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ARTIFICIAL RECHARGE IN THE WATERMAN CANYON-EAST TWIN CREEK AREA SAN BERNARDINO COUNTY, CALIFORNIA

By

James W. Warner and Joe A. Moreland

Prepared in cooperation with the
San Bernardino Valley Municipal Water District

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ILLUSTRATIONS

[Plates are in pocket]

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ABSTRACT

This is a study of the feasibility of recharging, in the Waterman Canyon-East Twin Creek area, imported water from northern California by way of the State Water Project beginning in 1972.

The feasibility of recharging 30,000 acre-feet of water a year in the Waterman Canyon-East Twin Creek area will depend on the effectiveness of fault K as a barrier to ground-water movement near the land surface. The results of test drilling and an infiltration test indicate that the subsurface material at the spreading grounds is permeable enough to allow recharged water to percolate to the water table. The data indicate that fault K extends into the Waterman Canyon-East Twin Creek area and may impede the lateral movement of recharged water. Fault K has no known surface expression and therefore probably does not affect the highly permeable younger alluvium. If that is so, fault K will be less effective as a barrier to ground-water movement as the recharge mound rises. Monitoring of the observation wells near the spreading grounds as the planned recharge operation proceeds should provide data about the hydrologic effects of fault K near the land surface.

INTRODUCTION

The San Bernardino Valley Municipal Water District (fig. 1) was formed in 1954 primarily to provide supplemental water for the San Bernardino area. To meet the growing water needs of the area, the district entered into a contract with the California Department of Water Resources to receive water from northern California by way of the State Water Project beginning in 1972. The district's initial entitlement is 46,000 acre-feet of water per year but will be increased gradually to about 102,000 acre-feet per year by 1990. The district plans to distribute this imported water for artificial recharge to the local ground-water system.

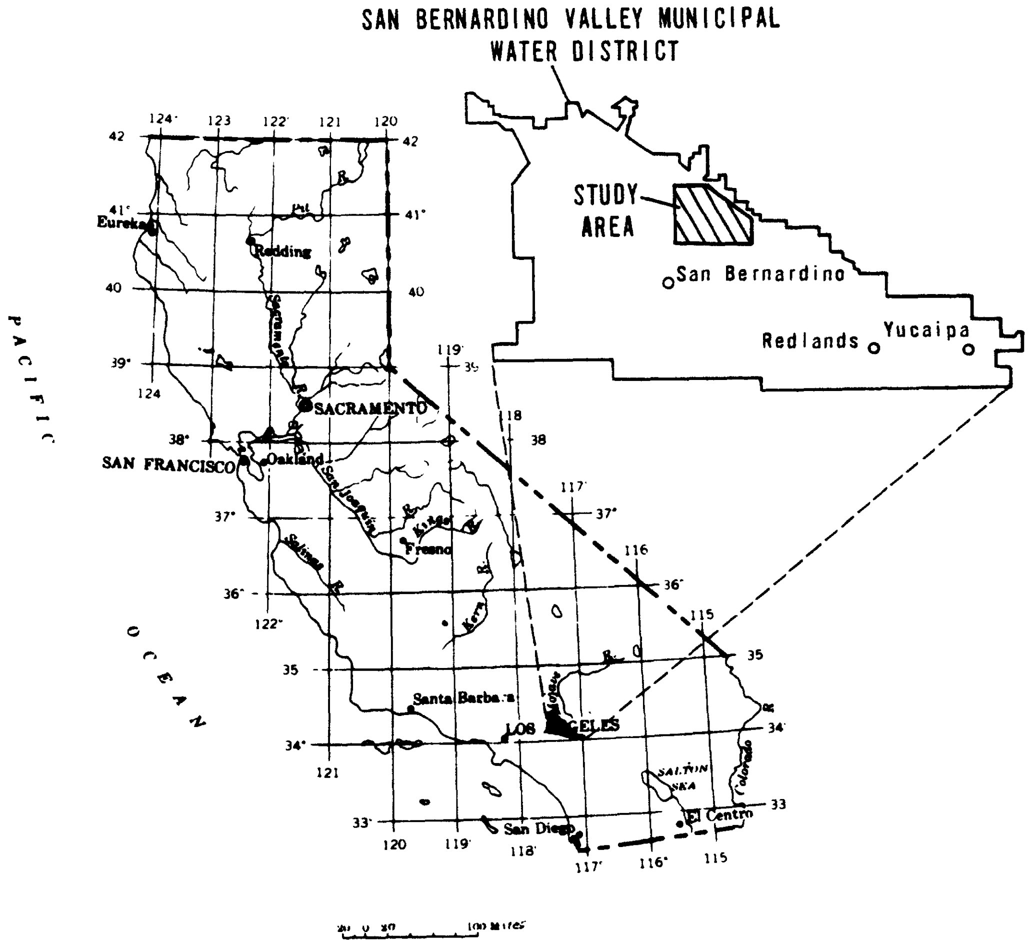


FIGURE 1.--Index map.

The State Water Project will bring the imported water as far south as Devil Canyon northwest of the area of intensive study (fig. 2). From there the water district plans to transport the water by pipeline southeastward along the base of the San Bernardino Mountains. The pipeline is to be built only as far as the Waterman Canyon-East Twin Creek spreading grounds (fig. 2) by 1972 when the initial allotment of imported water is to arrive. The pipeline is planned for extension to the area of Yucaipa (fig. 1) by about 1980 to handle the scheduled increases in annual allotment of imported water. The initial annual allotment of 46,000 acre-feet of water is to be recharged into spreading grounds at the mouths of Devil and Badger Canyons (fig. 2) and at the Waterman Canyon-East Twin Creek spreading grounds (fig. 2). The district plans to spread more than 30,000 acre-feet per year in the Waterman Canyon-East Twin Creek spreading grounds (fig. 2).

The San Bernardino Valley Municipal Water District entered into a cooperative agreement with the U.S. Geological Survey to study the feasibility of artificial recharge in the Waterman Canyon-East Twin Creek area. This report summarizes the results of that study.

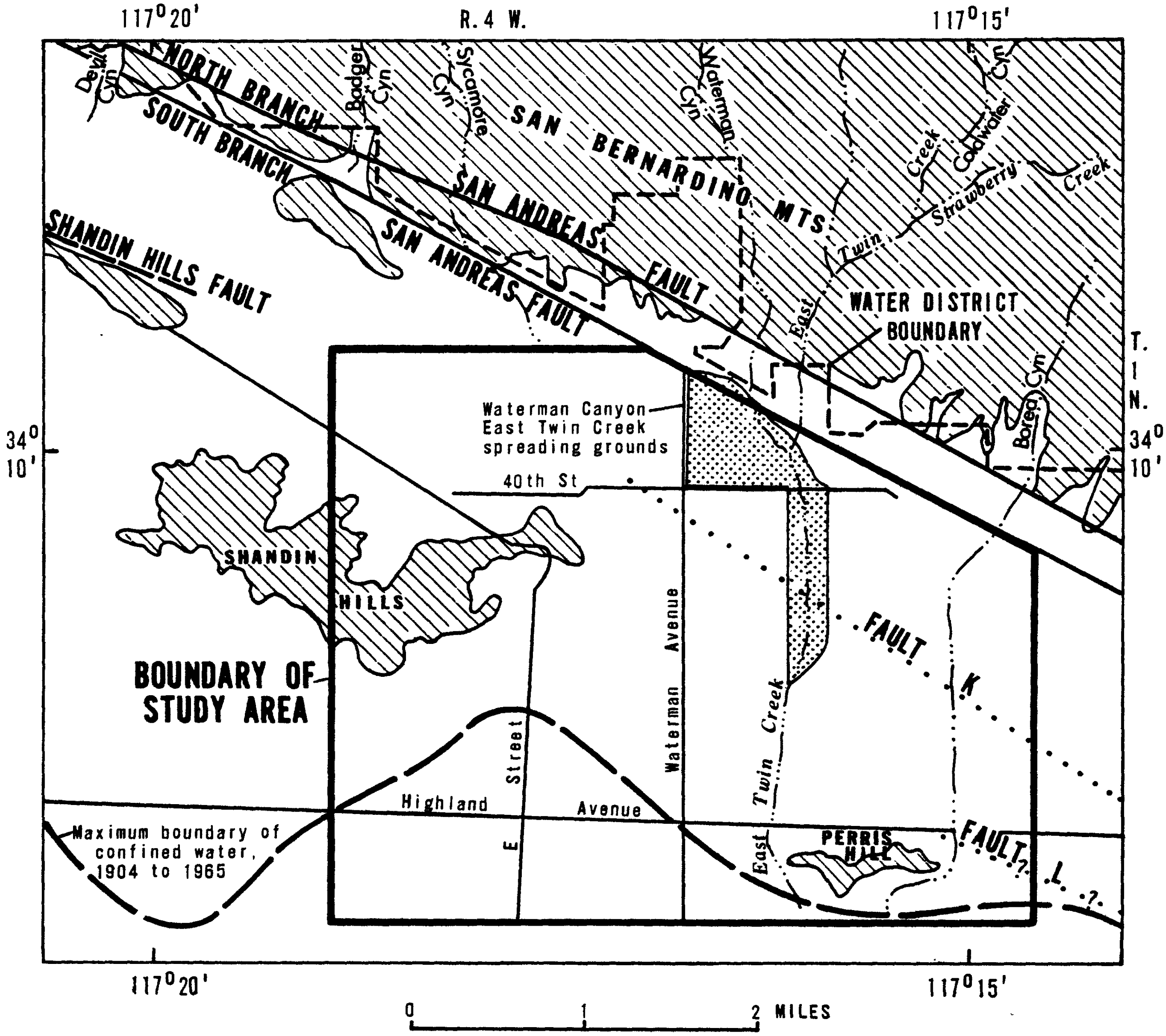


FIGURE 2.—Major physiographic and structural features, boundary of study area, and maximum boundary of area of confined water.

