave River system.

The processes that have caused the degradation in water quality in the area will probably continue and even be intensified in future years. Two developments might arise to lessen the degradation (1) lessened use of ground water upstream from the center (a highly improbable turn of events), (2) a series of wetter-than-average years that would recharge the Barstow subunit with sufficient water of good quality so as to enhance the overall quality of water pumped from wells (a relief mechanism largely subject to the whim of nature during a given period of time, particularly in light of the proposed flood-control structure discussed previously).

Possible solutions to the quality problem would be (1) to obtain part of all of the supply for the Nebo area from the Yermo subunit, provided the present chemical quality of water at the Yermo Annex persists, (2) treatment of the water supply to remove a part of the dissolved material, (3) utilization of good quality water imported into the area as part of the State of California Water Plan, or (4) some combination of the above.

TEST-DRILLING PROGRAM

Three test wells were drilled by the rotary method during the spring and summer of 1966 to obtain information about the water-bearing properties of the alluvial fan deposits in the large syncline between Daggett Ridge and the Mojave River. The aggregate depth of these 3 holes is about 2,170 feet. In 1965 and 1966 several shallow holes were bored into the river-channel deposits at various places along the Mojave River. These holes were bored to obtain information about the geologic structure, geologic history, and water-bearing characteristics of the deposits beneath the channel of the Mojave River. The aggregate depth of the auger holes is about 2,150 feet.

Information from the three rotary wells strongly suggests that the older alluvial fan deposits in the syncline south of Nebo are of low permeability, and that some of the ground water in storage in those deposits is of poor chemical quality. Data from the test wells also suggest that ground water in the deeper part of the Barstow subunit (fig. 2, section A-A') is of poorer chemical quality and under higher head than water in the shallow part of the subunit. The effect of pumping more of the poor quality water at depth could be evaluated either by a selective pumping test using packers to isolate part of the aquifer in one of the deep wells at Nebo or by drilling a small diameter test hole approximately 500 feet deep to obtain information on quality change with depth.

TABLE 2.--*Summary of data on rotary test wells, Nebo area*

Well number	Date drilled	Borehole		Casing		Perforated interval (feet)	Chemical quality dissolved solids (mg/l)	Depth to water from land surface (feet)
		Depth (feet)	Diameter (inches)	Depth (feet)	Diameter (inches)			
9N/1E-19J1	April 1966	755	12¼	680	8	415-660	2,200	160
19J2[1]	-	-	-	294	1¼	292-294		170
19J3[1]	-	-	-	252	1¼	250-252		180
19J4[1]	-	-	-	335	1¼	180-250	830	180
9N/1W-15Q1	June 1966	850	6	475	1¼	472-475	750	215
15Q2		-	-	290	1¼	288-290	580	220
9N/1W-27D1	June 1966	568	6	548	1¼	546-548	430	430

[1]Taps different aquifers in same well.

Data on the three test wells are shown in table 2. Chemical analyses of samples of water from the test wells are shown in table 1.

Test well 9N/1E-19J1 (fig. 2) was drilled to a depth of 755 feet. Casing 8 inches in diameter was set in the hole to a depth of 680 feet, and gravel was placed in the annulus between the casing and the wall of the borehole. Preperforated casing was set in the more permeable intervals between a depth of 415 feet and 660 feet. The perforations were vertical, 0.14 inch wide by 2.0 inches long, 10 perforations around, 2 rows per foot. Before the initial development, pipes 1¼ inches in diameter were set in the borehole outside the casing to depths of 252 feet and 294 feet. The well was developed by surging with a tight-fitting swab for 8 hours, by bailing, and by acidizing with 250 gallons of a 15-percent solution of hydrochloric acid. The static water level in the well after development was 160 feet below land surface, although there was evidence that this level was lowered somewhat by upward leakage along the outside of the casing. The well was then cleaned and pumped for 22 hours at rates varying from 10 gpm to 47 gpm. The drawdown during test pumping ranged from 35 feet to 165 feet. The specific capacity of the well was 0.35.

