A STUDY OF DEEP AQUIFERS UNDERLYING COASTAL ORANGE COUNTY CALIFORNIA

OPEN–FILE REPORT

U.S. DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
Water Resources Division
Menlo Park, California, 1969

PREPARED IN COOPERATION WITH THE
ORANGE COUNTY WATER DISTRICT

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
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By

Joe A. Moreland and John A. Singer

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By Joe A. Moreland and John A. Singer

ABSTRACT

Deep untapped aquifers of late Pliocene age, which contain water having 1,000 to 2,000 milligrams per liter of dissolved solids, underlie most of the coastal part of Orange County. Inland from the Newport-Inglewood structural zone, the depth to the base of aquifers containing fresh water ranges from 1,000 to 2,500 feet below mean sea level.

The aquifers are composed of fine to medium sand with locally occurring beds of coarse sand and gravel. Permeability generally ranges from less than 50 gallons per day per square foot to 300 gallons per day per square foot.

Pressure head increases with depth of the aquifer to as much as 40 feet above land surface near the base of fresh water. The water is of the sodium bicarbonate type, increasing in salinity with depth. Organic material imparts an amber color to the water, which becomes more distinct with depth.

A test well, drilled to 926 feet and perforated from 784 to 884 feet, yielded 1,950 gallons per minute with about 90 feet of drawdown. The water is of the sodium bicarbonate type with dissolved solids of 225 mg/1.

Additional studies are needed to evaluate the possibilities of subsidence due to pumping from the deep aquifers, to determine the vertical and horizontal permeabilities of confining beds, and to monitor the changes in water quality and water level.

INTRODUCTION

Purpose of the Investigation

The deep aquifers in the coastal part of Orange County are the sands containing fresh to slightly saline water in the upper member of the Fernando Formation, here of late Pliocene age. Those aquifers are not presently used as sources of water, but are becoming more important as a potential source as the needs of the county continue to grow. They are primarily important as sources of supply for maintaining hydraulic barriers to sea-water intrusion, but are also important as potential direct sources of usable water.

Because the quantity and quality of the available water must be known to evaluate the feasibility of pumping, the purpose of this investigation was to determine the areal and vertical extent of the sands containing usable water, the permeability and yield characteristics of the aquifers, and the quality of the water.

Scope of the Report

This report presents the data obtained from the analysis of electrical logs of oil wells, tests in an abandoned oil well, and tests in a deep well drilled during the investigation, and presents the conclusions and suggestions resulting from the study.

The study was restricted to the coastal part of Orange County extending from Bolsa Chica Mesa to Newport Mesa and from the Pacific Ocean inland approximately 6 miles (figs. 1 and 2).

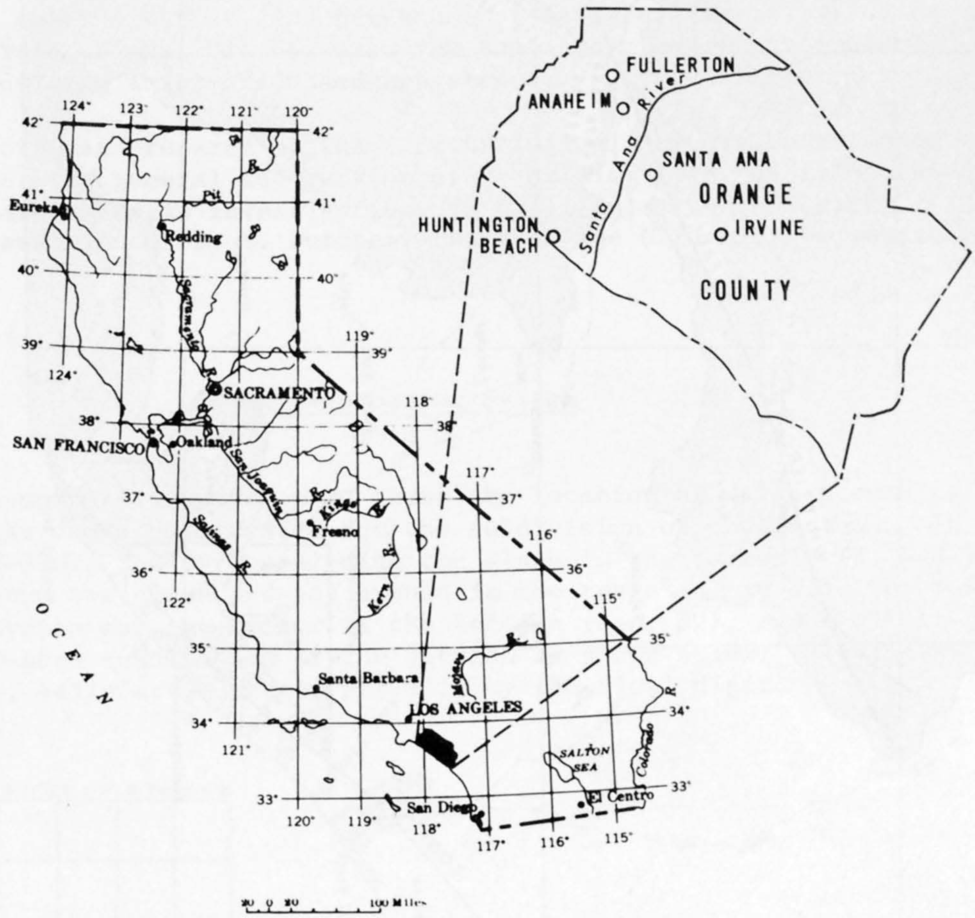


FIGURE 1.--Location of Orange County.

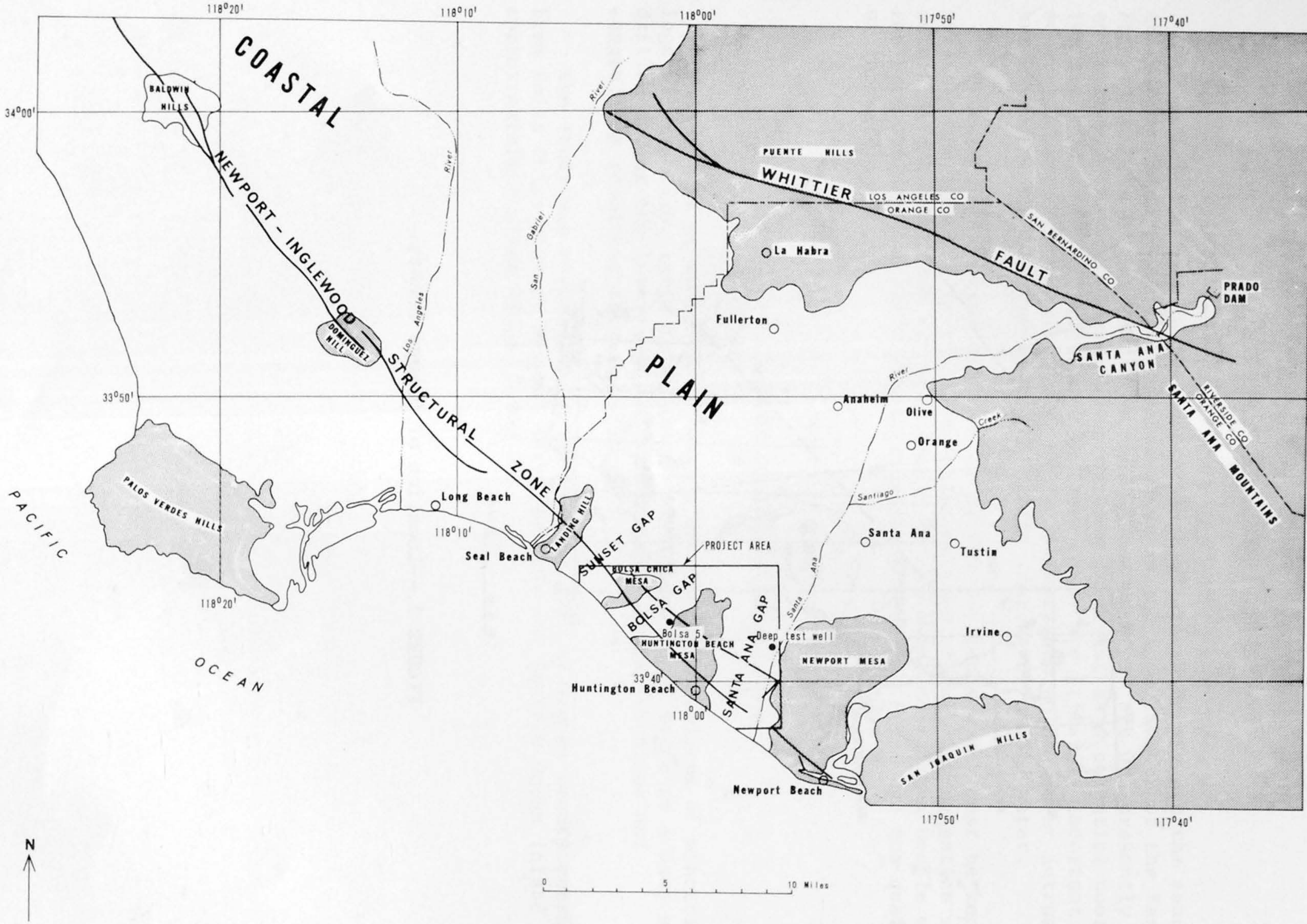


FIGURE 2.--Major physiographic and structural features of the coastal plain of southern California.