Purpose and Scope

The purpose of this study was to: (1) determine the feasibility of artificial recharge in the Waterman Canyon-East Twin Creek area, (2) determine if fault K of Dutcher and Garrett (1963, p. 42) extends into the Waterman Canyon-East Twin Creek area, and (3) develop a water-level monitoring program to determine the effects of the spreading operation.

All wells in the study area were canvassed to determine what data were available, which existing wells could be used in a monitoring program, and where additional observation wells would be needed. Drillers' logs were studied and geologic sections of the area were constructed to determine the probable location and extent of horizons of low permeability. Near the spreading grounds five test wells were drilled by the hydraulic-rotary method and cased to use in the monitoring program, to gain additional lithologic and hydrologic information, and to discover any discontinuity in the water table caused by fault K. Five shallow holes were augered and cased near the spreading grounds to detect any perched water bodies that might form during operation of the spreading grounds and to obtain additional lithologic information within 100 feet of the surface. Data on pumping tests for wells near fault K were collected to aid in interpreting the effect of the fault on the specific capacities of these wells. The infiltration rate was measured to determine an approximate rate of recharge that could be expected.

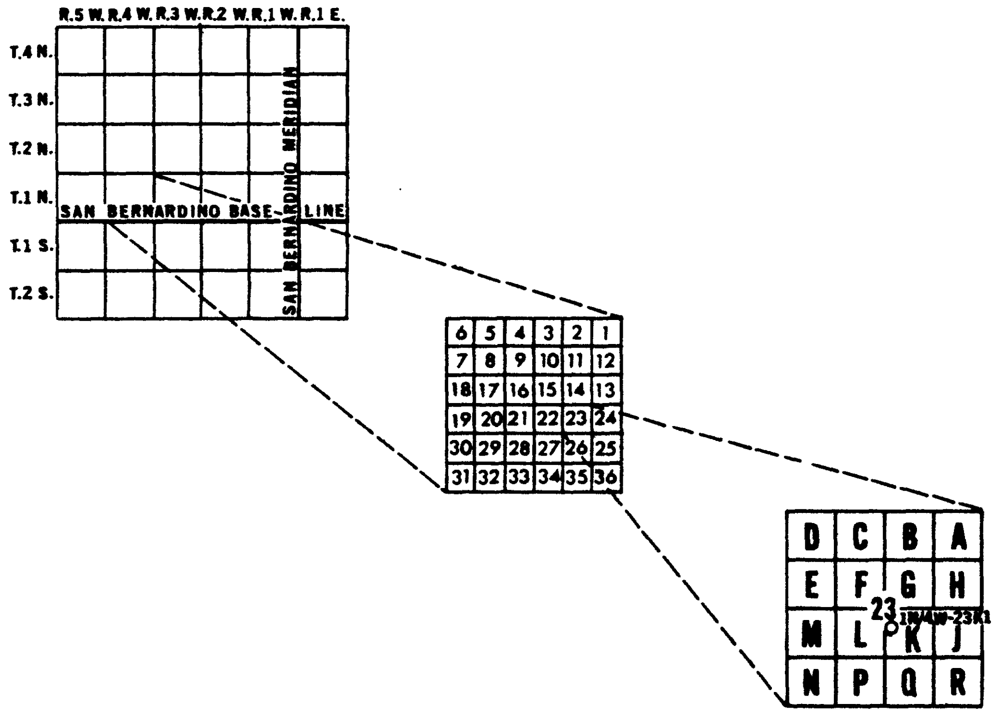
Acknowledgments

This study was made possible with the aid and cooperation of many landowners, water companies, and county and State agencies. Special thanks are given to San Bernardino County Flood Control District for granting permission to drill the test wells on district property. The San Bernardino Valley Municipal Water District contracted for the drilling of the test wells.

This report was prepared by the Geological Survey under the general supervision of R. Stanley Lord, district chief in charge of water-resources investigations in California, and under the immediate supervision of James L. Cook and R. E. Miller, successive chiefs of the Garden Grove subdistrict. Technical review of this report was by L. C. Dutcher, R. W. Page, P. R. Wood, and Fred Kunkel.

Well-Numbering System

Wells in the study area are numbered according to their location in the rectangular system for the subdivision of public land. In the well number 1N/4W-23K1, the part preceding the slash is the township (T. 1 N.), the part between the slash and the hyphen is the range (R. 4 W.), the number between the hyphen and the letter is the section (sec. 23), and the letter K is the 40-acre subdivision of the section as shown by the diagram. Within the 40-acre tract, wells are numbered serially by the final digit. The area covered by the report lies in the northwest quadrant of the San Bernardino base line and meridian.



GEOLOGY

Plate 1 shows the generalized geology of the Waterman Canyon-East Twin Creek area. In this study three lithologic units have been identified--basement complex, sandstone, and alluvium.

The basement complex underlies the alluvium and sandstone and forms the bordering hills and mountains. It is composed of igneous and metamorphic rocks of pre-Tertiary age. For the purpose of this study, the basement complex is considered to be non-water-bearing. These rocks are nearly impermeable except where fractured or weathered and are not a major source of pumped ground water.

The sandstone, of Tertiary age, is found in the study area only between the north and south branches of the San Andreas fault. The sandstone is fine to coarse grained with some siltstone and shale layers and is not considered a source of ground water.

Alluvium, of Quaternary age, overlies the sandstone and basement complex. The alluvium, derived from the highland areas to the north, consists of lenticular deposits of clay, silt, sand, gravel, and boulders. In general, the alluvium closer to the mountain front is coarser and more poorly sorted than the alluvium farther from the mountain front. The better sorted lenses of sand and gravel compose the more permeable deposits and, where saturated, yield water freely to wells. Also along the river channels, principally along East Twin Creek and Waterman Canyon, the alluvium is generally well sorted and permeable--a fact of particular importance because it makes these deposits highly useful as sites for spreading grounds.

Faults in the area are important not only because of their influence on the general topography but also because of their influence on the flow of ground water. Faults commonly fracture consolidated rocks and thus may serve as conduits for ground-water flow. Conversely, faults that transect unconsolidated deposits commonly impede ground-water flow. Although the barrier effects of faults are not completely understood, ground-water movement across faults may be impeded principally by the offsetting of permeable beds against less permeable beds, by the presence of clayey fault gouge which is usually less permeable than the aquifer, by local folding of beds near the fault, or by the cementation of the fault zone and the material immediately adjacent to the fault by deposition of mineral material from ground water.

The San Andreas fault, as shown by figure 3, consists of two subparallel branches about a quarter of a mile apart (Bechtel, 1970). Along most of the trace of the northern branch, basement complex is faulted against either sandstone or alluvium. Along the trace of the southern branch, alluvium is faulted against alluvium or against sandstone.

Fault K, about three-fourths of a mile southwest of the south branch of the San Andreas fault, is nearly parallel to the San Andreas fault. This fault is not evident from surface expression but is postulated from geophysical (Dana, 1968; Bechtel, 1970) and water-level data (Dutcher and Garrett, 1963). According to Dutcher and Garrett (1963, p. 42), the area between the San Bernardino Mountains and fault K may be a graben. Fault K is important because of the effects it may have on the recharge capacity of the ground-water reservoir underlying the Waterman Canyon and East Twin Creek spreading grounds.

Fault L, in the area to the east as mapped by Dutcher and Garrett (1963, p. 42-43), is about half a mile southwest of fault K. According to Dutcher and Garrett, there is no evidence that fault L extends into the Waterman Canyon-East Twin Creek area.

HYDROLOGY

Occurrence and Movement of Ground Water

Recharge to the area occurs as runoff from the San Bernardino Mountains, infiltration of precipitation, and ground-water underflow from the northwest. Ground-water movement into the area from the northeast is impeded by the San Andreas fault which acts as a nearly complete barrier to ground-water movement. The effect that the south branch of the San Andreas fault has on ground-water movement is shown by the difference in altitude of the water level in wells on either side of the fault. The water-level altitude in well 1N/4W-24D2, which is south of the fault, is about 1,130 feet above sea level or about 230 feet below land surface; whereas the water in well 1N/4W-24D1, which is north of the fault and about 300 feet north of well 1N/4W-24D2, is flowing, and the altitude of water surface is about 1,380 feet above sea level.

Ground-water movement in the Waterman Canyon-East Twin Creek area is complex. Ground-water flow is affected by the Shandin and Perris Hills, by the San Andreas and K faults, and by many pumping wells. Generally, the pattern of ground-water flow under natural conditions was from north to south. Most ground-water movement into the area is from the recharge area to the northwest between Shandin Hills and the San Bernardino Mountains. Most ground-water movement out of the area is to the south between the Shandin and Perris Hills. The effect of faults on the ground-water movement in the area is to impede movement to the southwest and encourage movement to the southeast.

Water-Level Fluctuations

The water supply of the San Bernardino area is almost entirely from wells. The depth to water in wells ranges from 200 to 300 feet below land surface. Typical water-level fluctuations in wells (fig. 3) show a long-term water-level decline.

The hydrographs of wells 1N/4W-23K1, 35L1, and 27G1 are representative of wells south of fault K. Between 1915 and 1938 the water level declined an average of nearly 3 feet a year. Between 1938 and 1947 the water level rose about 40 feet due to a number of wet years during this period. However, from 1947 to 1968 the water level in wells declined almost 180 feet at a rate of about 10 feet a year. This increased rate of decline of the water level was due to a combination of increased pumpage and reduced recharge caused by below-normal precipitation. Water levels have risen slightly since 1968 because of the extremely heavy precipitation that occurred in 1969.