Chemical analysis of two samples of water, one taken 15 hours and one taken 22 hours after the start of pumping, shows the water is not suitable for ordinary domestic purposes. The dissolved-solids content of the water is about 2,300 mg/l, of which about 1,200 mg/l is sulfate.

After the initial test pumping, the pump was removed, and the casing was filled with sand to a depth of 335 feet below land surface. A concrete plug about 2 feet thick was poured on top of the sand. Enough cement was pumped through the pipe set outside the casing wall to 294 feet to fill about 20 feet of the annular space in an attempt to seal the hydraulic connection along the annulus between the lower and upper strata. The 8-inch casing was then perforated with a Mills knife at permeable zones from depths of 180 feet to 250 feet, and the well was again surged and pumped. Yield of the well was 20 gpm with 50 feet of drawdown. The static water level was 180 feet below land surface. A sample of water taken during the test pumping contained 830 mg/l of dissolved solids. Later the entire interval between 180 feet and 255 feet was perforated with a Mills knife, and the well was developed and pumped for 16 hours. Yield of the well was 20 gpm with a maximum drawdown of 45 feet.

Test well 9N/1W-27D1 (fig. 2) was drilled to a depth of 568 feet. The well was cased to a depth of 548 feet with 1¼-inch inside diameter pipe; a 60-mesh sand point 2 feet long was attached to the lower end of the pipe. This well was developed by alternately pumping water down the well with a centrifugal pump and lifting water from the well by compressed air forced through a hose suspended inside the pipe. After development was completed the static water level was 430 feet below land surface. The well produced about 0.2 gpm by air lift. This low yield and an examination of the electrical log indicate that the water-bearing material is of low permeability. A sample of water for chemical analysis was taken after the air lift had been operating about 6 hours. Chemical analysis indicates that the water is of fairly good quality (table 1). The concentration of dissolved solids in the water is about 430 mg/l, and no single constituent is present in objectionable concentrations.

The test hole at 9N/1W-15Q1,2 was drilled to a depth of 850 feet and completed as a double well. The hole was cased with 2 pipes, each 1¼-inch inside diameter, equipped with 60-mesh sand points 2 feet long. One sand point (15Q1) was set in a permeable zone at a depth of 475 feet; the other (15Q2) was set in a permeable zone at a depth of 290 feet. The two sand-point wells were developed by the same methods used to develop well 9N/1W-27D1. After developing, the water level in the deep well (15Q1) was about 215 feet below land-surface datum; the level in the shallow well (15Q2) was about 220 feet below land-surface datum. Each well produced about 1 gpm by air lift. Chemical analyses of water from the two wells are shown in table 1.

Test holes were bored into the alluvium beneath the channel of the Mojave River near Victorville, Barstow, Nebo, and Afton.

The test holes at Nebo were bored to obtain information about the location of the Waterman fault. Eight holes were cased with 1¼-inch diameter pipe so that water samples could be obtained and water levels could be measured. Water-level data from these and water-level measurements taken inside the hollow-stem auger during construction indicate a local perched or semiperched water table. The barrier effect on ground water of the Waterman fault is shown in figure 10. The difference in water level across the fault was verified by boring two additional holes about 1,000 feet northwest of the section shown in figure 10 along the projected trace of the fault. The difference in water level across the fault here is about 45 feet. A similar difference in water level probably occurs a short distance northeast of Nebo supply well 5 (9N/1W-13E2) where the Waterman fault is concealed by fan deposits. The unusually low specific capacity of supply well Nebo 5 (table 3) might in part be attributed to the barrier effect of this fault (Ferris and others, 1962, p. 145).

Auger holes in the channel of the Mojave River show that maximum thickness of the unconsolidated water-bearing material overlying crystalline bedrock is about 60 feet at the Upper and Lower Narrows near Victorville, about 220 feet near Barstow, and about 25 feet near Afton.

