GROUND-WATER QUALITY IN INDIAN WELLS VALLEY CALIFORNIA

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations 8-75

PREPARED IN COOPERATION WITH THE
DEPARTMENT OF THE NAVY AND THE
INDIAN WELLS VALLEY COUNTY WATER DISTRICT

BIBLIOGRAPHIC DATA SHEET	1. Report No.	2.	3. Recipient's Accession No.
4. Title and Subtitle GROUND-WATER QUALITY IN INDIAN WELLS VALLEY, CALIFORNIA			5. Report Date June 1975 6.
7. Author(s) James W. Warner			8. Performing Organization Rept. No. USGS/WRI-8-75
9. Performing Organization Name and Address U.S. Geological Survey, Water Resources Division 345 Middlefield Road Menlo Park, California 94025			10. Project/Task/Work Unit No. 11. Contract/Grant No.
12. Sponsoring Organization Name and Address U.S. Geological Survey, Water Resources Division 345 Middlefield Road Menlo Park, California 94025			13. Type of Report & Period Covered Final 14.

15. Supplementary Notes Prepared in cooperation with the Department of the Navy and the Indian Wells Valley County Water District

16. Abstracts Indian Wells Valley is in a semiarid region of the Mojave Desert. The U.S. Naval Weapons Center at China Lake and nearby communities depend upon an adequate source of ground water for their existence. Much of the ground water is of poor quality. Most of the ground-water pumping occurs in the Inyokern, intermediate, and Ridgecrest areas. The quality of ground water in these well fields is considered excellent for public use. The increasingly larger pumping depressions in the well fields do not seem to have significantly changed the natural flow pattern of the poor-quality ground water in the shallow aquifer toward the China Lake playa. In 1972 the flow pattern of the poor-quality ground water was not toward these pumping depressions. The recharge to the ground water of sewage effluent from the U.S. Navy sewage ponds and the Ridgecrest Sanitation District sewage ponds has not significantly affected ground-water quality in the valley. There is no indication that recharge of sewage effluent from these ponds is migrating toward the well fields. The dissolved-solids concentration in the ground water in some areas is increasing slightly, but where this has occurred, it is not yet serious.

17. Key Words and Document Analysis. 17a. Descriptors

*Water quality, *Underground waste disposal, *Sewage lagoons, Evapotranspiration, Groundwater barriers, California

17b. Identifiers/Open-Ended Terms

Naval Weapons Center at China Lake, Indian Wells Valley, Kern County

17c. COSATI Field/Group

18. Availability Statement	19. Security Class (This Report)	21. No. of Pages
No restriction on distribution	UNCLASSIFIED	64
	20. Security Class (This Page) UNCLASSIFIED	22. Price

FORM NTIS-35 (REV 3-72)

THIS FORM MAY BE REPRODUCED

USCOMM-DC 14952-P72

(200)
WRi
No. 8-75

GROUND-WATER QUALITY IN
INDIAN WELLS VALLEY
CALIFORNIA

By James W. Warner

U.S. GEOLOGICAL SURVEY [Water Resources Division]

Water-Resources Investigations 8-75

Prepared in cooperation with the
Department of the Navy and the
Indian Wells Valley County Water District

June 1975

UNITED STATES DEPARTMENT OF THE INTERIOR

Stanley K. Hathaway, Secretary

GEOLOGICAL SURVEY

V. E. McKelvey, Director

For additional information write to:

District Chief
Water Resources Division
U.S. Geological Survey
345 Middlefield Road
Menlo Park, Calif. 94025

CONTENTS

ILLUSTRATIONS

TABLES

CONVERSION FACTORS

Factors for converting English units to metric units are shown to four significant figures. However, in the text the metric equivalents are shown only to the number of significant figures consistent with the values for the English units.

English	*Multiply by*	*Metric*
acres	4.047×10^{-1}	ha (hectares)
acre-ft (acre-feet)	1.233×10^{-3}	hm^3 (cubic hectometres)
ft (feet)	3.048×10^{-1}	m (metres)
in (inches)	2.540×10	mm (millimetres)
mi (miles)	1.609	km (kilometres)

GROUND-WATER QUALITY IN INDIAN WELLS VALLEY, CALIFORNIA

By James W. Warner

ABSTRACT

Indian Wells Valley is in a semiarid region of the Mojave Desert. The U.S. Naval Weapons Center at China Lake and the communities of Ridgecrest, Inyokern, and China Lake depend on an adequate source of ground water for their existence. Indian Wells Valley is a virtually closed basin with limited available ground water, and much of the ground water is of poor quality. Most of the ground-water pumping occurs in the Inyokern, intermediate, and Ridgecrest areas. The quality of ground water in these areas is considered excellent for public use. The increasingly larger pumping depressions in the Inyokern, intermediate, and Ridgecrest areas do not seem to have significantly changed the natural flow pattern of the poor-quality ground water in the shallow aquifer toward the China Lake playa. In 1972 the flow pattern of the poor-quality ground water was not toward these pumping depressions.

The recharge to the ground water of sewage effluent from the U.S. Navy sewage ponds and the Navy golf course has not reversed the natural direction of ground-water underflow toward the China Lake playa across the northeast-trending fault near China Lake as was previously suspected. The fault is not an effective barrier to the movement of ground water near the land surface in the shallow aquifer. Reversal of the natural direction of flow in the shallow aquifer across the fault would allow the native poor-quality ground water that exists in the shallow aquifer to migrate toward the well fields and degrade the source of public supply.

The recharge to the ground water of sewage effluent from the Ridgecrest Sanitation District sewage ponds does not seem to have significantly changed the pattern of local ground-water flow. There is no indication that recharge of sewage effluent from these ponds is migrating toward the well fields. The Ridgecrest Sanitation District sewage ponds, the U.S. Navy sewage ponds, and the Navy golf course are not considered to be a significant source of pollution to the aquifers that supply water used by residents of the area.

The quality of the ground water deteriorates with depth in the central part of the valley from less than 300 milligrams per litre dissolved solids at a depth of 300 feet (90 metres) to about 1,000 milligrams per litre dissolved solids at a depth of 800 feet (240 metres). As water levels in wells in the area of pumping depressions continue to decline, a greater proportion of the water pumped from these wells will come from the deeper part of the aquifer, causing a trend toward increase in concentrations of dissolved solids.

Ground water in the valley is grouped into three general categories. Ground water in groups 1 and 2 is generally of good quality, whereas ground water in group 3 is generally of poor quality and is considered as unfit for most public uses. The areal extent of the three groups of water has not significantly changed during the past 25 years. More importantly, the areal extent of group 3 ground water has not increased.

The dissolved-solids concentration in the ground water in some areas is increasing slightly but, where this has occurred, it is not yet serious.

INTRODUCTION

The U.S. Naval Weapons Center at China Lake and the communities of Ridgecrest, Inyokern, and China Lake are in a desert environment and depend upon an adequate source of ground water for their existence. Indian Wells Valley is a virtually closed basin with limited available ground water, and much of this ground water is of such quality that it is poorly suited or totally unusable for ordinary municipal, industrial, and agricultural uses. Improper development of this ground-water resource could cause degradation of the usable ground water in the valley. Degradation of the ground-water system could occur rapidly without being readily apparent. The proper utilization of the ground water in Indian Wells Valley requires an integrated effort by all user groups in the valley to insure that a usable source of ground water is maintained.

In 1952 the U.S. Geological Survey, in cooperation with the Naval Weapons Center at China Lake, Calif., began a series of hydrologic studies of Indian Wells Valley (fig. 1) to determine the availability of ground-water supplies. Later studies in the area have included the cooperation with the Navy, as well as the California Department of Water Resources and the Indian Wells Valley County Water District. Published results of these later studies include a basic-data report, a comprehensive geohydrologic report, a hydrologic study using digital-modeling techniques, and many annual reports. These studies were concerned with the overall geohydrologic conditions in the valley as well as with local water problems.

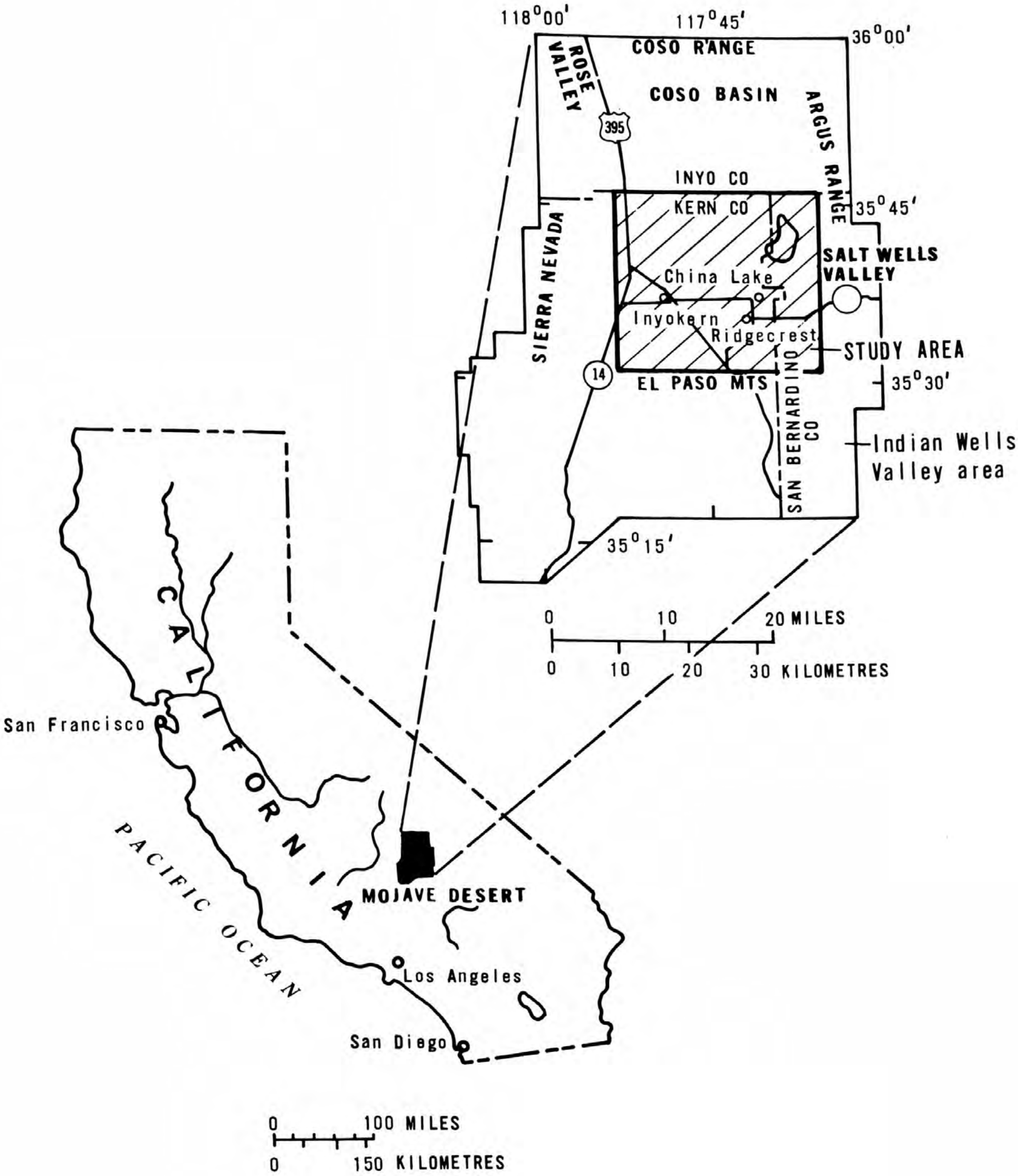


FIGURE 1.--Index map.

These studies indicated that increasingly larger pumping depressions in the Inyokern, intermediate, and Ridgecrest well fields (pl. 1) have changed the natural direction and rate of ground-water movement, and continued heavy pumping may cause water of poor quality from surrounding areas to migrate to the well fields and degrade the present water supply. An increasing concern is the possible undesirable effects on ground-water quality of sewage effluent from the U.S. Navy and the Ridgecrest Sanitation District sewage ponds (pl. 1). In addition, there are some indications that the water quality deteriorates with depth in the aquifer system.

As water levels continue to decline, it will become increasingly important to understand the quality of the deeper water and its potential effect on the ground-water supply. With these possible problems in mind, in 1971 the U.S. Department of the Navy and the Indian Wells Valley County Water District entered into a cooperative agreement with the Geological Survey to study the ground-water quality in Indian Wells Valley.

Purpose of the Investigation

This report provides information for the management and utilization of the usable ground water in the valley that may help to prevent degradation of this source of public supply. The purpose of the study was: (1) To evaluate changes in the vertical and areal distribution of water quality in the alluvial deposits; and (2) to determine the possible effects on water quality of the disruptions in the regional ground-water flow patterns caused by pumping, faults, and infiltration of treated sewage effluent.

Scope

The areas of intensive study were the shallow aquifer (pl. 1); the pumping depressions in the Inyokern, intermediate, and Ridgecrest areas; and the deep aquifer east of Ridgecrest near the Ridgecrest Sanitation District sewage ponds. Particular emphasis was placed on the area adjacent to the northwest-trending fault near China Lake (pl. 1), herein referred to as the China Lake barrier.

The scope of the study included an evaluation of existing water-level, lithologic, and chemical water data. Additional data collected included water-level measurements from 27 test wells drilled during the study near the China Lake barrier and water samples for chemical analysis from more than 60 wells throughout the area. The additional water-quality data collected along with the existing water-quality data, together including more than 250 samples, were used to determine historical areal changes in water quality and water-quality variation with depth in the basin. The water-level data were used to construct maps to determine the direction of flow of effluent from the sewage ponds and the effect of faults on the ground-water flow patterns. The lithologic data were used to define confining layers. The potential evapotranspiration from the Navy sewage ponds, the Navy golf course, and the Ridgecrest Sanitation District sewage ponds was estimated for the construction of a water budget to evaluate the quantity of ground-water recharge from these sources and to aid in the evaluation of the effects of the sewage ponds.

Location and Physiography of Study Area

Indian Wells Valley is in a semiarid region of the Mojave Desert east of the Sierra Nevada and about 125 mi (200 km) north of Los Angeles (fig. 1). The valley is bounded on the north by the Coso Range, on the south by the El Paso Mountains, on the west by the Sierra Nevada, and on the east by the Argus Range. Most of the central part of the valley is at an altitude between 2,150 and 2,400 ft (655 and 730 m) above sea level. Indian Wells Valley occupies parts of Kern, Inyo, and San Bernardino Counties. Streams flow from the bordering mountains and hills toward China Lake, which is the low point in the valley. China Lake is dry except after rare intense storms. The valley is a structural depression, and substantial deformation of the sedimentary deposits has occurred by faulting. Many faults in the study area have a significant effect on the flow of ground water. For purposes of this report the ground-water system is separated into a deep aquifer and a shallow aquifer. Considered in this report is the study area shown in figure 1.

Acknowledgments

Special thanks are given to Mr. E. G. Hannon of the Public Works Office, Naval Weapons Center, China Lake, who helped locate sites for many of the test wells and frequently gave other assistance. Thanks are also given to the Ridgecrest Sanitation District and to Mr. Joe Miller, landowner, for granting permission to drill observation wells on their properties.

Well-Numbering System

Wells are numbered according to their location in the rectangular system for subdivision of public land. For example, in the well number 1S/1W-2P1, that part of the number preceding the slash indicates the township (T. 1 S.); the number and letter following the slash indicate the range (R. 1 W.); the number following the hyphen indicates the section (sec. 2); the letter following the section number indicates the 40-acre (16-ha) subdivision of the section according to the lettered diagram below. The final digit is a serial number for wells in each 40-acre (16-ha) subdivision. The area lies entirely in the southeast quadrant of the Mount Diablo base line and meridian.

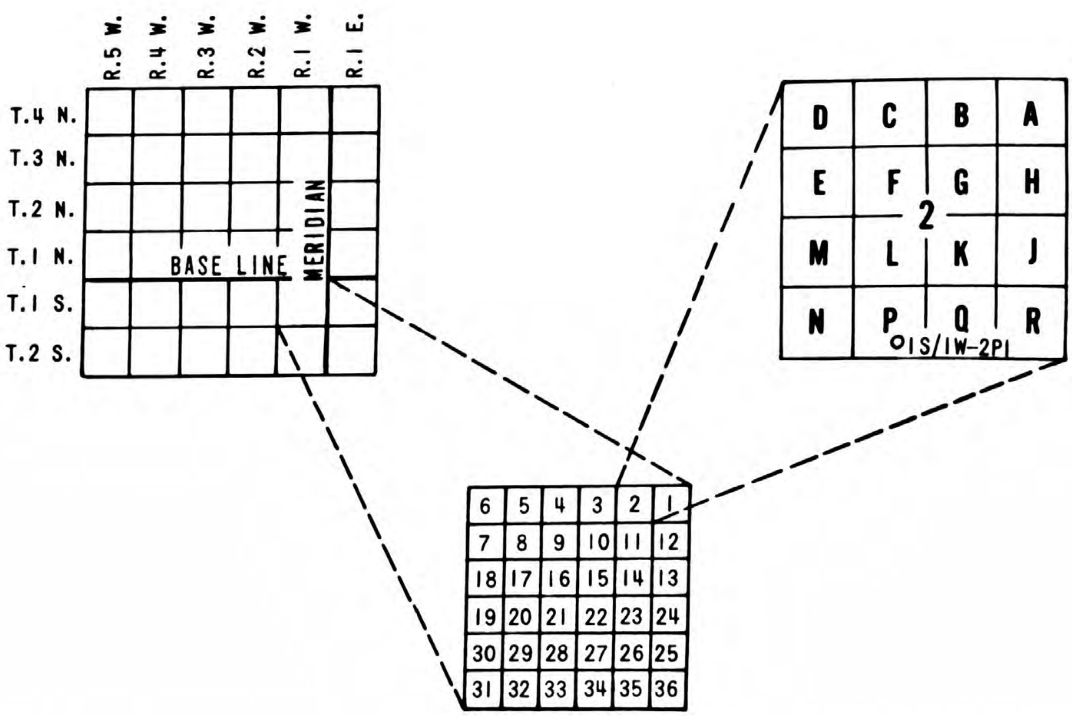


Table 1 is a cross index of the well numbers used by the U.S. Navy, the Indian Wells Valley County Water District, and the State well number used by the Geological Survey.

TABLE 1.--*Cross index of wells numbered by U.S. Navy, Indian Wells Valley County Water District, and U.S. Geological Survey*

Navy number	USGS number	USGS number	Navy number
SW2	25S/39E-35N1	25S/39E-4R1	SW21
SW3 (SNORT)	25S/39E-26H1	9J1	SW20
SW5	26S/40E-20N1	12R1	SW22
SW6	26S/40E-22P1	12R2	SWC-2
SW7	26S/40E-5P1	26H1	SW3
SW8	26S/40E-19N1	35N1	SW2
SW10	26S/40E-22N1	25S/41E-21E1	V-Range
SW11	26S/39E-24R1	28B1	SW30
SW12	26S/39E-19Q1	26S/39E-5F1	SW23
SW12A	26S/39E-19Q2	11E1	SW14
SW14 (SPA)	26S/39E-11E1	19K1	SW27
SW15	26S/39E-19P1	19P1	SW15
SW16A	26S/39E-30F3	19Q1	SW12
SW17	26S/39E-24Q1	19Q2	SW12A
SW18	26S/40E-19P1	23J1	SW28
SW18A	26S/39E-24P1	24M1	SW29
SW19	26S/40E-34N1	24P1	SW18A
SW20 (B-1 area)	25S/39E-9J1	24Q1	SW17
SW21 (LB area)	25S/39E-4R1	24R1	SW11
SW22 (C area)	25S/39E-12R1	30F3	SW16A
SW23 (B-4 area)	26S/39E-5F1	26S/40E-5P1	SW7
SW27	26S/39E-19K1	19N1	SW8
SW28	26S/39E-23J1	19P1	SW18
SW29	26S/39E-24M1	20N1	SW5
SW30	25S/41E-28B1	22N1	SW10
SWC-2 (capped)	25S/39E-12R2	22P1	SW6
V-Range	25S/41E-21E1	34N1	SW19

Water District number	USGS number	USGS number	Water District number
1	26S/40E-33P2	26S/40E-28H1	6
2	27S/40E-4C1	30K1	8
3	27S/40E-4C2	30K2	9
4	27S/40E-4L1	33A1	5
5	26S/40E-33A1	33P2	1
6	26S/40E-28H1	33P4	7
7	26S/40E-33P4	27S/40E-4C1	2
8	26S/40E-30K1	4C2	3
9	26S/40E-30K2	4L1	4

GEOLOGY

Lithologic Units

For purposes of this report the geology is generalized from Moyle (1963) to show geologic units that affect the hydrology and water quality of the area. Four geologic units (pl. 1) are identified: basement complex, lake deposits, alluvium, and playa and sand-dune deposits.

The basement complex, of pre-Tertiary age, is composed of igneous and metamorphic rocks that underlie Indian Wells Valley and form the bordering hills and mountains. The unit is considered to be virtually non-water-bearing except where fractured or weathered.

The lake deposits, of Pleistocene and Holocene age, include both the playa and the lacustrine deposits of Moyle (1963). The playa deposits, composed of unconsolidated silt and clay, occur at China Lake, Mirror Lake, and Satellite Lake (pl. 1). The lacustrine deposits, composed of cemented sand, silt, and clay, are exposed around Mirror Lake and about 4 mi (6 km) north of the intermediate area (pl. 1) and presumably also occur interbedded with alluvium at depth. The lacustrine deposits were formed by an ancestral lake much larger than the present China Lake (Kunkel and Chase, 1969, p. 19). Many wells in the valley penetrate a section of clay at depth (fig. 2), which is probably part of the lake deposits. The lake deposits are of low permeability and do not yield water freely to wells. Generally, the water contained in these deposits is of poor quality.