The hydrograph of well 1N/4W-25A1 is typical of wells north of fault K. The rate of water-level decline north of the fault has been less than that south of the fault. Between 1939 and 1965 the water level declined about 120 feet at the rate of nearly 5 feet a year. Since 1965 the water level north of fault K has risen slightly.

The hydrograph of well 1N/4W-16E1 is typical of wells in the recharge area to the northwest of the study area. Water levels in wells in this area have shown greater rises during periods of recharge than do wells in the study area. Since the unusually wet year of 1969, the water level has risen about 90 feet. Between 1945 and 1968 the water level declined about 150 feet at a rate of about 7 feet a year.

Area of Confined Water

An area of confined water exists south of the Waterman Canyon-East Twin Creek area (pl. 1). The boundary of confined water has varied over the years as water levels have changed. The position of the boundary is determined by the elevation of the water table as illustrated in figure 4. The maximum area of confined water (Bechtel, 1970, pl. A-10) is shown on plate 1. Change in the water level in wells in the confined area reflects change in head rather than change in the water table. There are two confining layers: the first layer is about 75 feet below land surface, and the second layer is about 200 feet below land surface. The water level in wells in the area of confined water depends on whether the well taps zone 1 or zone 2. Changes in the level of the water table in the study area at the boundary of the artesian system affect the pressure head in the area of confined water. Many wells in the area of confined water have flowed in the past, and at one time this part of San Bernardino was a marshland (Mendenhall, 1905, p. 29).

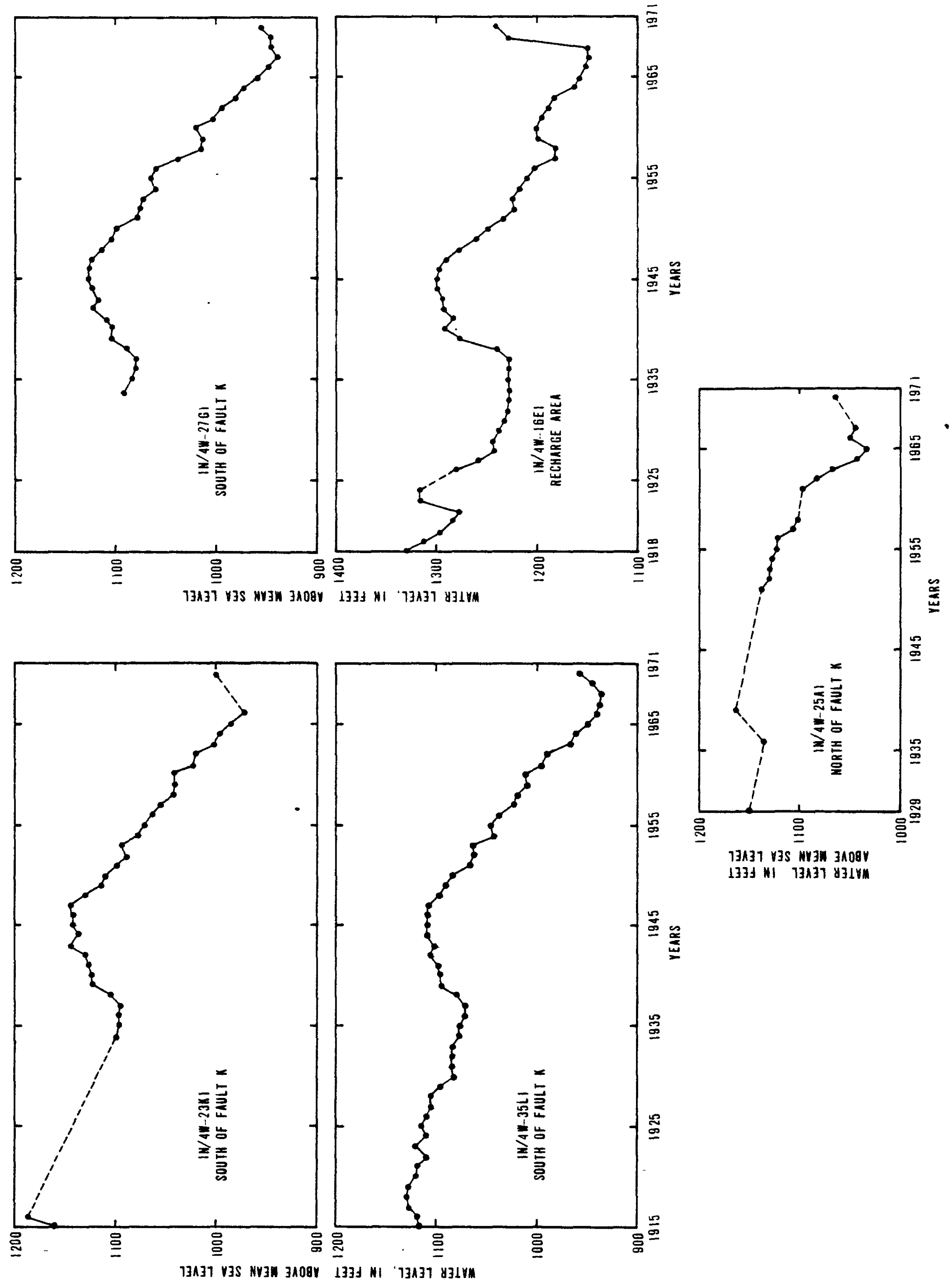


FIGURE 3.--Hydrographs of selected wells.

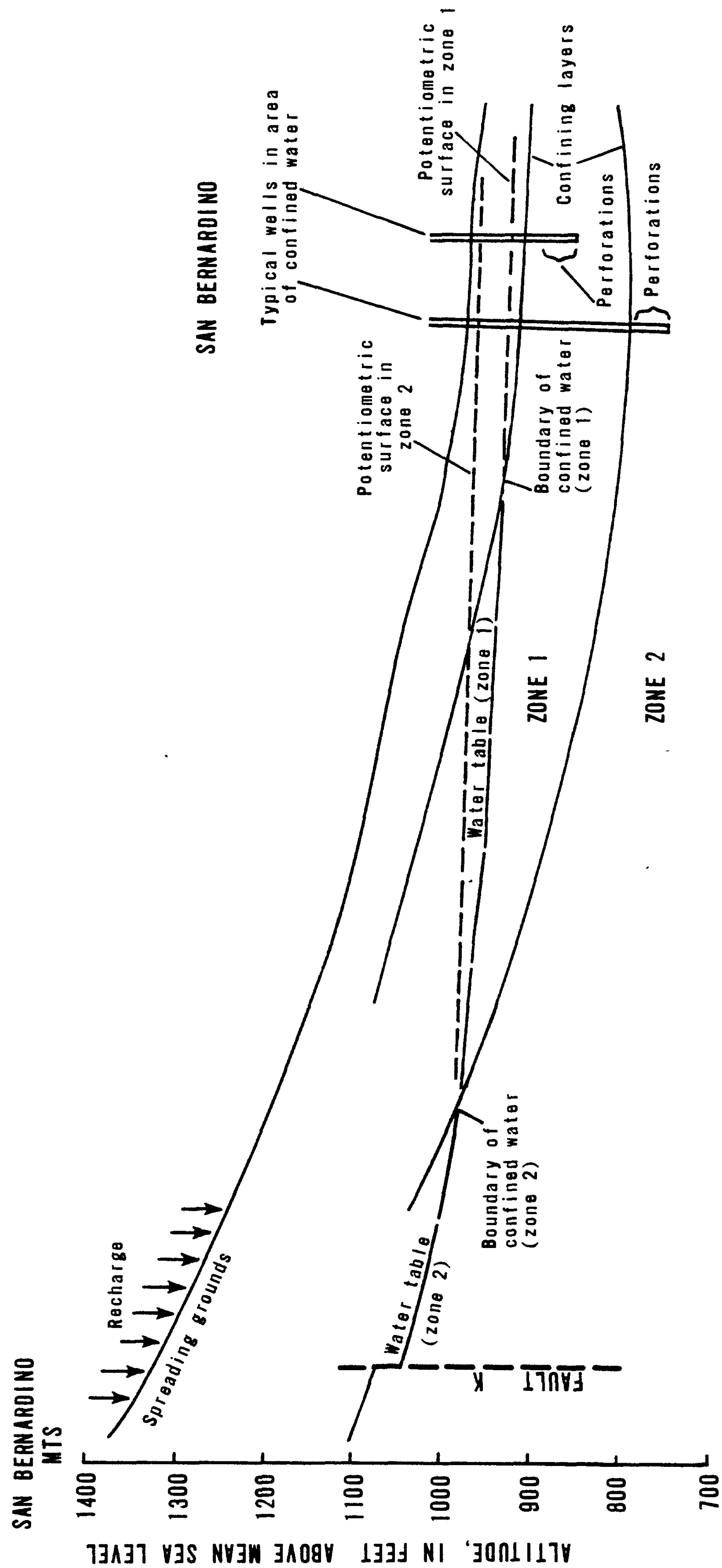


FIGURE 4.--Diagrammatic section of hydrologic conditions in the area of confined water.

FEASIBILITY OF ARTIFICIAL RECHARGE

At the start of the investigation all water wells in the study area were canvassed. The wells are plotted on plate 1. Water-level data obtained from the well canvass were insufficient to determine if fault K extended into the Waterman Canyon-East Twin Creek area. Few wells were located near the spreading grounds, and only two wells were north of the suspected extension of fault K. Consequently, it was decided that test wells should be drilled to better define the hydrologic and geologic conditions.