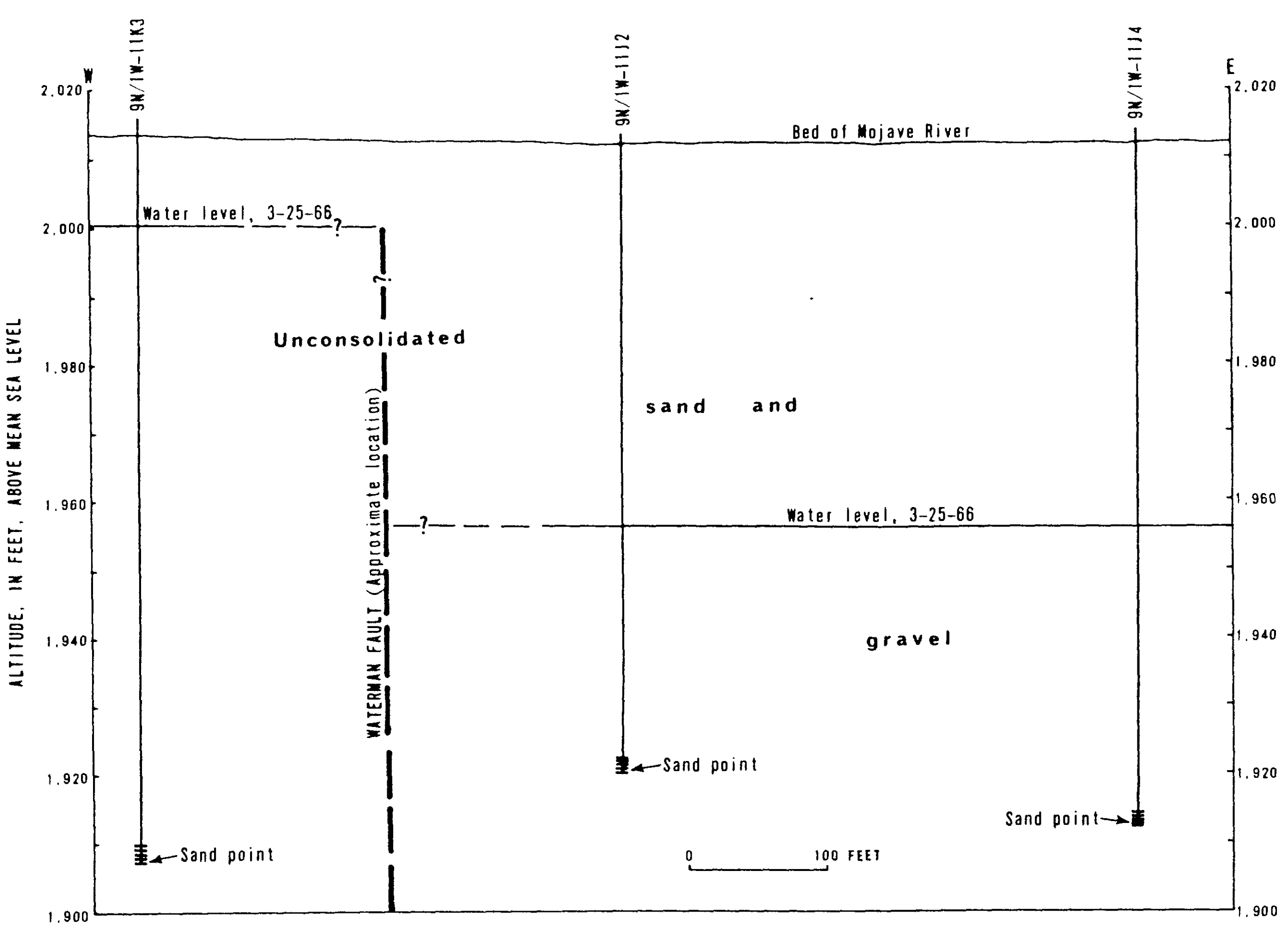

FIGURE 10.--Diagrammatic section showing effect of Waterman fault on water levels near Nebo.