The alluvium, of Pleistocene and Holocene age, includes younger and older alluvium, stream deposits, fan deposits, and dune sand as described by Moyle (1963), all derived by erosion from the bordering hills and mountains. The alluvium is composed of unconsolidated gravel, sand, silt, and clay. It overlies the basement complex and lake deposits and is exposed in most of the valley area. In the central part of the valley the alluvium is about 2,000 ft (610 m) thick (Dutcher and Moyle, 1970). It is moderately permeable and where saturated yields water freely to wells. Most of the ground water in the alluvium is of good quality--typically less than 600 mg/l (milligrams per litre) of dissolved solids--and most of the ground water pumped by wells is from this unit.

The playa and sand-dune deposits, of Holocene age, consist of windblown sand and small interdune playas, which are as much as 100 ft (30 m) across. These deposits, which overlie the lake deposits and alluvium, are at most 100 ft (30 m) in thickness. This unit occurs in the northeastern part of the study area, mostly in T. 25 S., R. 40 E. Shallow wells perforated in this unit yield small quantities of poor-quality water.

The relation of the geologic units is illustrated in the idealized geologic section (fig. 3).

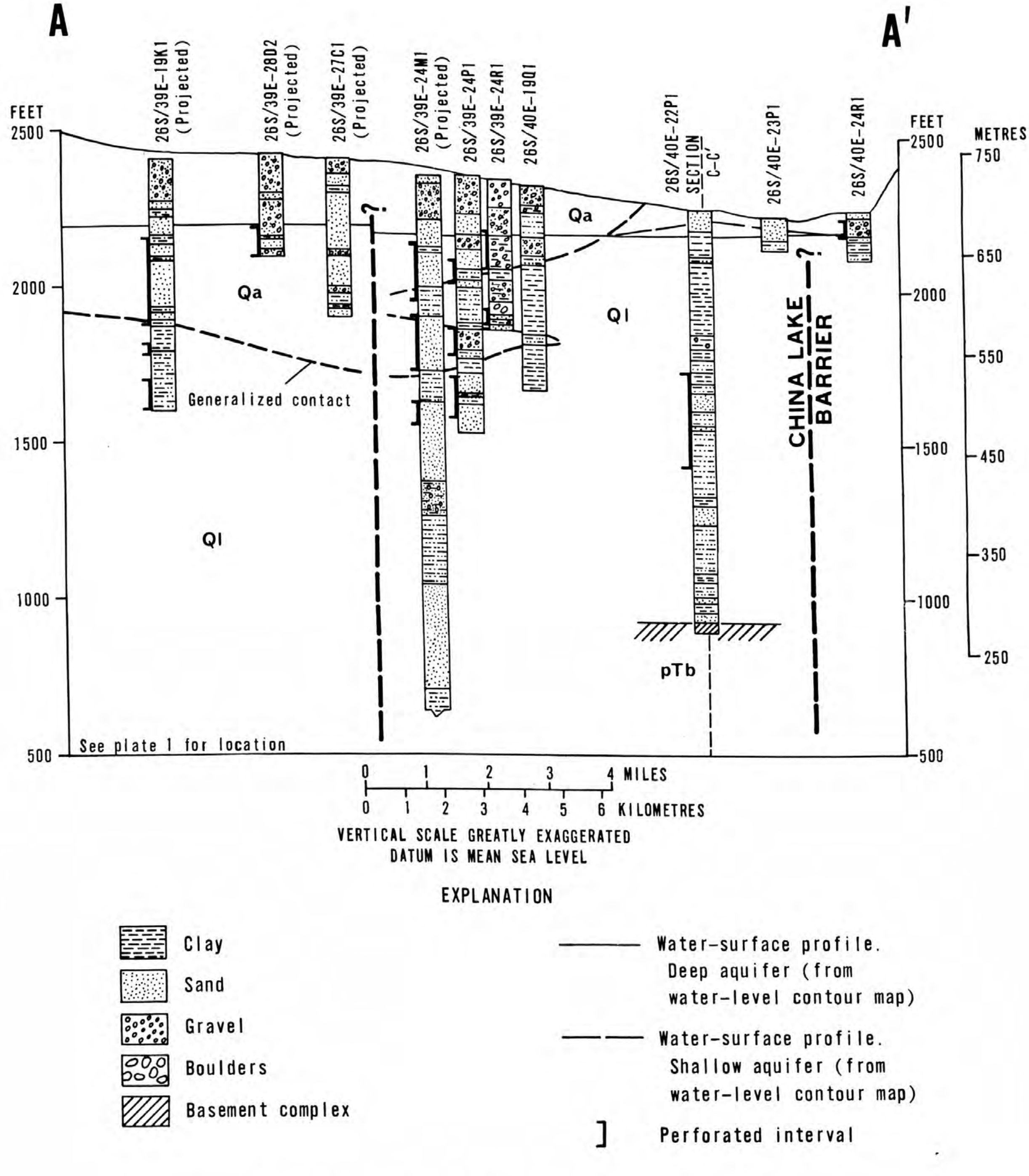


FIGURE 2.--Generalized lithologic section of study area.

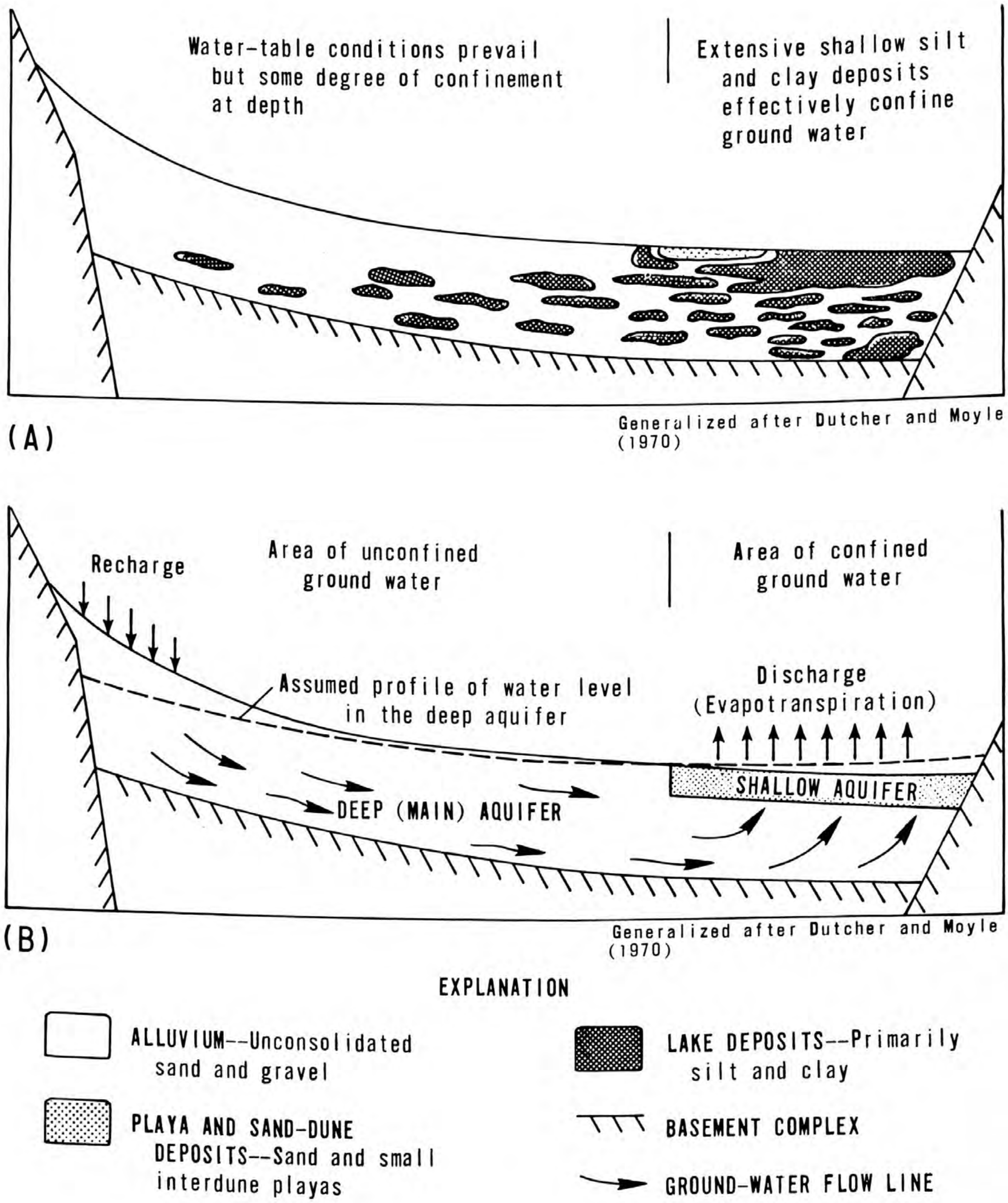


FIGURE 3.--Diagrammatic sections of (A) idealized geologic section and (B) ground-water flow system.

Faults and Ground-Water Barriers

The Indian Wells Valley area is a structural depression, and a substantial part of the deformation of the sedimentary fill in it has been caused by faulting. Major faults border the Sierra Nevada along the western side of the valley, and many smaller faults border the eastern side of the valley. Geologic, geophysical, and hydrologic data indicate that several faults occur within the valley, but the trace of most local faults is obscured, or concealed, by deposition of alluvium after faulting has occurred.

Faults in the study area have a significant effect on the flow of ground water. Fault zones in consolidated rocks commonly consist of a series of fissures that serve as conduits for ground-water flow. Conversely, faults in unconsolidated deposits commonly produce barriers to ground-water flow. Although the cause and nature of the barrier effects of faults are not completely understood, ground-water movement across faults may be impeded because of one or more of the following conditions: (1) The offsetting of permeable beds against less permeable beds; (2) the presence of clayey fault gouge, which is less permeable than the aquifer; (3) local deformation of beds near the fault; and (4) cementation of the fault zone and material immediately adjacent to the fault by deposition of minerals from ground water.

Data are not available in most areas to determine the depth below the land surface at which the fault becomes effective as a barrier to ground-water movement. Apparently, ground water above the faulted deposits can flow unimpeded (fig. 4). Most of the major faults in the valley strike northwest (pl. 1). Many of the short faults along the eastern side of the basin strike northeast (pl. 1).

HYDROLOGY

Ground water in the valley originates as precipitation that falls within the drainage area of Indian Wells Valley and the smaller adjoining Coso basin and Rose Valley (fig. 1). Recharge occurs as runoff from the Sierra Nevada, from the Coso and Argus Ranges, and from the El Paso Mountains. A small quantity of underflow enters the study area from Rose Valley, and a small quantity of water (about 20 acre-ft or 0.025 hm^3 per year) leaves the area as underflow to the southeast to Salt Wells Valley (fig. 1).

Although it would be possible to define or delineate many aquifers in the valley based on varying degrees of hydraulic confinement, in general a deep aquifer system and a shallow aquifer system can be assumed (Dutcher and Moyle, 1970). The idealized ground-water flow system is illustrated in figure 3. In the western and central parts of the valley water-table conditions prevail, but sandy silt and clay deposits cause some degree of confinement of ground water at depth (figs. 2 and 3). In the eastern part of the valley extensive shallow silt and clay deposits effectively confine the ground water. In this area the degree of confinement increases with depth, and head differences exist between closely spaced wells of different depths. A shallow water-table aquifer exists in this eastern area above the confining layers. The assumed areal extent of the shallow aquifer system is shown on plate 1 and in figure 4. The water-level contours for the shallow aquifer (fig. 4) were drawn only in areas of sufficient data. Similarly, contours for the deep aquifer (fig. 4) do not extend into the northeastern part of the study area, although a deep aquifer probably does.

EXPLANATION

Boundary of ground-water basin. Dashed where control is poor

? — Boundary of shallow aquifer and assumed limit of confining clay layers. Queried where location inferred

Fault

Dashed where approximately located; dotted where concealed

2200 — Water-level contour for deep aquifer

Contour intervals 5 and 10 feet (1.5 and 3.0 metres); datum is mean sea level

2160 — Water-level contour for shallow aquifer

Contour interval 10 feet (3.0 metres); datum is mean sea level

o Well used in construction of water-level contours for deep aquifer

● Well used in construction of water-level contours for shallow aquifer

Ground-Water Flow

Under natural conditions ground water flowed from the deep aquifer to the shallow aquifer and moved through the deep aquifer from the areas of recharge along the southwest, west, north, and northeast edges of the valley toward China Lake playa (pl. 1). Near the China Lake playa the head-depth relations in wells indicated that the water in the deep aquifer discharged into the shallow aquifer. This recharge to the shallow aquifer from the deep aquifer was the only significant source of natural recharge to the shallow aquifer and was the only significant source of natural discharge from the deep aquifer. Evaporation from the moist playa surfaces and transpiration from phreatophyte growth were the only significant agents of natural discharge from the shallow aquifer.

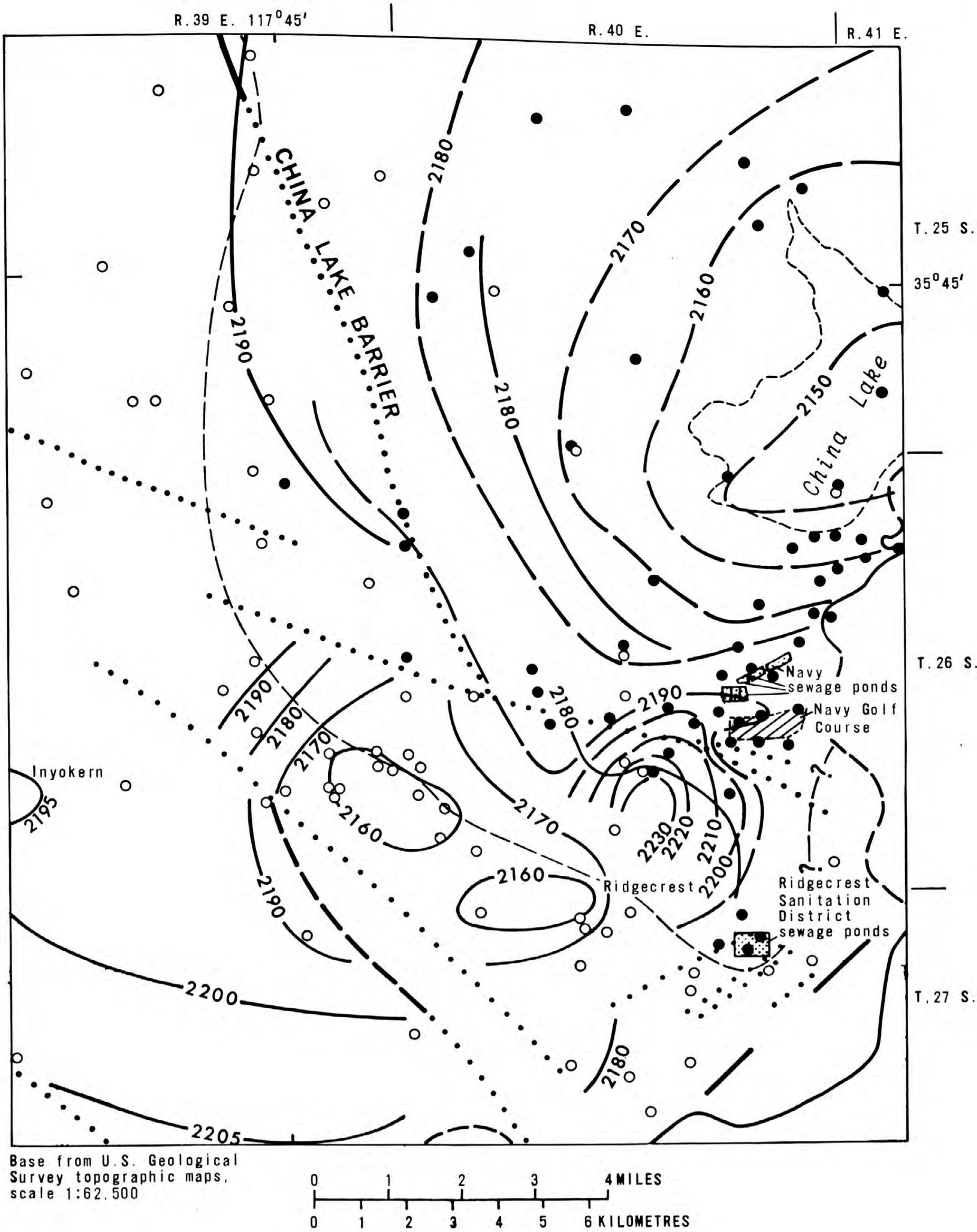


FIGURE 4.--Water-level contours for 1972.

However, the establishment of the Naval Weapons Center at China Lake and the growth of the town of Ridgecrest have resulted in heavy ground-water pumpage. This heavy pumpage along with recharge to the ground-water system of sewage effluent has changed local ground-water flow patterns but differently in the two aquifers. A water-level contour map (fig. 4) was constructed for both the deep aquifer and the shallow aquifer for 1972 to depict these local conditions.

In the study by Bloyd and Robson (1971, fig. 14), the model-generated water-level contours for the deep aquifer for 1968 indicate a reversal from the natural northeast direction of ground-water flow across the China Lake barrier in the region southeast of sec. 18, T. 26 S., R. 40 E. The study also suggests that south of the China Lake barrier ground water in the deep aquifer is no longer confined because pumping from the aquifer in the intermediate and Ridgecrest areas has caused the model-generated potentiometric surface to fall below the confining clay beds, thus producing water-table conditions. Therefore, the deep aquifer does not discharge into the shallow aquifer in this area. It was conjectured by Bloyd and Robson (1971, p. 23) that the southern and western extent of the shallow aquifer coincided with the China Lake barrier because the deep aquifer is the only significant natural source of recharge to the shallow aquifer.

Because of the paucity of data for the shallow aquifer, the effects of recharge of effluent from the Navy sewage ponds were unknown. Recharge of this effluent was suspected to have reversed the natural ground-water flow in the shallow aquifer across the China Lake barrier and to have reversed the natural movement of ground water between the deep and the shallow aquifers. Reversal of natural ground-water flow in the shallow aquifer across the barrier would cause the native poor-quality water to migrate southwestward toward the pumping depressions in the intermediate and Ridgecrest areas. Potentially, this condition could degrade the water there to such an extent that it would no longer be suitable for use as a public supply.

Twenty-seven shallow wells were augered in the vicinity of the Navy sewage ponds, in the area adjacent to the China Lake barrier, and in the area east of Ridgecrest near the Ridgecrest sewage ponds. Data from these wells indicated that not only is the shallow aquifer present in the area between the edge of the confining zone (pl. 1 and fig. 4) and the China Lake barrier, but that a recharge mound exists in this area, centered near sec. 27, T. 26 S., R. 40 E. (fig. 4).

In the area of this mound the differences in water level between the shallow and the deep aquifer are exemplified by the difference in water levels between wells 26S/40E-22P1 and 22P2 (pl. 1). In well 22P1, which was drilled to a depth of 1,358 ft (414 m) and plugged at 830 ft (253 m), the water-level altitude is about 2,177 ft (664 m) above sea level, whereas in well 22P2, which is 78 ft (24 m) deep and about 1,000 ft (305 m) east of well 22P1, the water-level altitude is about 2,228 ft (679 m) above sea level. Thus, in this area the head in the deep aquifer is about 50 ft (15 m) lower than in the shallow aquifer. The most plausible explanation for the higher head in the shallow aquifer is local recharge from watering of shrubbery and leakage from water and sewer lines. This mound maintains the natural northeast direction of flow in the shallow aquifer across the fault toward the China Lake playa. The water-level contour map for 1972 (fig. 4) indicates that recharge from the Navy sewage ponds has not reversed the natural direction of flow in the shallow aquifer across the fault.

The digital-model study (Bloyd and Robson, 1971) indicated that the China Lake barrier is a very effective barrier to ground-water flow in the region southeast of sec. 18, T. 26 S., R. 40 E. (fig. 4). This seems to be true for the deep aquifer only. Data from the present study strongly suggest that the fault does not affect ground-water flow in the shallow aquifer. There is no apparent surface expression of the fault in this area, and it probably does not affect the sedimentary deposits near the land surface. The unfaulted sedimentary deposits apparently extend across the fault and seem to allow water in the shallow aquifer to flow across the fault without interruption. This is evidenced by the profiles of the water-level surface across the fault (fig. 5). Neither of the water-surface profiles indicates any discontinuity in the water table in the vicinity of the fault. Because the China Lake barrier apparently is not an effective barrier to ground-water flow in the shallow aquifer, it is especially important to maintain the natural direction of flow across the fault toward the China Lake playa to prevent the poor-quality water in the shallow aquifer from migrating toward the pumping depressions in the Ridgecrest and intermediate areas.

The Ridgecrest Sanitation District operates sewage ponds that are located just within the southern areal extent of the shallow aquifer. The sewage-pond area is bordered on the northwest and southeast by unnamed faults (fig. 4). Native water of poor quality exists in the deep aquifer along the fringe of the valley to the east and south of the ponds. The digital model study by Bloyd and Robson (1971, p. 32) suggested that these faults are effective barriers to ground-water movement in the deep aquifer, and thus impede the flow of poor-quality water from the fringe of the valley toward the pumping depressions in the intermediate and Ridgecrest areas. There is no apparent surface expression of the faults, and they probably do not affect the sedimentary deposits near the land surface. To obtain data on the ground-water gradient in the shallow aquifer across the fault, northwest of the sewage ponds, two wells were augered on each side of the fault. The altitude of the water table was about the same on both sides of the fault, and thus little or no movement of ground water across the fault occurs here in the shallow aquifer.