Test Drilling

Five test wells were drilled at the spreading grounds (pl. 1) to determine if the water table was offset by fault K at the Waterman Canyon-East Twin Creek spreading grounds and to complement the water-level monitoring program. Three wells were drilled north of the suspected location of fault K, and two wells were drilled to the south. The test wells were drilled by conventional rotary methods to depths of about 400 feet. Electrical logs were run in each borehole to determine the depth and thickness of any layers of low permeability. Each test well was cased with 4-inch-diameter casing. In addition, 2-inch-diameter casings were installed in each hole to depths just above layers of low permeability to provide water-level records on the buildup and decay of perched water bodies during recharge operations.

A composite log for each well (figs. 5-9) was constructed using the driller's log and the electric log. The results of the test drilling indicated that the subsurface material at the spreading grounds is generally permeable enough to allow recharged water to percolate to the deepest water table. Some sandy clay, silt, and cemented sand and gravel were found which may retard downward percolation of the recharge water to the water table and cause local perched ground-water bodies. However, none of these layers of low permeability was extensive enough, either laterally or in thickness, to seriously impede recharge in the basin. The logs of the test wells show a definite trend from coarser-grained material to finer-grained material from north to south in the spreading grounds.

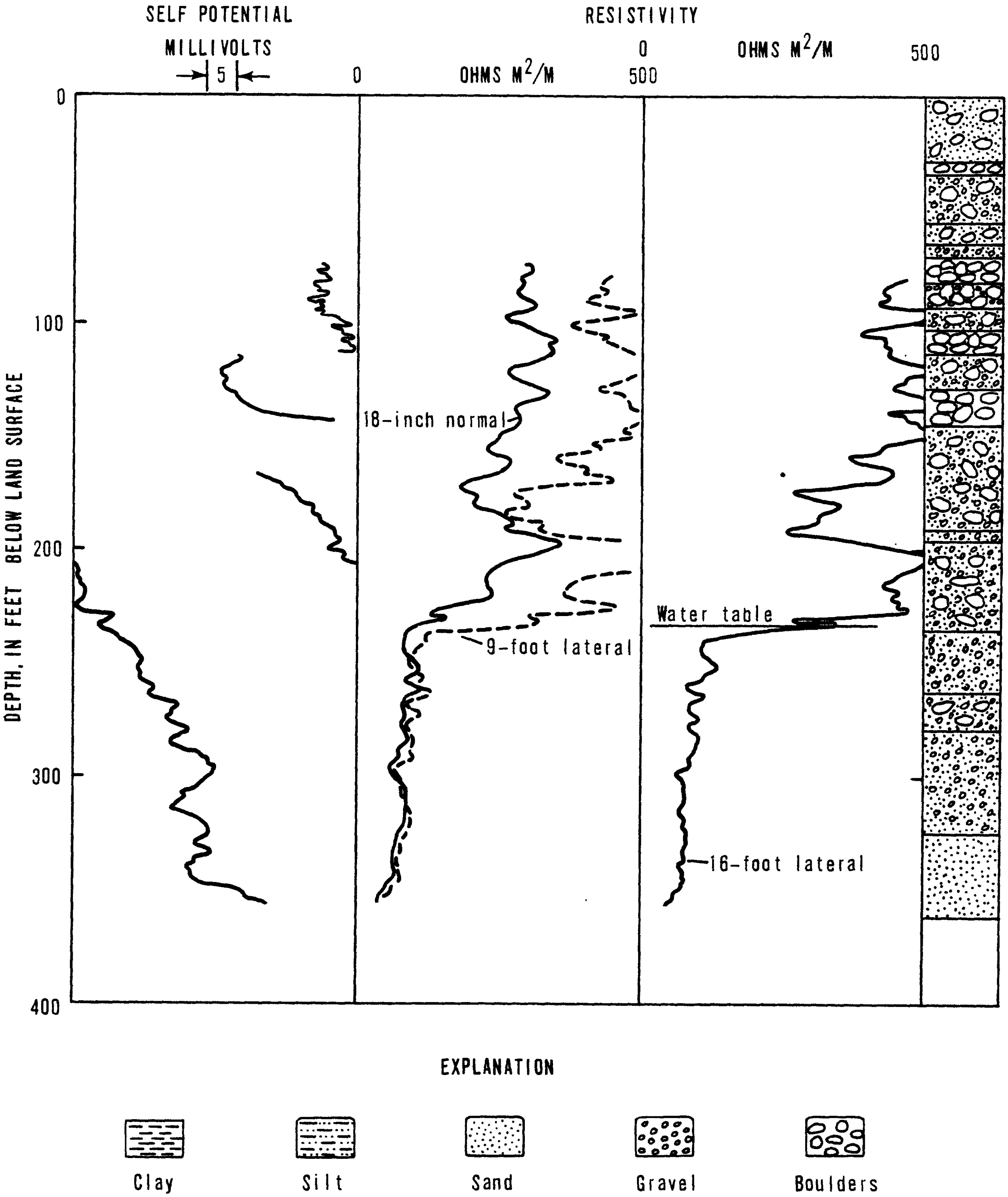


FIGURE 5.--Geophysical and lithologic logs of test well 1N/4W-23B1.

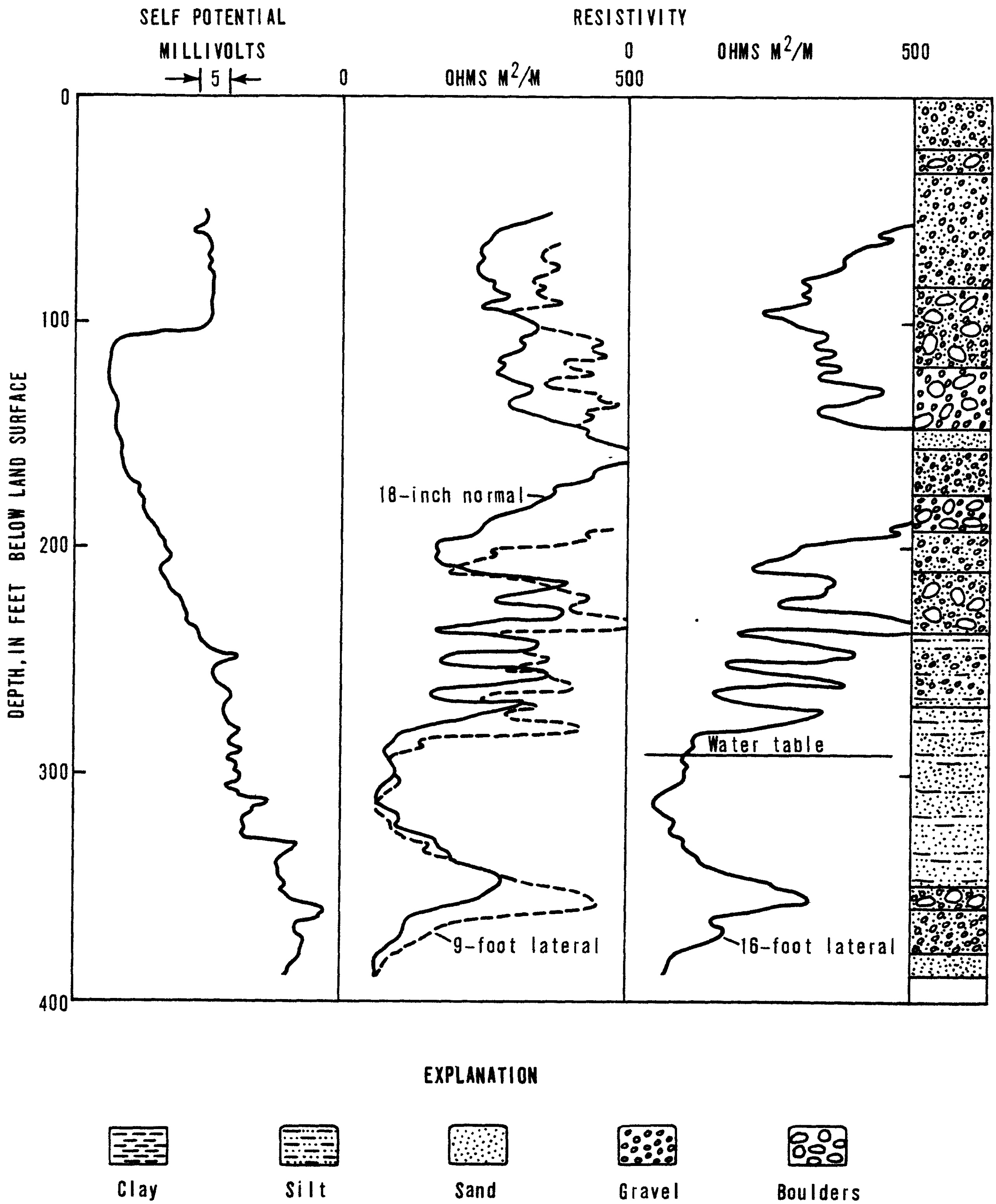


FIGURE 6.--Geophysical and lithologic logs of test well 1N/4W-23G1.