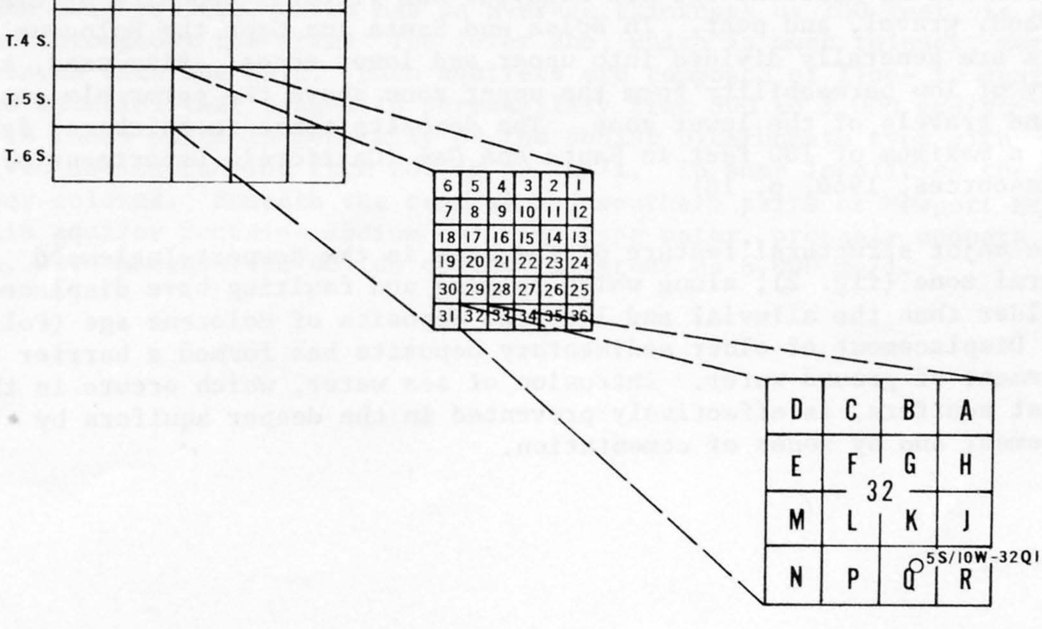
Acknowledgments

The authors acknowledge the cooperation of many landowners and public and private agencies in Orange County. Mr. J. B. Fairchild, geologist, Orange County Water District, and personnel of Marshburn Farms, Standard Oil Co. of California, Signal Oil Co., and the Bolsa Corp. were particularly helpful in providing information and assistance.

This report was prepared by the U.S. Geological Survey, Water Resources Division, under the general supervision of R. Stanley Lord, district chief in charge of water-resources investigations in California, and under the immediate supervision of L. C. Dutcher, chief of the Garden Grove subdistrict office.

Well-Numbering System

The well-numbering system used shows the location of wells according to the rectangular coordinate system for the subdivision of public land. In the number 5S/10W-32Q1, the part preceding the slash is the township (T. 5 S.), the part between the slash and the hyphen is the range (R. 10 W.), the number between the hyphen and the letter is the section (sec. 32), and the letter (Q) is the 40-acre subdivision of the section as shown below. Within the 40-acre tract, wells are numbered serially by the final digit.



GENERAL GEOLOGY OF THE AREA

The study area, which is part of the coastal plain of southern California, is underlain by a structural depression that has been the site of almost continuous subsidence and deposition since Late Cretaceous time (Yerkes and others, 1965, p. A1). Igneous and metamorphic basement rocks are overlain, in the deepest part of the basin, by about 30,000 feet of chiefly marine sediments ranging in age from Cretaceous to Holocene (Recent).

The lowest sedimentary rocks overlying the basement consist of about 10,000 feet of chiefly sandstone and conglomerate of Cretaceous to early Miocene age. Those rocks, in turn, are overlain by several thousand feet of middle and upper Miocene rocks assigned to the Topanga and Puente Formations (Yerkes and others, 1965). The rocks are known from deep wells in oil fields near Huntington Beach.

Rocks of Miocene age are overlain by approximately 2,000 feet of marine siltstone, sandstone, and conglomerate of the lower member of the Fernando Formation (Repetto Formation of former usage; Durham and Yerkes, 1964, p. B24 and B25), here of early Pliocene age. The rocks are overlain by 3,000 to 4,000 feet of semiconsolidated marine and nonmarine gravel, sand, silt, and clay of the upper member of the Fernando Formation, of late Pliocene age, locally called the Pico Formation (Durham and Yerkes, 1964, p. B24 and B25).

Pleistocene deposits ranging in thickness from 200 to 1,000 feet, are divided into the San Pedro Formation of early Pleistocene age, unnamed upper Pleistocene deposits, and the Palos Verdes Sand of late Pleistocene age (Poland, Piper, and others, 1956, p. 52). In Santa Ana Gap the entire upper Pleistocene section, which ranges in thickness from zero to 400 feet, has been identified by the California Department of Water Resources (1961) as the Lakewood Formation.

Sediments of Holocene age are alluvial and littoral deposits of clay, silt, sand, gravel, and peat. In Bolsa and Santa Ana Gaps the Holocene deposits are generally divided into upper and lower zones. Fine sand, silt, and clay of low permeability form the upper zone above the permeable coarse sands and gravels of the lower zone. The deposits range in thickness from zero to a maximum of 180 feet in Santa Ana Gap (California Department of Water Resources, 1966, p. 18).

The major structural feature of the area is the Newport-Inglewood structural zone (fig. 2), along which folding and faulting have displaced all rocks older than the alluvial and littoral deposits of Holocene age (Poland, 1959). Displacement of older sedimentary deposits has formed a barrier to the movement of ground water. Intrusion of sea water, which occurs in the uppermost aquifers, is effectively prevented in the deeper aquifers by displacement and by zones of cementation.

GENERAL HYDROLOGY OF THE AREA

The ground-water reservoir of the study area consists of all the permeable deposits that overlie the virtually impermeable igneous and metamorphic basement rocks. The ground water in the reservoir consists of a deep salt-water body, which is overlain by a thick body of fresh water occurring in several identifiable aquifer units. The base of the fresh-water body is the contact above which the estimated dissolved-solids content of the water is less than 1,500 mg/l (milligrams per liter; milligrams per liter is equivalent to parts per million in concentrations less than 7,000), and below which the estimated dissolved-solids content of the water is greater than 1,500 mg/l. For the purposes of this study only the fresh-water body is considered in detail.

In the study area the California Department of Water Resources (1966, p. 25) identified nine fresh-water aquifer units above the salt-water body: The Pico of late Pliocene age; the Main, lower Rho, upper Rho, and Omicron of early Pleistocene age; the Lambda, Beta, and Alpha of late Pleistocene age; and the Talbert of Holocene age. In Bolsa Gap, the Bolsa aquifer or 80-foot gravel is equivalent to the Talbert (table 1). In this report the Talbert includes the Bolsa or 80-foot gravel aquifers, unless specified.

The Pico aquifer, which underlies the entire area from Bolsa Chica Mesa to Newport Mesa, ranges in thickness from about 1,200 feet at Huntington Beach Mesa to less than 1 foot at Newport Mesa. The permeable zones in the aquifer are generally of fine to medium sand with permeability ranging from 200 to 300 gpd/ft^2 (gallons per day per square foot). Fresh water of the sodium bicarbonate type in the upper part of the Pico aquifer becomes increasingly saline with depth. The color of water in samples derived solely from the Pico is light to dark amber. The primary concern of this report is the hydrology of the Pico aquifer system.

The Main aquifer, which has an average thickness of 100 feet, is also present throughout the area. The lower Rho, which is much thinner, merges in some places with the Main. Both aquifers are composed of fine- to coarse-grained material that ranges in permeability from 300 to 1,000 gpd/ft^2. The water in those units is generally of the sodium bicarbonate type with dissolved solids ranging from 200 to 400 mg/l. In some localities the water is amber colored. Beneath the central and southern parts of Newport Mesa, the Main aquifer contains sodium chloride type water, probably connate in origin, with a dissolved-solids content as great as 6,000 mg/l.

TABLE 1.--*Fresh-water aquifer units in the study area*

Geologic age	Aquifer unit	Permeability gpd/ft^2	Aquifer system designation used in this report
Holocene	Talbert (Bolsa)	[1] 1,900-2,500	Upper
Late Pleistocene	Alpha Beta Lambda	[1] 500-2,200	Upper
Early Pleistocene	Omicron Upper Rho Lower Rho Main (zone E,[2] Bolsa 5)	[1] 300-1,200	Middle
Late Pliocene	Pico { Aquifer tested in 5S/10W-32K Zone D,[2] Bolsa 5 Zone C,[2] Bolsa 5 Zone B,[2] Bolsa 5 Zone A,[2] Bolsa 5	[3] 50-300	Lower "deep"

[1]California Department of Water Resources, 1966.
[2]Individual aquifer zones tested in this study.
[3]Estimates by U.S. Geological Survey.