Recharge of Sewage Effluent

The water-level contour map (fig. 4) suggests that little recharge to the shallow aquifer has occurred from either the Navy sewage ponds or the Navy golf course. The Navy golf course is watered with treated effluent obtained from the Navy sewage ponds. About 1960, several of the ponds were lined with clay to reduce infiltration so that more water would be available for use on the golf course.

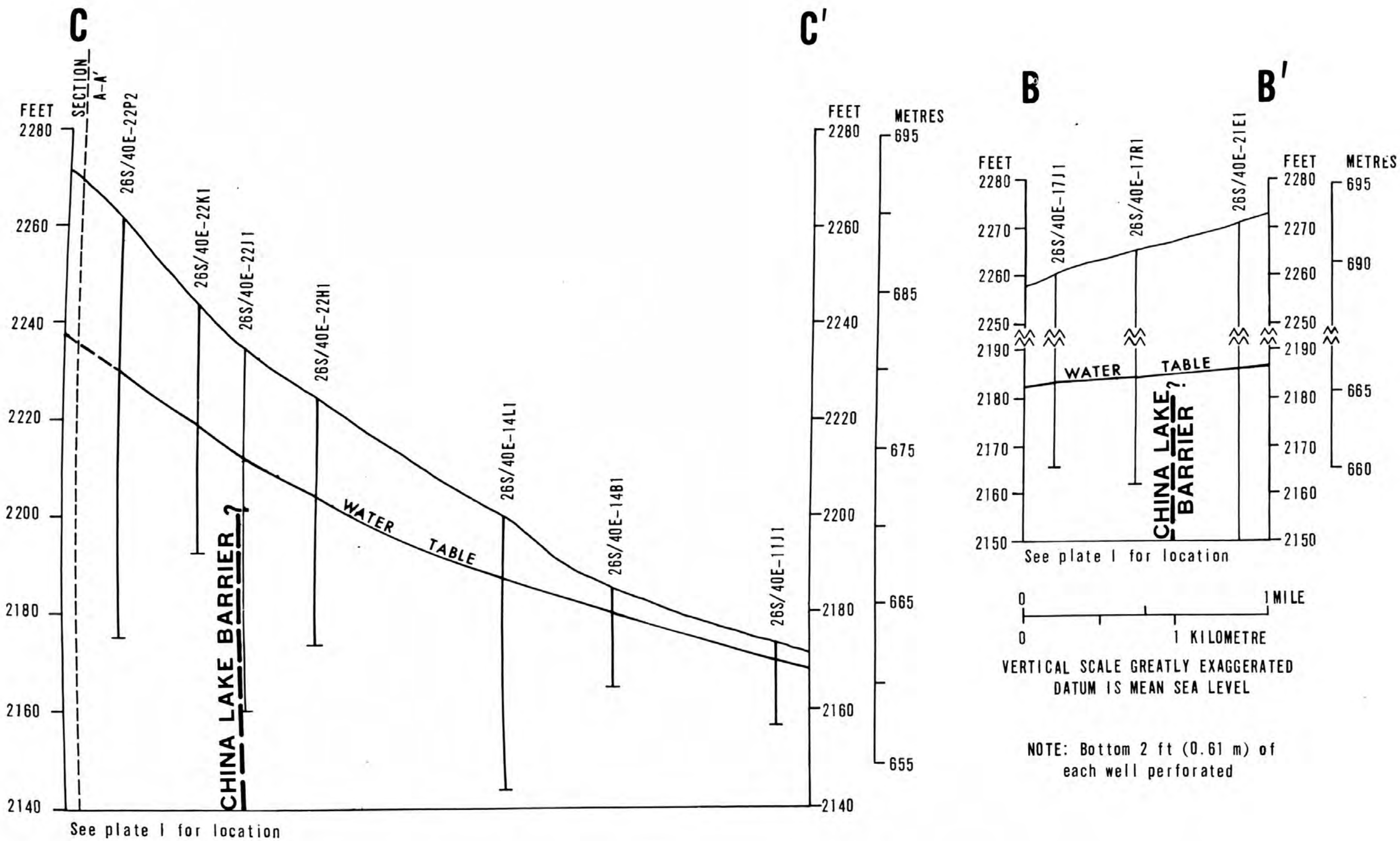


FIGURE 5.--Water-surface profiles of the shallow aquifer across China Lake barrier.

Ground-water recharge from the Navy sewage ponds is the calculated difference between the flow into the ponds and the flow out of the ponds for watering the golf course, minus the evaporation from the pond area. Evaporation from the sewage ponds was assumed to be 115 in (2,920 mm) per year. The ponds occupy about 90.5 acres (36.6 ha); thus, the evaporation from the ponds is about 865 acre-ft (1.07 hm^3) per year. The flow into the ponds averaged about 1,770 acre-ft (2.18 hm^3) per year during 1967-72. The outflow for watering the golf course during this period averaged about 670 acre-ft (0.83 hm^3) per year. Hence the calculated recharge to the ground-water system during this period has averaged about 240 acre-ft (0.30 hm^3) per year. Only about 14 percent of the inflow into the sewage ponds infiltrates to the ground-water system. Bloyd and Robson (1971, p. 21) assumed that half the total recharge from the ponds percolates into the shallow aquifer and that the other half percolates into the deep aquifer. Therefore, average recharge to the shallow aquifer from this source is estimated to be 120 acre-ft (0.15 hm^3) per year.

Ground-water recharge from the irrigation of the Navy golf course was calculated as the water applied on the golf course minus the evapotranspiration. Evapotranspiration is the loss of applied water during the irrigation process--both by evaporation from the soil and by transpiration from plants. Evapotranspiration from the golf course was estimated, using the method of Blaney and Criddle (1949), to be 48 in (1,220 mm) per year. The golf course occupies about 185 acres (75 ha) and thus potential evapotranspiration is about 740 acre-ft (0.91 hm^3) per year. Water applied on the golf course during 1967-72 averaged about 670 acre-ft (0.83 hm^3) per year. Therefore, it is assumed that no significant recharge to the ground-water system occurs from the golf course. Neither the Navy sewage ponds nor the Navy golf course seems to be a significant source of recharge to the shallow aquifer.

Recharge of sewage effluent from the Ridgecrest Sanitation District sewage ponds to the ground-water system was estimated by the same method that was used for the Navy sewage ponds. The Ridgecrest Sanitation District sewage ponds occupy about 20 acres (8 ha). Assuming evaporation is about 115 in (2,920 mm) per year, the evaporation from the ponds is about 190 acre-ft (0.23 hm^3) per year. About 97 acres (39 ha) of alfalfa is irrigated with sewage effluent from the Ridgecrest Sanitation District ponds. The water applied to the alfalfa is unmetered but evapotranspiration from alfalfa (Blaney and Criddle, 1949) was estimated to be 55 in (1,400 mm) per year. The evapotranspiration from the irrigated alfalfa therefore is about 450 acre-ft (0.55 hm^3) per year. The total evaporation from the Ridgecrest Sanitation District sewage ponds is about 640 acre-ft (0.79 hm^3) per year. The flow into the ponds during 1967-72 averaged about 790 acre-ft (0.97 hm^3) per year. Hence, the recharge to the ground-water system during this period averaged about 150 acre-ft (0.18 hm^3) per year. As of 1972 the Ridgecrest Sanitation District sewage ponds were not a significant source of recharge to the ground-water system.

Water-Level Decline in the Well Fields

Since the establishment of the Naval Weapons Center at China Lake in 1943, heavy ground-water pumpage has caused increasingly larger pumping depressions in the Inyokern, intermediate, and Ridgecrest areas. The hydrographs of wells 26S/39E-24K1 and 25D1 (fig. 6) are typical of the long-term water-level fluctuation in the intermediate area. The hydrographs show that the water-level decline in this area has been about 35 ft (10.7 m) since about 1947. Most of this decline in the intermediate area has occurred in response to increased pumping since about 1963. The 1963-72 decline averaged about 2.5 ft (0.7 m) per year.

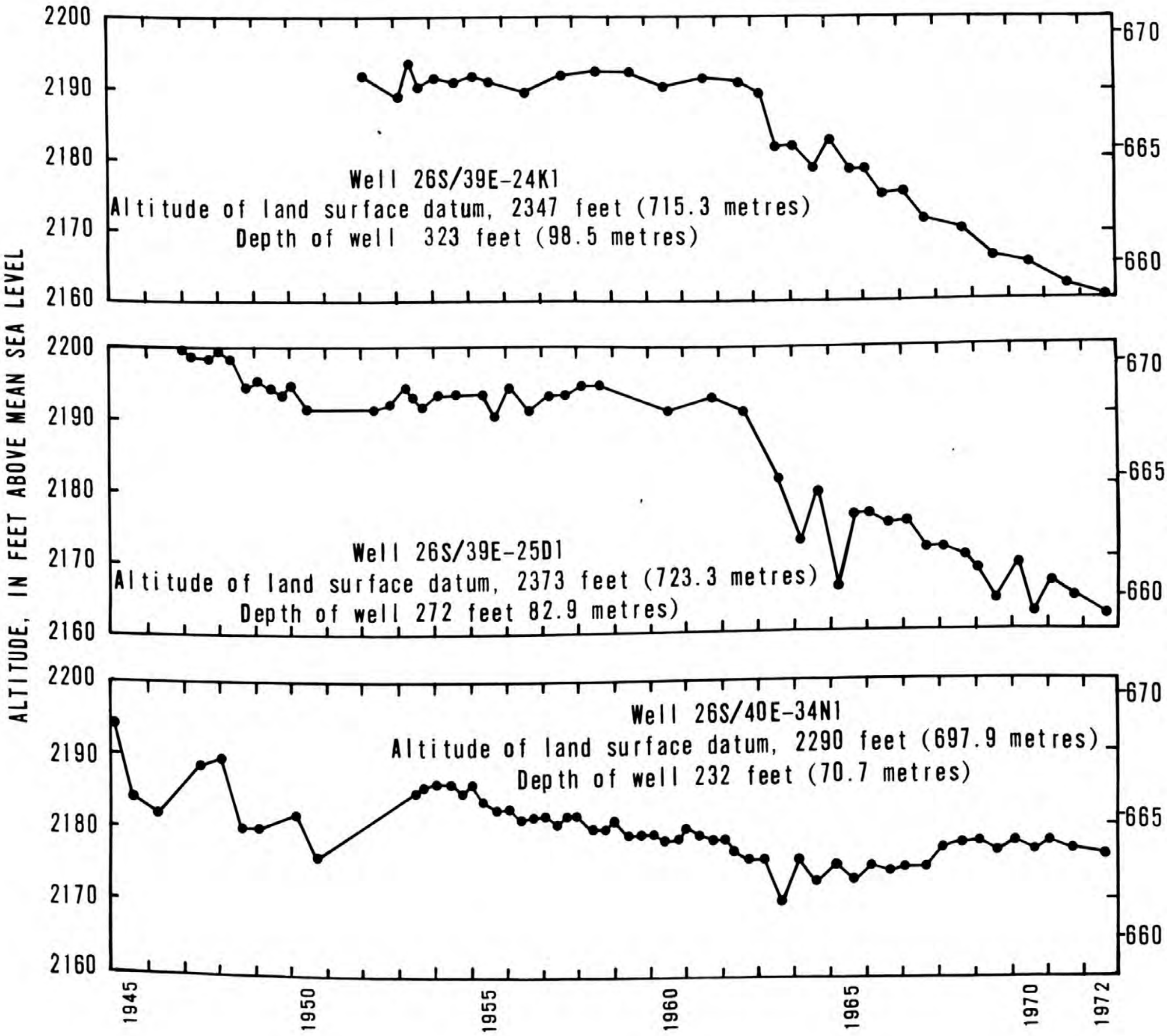


FIGURE 6.--Hydrographs of selected wells.

The hydrograph of well 26S/40E-34N1 (fig. 6) is typical of the long-term water-level fluctuation in the Ridgecrest area. The hydrograph shows that the water-level decline near that well has been more than 10 ft (3 m) since 1945. However, the total decline of the water level in the area between 1954 and 1963 was about 15 ft (4.6 m). The rate of decline during this period averaged about 1.2 ft (0.36 m) per year. Since 1963 the water level in wells in the Ridgecrest area has risen about 5 ft (1.5 m) at an average rate of about 0.6 ft (0.18 m) per year.

The pumping depressions have reversed the natural ground-water gradient in the deep aquifer across the China Lake barrier in the region near the town of China Lake. However, no reversal has occurred in the natural ground-water gradient in the shallow aquifer across the China Lake barrier from these pumping depressions.

CHEMICAL QUALITY OF GROUND WATER

The ground water is classified into three water-quality groups. Ground water in groups 1 and 2 is generally of good quality, whereas ground water in group 3 is generally of poor quality and is considered unfit for most public uses. The chemical classification of ground water in Indian Wells Valley in this study follows that by Kunkel and Chase (1969, p. 51) and Dutcher and Moyle (1970). The general chemical characteristics of ground-water quality in each group are given in table 2.

TABLE 2.--*General chemical characteristics of ground-water quality by classification groups*

[Milligrams per litre]

Group	Dominant ions	Dissolved solids	Calcium plus magnesium	Sodium plus potassium	Chloride	Bicarbonate plus carbonate	Boron	Fluoride
1	Variable	<600	30-100	<150	<100	a100-200	<1	<1
2	Sodium and bicarbonate	<600	<30	50-250	<150	a150-400	a<3	1-3
3	Sodium and chloride	>1,000->50,000	0->250	>200->3,000	>250->3,000	0->750	>2->10	1-6

a. Locally may be higher.

Water samples for chemical analysis were obtained from 61 wells in May and June 1972. The Navy sewage ponds and the Ridgecrest Sanitation District sewage ponds were also sampled during the study. These analyses are shown in table 3. Data in this report were also derived partly from many previous studies, especially Wilcox, Hatcher, and Blair (1951); Moyle (1963); and Kunkel and Chase (1969). Wilcox, Hatcher, and Blair (1951) collected many water samples from wells for chemical analysis in the northwestern and north-central part of the valley. Kunkel and Chase (1969) collected many water samples for chemical analysis in the northeastern and south-central part of the valley. These previous studies were utilized to define the areal extent of water in groups 1, 2, and 3 for the years 1946 and 1953. As reported by Koehler (1971, p. 12), the Geological Survey laboratory and the Navy laboratory used different methods to determine the concentration of dissolved solids. For consistency, all dissolved-solids values reported by the Navy laboratory were converted to the sum of the dissolved solids of the various constituents.

Representative chemical analyses of ground water from wells throughout the valley are shown by the water-quality diagrams in figures 7, 8, and 9 for the years 1946, 1953, and 1972. These diagrams show the general quality of the water and the areal differences in water quality. Analyses with similar diagrams represent water of similar chemical characteristics. Changes in configuration of the diagrams reflect changes in chemical character. The width of the diagram is an approximate indication of the concentration of dissolved solids--larger widths reflect greater dissolved-solids concentration.

Areal Distribution of Ground-Water Quality

The areal extent of the three water groups is shown in figures 7, 8, and 9. About 250 chemical analyses of ground water from wells were plotted by water group to indicate the approximate areal extent of each group. The depth for each well is shown in table 4. A comparison of the areal extent of water groups in each figure indicates the flow pattern of the water groups during the period 1946-72. No appreciable change has occurred in the areal extent of any of the water groups since 1946. Most significantly, the areal extent of group 3 water has not increased, and, in fact, there are some indications that a decrease in areal extent of group 3 water may have occurred.

Group 1 water occurs in most of the central and western part of the valley, primarily in Tps. 25, 26, and 27 S., Rs. 38 and 39 E. Group 1 water is found in the Inyokern area and parts of the intermediate and the Ridgecrest areas.

Group 2 water occurs mainly in the central part of the valley in parts of Tps. 26 and 27 S., R. 40 E. Group 2 water is also found in a zone about 3 mi (4.8 km) wide and 3 mi (4.8 km) long that extends approximately between Inyokern Road and Armitage Field and as a strip about 1 mi (1.6 m) wide that extends south of the Naval Weapons Center main gate (NE cor., sec. 28, T. 26 S., R. 40 E.) for a distance of about 4 mi (6.4 km). It is also found in the northern one-third of T. 25 S., Rs. 38 and 39 E. Group 2 water occurs as a transition between group 1 water and group 3 water. Group 2 water was probably at one time group 1 water but has undergone ion exchange whereby calcium and magnesium are replaced by sodium and potassium (Kunkel and Chase, 1969, p. 53). This exchange occurs as the ground water moves through the lake deposits toward the China Lake playa. The lake deposits occur at depth in the central part of the valley, and therefore presumably group 2 water is found at depth below group 1 water in this area. Parts of the Ridgecrest and the intermediate well fields also produce group 2 water.

The areal extent of group 3 water includes most of the northeastern part of the valley centered about the China Lake playa. Group 3 water also occurs along the eastern and southern fringes of the valley (western half of T. 26 S., R. 40 E., and southern two-thirds of T. 27 S., R. 40 E).

Almost all the water in the shallow aquifer is group 3 water. There is evidence that in some areas group 2 water may occur in the deeper aquifer below the group 3 water. In T. 25 S., R. 40 E., the shallow aquifer system is mostly sand and interdune playa deposits, and almost all the wells drilled are less than 50 ft (15 m) deep, perforated in these deposits. No chemical analyses were available of water from deeper wells in this area, except for a partial analysis of water from well 25S/40E-20F1 (Moyle, 1963, p. 140), which is 183 ft (55.8 m) deep. The water in this well probably is group 2 water.

In 1953 water from wells 25S/39E-26H1 and 25S/40E-27E1 was group 3 water. In 1972 water from both these wells was group 2 water. However, near the Ridgecrest Sanitation District sewage ponds the areal extent of group 3 water in the shallow aquifer seems to have increased. In 1946, before the construction of the sewage ponds, ground water in the shallow aquifer in this area was group 1 and group 2 water. In 1972 water in the shallow aquifer in this area was group 3 water. There was no indication in 1972 that the flow pattern of group 3 water was toward the pumping depressions in the intermediate and Ridgecrest areas.

The ground-water quality from some wells has fluctuated between group 1 water and group 2 water. Normally, this has occurred in deep wells that may tap more than one type of water. Water from these wells may represent a blend of the two water groups, and the change in quality may be related to the pumping history prior to sampling.

TABLE 3.--*Chemical analyses of water*

Values for dissolved solids indicate the residue on evaporation at 180°C, except those preceded by the letter "a," which have been calculated (sum of dissolved solids).