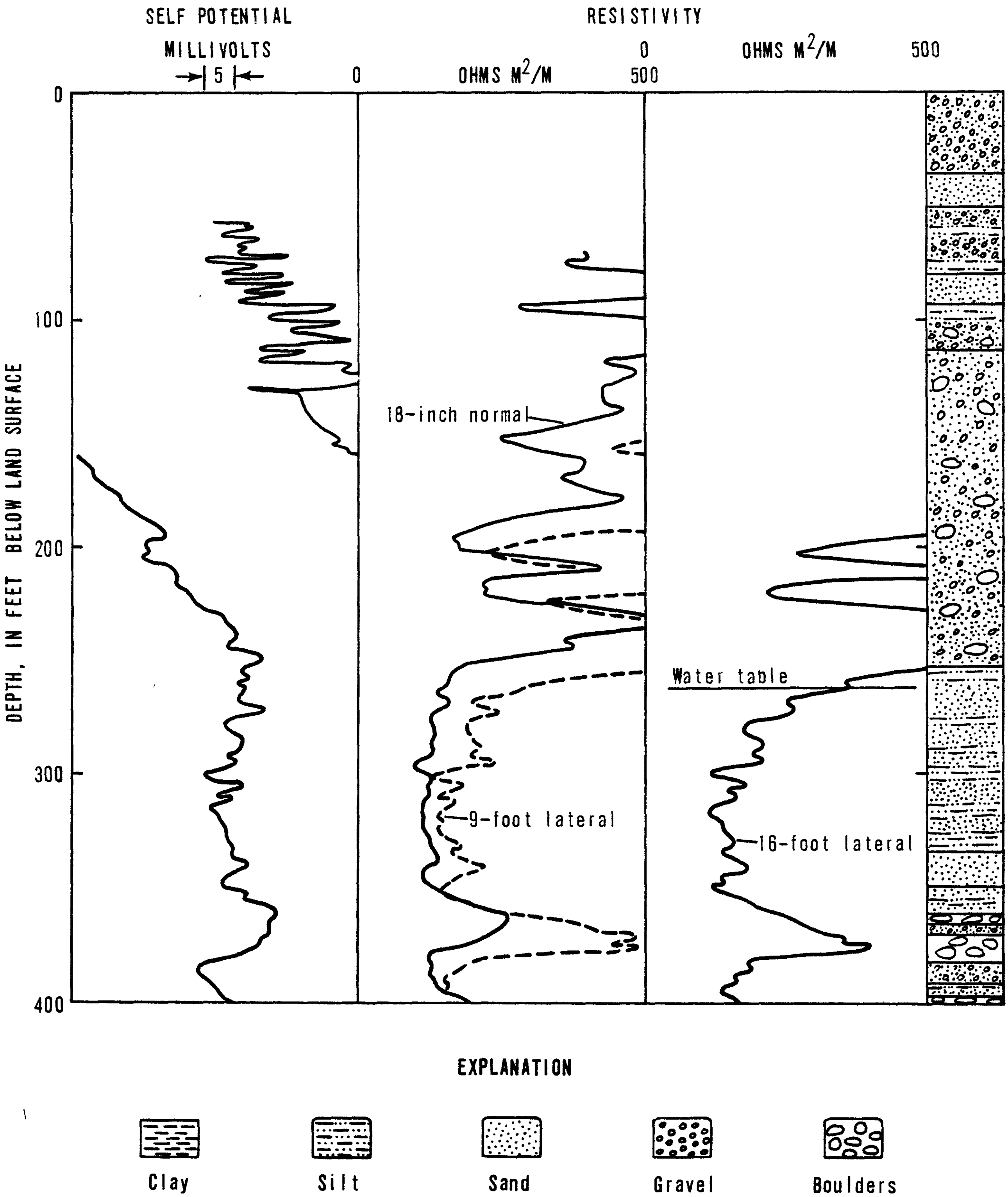


FIGURE 7.--Geophysical and lithologic logs of test well 1N/4W-23J1.

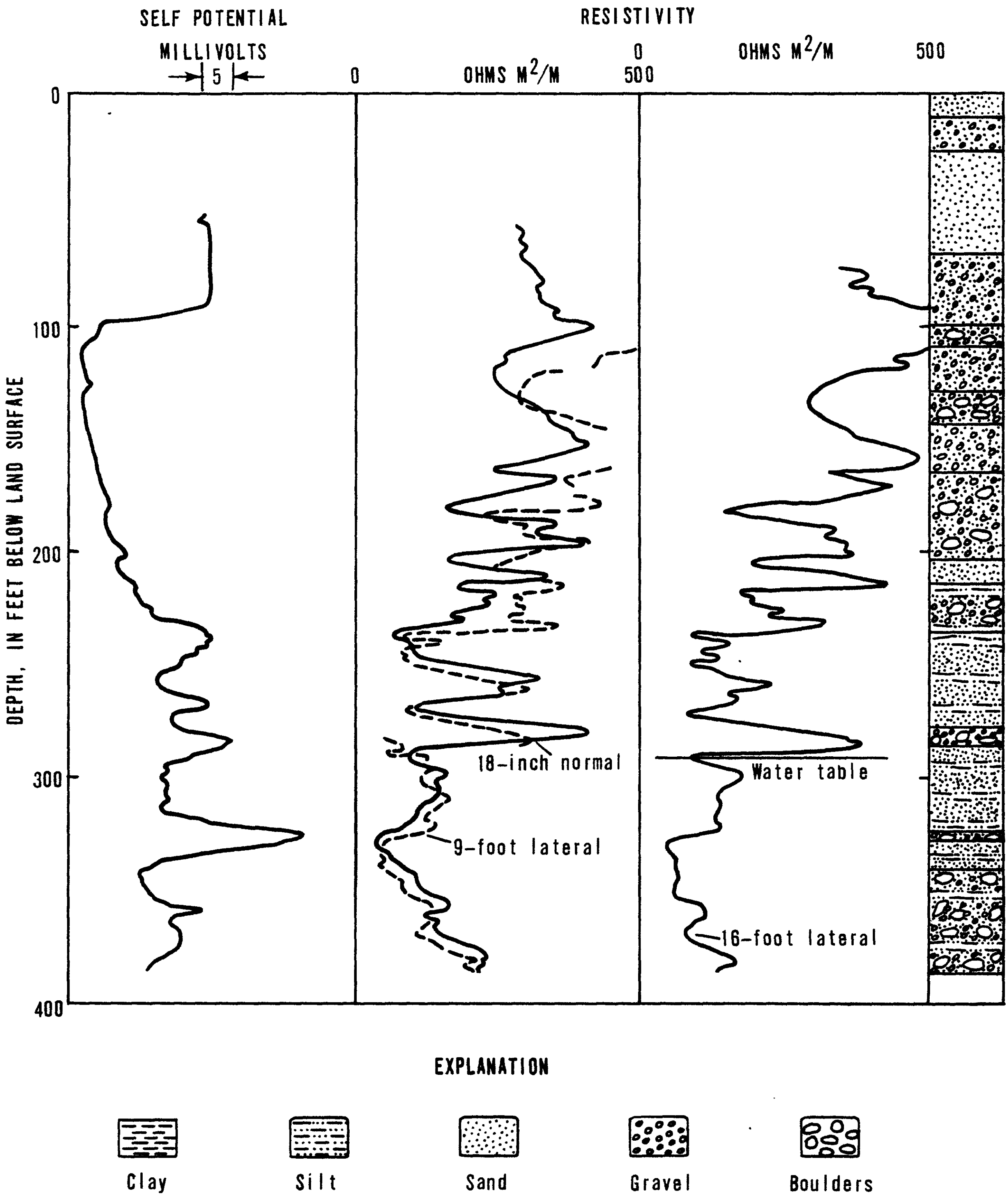


FIGURE 8.--Geophysical and lithologic logs of test well 1N/4W-23Q2.