The upper Rho aquifer, generally less than 20 feet thick, is unimportant as a source of water. The Omicron aquifer, which, in some places, is as much as 75 feet in thickness, is an important source of water. The permeability of the Omicron ranges from 600 to 1,200 gpd/ft^2, and the water is similar in quality to that of the underlying lower Rho and Main aquifers. Seaward from the Newport-Inglewood structural zone, the unit is saturated with poor-quality sodium chloride water.

The upper Pleistocene aquifers--Lambda, Beta, and Alpha--are composed of fine to coarse sand and locally of coarse gravel. The aquifers are subject to intrusion of sea water from the overlying Talbert aquifer where the units are in hydraulic continuity. The aggregate thickness of the three aquifers is as much as 200 feet, and permeability ranges from 500 to 2,200 gpd/ft^2. Sodium bicarbonate water at the base of the upper Pleistocene sequence gradually changes to a calcium bicarbonate water in the uppermost part of the system. The chloride ion is dominant in those parts of the system that have been intruded by sea water or infiltrated by oil-field brine.

The Talbert aquifer is an important source of water in the study area. The medium- to coarse-grained sediments with extensive gravel deposits have a range in permeability of 1,900 to 2,500 gpd/ft^2. The Talbert aquifer has an average thickness of 70 feet in Santa Ana Gap; in Bolsa Gap, the gravels range from 5 to 40 feet in thickness (California Department of Water Resources, 1967b, p. 24).

Because there has been little, if any, displacement of the Holocene sediments across the Newport-Inglewood structural zone, and because of extensive ground-water extraction, the Holocene aquifers have been grossly intruded by sea water. The native water is of the calcium bicarbonate type, changing to the sodium bicarbonate type where recharge from the underlying upper Pleistocene aquifers has occurred. In the areas intruded by sea water, salinity generally increases with depth, indicating a definite wedge. Saline water from the disposal of oil-field brine on Huntington Beach Mesa has also degraded the water in the Holocene aquifers. There are some indications of degradation from the upwelling of saline water from the underlying aquifers (California Department of Water Resources, 1966, p. 66).

HYDROLOGY OF THE DEEP AQUIFERS

Test Wells

Because of the high cost of drilling test wells to the depths of the deep aquifers, an abandoned oil well was selected for part of this study--Bolsa 5, drilled by the Standard Oil Co. of California in 1932 (fig. 3). That well is on the eastern edge of Bolsa Gap, in the 40-acre subdivision 5S/11W-34M, on land leased from the Bolsa Corp.

As a part of this investigation acoustic-velocity and neutron logs were made on Bolsa 5 to determine the location of casing collars, the location and extent of cement around the casing, and the location of permeable zones. On the basis of the logs and an electrical log of nearby Bolsa 45, five zones were selected for testing (fig. 3).

The well was bailed to affirm the watertightness of the casing before perforations were made. Zone A was perforated with shaped charges, zone B with bullets, and zones C, D, and E with a Mills knife. After perforation of each zone, the well was allowed to flow or was bailed until the electrical conductivity indicated that a representative sample could be obtained. A water sample was then collected with a bailer for chemical analysis, and the static water level was measured.

At the conclusion of testing in each zone, the perforated interval was covered with sand or gravel, a cement plug was installed to seal off the zone, and the casing was tested for watertightness.

After all zones were tested, the well was cleaned to a depth of 1,050 feet, and three piezometer tubes were installed opposite zones C, D, and E. Cement plugs were installed between the three zones, and each piezometer tube was pumped to insure hydraulic continuity with the zones tapped. The five tested zones are described in table 2.

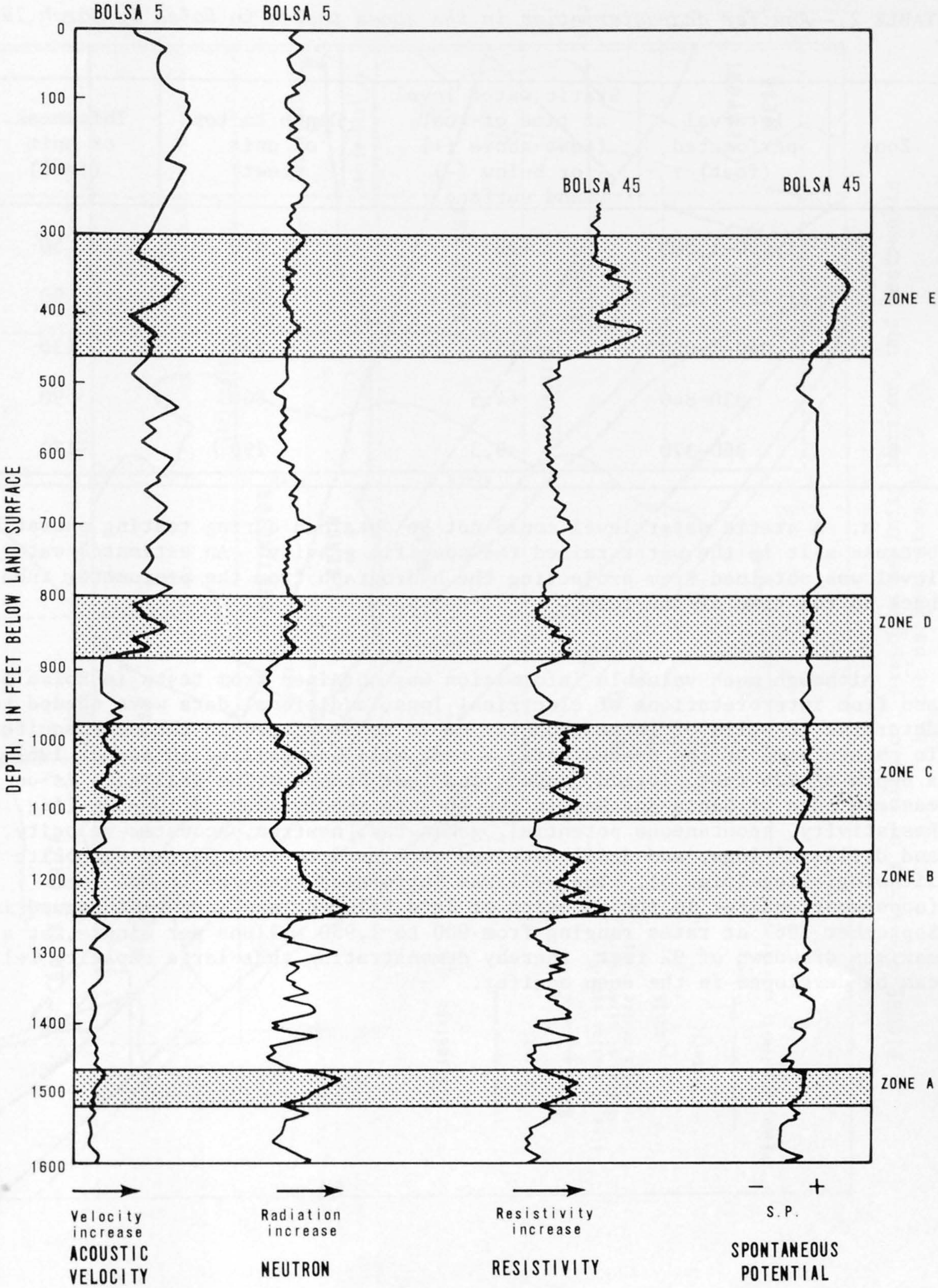


FIGURE 3.--Geophysical logs from Bolsa 5 and Bolsa 45 showing zone designation of the intervals tested.

TABLE 2.--*Aquifer characteristics in the zones tested in Bolsa 5, March 1967*

Zone	Interval perforated (feet)	Static water level at time of test (feet above (+) or below (-) land surface)	Depth to top of unit (feet)	Thickness of unit (feet)
A	1,490-1,500	+23	1,470	50
B	1,225-1,235	+41.5	1,160	90
C	1,040-1,050	a∿+15	980	130
D	830-840	+4.5	800	90
E	360-370	-9.3	290	170

a. A static water level could not be obtained during testing operations because silt in the water raised the specific gravity. An estimated water level was obtained from projecting the hydrograph from the piezometer tube back to the time of the test.

Although much valuable information was obtained from tests in Bolsa 5 and from interpretations of electrical logs, additional data were needed to determine if wells of large capacity could be developed in the deep aquifers. To obtain some of the needed data, a test well was drilled in August 1967 to a depth of 926 feet, logged, cased, and test pumped. The well site is on the eastern edge of Santa Ana Gap in the 40-acre subdivision 5S/10W-32K (fig. 4). Resistivity, spontaneous potential, gamma ray, neutron, acoustic-velocity, and drillers' logs, and drill cuttings were used to construct a composite lithologic log (fig. 5). The well was perforated from 784 to 884 feet (uppermost aquifer in the deposits of late Pliocene age) and test pumped in September 1967 at rates ranging from 900 to 1,950 gallons per minute, at a maximum drawdown of 92 feet, thereby demonstrating that large capacity wells can be developed in the deep aquifer.