Laboratory: N, Environmental Engineering Laboratory, Southwest Division, Naval Facilities Engineering Command, San Diego, Calif.; GS, U.S. Geological Survey, Salt Lake City, Utah

Well number	Date of collection	Depth of well (feet)	Water temperature (°C)	Results in milligrams per litre, except iron and boron in micrograms per litre: Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)
U.S. Public Health Service drinking-water standards (1962)					0.3					
INYOKERN AREA										
26S/39E-19K1	6- 6-72	803	--	24	--	83	11	69	3.4	68
19P1	6- 6-72	446	--	21	--	38	3.9	55	2.2	120
19Q2	6- 6-72	510	--	19	--	53	5.8	68	2.6	98
30F3	6- 6-72	450	--	17	--	34	4.4	64	2.5	120
INTERMEDIATE AREA										
26S/39E-23J1	6- 6-72	800	--	21	--	28	6.8	33	2.9	120
24M1	6- 6-72	800	--	20	--	22	4.9	44	2.1	120
24P1	6- 6-72	825	--	15	--	12	2.7	64	1.8	120
RIDGECREST AREA										
26S/40E-34N1	6- 6-72	232	--	23	--	36	10	55	5.0	120
OUTLYING AREAS										
25S/39E-4R1	6- 6-72	200	--	25	--	21	21	170	26	280
9J1	6- 6-72	200	--	33	--	48	20	110	8.9	350
12R2	6- 6-72	147	--	24	--	44	23	180	12	340
26H1	6- 6-72	302	--	21	--	20	12	210	6.8	300
35N1	6- 6-72	152	--	28	--	44	12	100	2.9	200
25S/40E-27E1	6-28-72	16	23.0	60	200	14	7.5	250	18	400
35P1	6-18-72	15	25.0	51	40	1.7	.2	2,700	16	1,310
26S/39E-5F1	6- 6-72	200	--	21	50	56	12	130	3.4	190
11E1	6- 6-72	250	--	20	--	57	7.8	61	2.7	180
26S/40E-1J1	6-13-72	18	21.0	11	140	100	65	16,000	340	240
26S/40E-5P1	6- 6-72	89	--	29	--	46	6.3	220	4.4	250
10F1	6-13-72	39	21.0	59	260	19	3.3	160	4.5	310
11J1	6-13-72	18	21.0	78	5,900	110	30	1,900	36	190
13C1	6-14-72	22	22.0	21	10	200	19	540	20	180
13M1	6-14-72	22	19.0	18	110,000	54	2.2	190	4.3	6
26S/40E-14B1	6-12-72	22	20.0	67	260	320	62	810	20	330
14H1	6-21-72	18	22.0	11	150,000	70	49	300	3.6	0
14L1	6-12-72	57	21.5	69	110	41	13	280	12	510
15E1	6-29-72	110	23.0	60	40	6.0	1.3	150	2.3	330
17J1	6-18-72	97	23.0	39	20	31	5.6	52	5.0	160

Well number	Results in milligrams per litre, except iron and boron in micrograms per litre--Continued: 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
U.S. Public Health Service drinking-water standards (1962)		250	250	1.0	45		500						
INYOKERN AREA													
26S/39E-19K1	--	98	170	0.8	6.2	--	a503	252	200	37	935	7.7	N
19P1	--	67	45	.7	10	520	a300	110	16	51	500	7.7	N
19Q2	--	73	100	.9	7.1	310	a378	156	76	48	670	7.6	N
30F3	--	63	51	1.0	8.0	680	a302	102	8	57	550	7.6	N
INTERMEDIATE AREA													
26S/39E-23J1	--	36	24	.8	8.9	200	a218	98	4	41	360	7.0	N
24M1	--	30	26	.8	11	320	a218	76	0	55	330	8.0	N
24P1	10	24	29	1.0	8.0	880	a211	41	0	76	340	8.6	N
RIDGECREST AREA													
26S/40E-34N1	--	63	62	.9	8.9	570	a321	132	38	46	555	7.5	N
OUTLYING AREAS													
25S/39E-4R1	--	150	88	.9	4.9	3,100	a644	188	0	68	1,180	7.8	N
9J1	--	70	53	1.1	1.8	1,800	a516	200	0	52	870	7.5	N
12R2	--	150	110	1.0	7.1	2,100	a723	208	0	64	1,150	7.9	N
26H1	--	120	150	2.6	4.0	800	a696	100	0	81	1,180	7.9	N
35N1	--	92	82	.7	.0	1,100	a463	158	0	58	810	7.5	N
25S/40E-27E1	18	94	140	.6	.1	2,000	a799	66	0	86	1,250	8.6	GS
35P1	940	750	2,100	5.8	1.4	24,000	7,620	5	0	100	11,200	9.5	GS
26S/39E-5F1	--	210	70	1.0	3.5	--	a602	196	38	58	895	7.5	N
11E1	--	48	70	.8	5.3	1,900	a366	174	22	43	635	7.7	N
26S/40E-1J1	0	1,600	25,000	2.1	.2	--	43,600	520	320	97	--	7.9	GS
26S/40E-5P1	--	85	180	1.2	2.2	2,800	a699	142	0	76	1,160	7.8	N
10F1	0	4.7	110	1.4	.1	6,800	520	61	0	84	796	8.3	GS
11J1	0	490	2,900	2.0	.7	9,400	5,880	400	240	90	9,400	7.1	GS
13C1	0	130	1,100	1.6	.8	3,500	2,680	580	430	66	3,810	7.1	GS
13M1	0	130	550	5.7	2.1	2,600	1,180	140	140	73	2,020	4.9	GS
26S/40E-14B1	0	620	1,400	.6	12	4,400	3,780	1,100	780	62	5,530	7.6	GS
14H1	0	410	540	15	.9	4,300	1,770	380	380	63	2,520	4.6	GS
14L1	0	220	160	1.2	5.8	1,100	1,070	160	0	78	1,450	7.6	GS
15E1	0	14	51	1.4	.1	15,000	a463	20	0	93	693	8.4	GS
17J1	0	63	35	.9	.4	190	308	100	0	51	476	7.9	GS

TABLE 3.--*Chemical analyses of water.*--Continued

Well number	Date	Depth	°C	SiO_2	Fe	Ca	Mg	Na	K	HCO_3	CO_3	SO_4	Cl	F	NO_3	B	Dissolved solids	Hardness	Noncarbonate	%Na	Spec. cond.	pH	Lab.
OUTLYING AREAS--Continued																							
26S/40E-17R1	6-18-72	107	23.0	52	30	33	5.7	47	5.3	160	0	43	31	0.8	0.1	230	304	110	0	48	440	7.4	GS
21A1	6-13-72	102	25.0	37	90	16	3.1	180	8.3	380	0	110	29	2.3	.1	1,600	612	53	0	86	888	7.8	GS
21E1	6-18-72	122	24.0	50	50	16	3.4	53	11	150	0	25	31	1.1	.5	240	280	54	0	63	382	7.9	GS
22B1	6-18-72	67	25.0	57	60	170	130	1,200	41	390	0	2,900	320	1.4	8.8	15,000	5,480	960	640	72	6,600	7.8	GS
22H1	6-12-72	52	24.0	70	30	470	380	890	88	200	0	4,100	260	2.7	11	12,000	7,160	2,700	2,600	40	7,110	7.6	GS
26S/40E-22H2	6-12-72	77	25.0	49	50	430	990	3,000	70	420	0	10,000	470	4.8	6.6	9,000	16,500	5,100	4,800	55	15,300	7.7	GS
22H3	6-13-72	97	24.0	53	360	390	220	880	43	280	0	3,200	190	3.1	.2	7,600	5,400	1,900	1,600	50	5,740	7.5	GS
22J1	6- 2-72	77	25.0	68	60	360	230	530	54	250	0	2,300	260	2.6	4.4	1,600	4,180	1,800	1,600	38	4,610	7.6	GS
22K1	6- 1-72	52	25.5	67	110	89	35	190	17	340	0	350	120	2.7	4.1	1,100	1,040	370	89	52	1,480	7.4	GS
22N1	6-28-72	203	25.0	54	80	40	23	100	9.2	200	0	230	24	2.2	.3	440	a581	190	32	51	842	8.1	GS
26S/40E-22P1	6-17-72	830	27.0	30	120	2.1	.4	370	4.9	700	50	18	140	2.7	.4	4,700	1,050	7	0	98	1,640	8.8	GS
22P2	6- 1-72	87	25.0	78	50	100	44	180	23	190	0	640	28	2.0	.3	590	1,200	430	270	46	1,540	7.6	GS
23A1	5-26-72	52	22.0	63	50	40	14	710	25	540	0	320	620	4.0	5.3	5,200	2,140	160	0	89	3,310	8.1	GS
23A2	5-26-72	77	22.5	74	70	15	5.3	430	16	390	0	61	430	2.3	.1	3,300	1,400	59	0	92	2,090	8.3	GS
23G1	5-24-72	67	22.0	60	100	120	64	3,800	61	370	0	3,700	3,000	3.0	.4	23,000	10,900	560	260	93	15,100	7.8	GS
26S/40E-23J1	5-24-72	62	22.0	69	220	30	12	540	17	400	0	210	510	2.6	3.7	3,800	1,720	120	0	89	2,650	8.2	GS
23L1	6- 2-72	72	25.0	53	40	19	9.1	710	14	670	0	630	260	3.7	.2	6,000	2,100	85	0	94	3,020	7.8	GS
24C1	5-26-72	45	21.0	31	100	44	17	760	9.4	660	0	460	570	5.6	71	3,700	2,500	180	0	90	3,560	8.1	GS
24M1	6-12-72	67	22.0	56	60	440	120	1,200	89	190	0	540	2,500	.8	42	4,400	6,080	1,600	1,400	60	8,830	7.2	GS
26F1	5-26-72	77	23.0	70	60	55	17	220	13	220	0	180	220	.6	.1	1,700	952	210	24	68	1,430	8.1	GS
26S/40E-28J1	6-17-72	--	27.0	55	20	16	2.9	60	12	130	0	59	21	1.2	.2	190	298	52	0	66	414	8.3	GS
29D1	6-17-72	--	26.0	48	10	24	5.8	35	10	120	0	39	25	.6	8	150	262	84	0	44	364	8.1	GS
32E2	6-17-72	300	27.0	28	40	32	8.5	42	3.1	100	0	44	51	.5	22	150	306	110	31	43	452	8.0	GS
35Q2	6-16-72	127	24.0	71	30	70	17	200	16	140	0	49	420	.8	.1	2,100	1,050	240	130	62	1,700	7.5	GS
27S/40E-1K2	6-17-72	164	25.0	55	10	95	13	390	11	110	0	65	650	1.4	19	2,600	1,510	290	200	74	2,420	7.7	GS
27S/40E-2A1	6-14-72	127	24.0	59	20	56	13	300	9.3	160	0	58	470	1.1	4	2,600	1,130	190	61	76	1,890	7.7	GS
2F1	6-16-72	127	24.0	60	20	26	5.2	82	5.8	140	0	36	79	1.0	2.9	700	374	86	0	66	559	8.1	GS
2G1	6-15-72	127	23.0	55	30	190	56	320	12	340	0	330	490	.7	53	4,200	1,880	700	420	49	2,690	7.3	GS
2H1	6-18-72	200	25.0	52	40	23	3.5	200	4.0	200	0	48	190	1.6	11	2,000	668	72	0	85	1,060	8.0	GS
2J1	6-17-72	220	25.0	56	20	86	15	320	6.5	250	0	76	460	1.0	25	3,100	1,230	280	75	71	2,040	7.7	GS
27S/40E-9P1	6-29-72	230	30.0	54	20	44	7.7	160	3.5	200	0	45	210	1.0	5.3	1,300	a632	140	0	70	1,060	8.2	GS
10A7	6-17-72	150	25.0	50	30	40	13	230	5.1	170	0	140	280	1.8	27	1,500	896	150	15	76	1,500	7.6	GS
15L1	6-29-72	278	30.0	43	160	170	40	250	12	120	0	100	670	.6	20	1,800	a1,370	590	490	47	2,520	7.7	GS
SEWAGE PONDS																							
Navy	2-26-69	--	--	44	100	23	9.8	130	8.8	180	0	110	98	.8	4.9	1,100	a520	98	0	72	--	7.5	N
Ridgecrest Sanitation District	6-18-72	--	25.0	45	360	14	4.7	160	14	370	0	29	110	3.4	.04	1,600	a566	54	0	83	1,060	7.1	GS

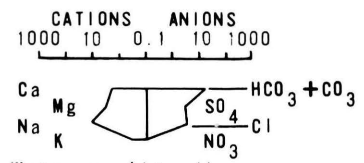
EXPLANATION

Boundary of ground-water basin. Dashed where control is poor

Boundary of shallow aquifer and assumed limit of confining clay layers. Queried where location inferred

Fault

Dashed where approximately located; dotted where concealed



Water-quality diagram

Constituents, in milliequivalents per litre, are calcium (Ca), magnesium (Mg), sodium (Na), potassium (K), bicarbonate (HCO_3), carbonate (CO_3), chloride (Cl), sulfate (SO_4), and nitrate (NO_3). The area of the diagram is an indication of the dissolved solids--the larger the area of the diagram the greater the dissolved solids. Differences in configuration reflect differences in chemical character

2Q1

Well and number

Ground water from this well is in group 1

13D1

Well and number

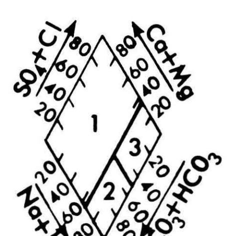
Ground water from this well is in group 2

15N1

Well and number

Ground water from this well is in group 3

See text for explanation of well number



Graphical representation of water-quality groups

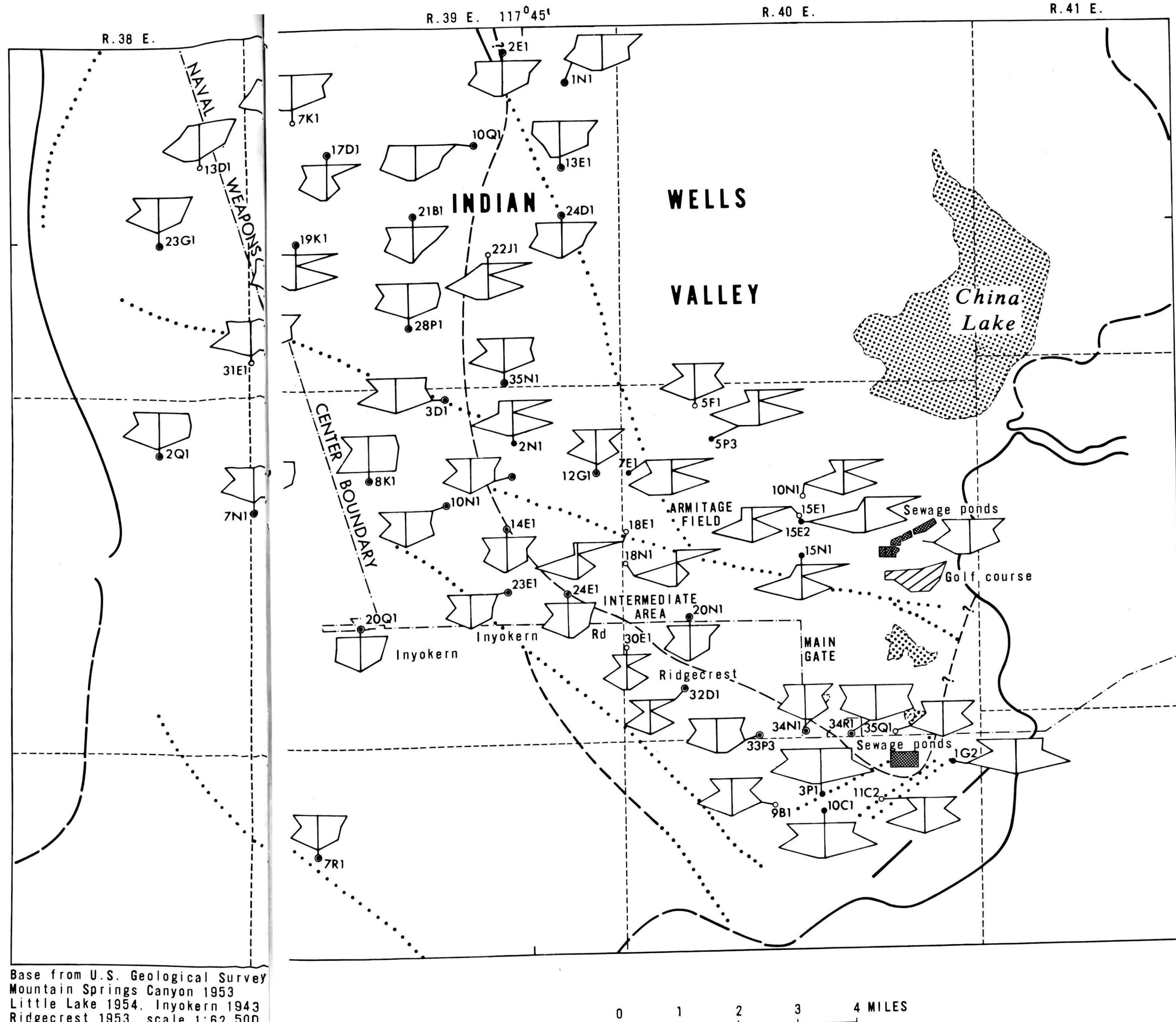


FIGURE 7.--Water-quality diagrams for selected wells for 1946.

FIGURE 7.--Continued.

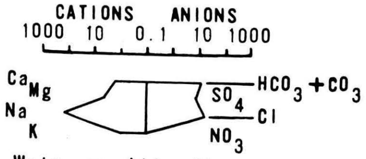
EXPLANATION

Boundary of ground-water basin. Dashed where control is poor

Boundary of shallow aquifer and assumed limit of confining clay layers. Queried where location inferred

Fault

Dashed where approximately located; dotted where concealed



Water-quality diagram

Constituents, in milliequivalents per litre, are calcium (Ca), magnesium (Mg), sodium (Na), potassium (K), bicarbonate (HCO_3), carbonate (CO_3), chloride (Cl), sulfate (SO_4), and nitrate (NO_3). The area of the diagram is an indication of the dissolved solids--the larger the area of the diagram the greater the dissolved solids. Differences in configuration reflect differences in chemical character

•7N1 Well and number

Ground water from this well is in group 1

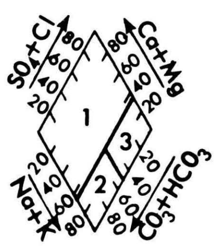
∘9P1 Well and number

Ground water from this well is in group 2

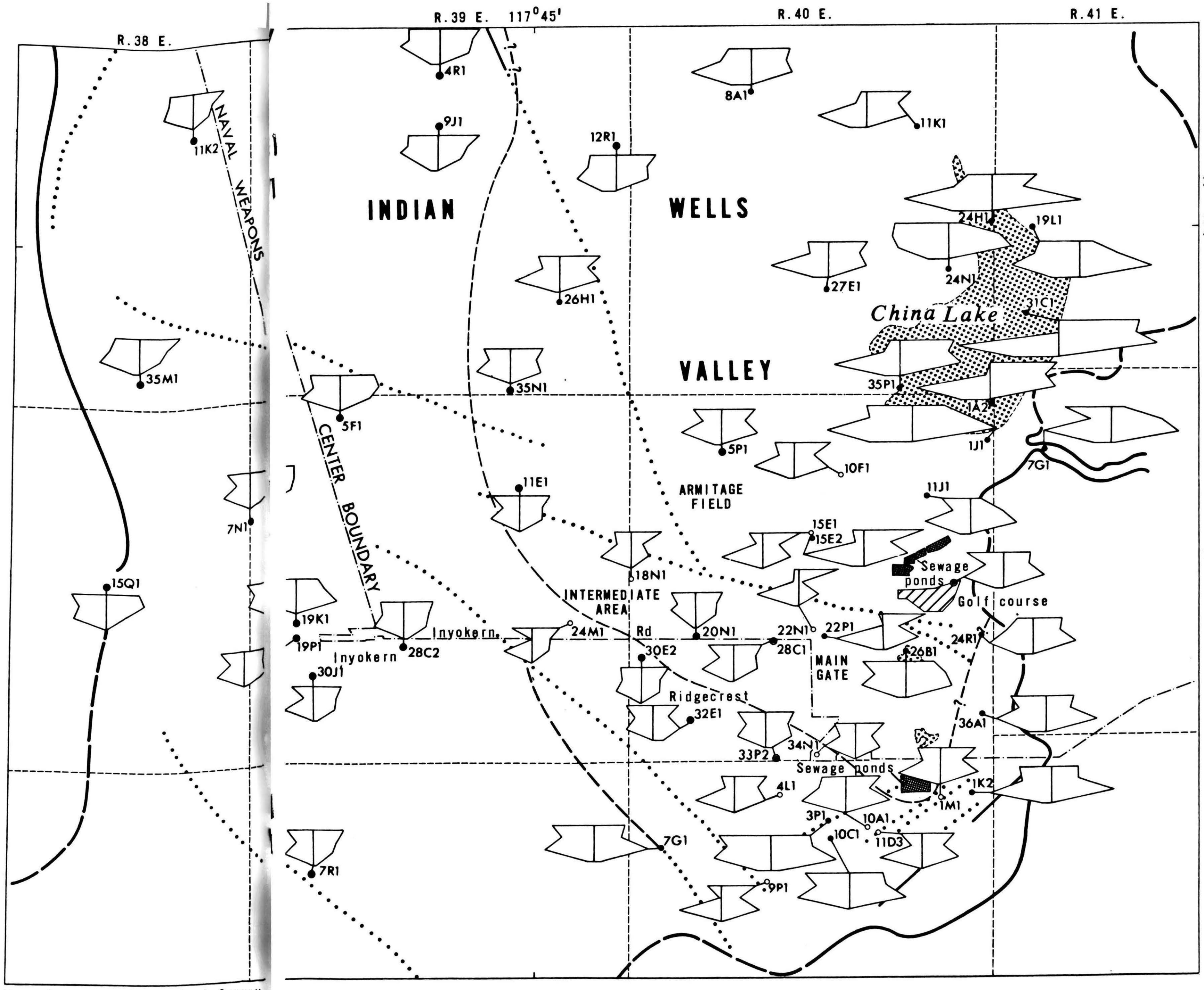
•8A1 Well and number

Ground water from this well is in group 3

See text for explanation of well number



Graphical representation of water-quality groups



Base from U.S. Geological Survey Mountain Springs Canyon 1953 Little Lake 1954, Inyokern 1943 Ridgecrest 1953, scale 1:62 500

0 1 2 3 4 MILES

0 1 2 3 4 5 6 KILOMETRES

FIGURE 8.--Water-quality diagrams for selected wells for 1953.

FIGURE 8.--Continued.