TABLE 3.--*Data on supply wells*

Well number		Year drilled	Depth (feet)	Depth to water (feet below land-surface datum)		Discharge (gpm)		Drawdown (feet)		Specific capacity[1]		Chemical quality autumn 1964	
USMC	USGS			When drilled	Autumn 1964	When drilled	1964	When drilled	1964	When drilled	1964	Dissolved solids (mg/l)	Chloride (mg/l)
Nebo 1	9N/1W-14B1	1942	192	46.3	61.1	1,107	630	17	14	62	45	610	81
Nebo 2	9N/1W-14A2	1958	408	61.0	69.8	1,103	780	--	15	--	52	510	94
Nebo 3	9N/1W-14B2	1947	280	60.0	69.6	420	325	35	9.4	12	35	550	74
Nebo 4	9N/1W-13E1	1954	348	48.0	71.2	675	940	--	11	--	85	740	143
Nebo 5	9N/1W-13E2	1961	450	60.0	62.0	500	550	148	80	5.7	6.9	640	100
Yermo 1	9N/1E-4J1	1942	278	82.5	106.9	264	200	9.7	25	27	8	295	40
Yermo 2	9N/1E-4R1	1942	174	68.6	110.8	338	208	9.2	8.0	37	26	335	56
Yermo 3	9N/1E-10L1	1942	214	69.0	98.9	730	920	15.0	8.3	49	111	265	25
Yermo 4	9N/1E-4J2	1961	350	98.1	109.3	800	1,000	8.9	8.6	90	117	360	56

[1]Gallons per minute per foot of drawdown.

SUMMARY OF WATER-SUPPLY CONDITIONS

The quantity of available water at the Marine Corps Supply Center, Barstow, is adequate for many years at projected rates of use. Problems related to the chemical quality of water will probably become acute before the quantity available for use becomes a matter of concern.

Present and future water supply.--The total water resources presently available to the supply center consist of water stored in the Barstow and Yermo subunits, less whatever part of this is discharged by natural means and by other users. The supply center presently pumps water from 9 wells; 5 of these supply the Nebo Depot from the Barstow subunit, and 4 supply the Yermo Annex from the Yermo subunit. The combined yield of the 5 wells at Nebo is about 3,200 gpm, or about 5,200 acre-feet per year. The combined yield of the 4 wells at the Yermo Annex is about 2,300 gpm, or about 3,700 acre-feet per year. These wells supplied about 1,550 acre-feet annually to the center during the period 1957-63. Data for these wells are shown in table 3.

The future water supply for the center consists of water stored in the two subunits plus future recharge minus whatever part of this water is discharged by other users and by natural discharge. Water in storage is about 1,900,000 acre-feet and annual recharge is about 12,000 acre-feet.

The present rate of withdrawal, the rate of water-level decline, and the estimates of recharge and storage suggest that the water supply for the Marine Corps Supply Center is adequate for many years. The chemical quality of ground water in the Barstow subunit is progressively becoming worse and may limit its utilization before the quantity of water available is depleted.

Additional ground-water supplies.--No ground-water supplies are readily available to the supply center other than those in the Barstow and Yermo ground-water subunits of the Mojave River system. Other subunits, both downstream and upstream from the supply center, are several miles away and are being developed and utilized locally.

Imported water.--The supply center is within the boundary of the Mojave Water Agency, which is currently making plans to import water to the area. The initial small deliveries will reportedly begin in 1972 and will be increased gradually to about 55,000 acre-feet annually by about 1990. The method of delivery and area to be served are not presently known. The cost of water delivered to the agency probably will be several times that of local ground water. The imported water would have the advantage of convenience, dependability, and the assurance of good quality. Steps should be taken to assure that this water will be made available to the supply center, if needed, when it is imported to the area.

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