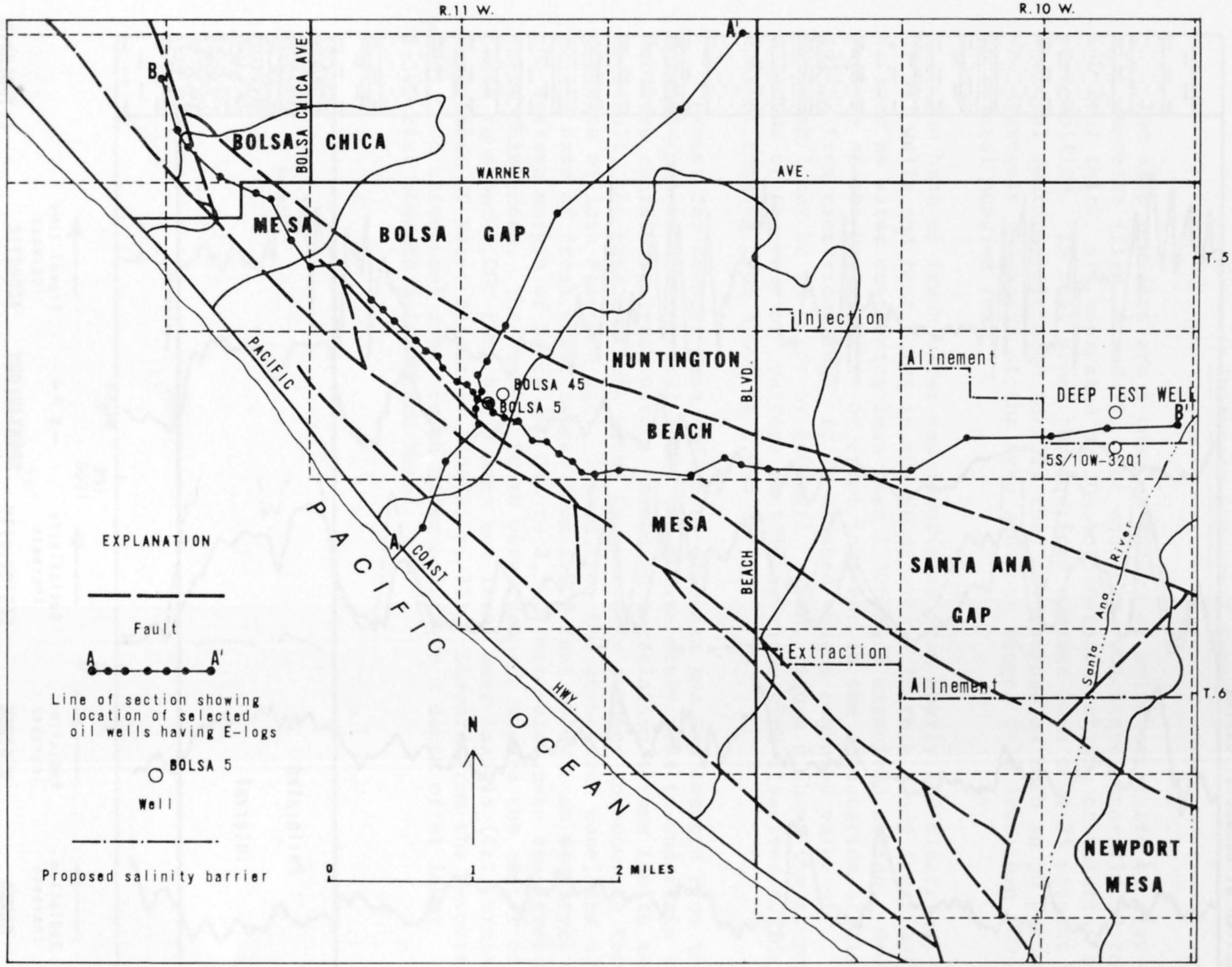


FIGURE 4.--Lines of section, proposed salinity barrier, and test wells in the project area.

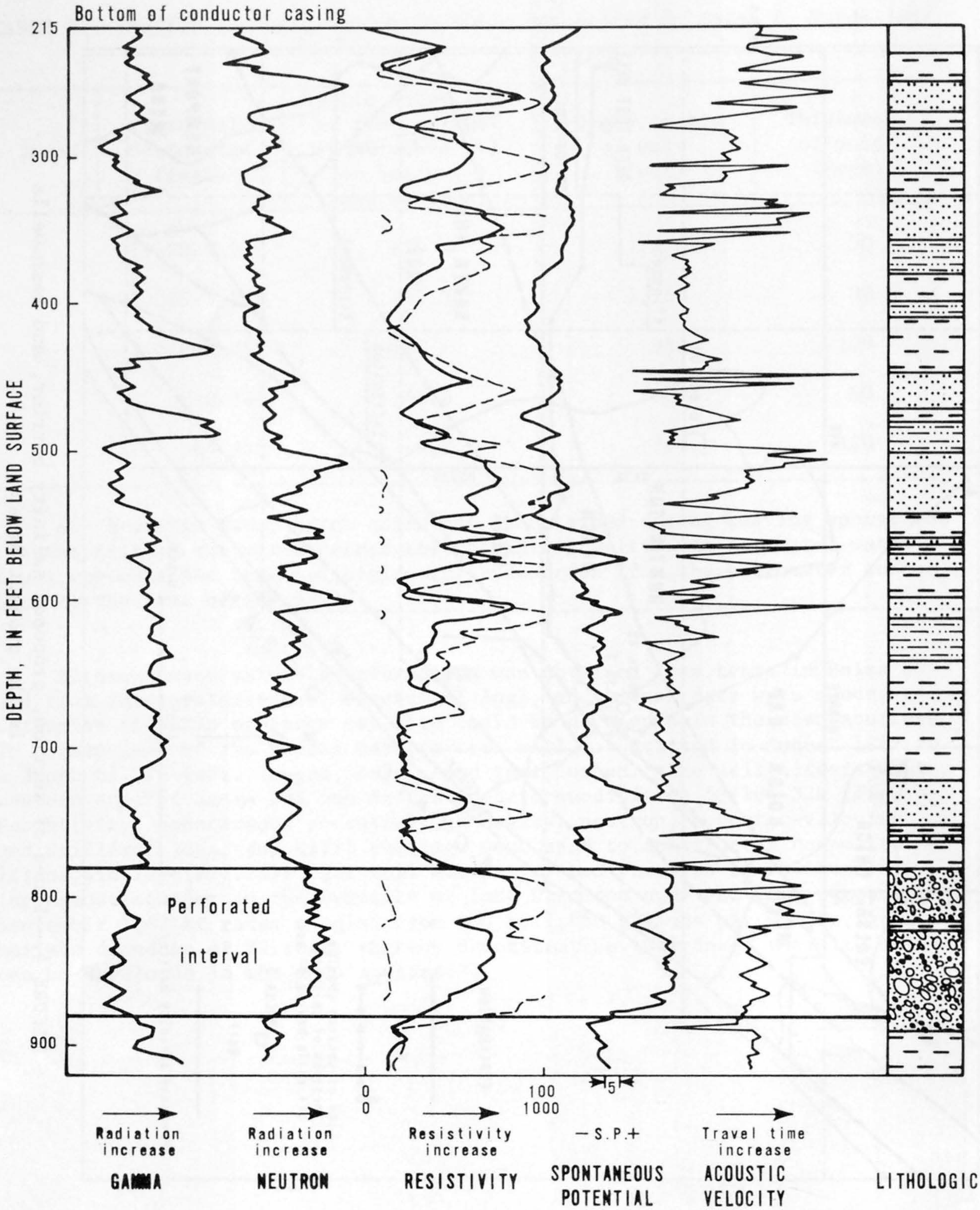


FIGURE 5.--Geophysical logs and composite lithologic log of the deep test well.

Thickness and Areal Extent

The deep aquifers are a complex system of units separated by clay and silt deposits (figs. 6 and 7). The aquifers, which are generally 50 to 100 feet thick, are separated by 50- to 500-foot sections of material of low permeability. In most areas the aquifers compose less than 25 percent of the vertical section, although locally they may compose as much as 50 percent. The aggregate thickness of the deep aquifers ranges from less than 100 feet to several hundred feet.

The base of fresh water was identified from nearly 400 electrical logs of oil wells and test holes in the study area. In this study fresh water is defined as water containing less than 1,500 mg/l dissolved solids. However, because of the many sources of error inherent in the computation of dissolved solids from electrical logs, it is assumed that a computed value of 1,500 mg/l may be in error by 500 mg/l. Thus, figure 8 shows the approximate altitude of the base of aquifers containing water with dissolved-solids content ranging from 1,000 to 2,000 mg/l.