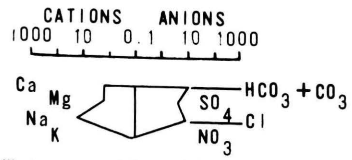
EXPLANATION

Boundary of ground-water basin. Dashed where control is poor

Boundary of shallow aquifer and assumed limit of confining clay layers. Queried where location inferred

Fault

Dashed where approximately located; dotted where concealed



Water-quality diagram

Constituents, in milliequivalents per litre, are calcium (Ca), magnesium (Mg), sodium (Na), potassium (K), bicarbonate (HCO_3), carbonate (CO_3), chloride (Cl), sulfate (SO_4), and nitrate (NO_3). The area of the diagram is an indication of the dissolved solids--the larger the area of the diagram the greater the dissolved solids. Differences in configuration reflect differences in chemical character

29D1

Well and number

Ground water from this well is in group 1

10F1

Well and number

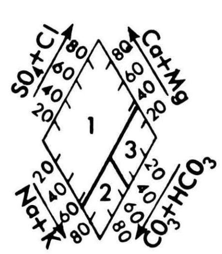
Ground water from this well is in group 2

15L1

Well and number

Ground water from this well is in group 3

See text for explanation of well number



Graphical representation of water-quality groups

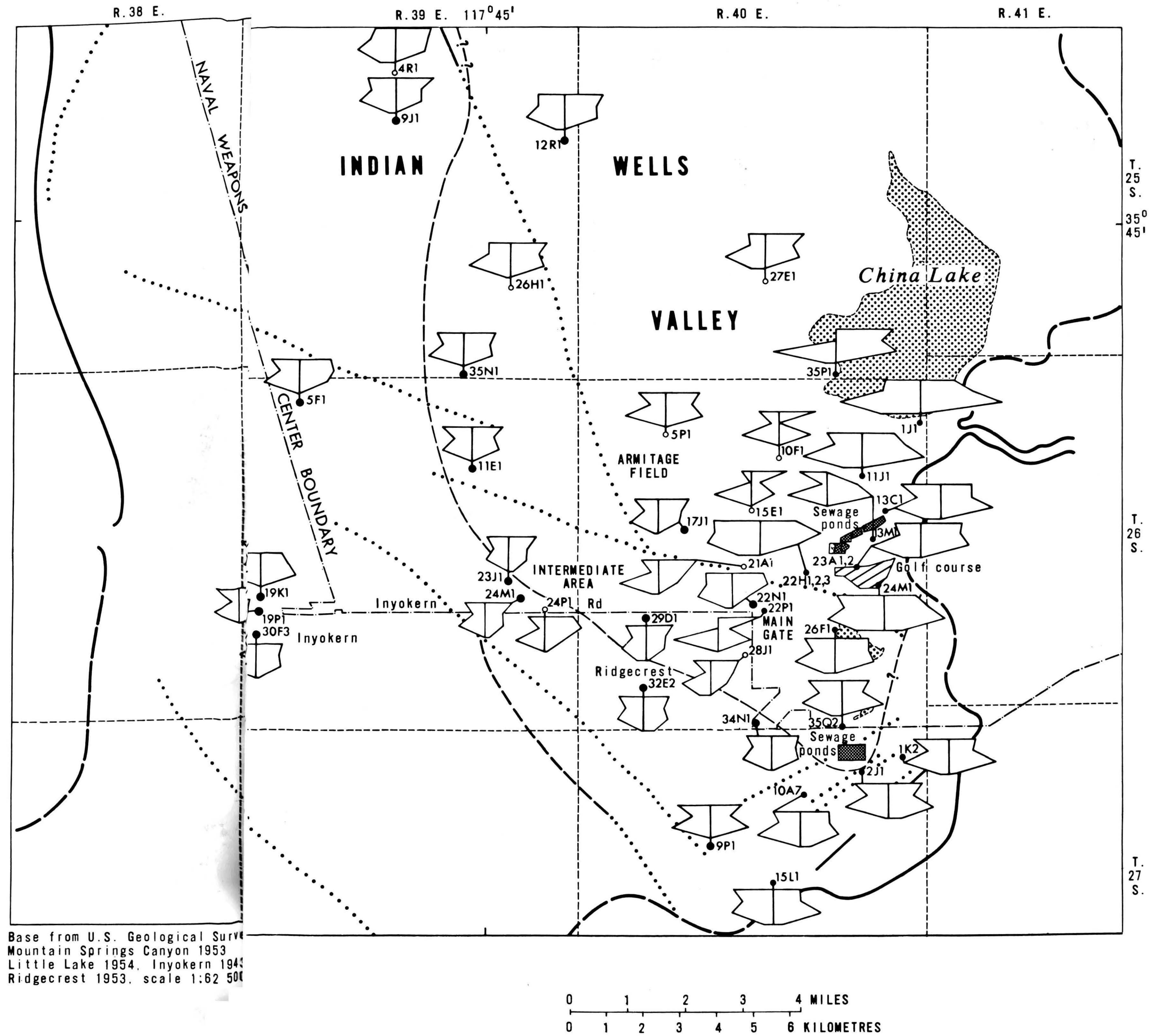


FIGURE 9.--Water-quality diagrams for selected wells for 1972.

FIGURE 9.--Continued.

TABLE 4.--*Depth of wells*

Well No.	Depth (feet)	Well No.	Depth (feet)	Well No.	Depth (feet)
25S/38E-23G1	259	26S/39E-11Q1	191	26S/40E-14H1	18
25S/39E-1N1	39	12G1	137	14L1	57
2E1	211	12N1	144	15E1	110
4R1	200	14E1	242	15E2	198
7K1	57	19K1	803	15N1	225
9J1	200	19P1	446	17J1	97
10E1	81	19Q1	368	17N1	178
12R1	180	20Q1	505	17R1	104
17D1	88	23E1	190	18N1	555
19K1	231	23J1	800	19P1	261
21B1	106	24E1	171	20N1	190
22B1	158	24M1	800	21A1	104
22J1	140	24P1	825	21E1	117
26H1	302	24Q1	361	22B1	103
31E1	164	24R1	480	22H1	53
35N1	152	28C2	364	22H2	77
25S/40E-3N1	7	30J1	430	22H3	97
8A1	18	26S/40E-1A2	198	22J1	75
11K1	62	1J1	18	22K1	55
12M1	60	5F1	25	22N1	203
24H1	40	5P1	89	22P1	850
24N1	30	5P3	27	22P2	78
27E1	16	6E1	45	23A1	55
33L2	21	7E1	86	23A2	80
35P1	16	7N1	137	23C1	40
25S/41E-19L1	24	8N1	185	23G1	60
31C1	9	8Q1	83	24C1	45
26S/38E-2Q1	270	10E1	176	24N1	71
26S/39E-2C1	76	10F1	39	24R1	149
2N1	159	10N1	134	26B1	49
3D1	68	11A1	5	26F1	80
5F1	200	11J1	18	28C1	147
7N1	368	13C1	22	30E2	402
8K1	182	13M1	22	32D1	279
11E1	250	14B1	25	32E1	300

TABLE 4.--*Depth of wells*--Continued

Well No.	Depth (feet)	Well No.	Depth (feet)	Well No.	Depth (feet)
26S/40E-32E2	300	27S/40E-1K2	164	27S/40E-4L1	252
33A1	400	1M1	199	7G1	410
33A2	350	2A1	130	8A1	440
33P1	130	2F1	130	9P1	230
34N1	232	2G1	131	10A1	150
24R1	78	2H1	200	10A2	126
35Q1	120	2J1	220	10A7	150
35Q2	130	3P1	108	10C1	250
36A1	270	3R1	162	10J1	180
26S/41E-7E1	32	4B2	375	11C2	140
7G1	32	4C1	300	11D3	165
7G2	49	4C2	280	15L1	278
27S/39E-7R1	377				

Vertical Distribution of Ground-Water Quality

Water quality differs in Indian Wells Valley not only areally, but also with depth in the basin. The general increase in dissolved solids with depth in the aquifer is shown in figure 10. Many of the diagrams in figures 7, 8, and 9 represent samples that are a composite of water pumped from different depth intervals where water of differing quality occurs. Many deep wells in the valley penetrate at lower depths a section of blue clay, probably lake deposits (fig. 2). Generally, the water from the lake deposits is of poor quality, but most of the wells that penetrate these deposits are not perforated in this material. However, well data (fig. 2) indicate that the lower part of some well casings are perforated in the lake deposits. Well 26S/39E-19K1 is perforated in three zones, the two lower perforated intervals are probably in the lake deposits. In 1965 U.S. Navy personnel tested the chemical quality of water in each of the three perforated intervals. Water from the two lower perforated intervals contained from 956 to 1,150 mg/l dissolved solids, whereas water from the upper interval contained 454 mg/l dissolved solids. Well 26S/40E-22P1 is probably perforated in lacustrine deposits. Water from this well contains about 1,000 mg/l dissolved solids.

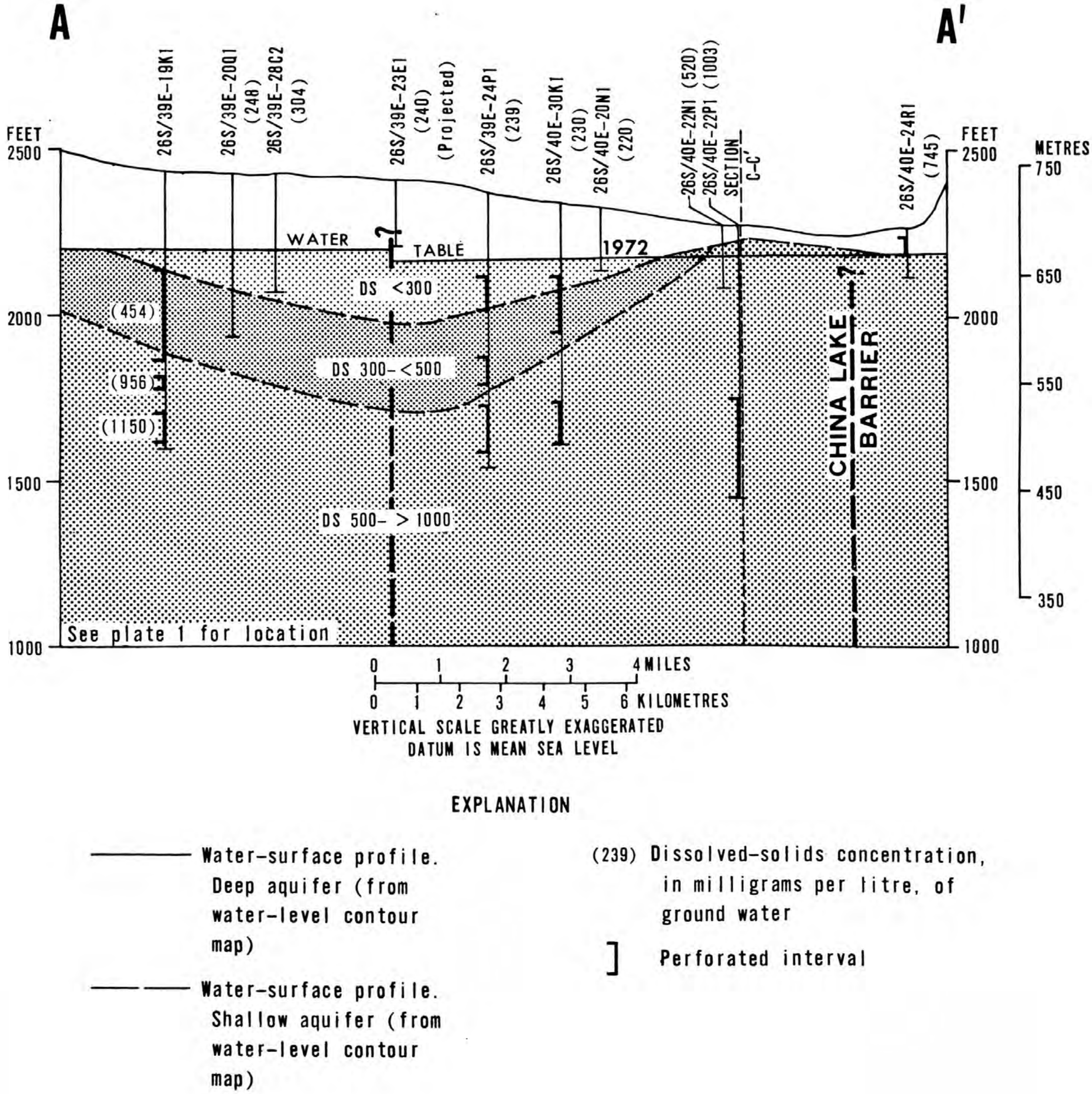


FIGURE 10.--Ground-water quality profile.

As the water levels in wells in the pumping depressions continue to decline, a greater part of the water pumped by these wells will probably come from the lake deposits causing a trend toward increase in dissolved solids for these wells. Such a trend is shown in figure 11 for well 26S/39E-24P1 in the intermediate area and for well 26S/40E-34N1 in the Ridgecrest area. Wells less than about 300 ft (90 m) deep west of the area of confined water do not penetrate the lake deposits, and therefore, the chemical quality of water from these wells has not been affected by water-level declines. Also, the chemical quality of water in wells that penetrate the lake deposits but are not perforated in this material is not as affected by the water-level decline.

Water Quality and Water-Quality Trends

Analysis and interpretation of the water-quality graphs indicate that water quality in the valley has not changed appreciably in the past 25 years. The trend toward a slight increase in the concentration of dissolved solids in the ground water in some areas is not thus far a serious problem.

Graphs showing several constituents related to water quality were constructed for several wells with group 1 and group 2 type water because they are sources of public water supply. The graphs consist of plots of time versus dissolved-solids concentration, sodium plus potassium concentration, chloride concentration, and bicarbonate concentration. The graph of dissolved-solids concentration is a measure of the history of the general quality of ground water from the well. When all the major chemical constituents are determined in the analysis, the dissolved-solids concentration is reported as the sum of the dissolved solids (SDS). However, in some analyses reported in earlier studies, silica, a major constituent, was not determined. When any of the significant chemical constituents were not determined, then the dissolved-solids concentration was reported herein as the sum of the determined constituents (SDC). The graphs of the concentration of sodium plus potassium, chloride, and bicarbonate plus carbonate may be used as indicators of changes in the chemical character of the ground water. These graphs are useful indicators of minor changes in chemical character that are insufficient to cause a change in classification by group of ground water from the well.

As stated earlier, many of the chemical analyses are a composite of water pumped from different depth intervals where water of differing quality occurs. Group 3 water is normally a sodium chloride water. The graphs of the concentrations of sodium plus potassium and chloride are particularly good indicators of changes in the proportion of group 3 ground water in wells. Substantial increases in the graph of sodium plus potassium and chloride would indicate intrusion of group 3 water in the area.

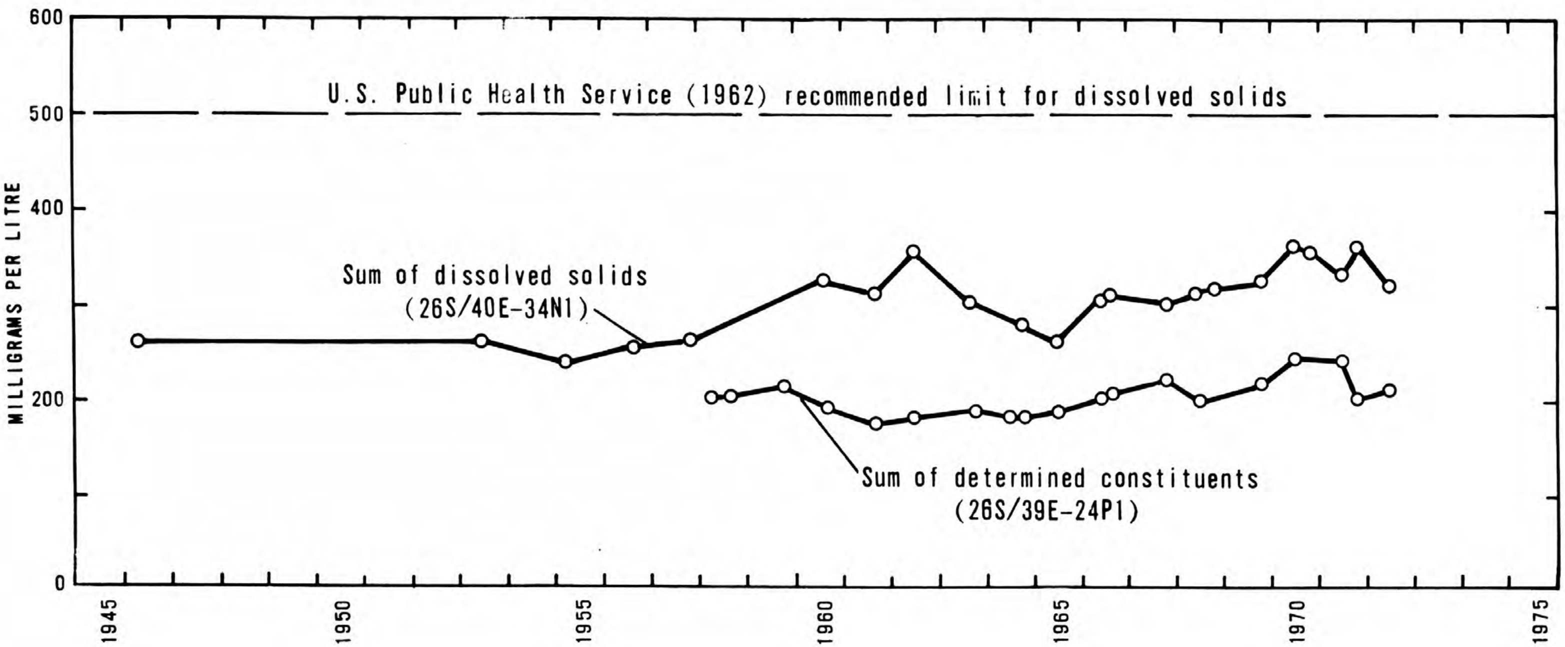


FIGURE 11.--Dissolved-solids concentration for wells 26S/39E-24P1 and 26S/40E-34N1.

The water quality in well 26S/39E-19P1 (fig. 12) is typical of wells in the pumping depression in the Inyokern area for the period 1952-72. The graph indicates that minor changes have occurred in dissolved-solids concentration and the concentrations of the individual constituents, but the general water quality has remained about the same.

The water quality in wells 26S/39E-24P1 and 24Q1 (fig. 13) is typical of wells in the pumping depression in the intermediate area for the period 1952-72. Between 1952 and 1960 there was no significant change in the concentration of dissolved solids. Since 1962 there has been a slight, somewhat erratic, trend toward a minor increase (about 50 mg/l) in the concentration of dissolved solids. There has been a corresponding increase in concentrations of calcium plus magnesium (not shown) and sulfate (not shown). The concentrations of all the other individual constituents have remained almost unchanged.

The water quality in wells 26S/40E-34N1 and 27S/40E-4L1 (figs. 14 and 15) is typical of wells in the pumping depression in the Ridgecrest area for 1946-72. Between 1946 and 1957, the dissolved-solids concentration remained relatively unchanged. Beginning in about 1958 the graphs indicate a trend toward a slight increase in dissolved-solids concentration. The increase in dissolved-solids concentration since then has been about 70 mg/l in well 34N1 and about 100 mg/l in well 4L1. There has been a corresponding increase in concentrations of chloride and sulfate (not shown) in both wells. These increases in chloride and sulfate concentrations are balanced by an increase in sodium plus potassium concentration in well 27S/40E-4L1 and balanced by an increase in calcium plus magnesium (not shown) and by a decrease in carbonate plus bicarbonate concentration in well 26S/40E-34N1. This trend is expected to continue as the pumping depression in the Ridgecrest area deepens and continues to enlarge, thus drawing a greater percentage of water from the lower part of the deep aquifer system.

The quality of ground water in the Inyokern, intermediate, and Ridgecrest areas is considered excellent for domestic use (U.S. Public Health Service, 1962). Ground water from wells in these areas is the major source of public water supply, and the concentrations of all the major constituents in the water are within the limits recommended by the U.S. Public Health Service (1962). However, the concentration of arsenic (30 μg/l [micrograms per litre]) in a sample taken in October 1971 from well 27S/40E-4L1 was greater than the recommended maximum concentration of 10 μg/l established by the U.S. Public Health Service (1962). A concentration of arsenic of more than 50 μg/l is grounds for rejection of a public water supply (U.S. Public Health Service, 1962).

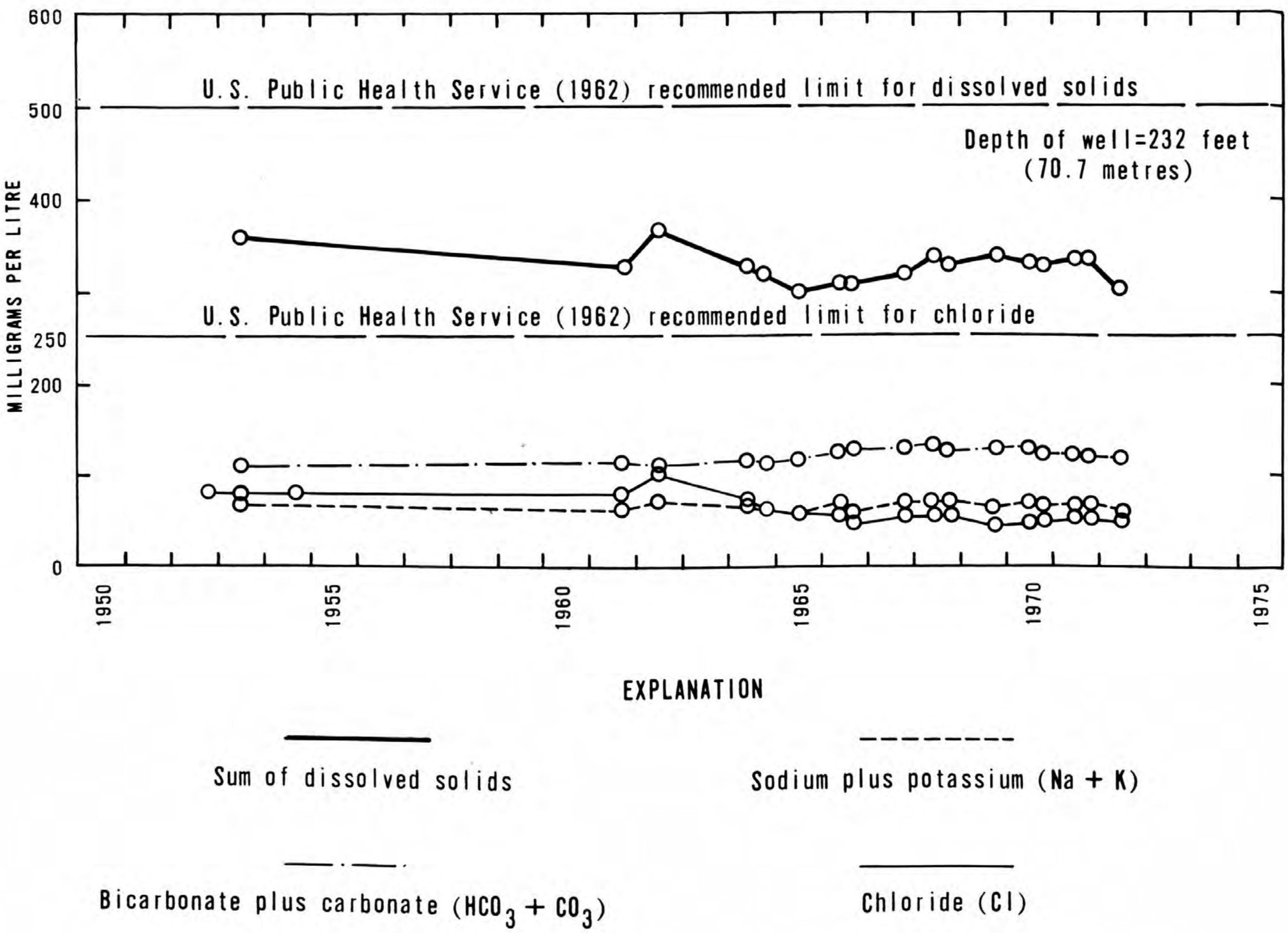


FIGURE 12.--Water quality of well 26S/39E-19P1, Inyokern area.