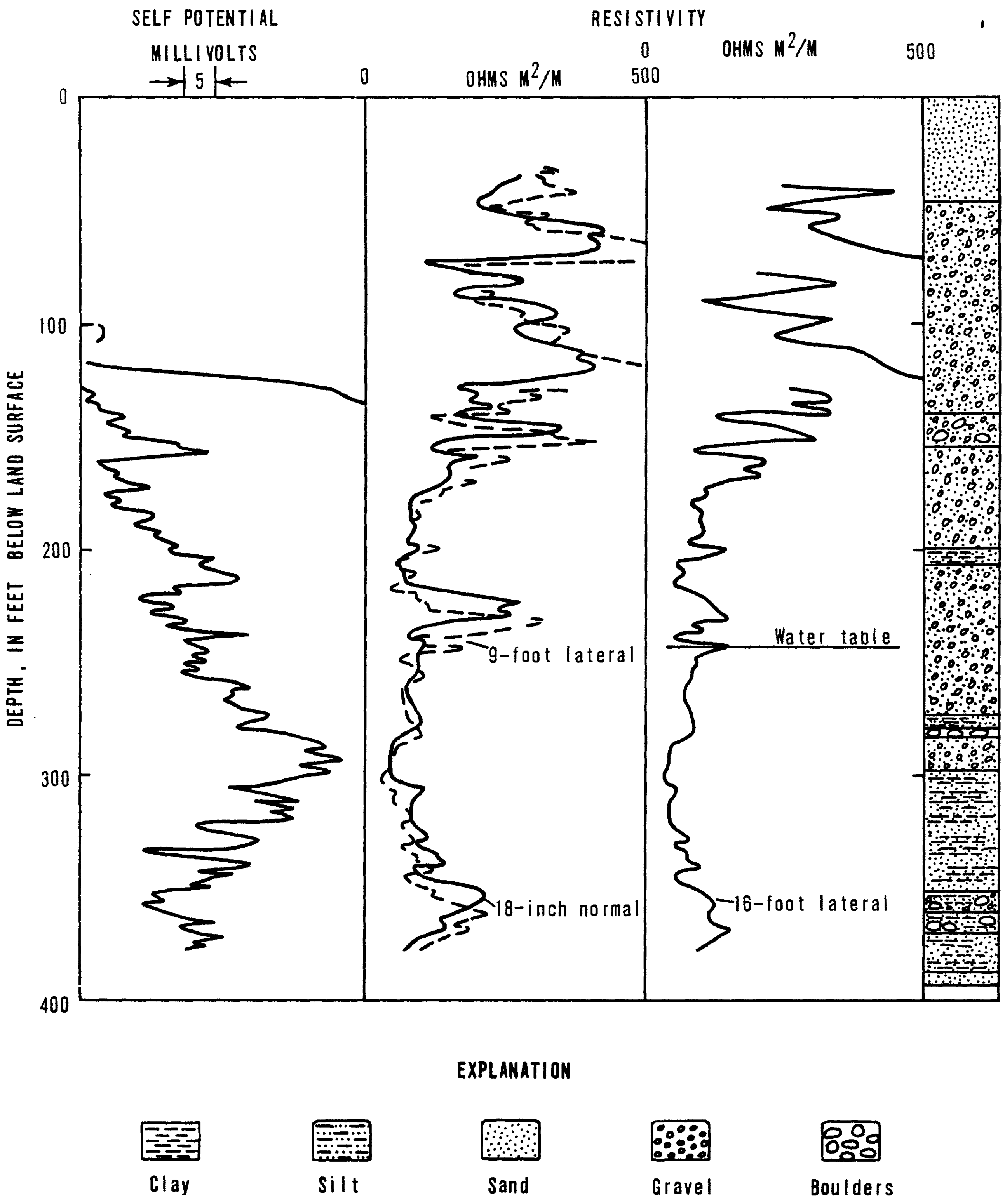


FIGURE 9.--Geophysical and lithologic logs of test well 1N/4W-23R2.

Five test holes (pl. 1) were augered by the Geological Survey at the spreading grounds to obtain lithologic information on deposits within 100 feet of the land surface. The log of each hole is shown in figure 10. Data from these holes confirmed the conclusion based on data from the test wells: that near-surface conditions at the spreading grounds were favorable for artificial recharge. Clayey material was found at a depth of 35 feet in hole 1N/4W-26B1 (fig. 10) just south of the spreading grounds. However, this clayey material was absent in the upper 75 feet in hole 1N/4W-23Q5 (fig. 10) 0.1 mile north.

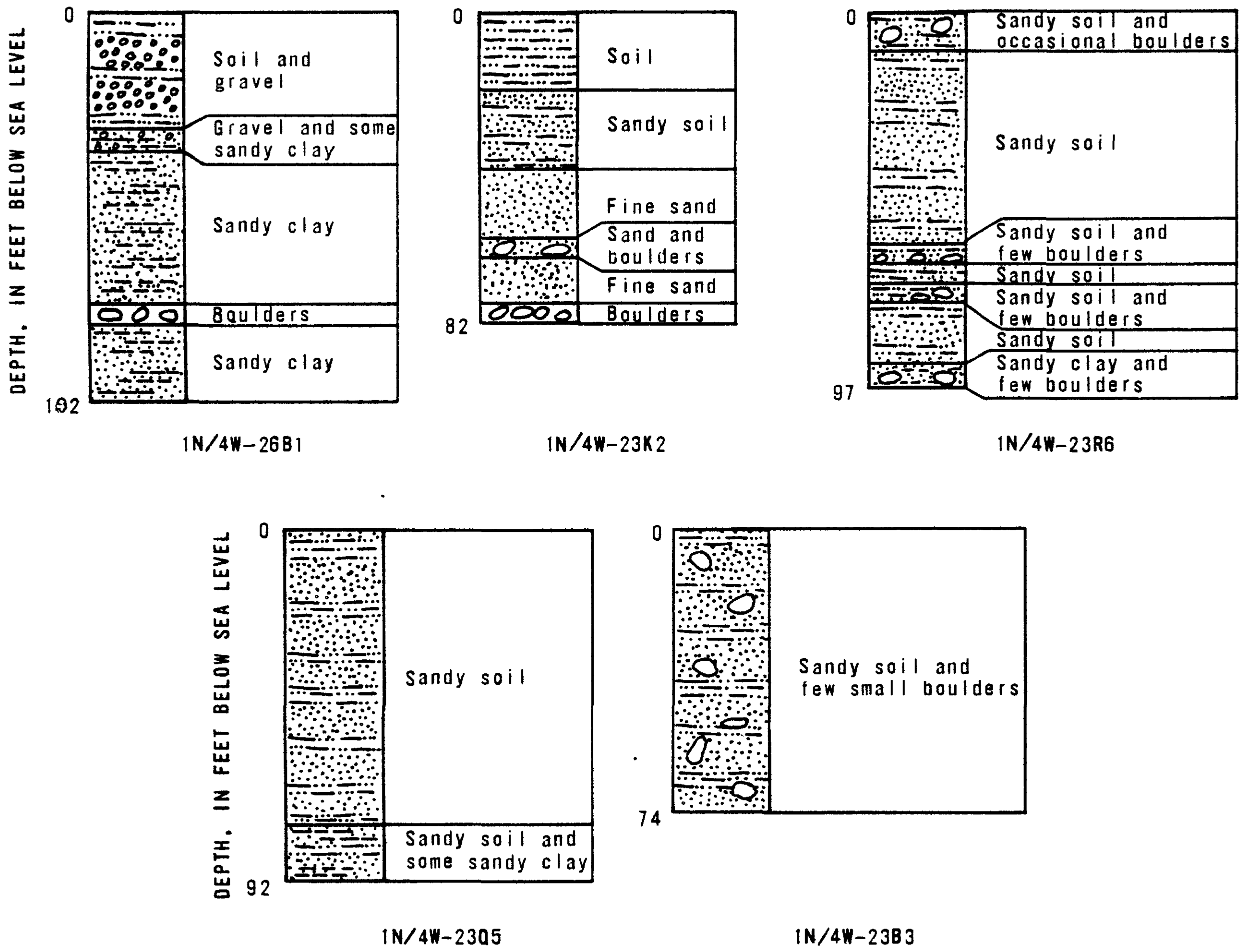


FIGURE 10.--Lithologic logs of auger holes.

Infiltration Rate

The capability of a spreading ground to accept recharge through surface spreading depends on its infiltration capacity. Moreland (1972, p. 20) obtained an infiltration rate of 38 feet per day in the East Twin Creek spreading grounds during a 3-1/2 hour ring-infiltrometer test. This result suggests that the infiltration capacity of the spreading grounds is high. Moreland estimated that a long-term rate of 3 feet per day could be maintained if silt deposits were periodically removed from the site to prevent clogging. Assuming an infiltration rate of 3 feet per day, the infiltration capacity of the East Twin Creek spreading grounds is about 55,000 acre-feet per year.

The San Bernardino County Flood Control District conducted a flooding-type infiltration test in the Waterman Canyon spreading grounds in 1952 and obtained an infiltration rate of 3 feet per day (San Bernardino County Flood Control District, 1954).

During natural inflow into the basin in December 1970, the infiltration rate at the East Twin Creek spreading grounds was measured as 0.10 foot per day. This rate is too low to allow recharge of 30,000 acre-feet per year. However, this low rate was due to surface clogging by silt and flood debris. A higher rate can be expected in clean spreading grounds. This result emphasizes the necessity of keeping the spreading grounds clean to insure an adequate rate of infiltration.

Three geologic sections of the study area (figs. 11-13) show a trend from coarse-grained material to fine-grained material from north to south. At the spreading grounds no extensive impermeable layers are apparent. A clayey layer at a depth of about 200 feet below land surface begins about a quarter of a mile south of the spreading grounds (figs. 4 and 11-13). A second clayey layer, about 75 feet below land surface, begins about a mile south of the spreading grounds (figs. 4 and 11-13). Neither layer should impede recharge in the Waterman Canyon-East Twin Creek spreading grounds.