Except for Newport Mesa and parts of Santa Ana Gap seaward from the Newport-Inglewood structural zone, the entire study area is underlain by deep aquifers containing fresh water. Although correlation across faults is difficult, the base of fresh water is generally assumed to occur in the deposits of late Pliocene age. Inland from the structural zone, the altitude of the base of fresh water ranges from 1,000 feet below mean sea level along the eastern margin of Santa Ana Gap to 2,500 feet below mean sea level at Bolsa Chica Mesa. The base of fresh water deepens toward the center of the basin to about 4,000 feet below mean sea level near Anaheim (California Department of Water Resources, 1967a, p. 35). Seaward from the Newport-Inglewood structural zone, fresh water occurs to a depth of at least 1,500 feet beneath Bolsa Chica Mesa.

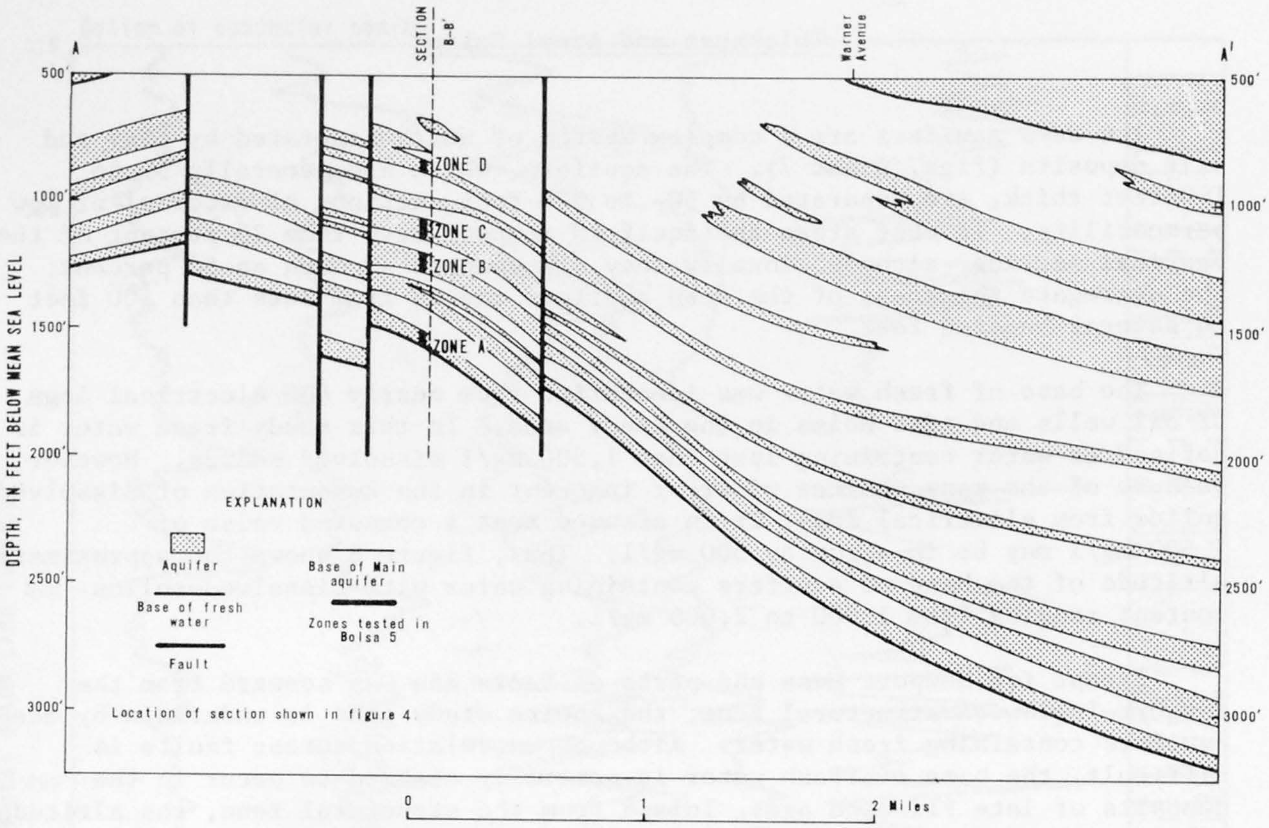


FIGURE 6.--Diagrammatic section A-A' showing fresh-water aquifer units and zones tested.

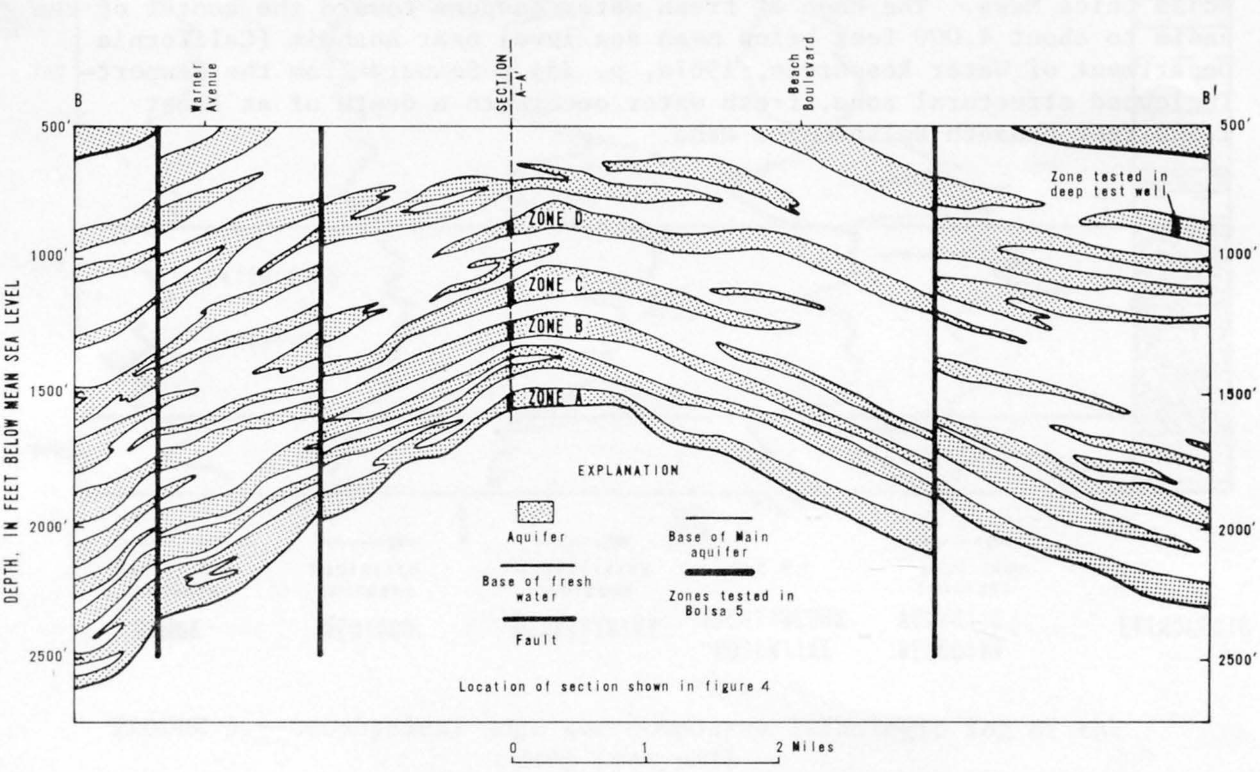


FIGURE 7.--Diagrammatic section B-B' showing fresh-water aquifer units and zones tested.