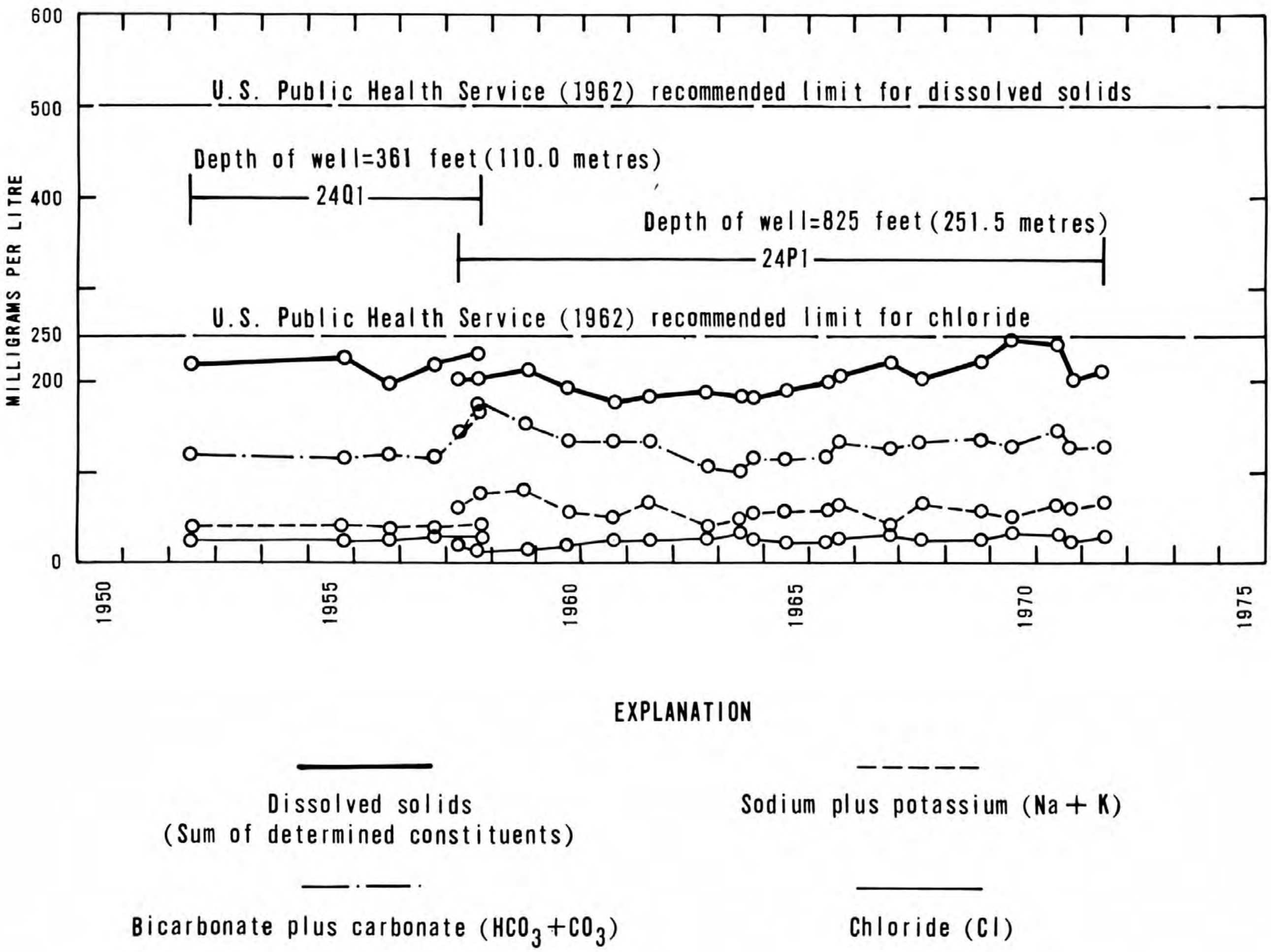


FIGURE 13.--Water quality of wells 26S/39E-24P1 and 24Q1, intermediate area.

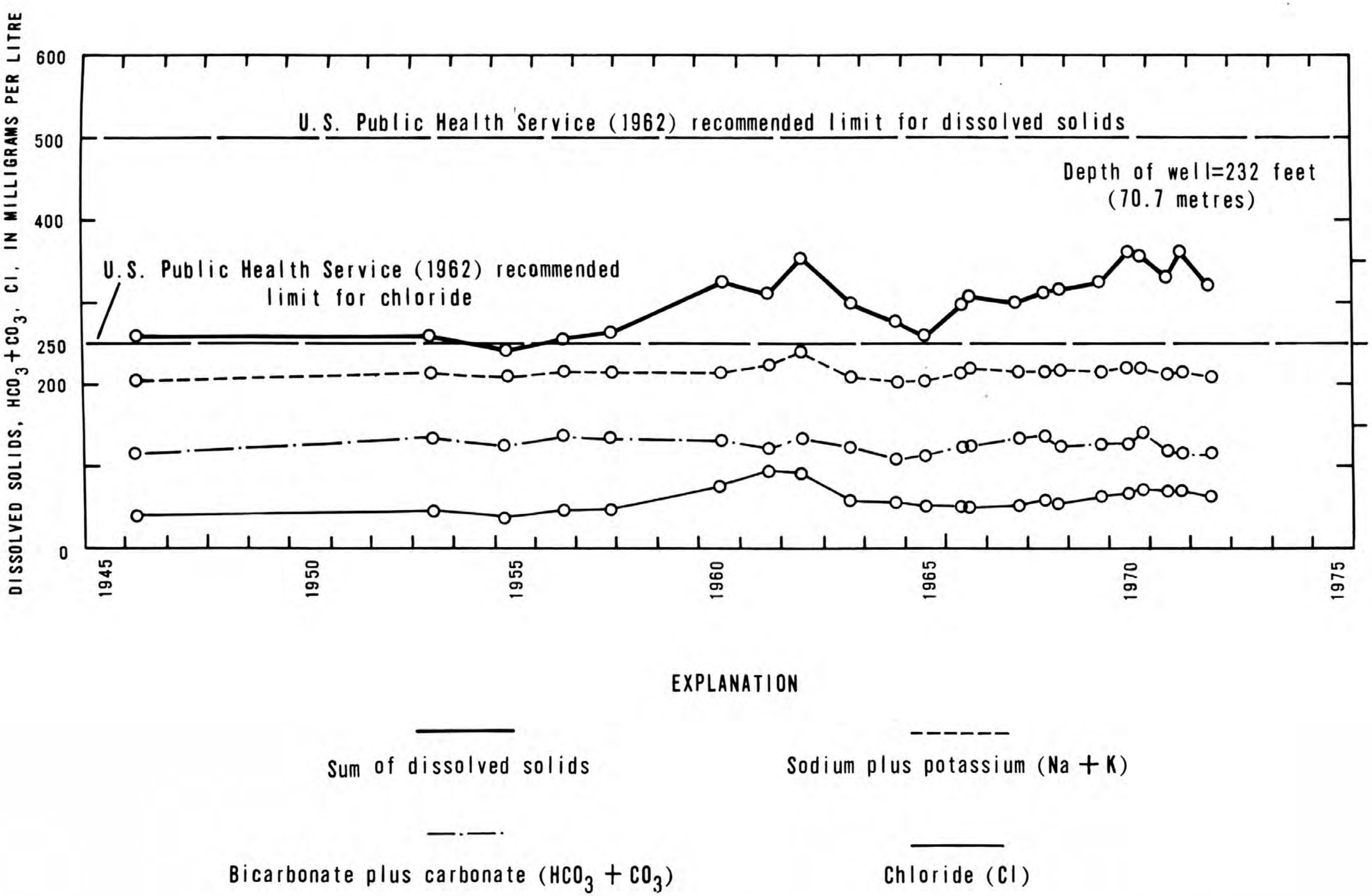


FIGURE 14.--Water quality of well 26S/40E-34N1, Ridgecrest area.

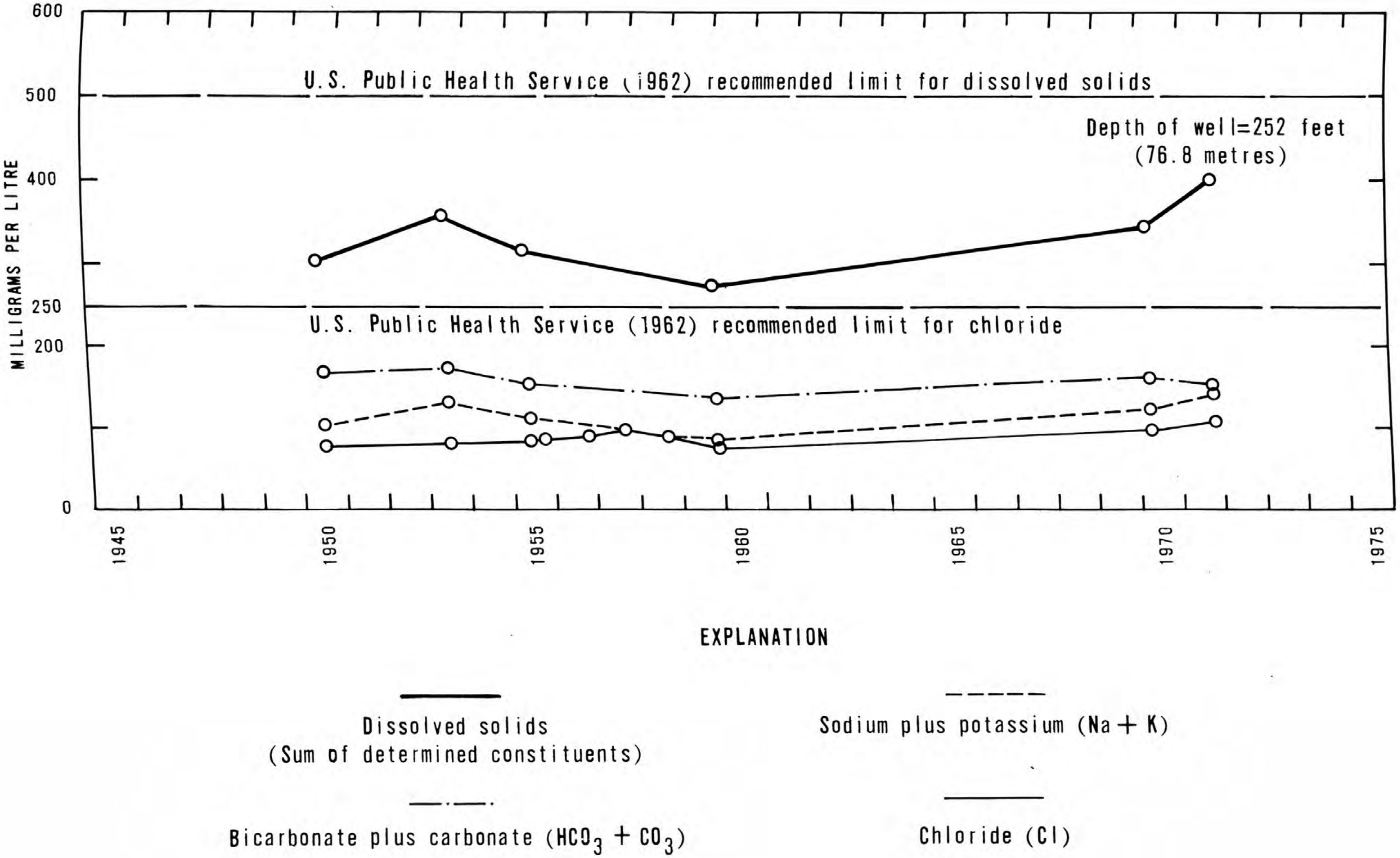


FIGURE 15.--Water quality of well 27S/40E-4L1, Ridgecrest area.

During the present study (1972) ground water from six wells was analyzed for arsenic (table 5). Well 26S/40E-29D1 is near the intermediate area, and well 26S/40E-28J1 is near the Ridgecrest area. Well 28J1 is used to supply the Ridgecrest Community Hospital. The concentration of arsenic in the ground water from neither well exceeded the recommended limit. However, water from the other four wells contained arsenic concentrations greater than the recommended limit of 10 μg/l, and for three wells the arsenic concentration was greater than the U.S. Public Health Service limit of 50 μg/l set for rejection of the water as a public supply. The ground water from three of the wells high in arsenic is pumped from the shallow aquifer. The fourth well, 26S/40E-22N1, is a deep well near the Naval Weapons Center main gate. These four wells are observation wells, and none of the water is used for drinking.

TABLE 5.--*Analyses of arsenic concentration in ground water*

Well number	Arsenic concentration (micrograms per litre)
26S/40E-22H2	290
22N1	130
22P2	50
28J1	2
29D1	4
27S/40E-2A1	20

The area of high concentration of arsenic in the ground water probably occurs mainly in the shallow aquifer and in the deep aquifer along the fringe of the shallow aquifer. Although data are sparse in much of the area, there is no indication that high concentrations of arsenic exist in any other parts of the valley. Nevertheless, water from all wells used for public supply in the valley could be analyzed for arsenic, particularly those in the Ridgecrest area. Limited data show that the concentrations of other minor chemical constituents in the ground water from wells near the Inyokern, intermediate, or Ridgecrest areas do not exceed the recommended U.S. Public Health Service (1962) limits.

The water-quality graphs of water from wells 25S/39E-4R1, 9J1, 12R1 and 12R2, and 26H1 (figs. 16 through 19) are considered typical of wells in the northwestern part of the valley for the period 1952-72. Ground water in this area is predominantly group 1 water. The general quality here is not as good as that in the Inyokern, intermediate, and Ridgecrest areas. The graphs of wells 25S/39E-4R1 (fig. 16) and 9J1 (fig. 17) suggest an erratic trend toward a decrease in the concentration of dissolved solids. The decrease was as much as 150 mg/l for well 4R1 and about 80 mg/l for well 9J1. This decrease seems to be accounted for by corresponding decreases in concentrations of carbonate plus bicarbonate, calcium plus magnesium (not shown), and silica (not shown). The concentrations of all the other constituents have remained almost unchanged.

Wells 25S/39E-12R1, 12R2 (fig. 18), and 25S/39E-26H1 (fig. 19) are along the western fringe of the group 3 water. The concentration of dissolved solids in ground water from wells 12R1 and 12R2 remained relatively unchanged during the period of record. The trend toward a slight decrease in the concentration of bicarbonate plus carbonate seems to have been paralleled by a trend toward a slight increase in concentrations of sulfate (not shown). The concentration of all other constituents have for the most part remained almost unchanged.

Ground water from well 25S/39E-26H1 (fig. 19) has fluctuated between chemical groups 2 and 3 during the period of record. The concentration of dissolved solids in ground water from this well has fluctuated greatly, and the concentrations of the individual constituents show correspondingly similar fluctuation. This well reportedly is perforated in the lake deposits, and these sporadic but significant changes in water quality are probably due to variation in the length of pumping time prior to sampling. The longer the pumping duration the greater the quantity of ground water that is drawn from the lake deposits and the greater the concentration of dissolved solids in the water. Although the concentration of dissolved solids in ground water in the northwestern part of the valley exceeds the limit of 500 mg/l recommended by the U.S. Public Health Service (1962), the ground water in the area is locally considered satisfactory for most public uses.

Water from well 25S/39E-26H1 (fig. 19) seems to be of questionable quality for normal continuous drinking purposes. Some of the past analyses indicate that water from the well exceeded the U.S. Public Health Service (1962) limits for manganese of 0.05 mg/l and for copper of 1.0 mg/l. The concentration of fluoride in well 25S/39E-26H1 in 1972 was 2.6 mg/l, which is more than three times the optimum concentration set by the U.S. Public Health Service.

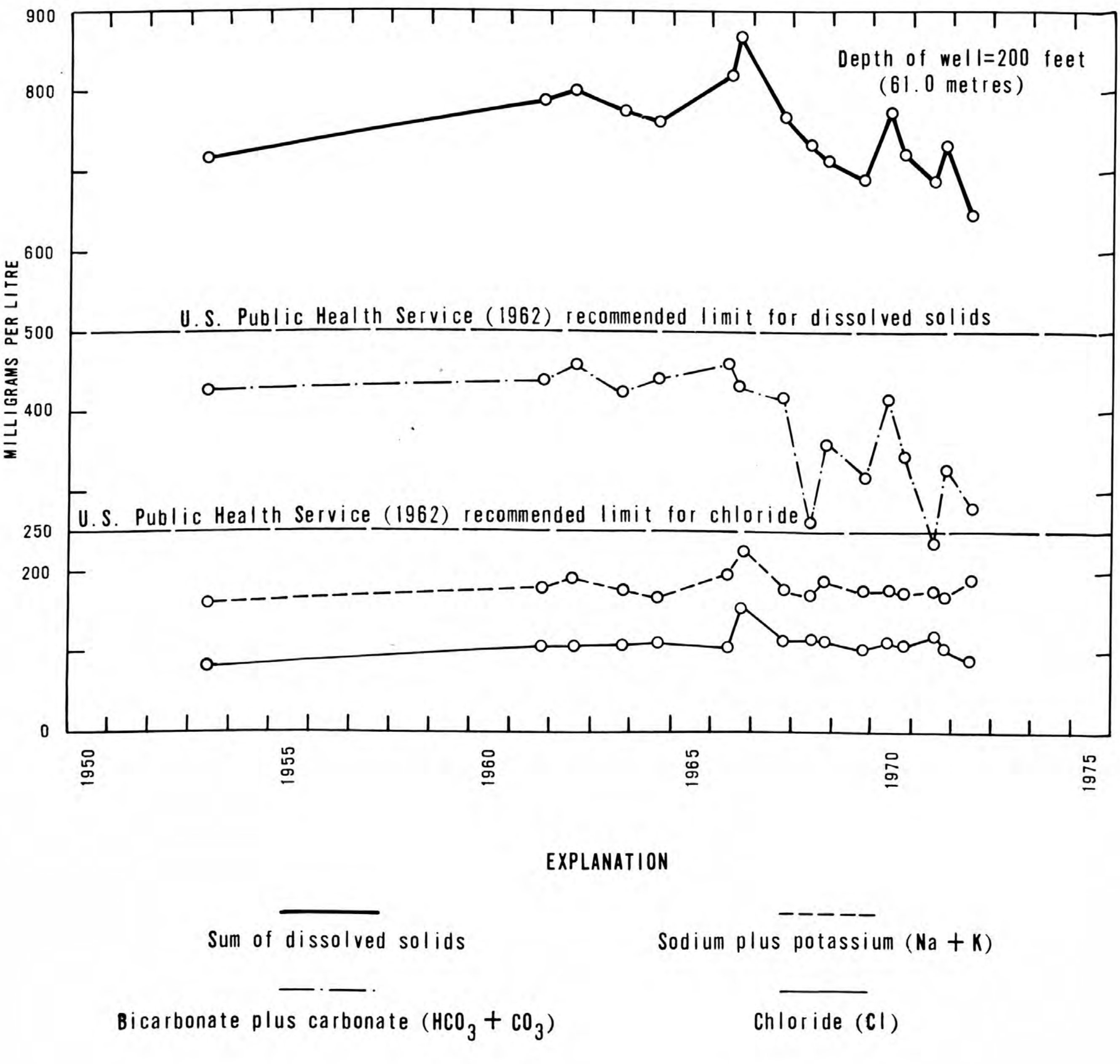


FIGURE 16.--Water quality of well 25S/39E-4R1.