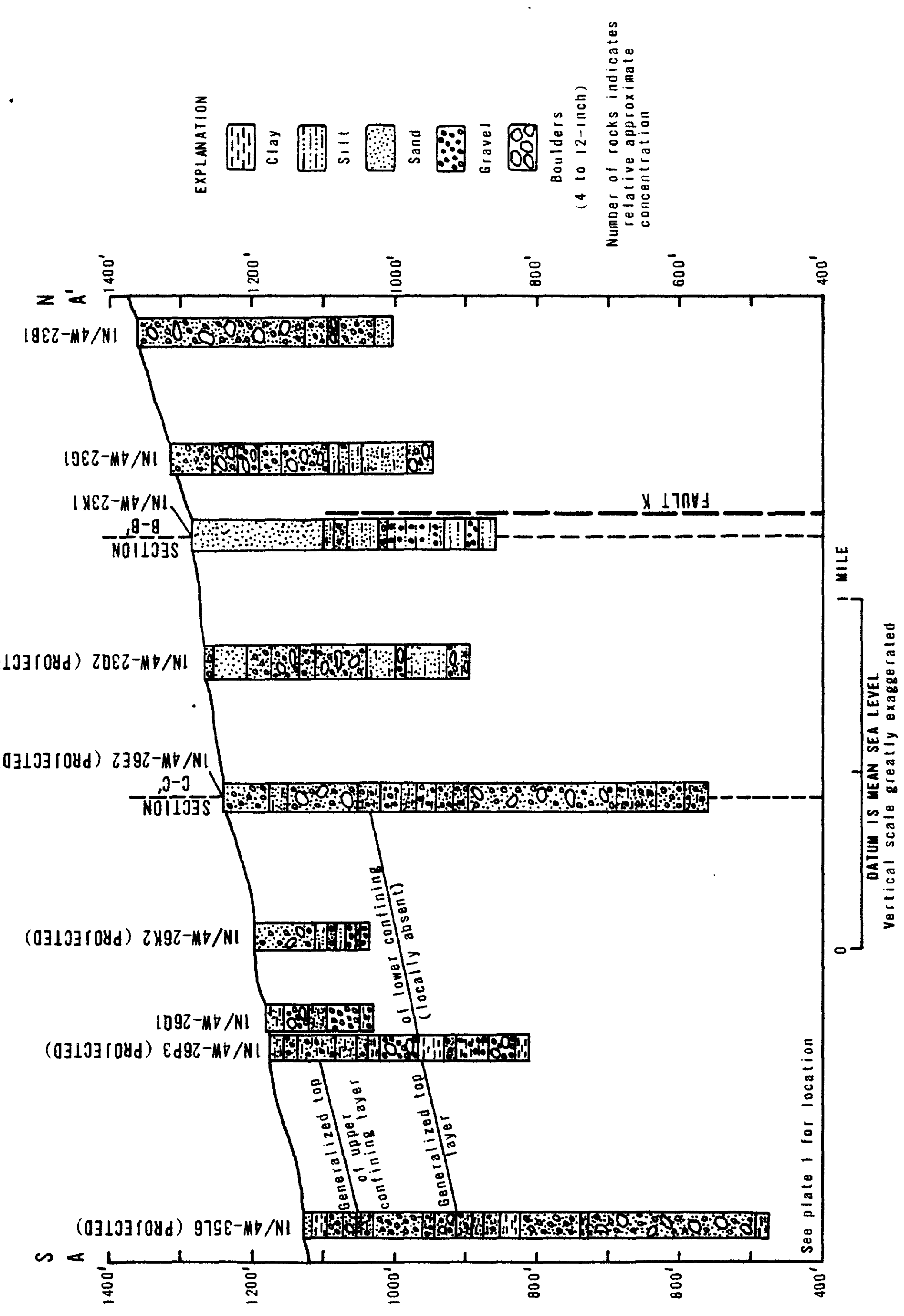


FIGURE 11.--Generalized geologic section A-A' of study area.

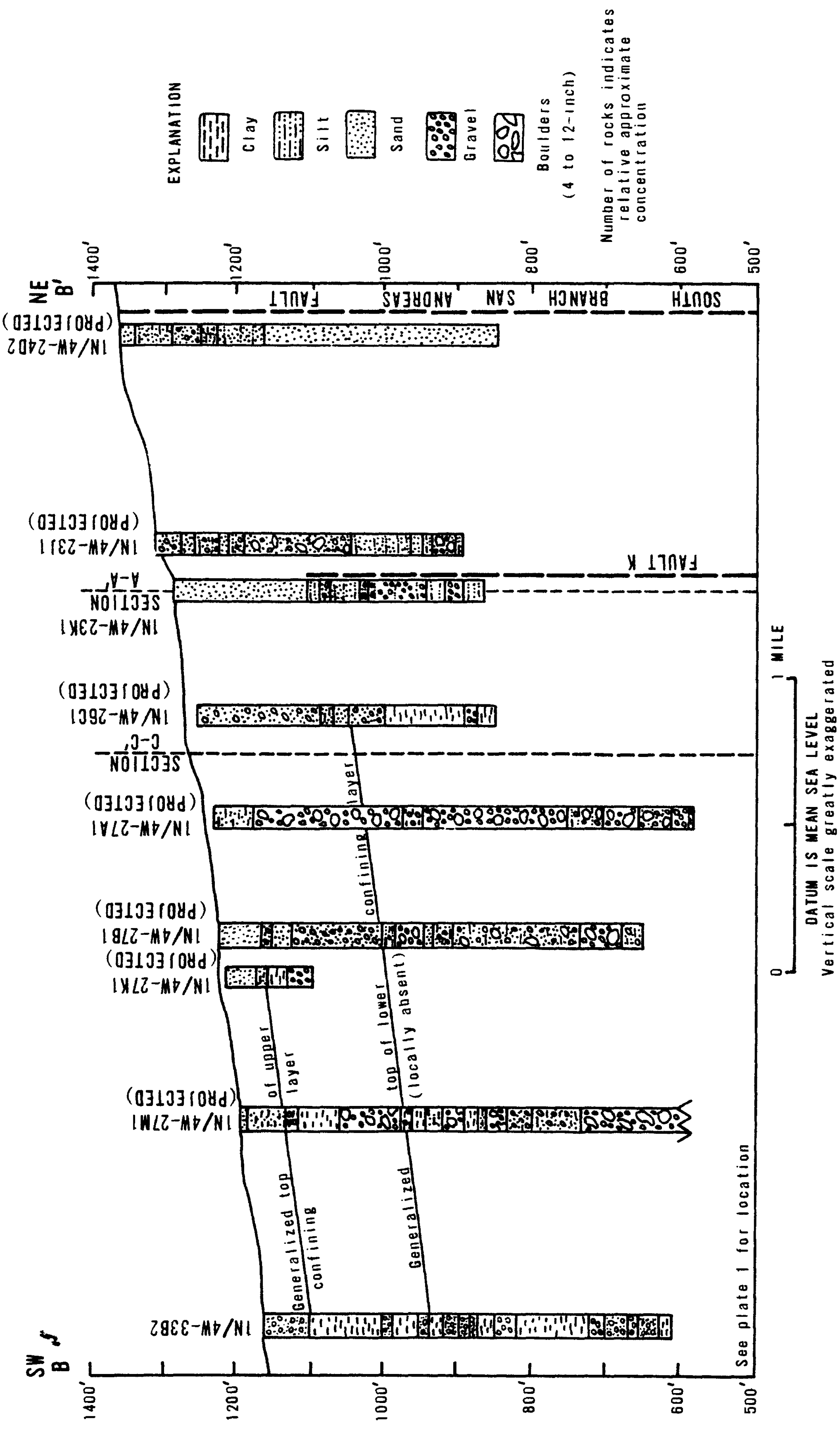


FIGURE 12.--Generalized geologic section B-B' of study area.

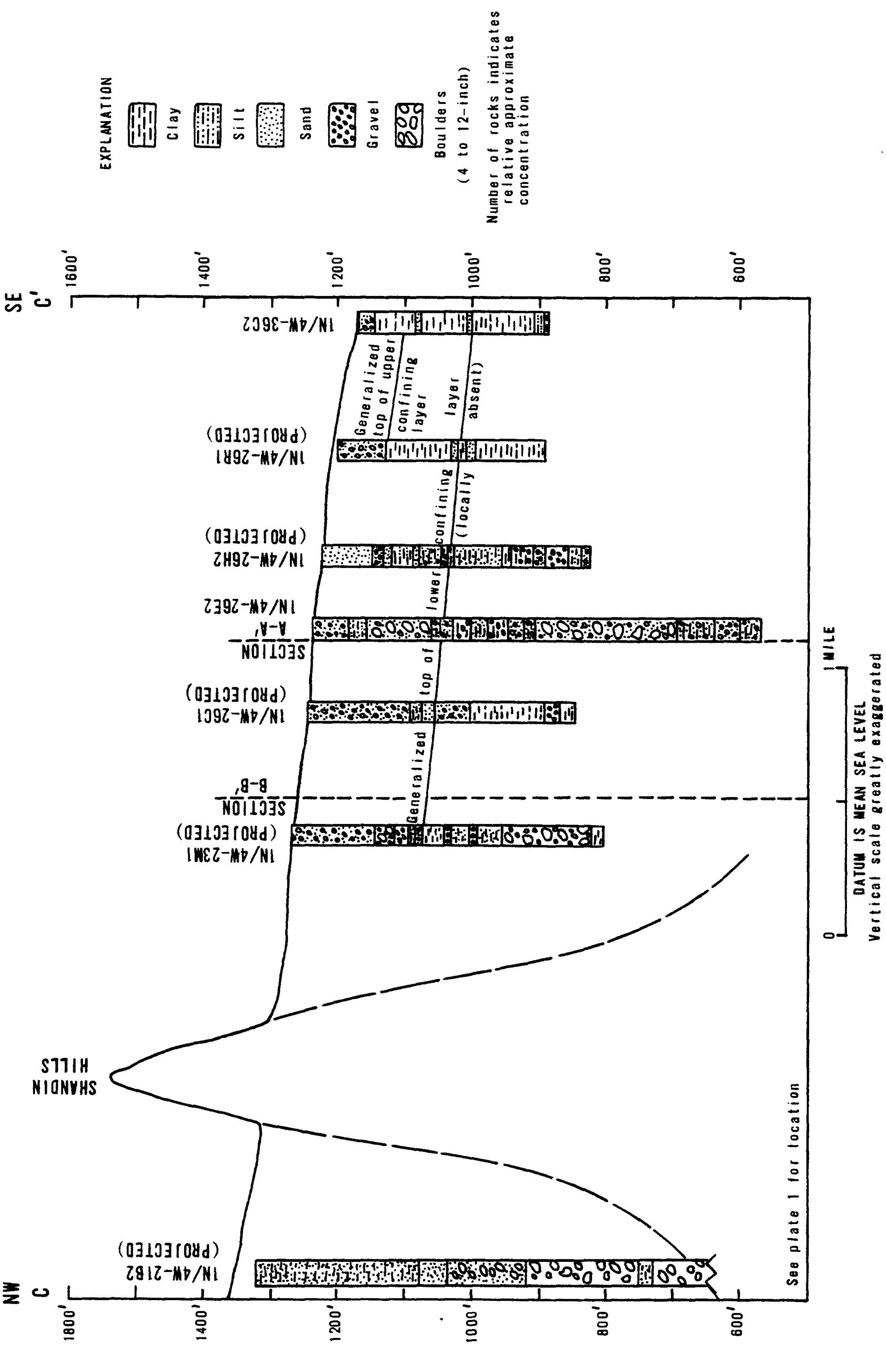


FIGURE 13.--Generalized geologic section C-C' of study area.