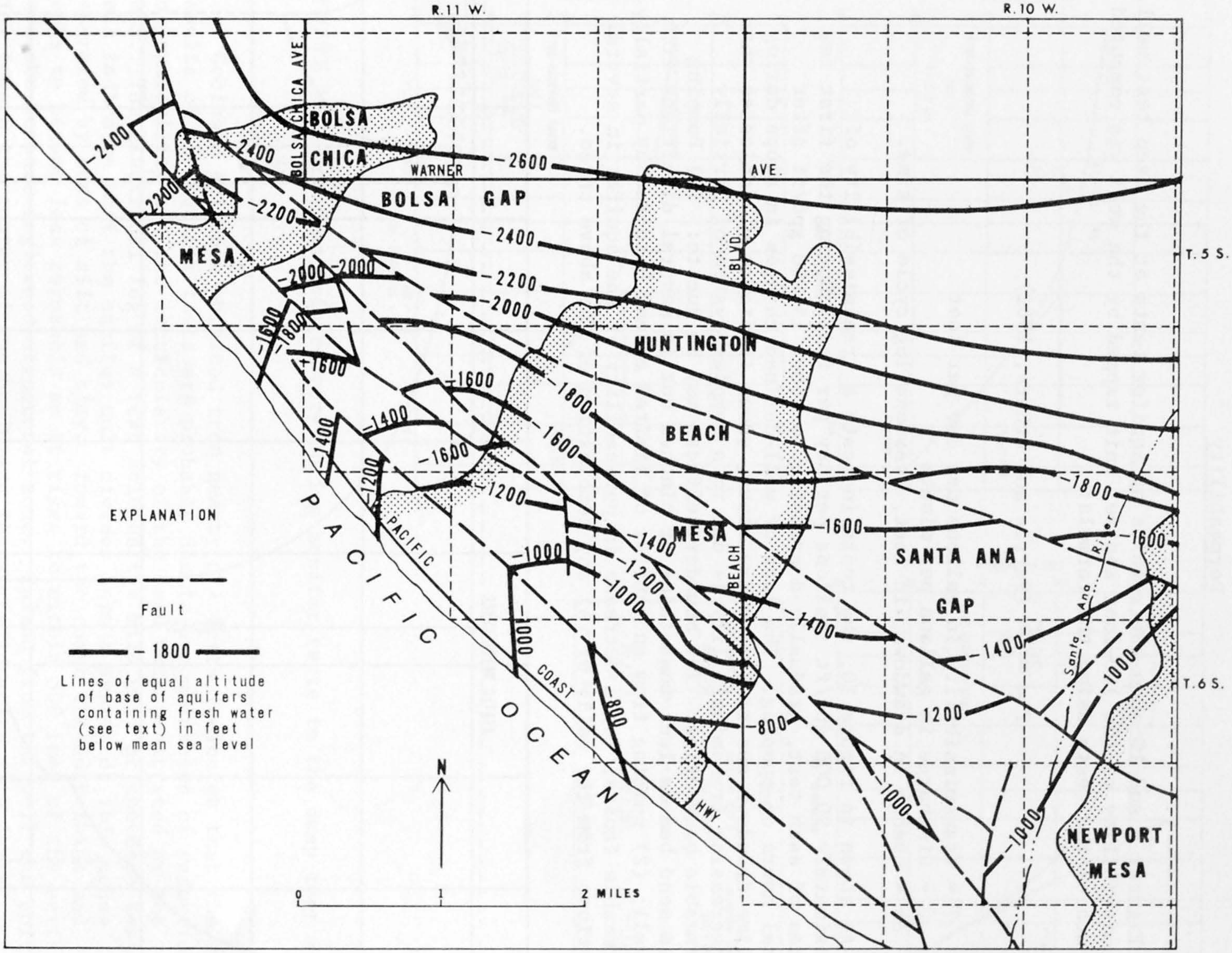


FIGURE 8.--Altitude of base of aquifers containing fresh water in the project area.

Permeability

Figures 9 and 10 show the results of aquifer tests at the deep test well. Transmissibility of the 100-foot aquifer unit tapped by the well was computed for each of the tests using the formula:

$$T = \frac{264Q}{\Delta s} \text{ (Ferris and others, 1962)}$$

where T = transmissibility in gallons per day per foot
Q = discharge in gallons per minute
Δs = change in drawdown, in feet, over one log cycle of time.

As shown in figure 10, the tests indicate a transmissibility of approximately 90,000 gpd/ft (gallons per day per foot) during the first few minutes of each test, gradually decreasing to about 15,000 gpd/ft after several hours of pumping. The lack of well-defined changes in slope during the time-drawdown and time-recovery tests, shown in figure 10, indicates that the decreasing transmissibility is due to a complex system of partially impermeable boundaries. The boundary effects may be due to: (1) Pumping from a sand bed or lens that thins or pinches out in several directions from the well; (2) pumping from an aquifer of limited extent bordered by partially impermeable faults; (3) a decrease in permeability of the aquifer in several directions from the well; or (4) any combination of the above three.

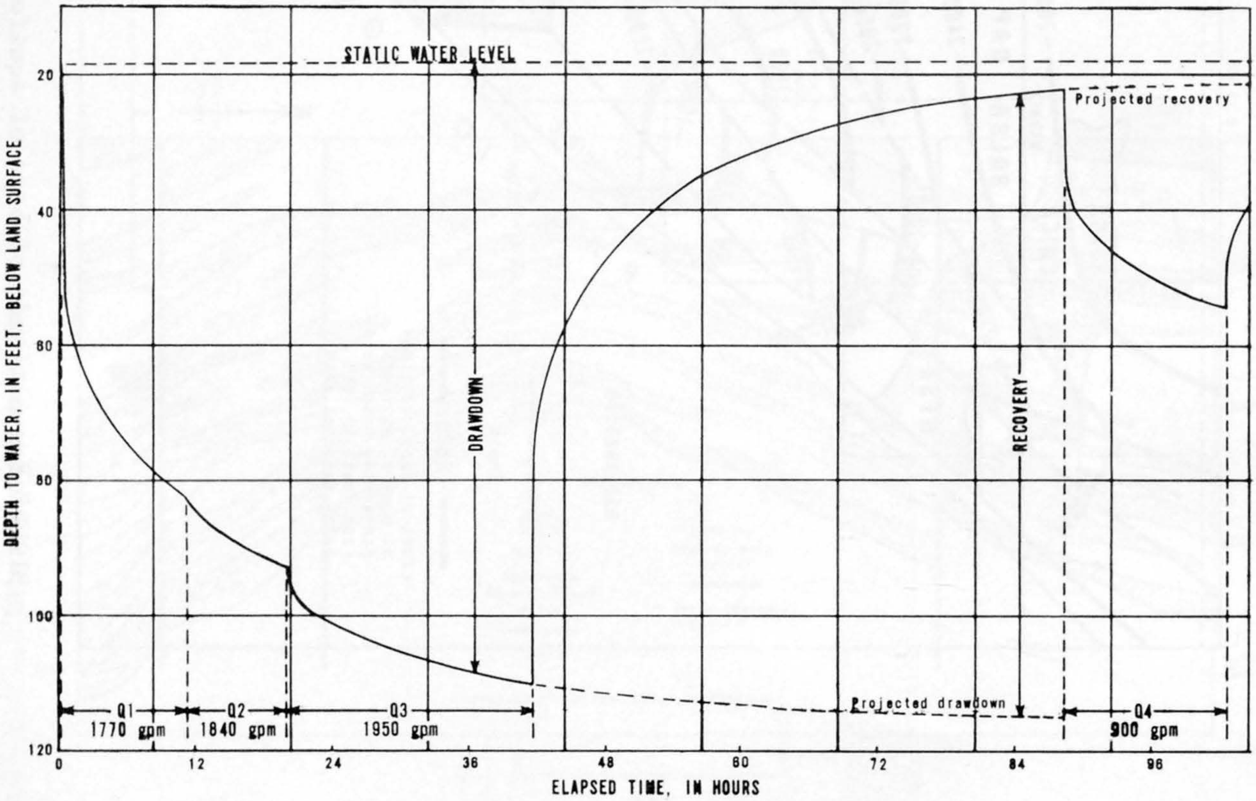


FIGURE 9.--Hydrograph of aquifer test on deep test well.

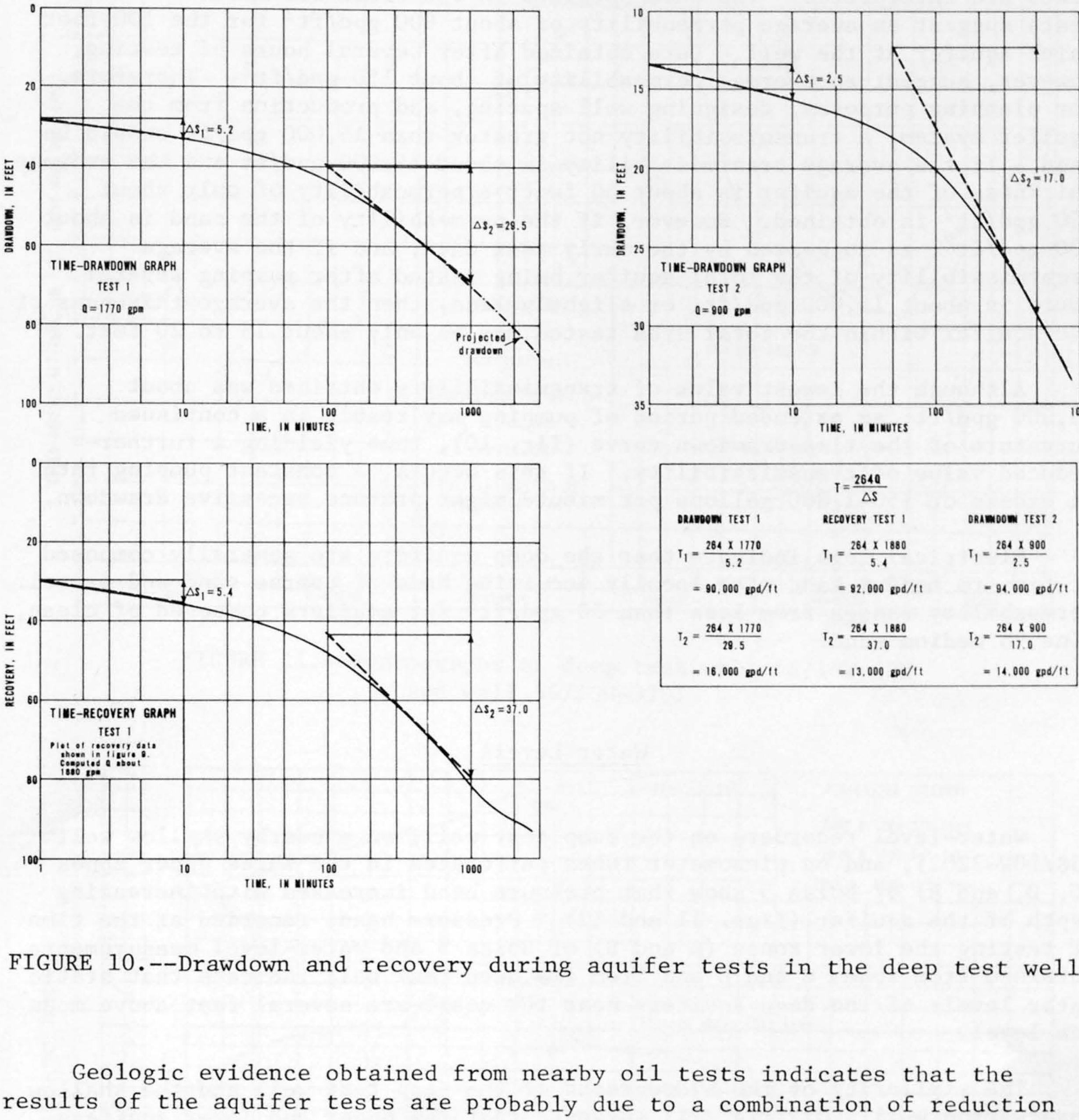


FIGURE 10.--Drawdown and recovery during aquifer tests in the deep test well.