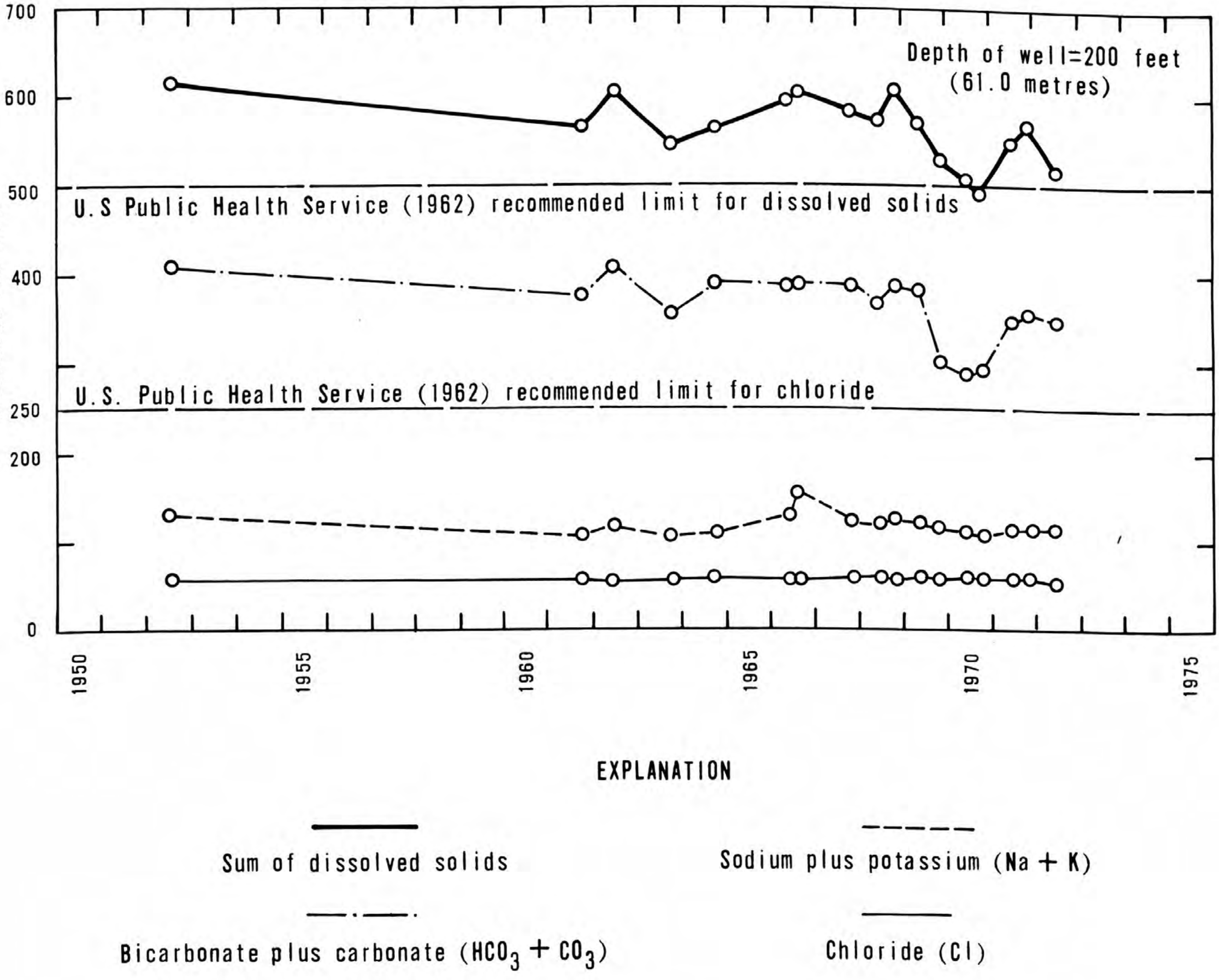


FIGURE 17.--Water quality of well 25S/39E-9J1.

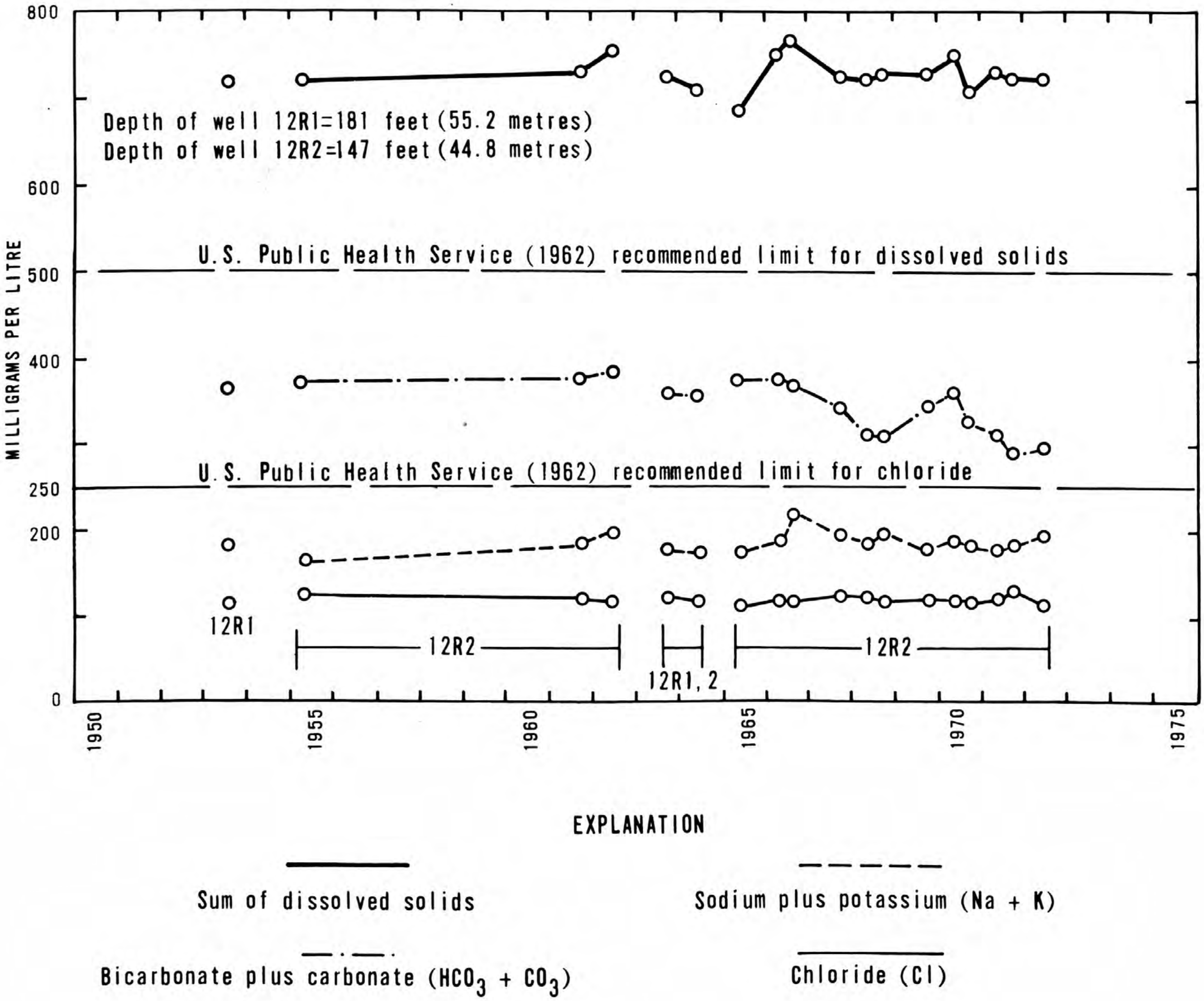


FIGURE 18.--Water quality of wells 25S/39E-12R1 and 12R2.

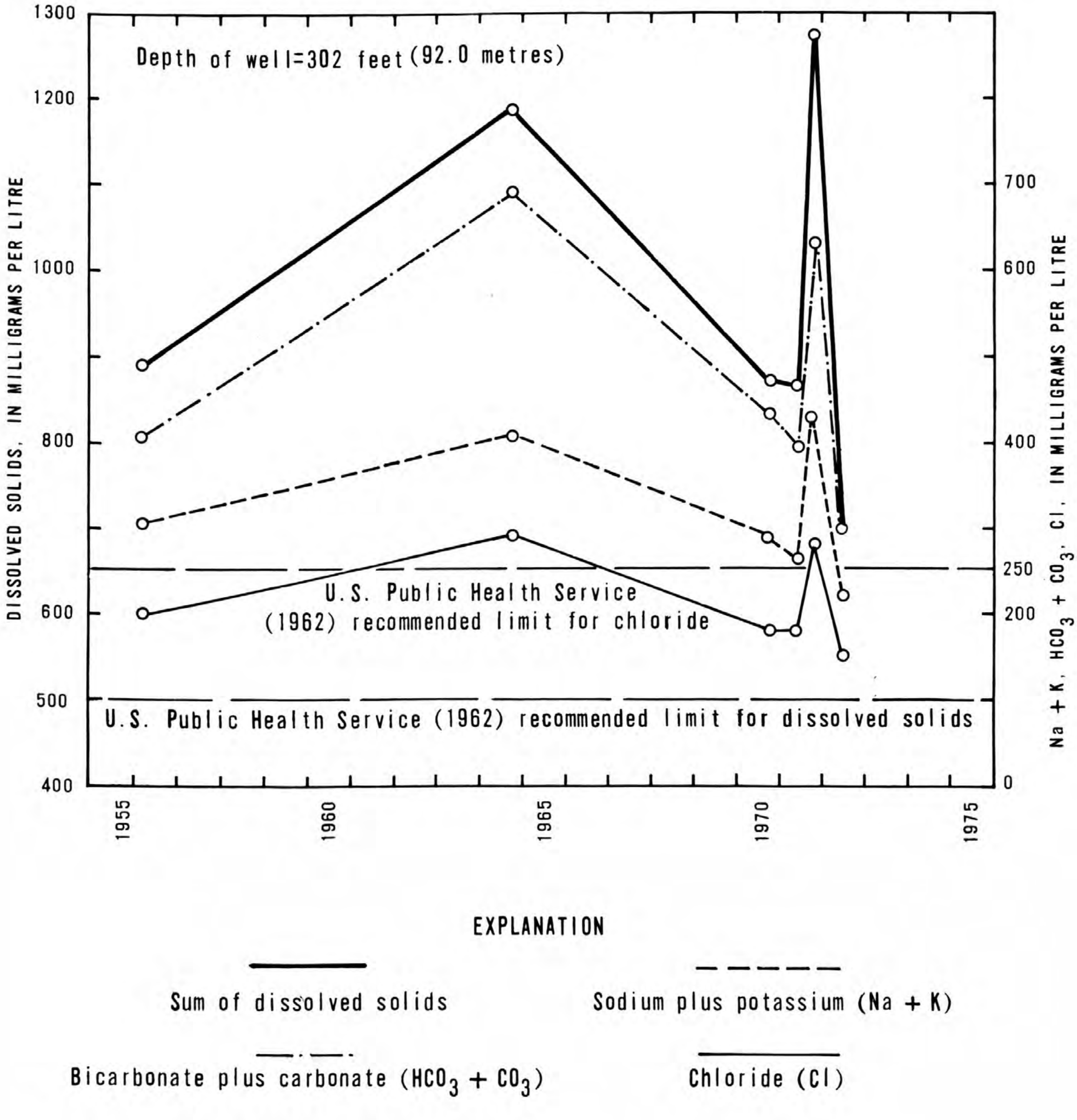


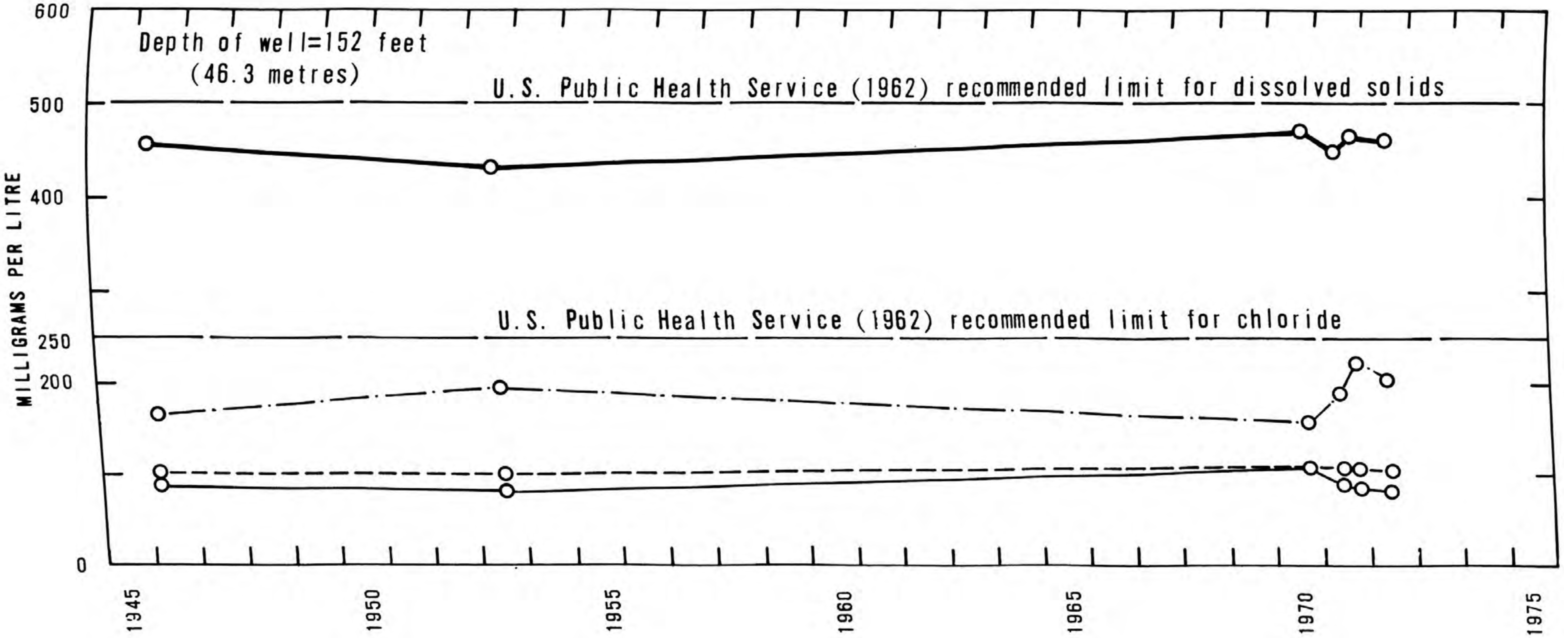
FIGURE 19.--Water quality of well 25S/39E-26H1.

Graphs of the history of water quality in wells 25S/39E-35N1, 26S/39E-5F1, 26S/39E-11E1, and 26S/40E-5P1 (figs. 20 through 23) are typical of wells in the northern half of the central part of the valley for 1946-72. The ground water in this area is predominantly group 1 water. The area is of considerable interest because it is a potential area for future Navy supply wells as pumping depressions in the Inyokern, intermediate, and Ridgecrest areas increase in size. The quality of the ground water here is generally better than that in the northwestern part of the valley and is satisfactory for most public uses. It is not quite as good as that in the pumping centers in the Inyokern, intermediate, and Ridgecrest areas. The concentrations of dissolved solids in the water from wells 26S/39E-5F1 and 26S/40E-5P1 exceeded the recommended limit of 500 mg/l (U.S. Public Health Service, 1962) but were below this limit in wells 25S/39E-35N1 and 26S/39E-11E1.

The graphs of water quality in wells 25S/39E-35N1 (fig. 20) and 26S/39E-5F1 (fig. 21) indicate that the concentration of dissolved solids in the water has not changed significantly. Fluctuations of concentrations of some of the individual constituents have occurred, but for the most part individual constituent concentrations have remained almost unchanged. None of the minor constituents exceeds the limits recommended by the U.S. Public Health Service (1962).

The graphs of wells 26S/39E-11E1 (fig. 22) and 26S/40E-5P1 (fig. 23) indicate a trend toward an increase in the concentration of dissolved solids in the ground water. Between 1946 and 1965 the dissolved-solids concentration remained relatively unchanged. Since about 1965, the dissolved-solids concentration has increased about 80 mg/l in the area. The trend toward an increase in the concentration of dissolved solids is paralleled by similar trends toward an increase in the concentration of all the individual constituents. Well 26S/40E-5P1 is along the southern fringe of the area of group 3 water. The historical increase in the concentration of dissolved solids in water from this well may be the result of intrusion of group 3 water into the area by leakage from the shallow aquifer, which may account for the erratic fluctuations in dissolved-solids concentration in this well.

The composite water-quality graph for wells 27S/40E-10A1, 10A7, and 10H1 (fig. 24) is typical for wells with group 2 water in the southeastern part of the central part of the valley. The area is nearly encircled by group 3 water. The ground water in this area is locally considered suitable for public use. The history of water quality seems to trend toward a slight increase in the concentration of dissolved solids.



EXPLANATION

Sum of dissolved solids

Sodium plus potassium (Na + K)

Bicarbonate plus carbonate ($HCO_3 + CO_3$)

Chloride (Cl)

FIGURE 20.--Water quality of well 25S/39E-35N1.

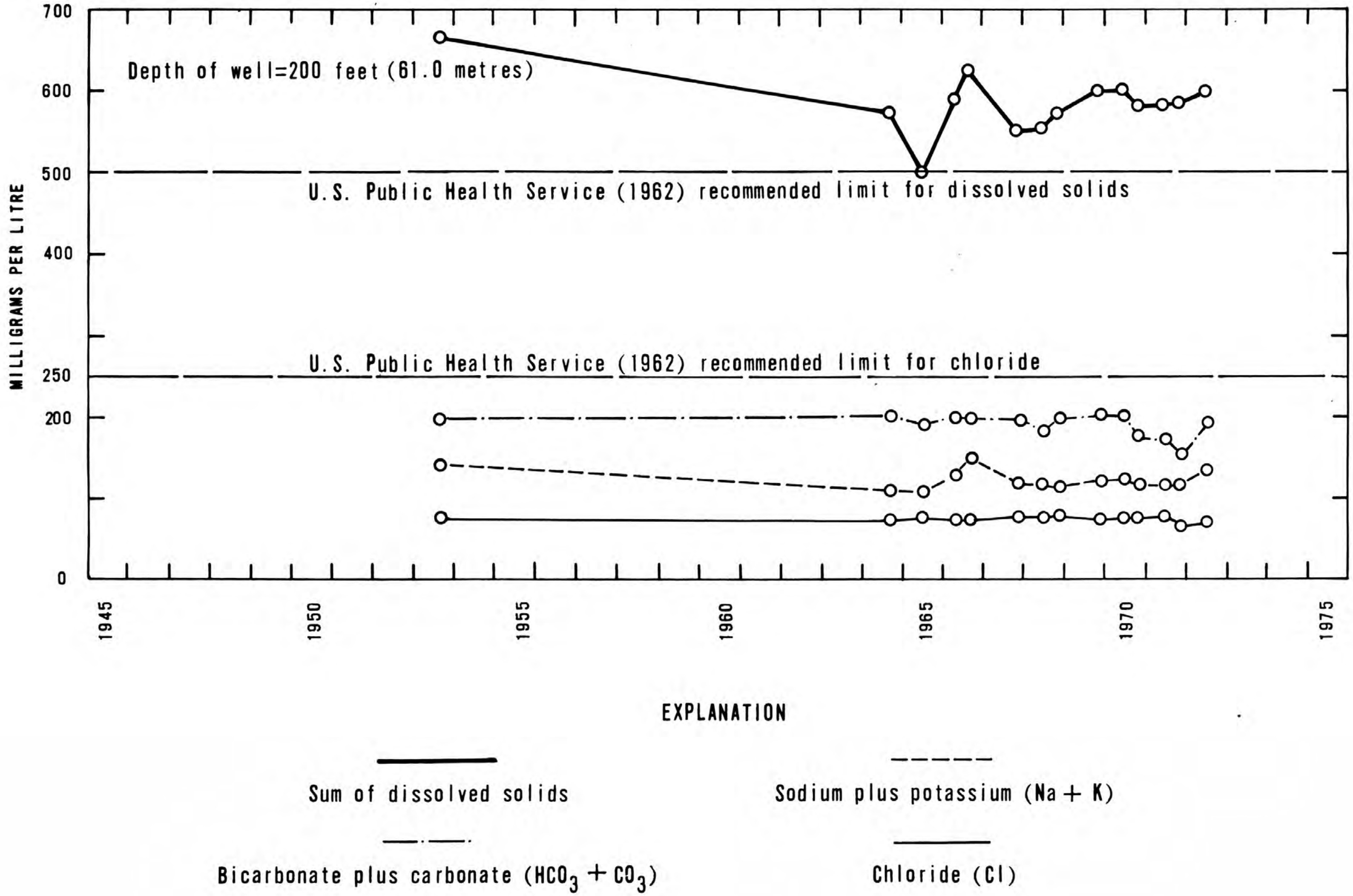


FIGURE 21.--Water quality of well 26S/39E-5F1.