Fault K

Dutcher and Garrett (1963, p. 42) hypothesized the existence of fault K on the following evidence: (1) Water at a temperature of 51°C (124°F) was found between 397 and 448 feet in well 1N/3W-33M1, which is 500 feet deep, compared to water at a temperature of 23°C (74°F) in nearby well 1S/3W-4C1, which is 440 feet deep (Dutcher and Garrett, 1963, pl. 4); (2) The large change in altitude between the bench of older alluvium north of East Highlands and the younger alluvium southwest of that bench (Dutcher and Garrett, 1963, pl. 1); (3) Inconsistent ground-water gradients are present in the area of East Highlands. As originally postulated, fault K ended about 1 mile southeast of the study area. Dutcher and Garrett (1963, p. 42) suggested that fault K may extend into the Waterman Canyon-East Twin Creek area, flanking the east side of the bedrock hill north of the Shandin Hills (fig. 2).

In this study, it was determined that fault K did continue northwest into the study area as shown on plate 1, from the position postulated by Dutcher and Garrett. The extension of fault K is based on comparisons of water levels in wells in the Waterman Canyon-East Twin Creek area (pl. 1). For example, the water-level altitude in wells 1N/4W-23K1 and 23M1 (pl. 1) has been nearly the same. Well 1N/4W-23K1 is 1,850 feet southeast of well 23M1. The water-level altitude in well 1N/4W-23J1, located about 1,700 feet southeast of well 23K1, is about 40 to 50 feet higher than that in either well 23K1 or 23M1.

Water-level differences in other wells in the area also suggest that in the Waterman Canyon-East Twin Creek area fault K is a barrier to ground-water movement. The difference in water-level altitude between wells 1N/4W-25C2 and 1N/4W-25A1 (3,000 feet east of well 25C2) has ranged from about 60 to 120 feet; the present (1971) difference is about 117 feet. The difference in water-level altitude between wells 1N/4W-25A1 and 1N/3W-30C2 (2,250 feet east of well 25A1) has historically been about 10 feet; the present (1971) difference is about 3 feet.

The past difference between the water-level altitude in wells 1N/4W-25C2 and 1N/4W-24N1 (1,500 feet north of well 25C2) was about 85 feet, whereas the difference in the water-level altitude in wells 24N1 and 1N/4W-24M1 (1,500 feet north of well 24N1) was about 20 feet.

A large pumping depression surrounds well 1N/4W-25C2 (pl. 2). Several other wells of comparable capacity and output are found in the area, but none has a comparably steep cone of depression around it. Pumping tests show that the specific capacity of well 25C2 has ranged from 30 to 52 gpm (gallons per minute) per foot of drawdown, whereas the specific capacities for other wells in the area range from 52 to 63. The lithology of the sediments penetrated by well 25C2 appears to be similar to lithologies penetrated by adjacent wells. A plausible explanation for the relatively low specific capacity of well 25C2 is that fault K impedes the movement of ground water from the north (fig. 10).

Dana (1968) conducted a gravity-meter survey in 1968 in the Waterman Canyon-East Twin Creek area to determine the location of faults. His data suggest that fault K is close to the location shown in this report. Dana (1968) interpreted fault K to be an extension of the Shandin Hills fault (fig. 2). However, this interpretation was not substantiated by water-level records obtained during the present study. Dana's survey corroborated the hypothesis of Dutcher and Garrett (1963, p. 42) that the area between fault K and the San Andreas fault is a graben.

Water levels in the wells near the Waterman Canyon-East Twin Creek spreading grounds indicate that during 1971 the altitude of the water table on the north side of fault K was 40 to 50 feet higher than on the south side of the fault (pl. 2). A seismic survey made along the East Twin Creek spreading grounds (Bechtel, 1970) suggested a change in the altitude of the water table of about 50 feet near fault K. Thus, fault K has a significant effect on the movement of ground water in the Waterman Canyon-East Twin Creek area (pl. 2) and acts as a partial barrier to ground-water movement.

The transmissivity of fault K is a measure of its effectiveness as a barrier to ground-water movement. The transmissivity of fault K can be calculated utilizing the law of continuity and Darcy's law. The underflow per unit width across the fault equals underflow per unit width away from the fault. Thus:

$$TI \text{ (across the fault)} = TI \text{ (away from the fault)}$$

where T is the transmissivity, in gallons per day per foot of width; I is the average hydraulic gradient, in feet per foot. The coefficient of transmissivity may be estimated by multiplying the specific capacity (rate of discharge of water from a well divided by the drawdown of water level) of wells by 2000 (Thomasson, Olmsted, and LeRoux, 1960). In the area near the spreading grounds, data suggest that the specific capacity may be about 50 to 60 gpm per foot of drawdown, which suggests a T, away from the fault, of about 100,000. The gradient, I, away from the fault, varies considerably because of nearby pumping wells but averages about 60 to 70 feet per mile. Assuming a fault width of about 500 feet and an offset of the water table of about 50 feet across the fault, solution of the above equation yields a value of 13,250 for the approximate transmissivity of fault K.

The barrier effects displayed by fault K are probably due to fault gouge or chemical cementation in adjacent sand and gravel beds or both. During the drilling of the test wells, cemented sand and gravel were found.

EFFECTS OF RECHARGE

One purpose of the project was to develop a water-level monitoring program to determine the effects of the planned spreading operations. As presently developed, the program is restricted to monitoring only the effects of recharge near the spreading grounds. Digital water-level recorders were installed at each of the test-well sites to monitor fluctuations in the water table. Multiple casings were installed in each of the test holes and checked monthly to monitor the possible formation of perched water bodies where layers of low permeability were suspected.

The effects of recharge on the ground-water regimen in the Waterman Canyon-East Twin Creek area will depend largely on how effective fault K is as a barrier near the land surface. Fault K has no apparent surface expression; therefore, the highly permeable younger alluvium probably has not been affected by the fault. If, during the spreading operations, the recharge mound rises above the top of the fault, then the difference in altitude of the water table on each side of fault K should decrease because the recharged water will move freely through the younger alluvium above the fault. However, if fault K is an effective ground-water barrier above the water table, the change in water-table altitude across the fault probably will increase. The effectiveness of fault K as a barrier in the material above the present (1971) water table can best be evaluated after recharge begins. Monitoring of the observation wells near the spreading grounds as the planned recharge operation proceeds should provide the data to determine the barrier effect of fault K near the land surface.

CONCLUSIONS

The feasibility of recharging 30,000 acre-feet of water a year in the Waterman Canyon-East Twin Creek spreading grounds will depend on the effectiveness of fault K as a barrier to ground-water movement near the land surface. The results of the test-drilling operations indicate that the subsurface material at the spreading grounds is permeable enough to allow recharged water to percolate to the water table. Some sandy clay, silt, and cemented sand and gravel were found that may retard downward percolation of the recharged water and cause local perched water bodies. However, none of these low permeability layers seemed to be extensive enough to seriously impede recharge in the basin.

As suggested by Dutcher and Garrett (1963), fault K extends into the Waterman Canyon-East Twin Creek area and may impede the lateral movement of recharged water. In this area the fault acts as a partial barrier to ground-water movement. The difference in the water level across the fault was about 40 to 50 feet in 1971. Fault K has no known surface expression and therefore probably does not affect the highly permeable younger alluvium. Thus, as the recharge mound rises nearer the land surface, the fault will be less effective as a barrier to ground-water movement. Monitoring of the observation wells near the spreading grounds as the planned recharge operation proceeds should provide data about the hydrologic effects of fault K near the land surface.

FUTURE INVESTIGATIONS

Prior to the planned recharge operations an expanded monitoring network should be set up over a wide area around the Waterman Canyon-East Twin Creek spreading grounds to determine the regimen of ground-water movement. Two critical areas that should be monitored are the area of confined water in central San Bernardino (pl. 1) and the area southeast of the spreading grounds and north of fault K.

Recharge of imported water may cause artesian wells in the area of confined water to flow. Monitoring the area to the southeast of the spreading grounds is needed to evaluate the effectiveness of fault K as a barrier to ground-water movement. If fault K is an effective barrier, much of the recharged water should move southeastward toward Sand and City Creeks (not shown). As there are few wells in the area east of the spreading grounds, several observation wells should be drilled to monitor the movement of ground water in that direction.

Fault L (fig. 2) should be investigated to evaluate its effects on ground-water movement. If fault K acts as an effective barrier during recharge, then much of the water recharged will move southeastward toward Sand Creek and City Creek. A seismic survey along Sand Creek (Bechtel, 1970) near fault K indicated no discontinuity in the water table. This suggests that fault K may not be an effective barrier to ground-water movement in that area. Therefore, water moving southeastward from the Waterman Canyon-East Twin Creek area may be able to cross fault K in this area. Thus, fault L may be more important as an influence on ground-water movement. The possible effects on ground-water movement become even more significant when potential artificial recharge in Sand or City Creeks is considered. An investigation of the barrier effects of fault L should be made before imported water is recharged in Sand or City Creeks.

A chemical survey of the quality of water should also be conducted before the arrival of the imported water. This survey will allow better determination of any change in water quality due to the mixing of imported water with native water.

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