Geologic evidence obtained from nearby oil tests indicates that the results of the aquifer tests are probably due to a combination of reduction in permeability and the lenticularity of the sand unit penetrated by the well. The electrical log of a test hole half a mile west of the deep test well indicates that the aquifer unit divides into a system of thin zones separated by beds of silt and clay. Toward the coast the unit thins and seems to become less permeable as it rises to within 500 feet of the surface near the Newport-Inglewood structural zone. Inland from the well the unit dips toward the center of the basin and loses its identity in a thick sequence of interbedded sediments.

This suggests that two things should be considered when the aquifer tests are interpreted. The data obtained in the first few minutes of the tests suggest an average permeability of about 900 gpd/ft^2 for the 100-foot thick aquifer at the well. Data obtained after several hours of testing, however, suggest an average permeability of about 150 gpd/ft^2. Therefore, for planning purposes, designing well spacing, and production from the aquifer system, a transmissibility not greater than 15,000 gpd/ft should be used. If the average transmissibility is about 15,000 gpd/ft and the average thickness of the aquifer is about 50 feet, a permeability of only about 300 gpd/ft^2 is obtained. However, if the permeability of the sand is about 900 gpd/ft^2, as suggested by the early test data, and if the average transmissibility of the total aquifer being tested after pumping several hours is about 15,000 gpd/ft, or slightly less, then the average thickness of the aquifer within the total area tested may be only about 15 to 20 feet.

Although the lowest value of transmissibility obtained was about 15,000 gpd/ft, an extended period of pumping may result in a continued curvature of the time-drawdown curve (fig. 10), thus yielding a further-reduced value of transmissibility. If this occurs, a constant pumping rate in excess of 750-1,000 gallons per minute might produce excessive drawdown.

Electrical logs indicate that the deep aquifers are generally composed of fine to medium sand with locally occurring beds of coarse sand and gravel. Permeability ranges from less than 50 gpd/ft^2 for aquifers composed of clean, fine to medium sand.

Water Levels

Water-level recorders on the deep test well, on a nearby shallow well (5S/10W-32Q1), and on piezometer tubes perforated in the three upper zones (C, D, and E) of Bolsa 5 show that pressure head increases with increasing depth of the aquifer (figs. 11 and 12). Pressure heads recorded at the time of testing the lower zones (A and B) of Bolsa 5 and water-level measurements obtained from zones C and D and from the deep test well indicate that static water levels of the deep aquifers near the coast are several feet above mean sea level.

The similarity of the hydrographs of the deep test well and the shallow observation well 32Q1 (fig. 11) suggests that the upper and lower aquifers respond to the same stresses. Although the lower aquifer tapped in the deep test well is not pumped in the immediate area, it seems to be in hydraulic continuity with the middle aquifer system which is tapped by several deep irrigation wells. The similarity of the two hydrographs results from simultaneous pumping from the upper and middle aquifers.

Test pumping in the deep test well produced no response in well 32Q1. Similarly, pumping from nearby shallow wells had no apparent effect on the lower aquifer. This indicates that the upper and lower aquifer systems function as separate units, at least during short periods of pumping.

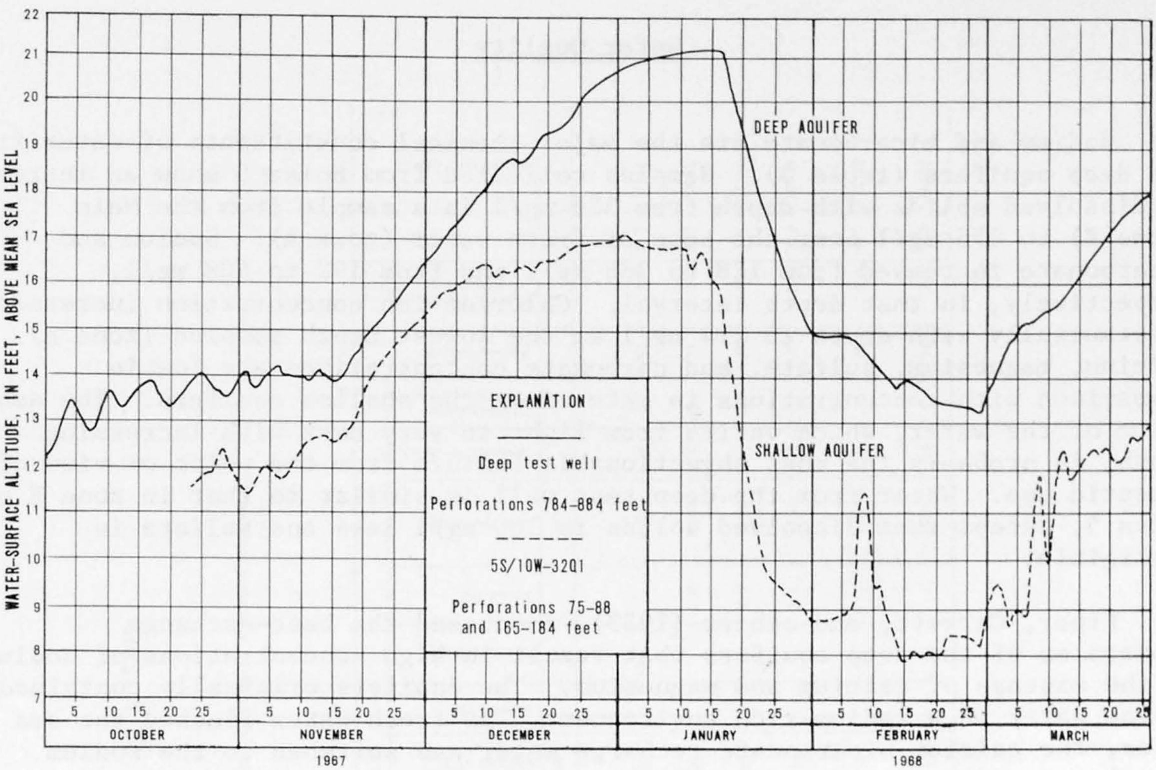


FIGURE 11.--Hydrographs of deep test well 5S/10W-32K and well 5S/10W-32Q1.

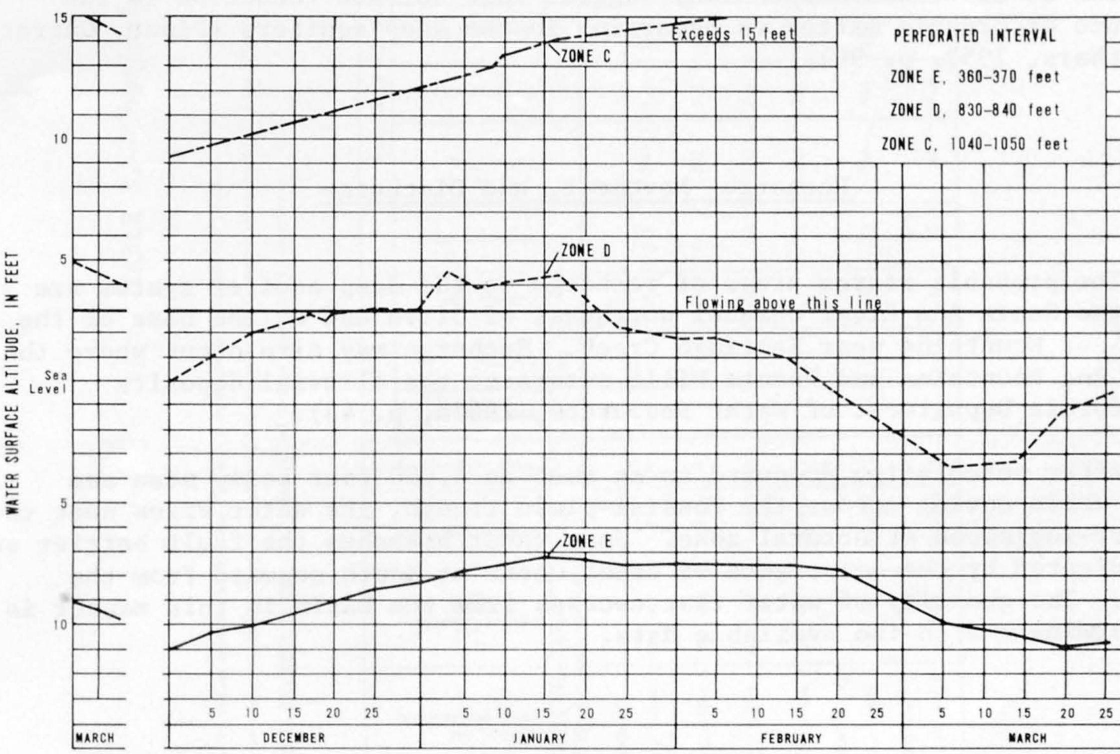


FIGURE 12.--Hydrographs of zones C, D, and E in Bolsa 5.