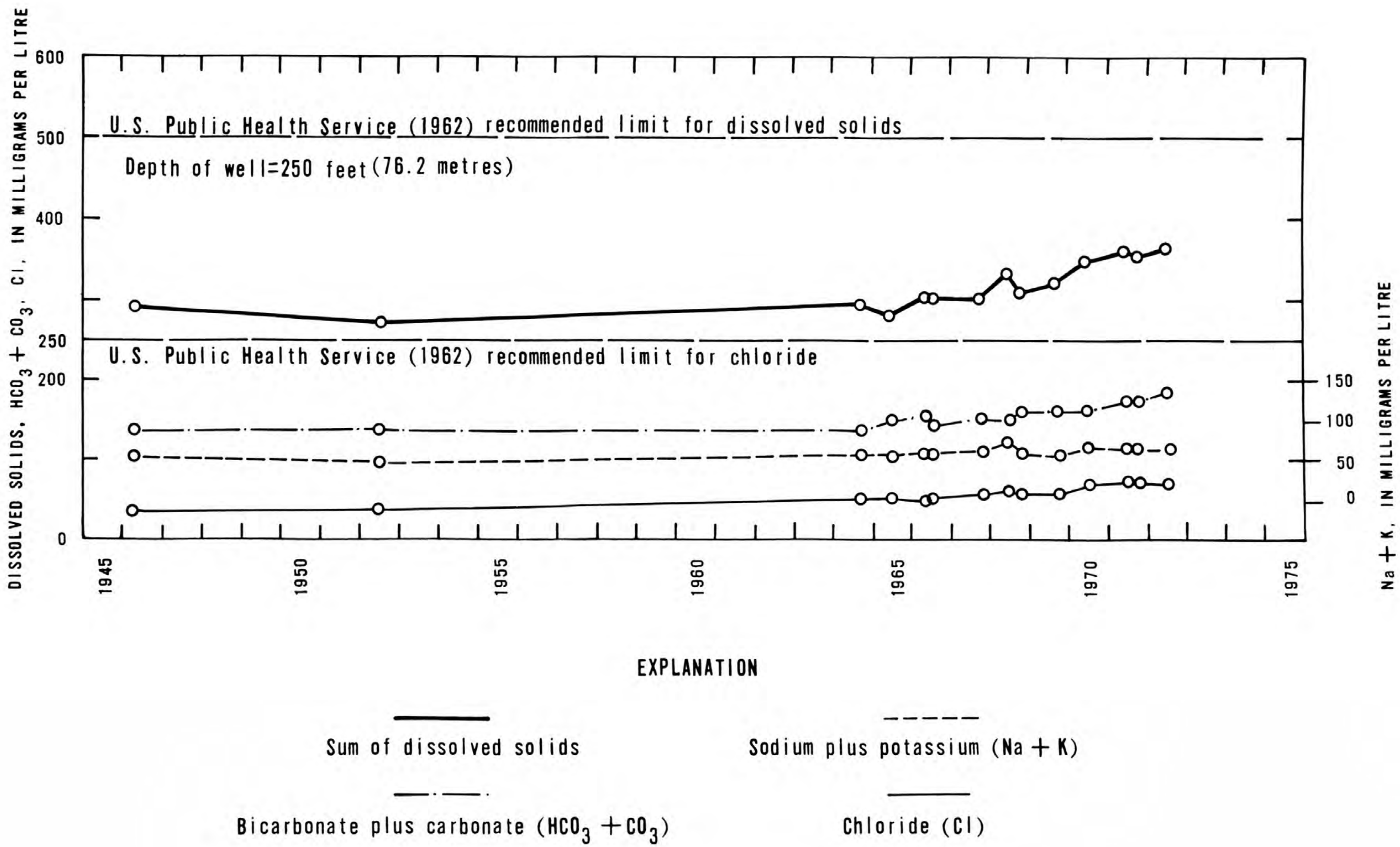


FIGURE 22.--Water quality of well 26S/39E-11E1.

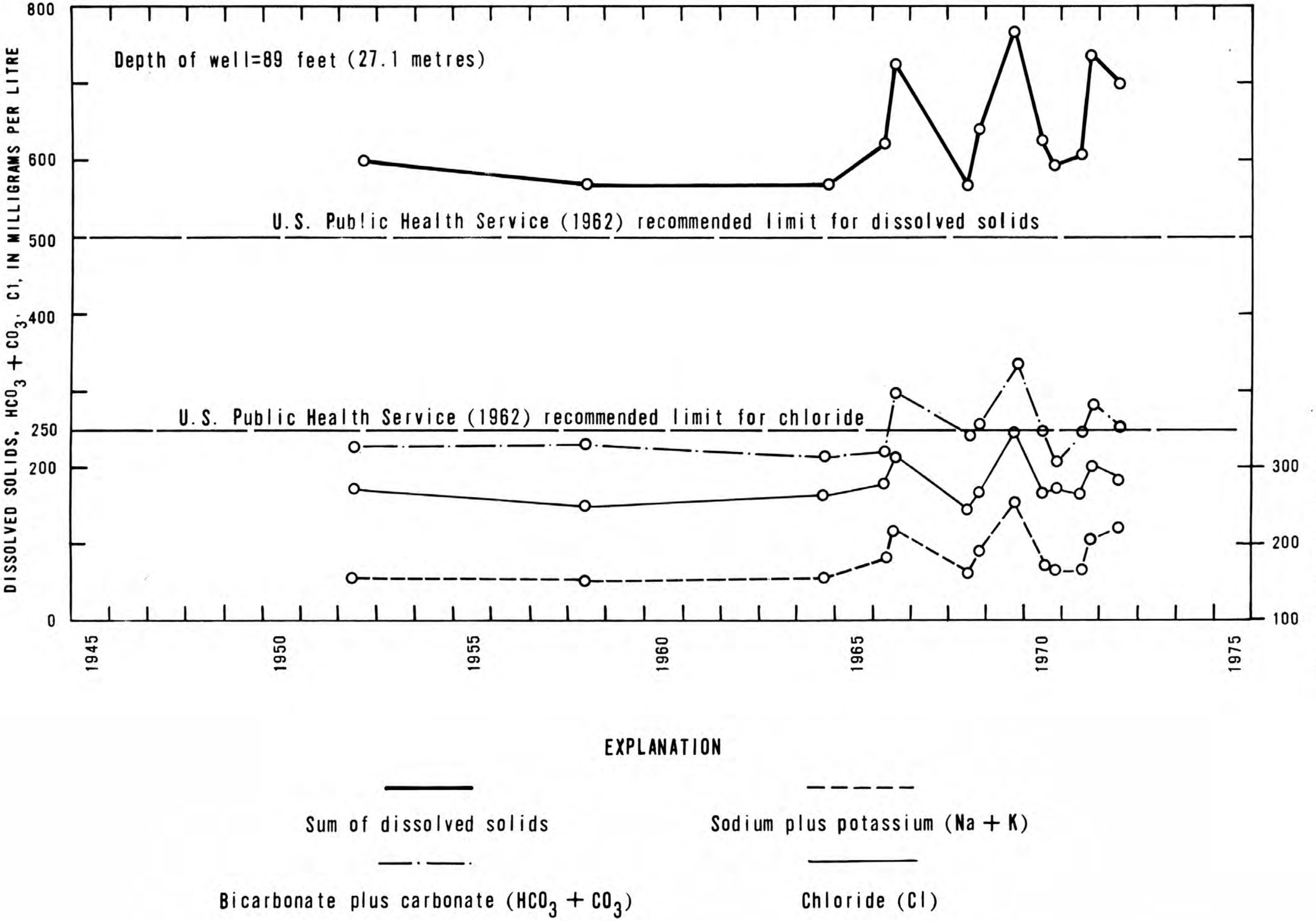


FIGURE 23.--Water quality of well 26S/40E-5P1.

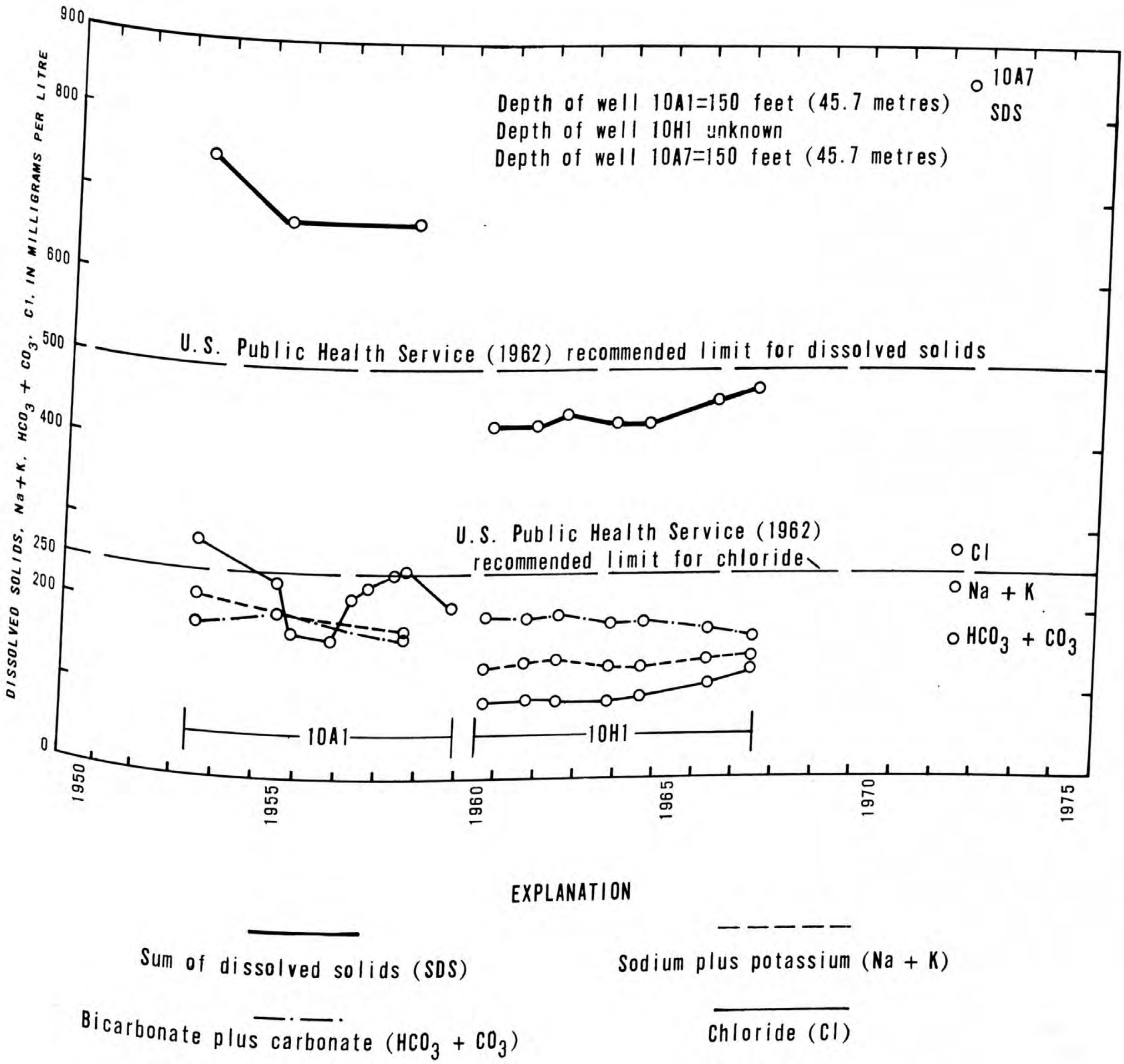


FIGURE 24.--Water quality of wells 27S/40E-10A1, 10A7, and 10H1.

Pollution Effects of Sewage Ponds

The recharge calculations indicate that recharge to the Navy ground-water system from the Navy sewage ponds, the Navy golf course, and the Ridgecrest Sanitation District sewage ponds is small. However, this limited recharge may be heavily laden with material that will degrade or pollute the local ground water. The native ground water in the shallow aquifer near the U.S. Navy sewage ponds and the Navy golf course is of historically poor quality and, using ordinary chemical analyses, it is difficult to differentiate from sewage effluent.

In addition to nitrate (NO_3), nitrogen in water generally takes the form of ammonia (NH_3, NH_4), organic nitrogen (protein and amino acids) or nitrite (NO_2). These forms of nitrogen can be oxidized to nitrate to give the high values normally associated with ground water affected by sewage effluent. Ordinary inorganic chemical analyses only include analysis for nitrite and nitrate. Analysis for total nitrogen was beyond the scope of this study. High concentrations of nitrate normally associated with sewage effluent are not present in wells in the area. East of the sewage ponds and the golf course an area of high nitrate concentration does exist (table 3). However, there are no indications that this high nitrate concentration was caused by recharged sewage effluent. Indications are that the recharged effluent follows the natural pattern of ground-water flow northward toward the China Lake playa and that none of the effluent flows southward toward the pumping depressions in the intermediate and Ridgecrest areas. The U.S. Navy sewage ponds and the Navy golf course are not considered to be a significant source of pollution to the ground water.

Near the U.S. Navy sewage ponds and the Navy golf course, multiple test wells were augered at two sites to various depths to obtain data about the vertical stratification of the water quality within the upper 100 ft (30 m) of the shallow aquifer. The sewage effluent was suspected to occur in distinct zones within the shallow aquifer. Indications are that the sewage effluent stays mainly within the top 20 ft (6 m) of the saturated part of the aquifer, although the degree of vertical stratification of the water quality is uncertain. At one site the quality of the ground water in the upper and lower intervals is better than that in the middle interval, whereas at the other site this was not found to be true.

An area of high concentration of nitrate also exists near the Ridgecrest Sanitation District sewage ponds. Ground water from well 27S/40E-2G1 (depth, 131 ft or 40 m), in the center of an alfalfa pasture irrigated with treated sewage effluent, has a nitrate concentration of 53 mg/l, which exceeds the limit of 45 mg/l recommended by the U.S. Public Health Service (1962). The area of high concentrations of nitrate exists only to the west, south, and east of the sewage ponds. Thus it seems that the recharged sewage effluent has not migrated toward the Ridgecrest area because the area of high nitrate concentration does not extend to the north or northwest of the sewage ponds. Available data indicate that the sewage effluent is present only in the shallow aquifer and does not affect the deep aquifer. Well 27S/40E-2F1 (depth, 130 ft or 40 m) is perforated in the deep aquifer just below the confining clay zone, and an analysis of water from this well indicates that no ground-water pollution to the deep aquifer from sewage effluent has occurred at this time. Therefore, as of 1972 the Ridgecrest Sanitation District sewage ponds are not a significant source of ground-water pollution.

Recharged sewage effluent from the Ridgecrest Sanitation District sewage ponds could be monitored. Continued growth of the city of Ridgecrest should result in an increase in the quantity of waste water recharged. In time, along with the increasingly large pumping depression in the Ridgecrest area, this could cause sewage effluent in the shallow aquifer to migrate to the Ridgecrest area, which is only 2 mi (3.2 km) west of the Ridgecrest Sanitation District sewage ponds, and degrade this source of public water supply.

FUTURE INVESTIGATIONS

The sampling program to monitor water quality in Indian Wells Valley could be expanded. Presently, only the Navy supply wells are sampled on a routine basis for chemical analysis. Thus, the program provides information about changes in water quality that have already occurred in the supply wells and does not allow sufficient lead time for detection and study of water-quality problems so that preventive measures can be developed. Several wells in the eastern half of the valley, along the fringe of the poor-quality group 3 water, if added to the sampling program would form a more continuous monitoring system of the poor-quality water. The water-quality monitoring could include analysis for total nitrogen.

A digital model of ground-water quality in Indian Wells Valley would be a useful tool in predicting future patterns of water quality. Such models have been successfully developed for modeling conservative constituents--for example, dissolved solids and chloride. In Indian Wells Valley the concentrations of both dissolved solids and chloride are good indicators of group 3 water. A digital ground-water quality model is similar in nature to and is dependent upon a hydrologic ground-water model. A verified hydrologic model is used to predict water-level conditions and flow patterns. In Indian Wells Valley, Bloyd and Robson (1971) completed a verified hydrologic model. On the basis of these tests, the ground-water quality model can be used to predict conditions of ground-water quality. Prediction of the flow pattern of the poor-quality ground water in Indian Wells Valley would be an important requirement for long-term basin management decisions to safeguard the sources of usable ground water.

CONCLUSIONS

The quality of ground water in the Inyokern, intermediate, and Ridgecrest areas is considered excellent for public use. There is no indication that the increasingly larger pumping depressions in these three areas have significantly changed the natural flow pattern toward the China Lake playa of the poor-quality water in the shallow aquifer or that the flow pattern of the poor-quality water is toward these pumping depressions.

The Ridgecrest Sanitation District sewage ponds and the U.S. Navy sewage ponds and golf course are not contributing significant quantities of sewage effluent to the ground-water system as of 1972. Recharge to the ground-water system of sewage effluent from the U.S. Navy sewage ponds and Navy golf course has not reversed the natural ground-water flow toward the China Lake playa in the shallow aquifer across the China Lake barrier as previously suspected. The digital model indicated that the fault was a very effective barrier to ground-water movement in the deep aquifer. However, the fault is not an effective barrier to ground-water movement in the shallow aquifer near the land surface. Therefore, it is important to maintain the natural northeast direction of underflow of poor-quality ground water across the fault in the shallow aquifer. Reversal of natural ground-water flow in the shallow aquifer across the fault would result in the native poor-quality water of the shallow aquifer migrating toward the Inyokern, intermediate, and Ridgecrest areas and degrading this source of public water supply.

The recharge of sewage effluent from the Ridgecrest Sanitation District sewage ponds has not significantly changed the local ground-water flow pattern. There is no indication that sewage effluent from the Ridgecrest Sanitation District sewage ponds is migrating toward the well fields. However, because the Ridgecrest Sanitation District sewage ponds are only about 2 mi (3.2 km) from the Ridgecrest well field, the direction and rate of movement of the recharged sewage effluent could be monitored.

The quality of ground water deteriorates with depth in the central part of the valley. As water levels in wells in the pumping depression continue to decline, a greater proportion of the water pumped from these wells will come from the deeper part of the aquifer, causing a trend toward a slight increase in dissolved-solids concentrations in the ground water pumped from these wells.

Chemical analyses of ground water from wells were grouped into three general categories. Ground water in group 1 has a variable ion composition and is the best quality water in the valley. Dissolved-solids concentration of group 1 water is normally less than 600 mg/l. Ground water in group 2 is a sodium bicarbonate water of generally good quality, and has a dissolved-solids concentration normally less than 600 mg/l. Ground water in group 3 is a sodium chloride water, is generally of very poor quality, and is unfit for most uses. The areal extent of group 1 water includes most of the central and western part of the valley. The areal extent of group 3 water includes most of the northeastern part of the valley and the fringe of the basin to the east, southeast, and south. Group 2 water is generally sandwiched between group 1 water and group 3 water and presumably occurs at depth in the central part of the valley. The areal extent of the water groups has not significantly changed in the past 25 years. More importantly, the areal extent of group 3 ground water has not increased. Water-quality graphs indicate either no change or a trend toward a slight increase in dissolved-solids concentration in the ground water, but where this has occurred, it is not serious.

SELECTED REFERENCES

American Public Health Association, 1971, Standard methods for the examination of water and wastewater [13th ed.]: 874 p.

Bailey, Paul, 1946, Report on the water supply of Indian Wells Valley, Kern County, California, to the Lands Division, Department of Justice: U.S. v. 529, 533 acres of land in the counties of Inyo, Kern, San Bernardino, etc., et al., no. 3472-H civil.

Banta, R. L., 1972, Ground-water conditions during 1971 in Indian Wells Valley, California: U.S. Geol. Survey open-file rept., 9 p.

Blaney, H. F., and Criddle, W. D., 1949, Consumptive use of water in the irrigated areas of upper Colorado River basin: U.S. Dept. Agriculture, Soil Conserv. Service, Div. Irrig. and Water Conserv., 59 p.

Bloyd, R. M., Jr., and Robson, S. G., 1971, Mathematical ground-water model of Indian Wells Valley, California: U.S. Geol. Survey open-file rept., 36 p.

Brown, Eugene, Skougstad, M. W., and Fishman, M. J., 1970, Methods for collection and analysis of water samples for dissolved minerals and gases: U.S. Geol. Survey Techniques Water-Resources Inv. book 5, chap. A1, 160 p.

Dutcher, L. C., and Moyle, W. R., Jr., 1973, Geologic and hydrologic features of Indian Wells Valley, California: U.S. Geol. Survey Water-Supply Paper 2007, 30 p.

Hem, J. D., 1970, Study and interpretation of the chemical characteristics of natural water [2d ed.]: U.S. Geol. Survey Water-Supply Paper 1473, 363 p.

Koehler, J. H., 1971, Ground-water conditions during 1970 in Indian Wells Valley, California: U.S. Geol. Survey open-file rept., 19 p.

Kunkel, Fred, and Chase, G. H., 1969, Geology and ground water in Indian Wells Valley, California: U.S. Geol. Survey open-file rept., 84 p.

Lee, C. H., 1913, Ground-water resources of Indian Wells Valley, California: California State Conserv. Comm. rept., 429 p.

Lohman, S. W., 1972, Ground-water hydraulics: U.S. Geol. Survey Prof. Paper 708, 70 p.

McKee, J. E., and Wolf, H. W., eds., 1963, Water quality criteria: California Water Resources Control Board, Pub. no. 3-A, 548 p.

Moyle, W. R., Jr., 1963, Data on water wells in Indian Wells Valley area, Inyo, Kern, and San Bernardino Counties, California: California Dept. Water Resources Bull. 91-9, 243 p.

Rainwater, F. H., and Thatcher, L. L., 1960, Methods for collection and analysis of water samples: U.S. Geol. Survey Water-Supply Paper 1454, 301 p.

Thompson, D. G., 1929, The Mohave Desert region, California: U.S. Geol. Survey Water-Supply Paper 478, 759 p.

U.S. Public Health Service, 1962, Drinking water standards 1962: Pub. 956, 61 p.

Whistler, J. T., 1923, Report on Indian Wells Valley and Fremont Valley, California: California Div. Water Rights rept., 83 p.

Wilcox, L. V., Hatcher, J. T., and Blair, G. Y., 1951, Quality of water in Indian Wells Valley, California: U.S. Dept. Agriculture, Salinity Lab. research rept. 54, 92 p.

Zbur, R. T., 1963, A geophysical investigation of Indian Wells Valley, California: U.S. Naval Ordnance Test Sta., China Lake, Calif., NOTS Tech. Pub. 2795, 98 p.

☆ U.S. GOVERNMENT PRINTING OFFICE: 1975-0-689-910/88