Water Quality

Sodium and bicarbonate are the major chemical constituents of water from the deep aquifers (table 3). Samples collected from Bolsa 5 show an increase in dissolved solids with depth from 326 mg/l in a sample from the Main (zone E) to 955 mg/l near the base of fresh water (zone A). Sodium and bicarbonate increased from 128 to 386 mg/l and from 192 to 608 mg/l, respectively, in that depth interval. Chloride ion concentration increased substantially with depth to 214 mg/l at the lowest depth sampled (zone A). Calcium, magnesium, sulfate, and carbonate concentrations are low in comparison with concentrations in water from the shallow aquifers. The amber color of the water, which varies from light to very dark with increasing depth, is probably the most objectionable feature from the point of view of domestic use. Water from the deep test well is similar to that in zone E of Bolsa 5, except that dissolved solids is 100 mg/l less and sulfate is negligible.

Piper, Garrett, and others (1953), discussed the base-exchange properties of the deep aquifers that result in high concentrations of sodium at the expense of calcium and magnesium. The aquifers originally contained saline water in a sodium-rich environment. As fresh water flushed the sea water, the calcium bicarbonate recharge water was softened to the sodium bicarbonate water now found in the deep aquifers.

Low sulfate concentrations, high bicarbonate concentrations, the presence of hydrogen sulfide odor, and the amber color, indicating organic material in colloidal suspension, suggest that sulfate reduction in the presence of organic matter is occurring in the deep aquifers (Piper, Garrett, and others, 1953, p. 90).

Recharge, Movement, and Discharge

The probable source areas of recharge to the deep aquifer system are near the Santa Ana River channel northeast of Olive and at the base of the Santa Ana Mountains near Santiago Creek. Recharge may also occur where the Santa Ana Mountains and Puente Hills intersect the alluvial deposits (California Department of Water Resources, 1967a, p. 44).

After percolating downward to as much as 4,000 feet below mean sea level while moving across the coastal-plain trough, the water rises near the Newport-Inglewood structural zone. Some water breaches the fault barrier as is indicated by the occurrence of fresh water at depth seaward from the fault. The quantity of water that escapes from the basin in this manner is indeterminate with the available data.

TABLE 3.--*Chemical analyses of water*

Values for sodium preceded by the letter "a" are a combination of sodium and potassium.

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

Laboratory and sample number: U.S. Geological Survey laboratory, Sacramento, Calif.

				Results in milligrams per liter (mg/l)																			
Aquifer and well designation	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 and sample number
U.S. Public Health Service drinking-water standards (1962)					0.3							250	250	1.2	45		500						
Pico aquifer																							
Zone A, Bolsa 5	3- -67	1,490-1,500	36			7.4	1.8	386	4.9	608	35	6.0	214		0		b955	26	0	96	1,660	8.8	55164
Zone B, Bolsa 5	3- -67	1,225-1,235	35			0	0	242	3.1	422	16	7.0	101			2.8	b580	0	0	99	1,040	9.1	55310
Zone C, Bolsa 5	3- -67	1,040-1,050	32			.3	.2	283	3.4	558	24	7.0	82			3.9	b678	2	0	99	1,180	8.5	55311
Zone D, Bolsa 5	3- -67	830-840	27			.2	.1	265	3.4	556	35	4.0	44			3.9	b630	1	0	99	1,080	8.8	55312
Main aquifer																							
Zone E, Bolsa 5	3- -67	360-370	19			.3	.1	128	4.0	192	4	42	54			.1	b326	1	0	98	558	8.5	55313
Pico aquifer																							
Deep test well	9- -67	784-884	28	16	0.02	5.5	.5	84	.7	209	0	1.0	12	1.0	.7	.1	b225	10	0	92	358	7.9	56137

The static water level in zone A in Bolsa 5 is considerably lower than in the overlying zone B. This anomalous low-pressure head may be due to a reduction of reservoir pressures in the underlying oil-bearing strata, but in view of the present practice of water flooding in the oil reservoir, reduced reservoir pressures are questionable. Although it is possible that zone A lenses out landward, thus restricting recharge, it is probable that water is escaping from zone A through the Newport-Inglewood structural zone at a higher rate than from the overlying aquifers because of a lack of cementation.

The similarity in water quality between the Main and the underlying deep aquifers suggests that the uppermost deep aquifers discharge vertically into the shallower aquifers. Near the coast, where the deep aquifers rise to within 500 feet of the surface, several shallow wells yield sodium bicarbonate water with a pronounced amber color. Additional data, such as vertical hydraulic gradients over the entire study area, thickness of confining beds, and vertical permeabilities of confining beds are needed before estimates of vertical discharge can be made.

PROBLEMS IN DEVELOPMENT OF THE DEEP AQUIFERS

Developing the deep aquifers as a water supply will be expensive. Several factors including depth, low permeability, thickness of clay and silt deposits, and required treatment of the extracted water will contribute to the cost.

To obtain the most water from deep wells tapping the low-permeability aquifers, it may be advisable to include custom-designed well screens rather than perforated casing. Although the initial cost of installing a well screen is substantially higher than installing a gravel-packed perforated casing, yield and life of the well might be considerably increased. Specific data including aggregate thickness of the aquifers and particle-size analysis of the aquifer material must be known to determine the best suited well design.

Use of the Water

Direct domestic use of the water is not probable because of the concentration of dissolved solids and the amber color. As an emergency water supply, however, beneficial use may be realized through proper treatment. By removing the amber color and blending with water containing a lower concentration of dissolved solids, water suppliers could greatly increase the quantity of water available for domestic use.

The water is undesirable for irrigation because of the high concentrations of sodium and boron. These factors, combined with the rapidly decreasing use of land in Orange County for agriculture, preclude the use of the deep aquifers as a source of water for irrigation.

Because of the amber color and the high sodium and bicarbonate concentrations, industrial use of the water is severely limited. However, as water shortage becomes a greater problem, the water may be used for purposes not critically affected by water quality.

The most probable use of the water from the deep aquifers is for recharge to the shallow aquifers to prevent or retard sea-water intrusion. The availability of a reasonably fresh water supply at the site of injection (fig. 4) makes the deep aquifers a valuable asset to the county. Because some of the injected water will move seaward where the water already is saline, there is no danger of degrading water in the shallow aquifers seaward from the injection wells. Injected water moving landward will probably interfinger with the water already present, because of different aquifer permeabilities, and cause pumped wells to produce a blend of the native and injected water. The quantity of water protected from sea-water intrusion will outweigh any reasonable impairment of quality caused by injection of water from the deep aquifers.

Land-Surface Subsidence

The possibility of land-surface subsidence due to production from the deep aquifers must be considered. If extraction from the deep zones is large, a general lowering of the piezometric surface will result. This, in turn, reduces the pore pressure in the clay and silt deposits and allows compaction to occur. The high pressures in the extensive deposits of clay and silt suggest that subsidence due to ground-water extraction could be considerable if the aquitards are highly compactible.

NEED FOR ADDITIONAL STUDIES

To properly evaluate the deep aquifers as a source of usable water, many additional data are needed. Studies that should be conducted in the future include:

1. Installation and testing of a number of deep wells that extend to the base of fresh water.

2. Testing of other abandoned oil wells. This would yield valuable data on water levels and water quality.

3. Collection of core samples of aquifers and aquitards. Data on vertical and horizontal permeability, grain size, degree of compaction, compressibility, clay-mineral assemblage, and ion-exchange capacity of aquitards are needed to predict yields of wells, movement of water, quality changes, and subsidence potential.

4. Installation of deep observation wells. Observation wells tapping the deep aquifers are needed throughout the county to monitor water-level and water-quality changes. Abandoned oil wells or oil-test holes could be utilized for this purpose in part.

5. Installation of a subsidence observation network if extensive withdrawal is planned. Overdraft in the deep aquifers might result in serious land-surface subsidence. If this seems likely, an early warning system is needed, but data listed under 3. should permit estimates indicating the general order of magnitude of compaction and subsidence to be anticipated per 100 feet of head decline.

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