# GROUND-WATER MONITORING AT SANTA BARBARA, CALIFORNIA

## PHASE 1—COASTAL MONITOR-WELL INSTALLATION AND INITIAL MEASUREMENTS

U.S. GEOLOGICAL SURVEY

Open-File Report 79-923

Prepared in cooperation with the
City of Santa Barbara

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

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By C. B. Hutchinson

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Menlo Park, California
July 1979

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## CONVERSION FACTORS

The inch-pound system of units is used in this report. For readers who prefer metric units, the conversion factors for the terms used in this report are listed below.

| Multiply | By | To obtain |
|---|---|---|
| acres | 0.4047 | ha (hectares) |
| acre-ft (acre-feet) | 0.001233 | $hm^3$ (cubic hectometers) |
| acre-ft/yr (acre-feet per year) | 0.001233 | $hm^3$/yr (cubic hectometers per year) |
| ft (feet) | 0.3048 | m (meter) |
| gal/min (gallons per minute) | 0.003785 | $m^3$/min (cubic meters per minute) |
| in (inches) | 25.4 | mm (millimeters) |
| Mgal/d (million gallons per day) | 3,785 | $m^3$/d (cubic meters per day) |
| mi (miles) | 1.609 | km (kilometers) |
| $mi^2$ (square miles) | 2.590 | $km^2$ (square kilometers) |

Abbreviations used:
- mg/L (milligrams per liter)
- µg/L (micrograms per liter)
- µmho/cm at 25°C (micromhos per centimeter at 25° Celsius)

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## ABSTRACT

Plans to reduce natural ground-water storage in the 7-square-mile Santa Barbara ground-water basin have caused concern about possible saltwater intrusion into the coastal freshwater aquifer. To give advance warning of such intrusion, two multipiezometer wells were installed along the coast, about half a mile and 1 mile from the pumping center. Each site contains four small-diameter wells, completed at depths between 95 and 800 feet, which monitor water levels and water quality in (1) the shallow zone above the producing zones, (2) the upper producing zone, (3) the lower producing zone, and (4) the deep zone below the producing zones.

The wells were measured and sampled initially in September 1978 during a 2-million gallons per day pumping phase of the municipal supply wells. In the eight samples collected, dissolved-solids concentrations ranged from 450 to 6,290 milligrams per liter and chloride concentrations ranged from 35 to 2,800 milligrams per liter. At the site farther from the center of pumping the well monitoring the upper producing zone was the only one with a water level below sea level, and it produced the water of poorest quality. At the site nearer the center of pumping water levels in both producing zones and the deep zone were between 2 and 18 feet below sea level, with the water of poorest quality occurring in the lower producing zone.

Although the dissolved-solids concentrations are high in several zones, the potential for saltwater intrusion can be reliably evaluated only after analysis of long-term records. A program for collecting such data includes monthly water-level measurements, semiannual water-quality analyses, and biweekly to monthly measurements of specific conductance and chloride concentration.

# INTRODUCTION

During the past 24 years the city of Santa Barbara has received 86 percent of its water supply from surface reservoirs and 14 percent from wells. Although water supplies are considered to be adequate through 1983 (City of Santa Barbara, Public Works Department, written commun., 1979) without modification of the present system, decreasing efficiency of the surface reservoirs because of siltation and the effects of the mid-1970's drought will place increasing stress on the resources of the Santa Barbara ground-water basin. On the basis of recommendations of an engineering report (Owen, 1976), the city plans to reduce the ground water in storage by about 10,000 acre-ft in the 7-square-mile ground-water basin over a period of 5 to 10 years. The withdrawal should lower water levels 25 to 50 ft in some areas of the basin, thereby providing storage space to receive additional natural recharge and artificial recharge (Brown and Caldwell, 1973). Pumping would be centered in the city less than 1 mi inland from the coast.

Grateful acknowledgment is herein made to City of Santa Barbara officials who facilitated the location of well-drilling sites. Special appreciation is extended to the officials at the city of Santa Barbara Animal Shelter for their cooperation during the construction at well site CM-2.

## Purpose and Scope

The anticipated decline in water levels caused by increased pumping in the Santa Barbara basin may allow saltwater intrusion into the freshwater aquifer. To evaluate the effects of the pumping, the city of Santa Barbara entered into a cooperative study with the U.S. Geological Survey to develop and implement a ground-water monitoring program.

The study is programed for 4 years and is divided into three phases:

1. Coastal monitor-well drilling. The coastal monitor wells will be used to obtain water-level measurements and water samples for chemical analysis at multiple depths to detect any saltwater intrusion into the freshwater aquifer at two locations along the coast.
2. Ground-water basin monitoring. A water-level and water-quality monitoring network throughout the basin will be implemented to observe the effects of increased ground-water withdrawals and to serve as a base for possible later construction of a computer model of the ground-water basin.
3. Ground-water model. A computer model would provide a management tool for efficient utilization of the resources of the ground-water basin. Implementation of this phase will be decided at a later date.

This report is about phase 1. It describes the construction of the coastal monitor wells, presents the results of initial measurements, and recommends a program for monitoring water levels and water quality. Phases 2 and 3 will be covered in subsequent reports.

## Geohydrologic Setting

The Santa Barbara ground-water basin underlies the city of Santa Barbara and is situated along the south coast of Santa Barbara County (fig. 1). The aquifer has a maximum thickness of about 2,000 ft and comprises poorly sorted gravel, sand, and clay of the marine Santa Barbara Formation of Pliocene and Pleistocene age interfingered with its continental equivalent, the Casitas Formation of Pleistocene age, and overlain by alluvium of Holocene age (Muir, 1968, p. A6). Consolidated rocks of Tertiary age underlie the reservoir.

The ground-water basin is bounded on the north by consolidated rocks, on the west by a ground-water divide and an unnamed fault, on the south by the Lavigia fault and either the Pacific Ocean or an unnamed offshore fault, and on the east by a ground-water divide. Hydrologically, the ground-water basin is divided into three storage units in the horizontal plane by the Mesa and Mission Ridge faults, which may be barriers to the movement of ground water. Electric logs of wells indicate that the water-bearing material of the basin constitutes one aquifer that can be subdivided into at least four zones by leaky confining clay layers that may not be continuous. These four zones are herein designated as the shallow zone, upper producing zone, lower producing zone, and deep zone. The shallow zone is usually cased off in municipal supply wells. The upper and lower producing zones are so named because they are tapped by all the supply wells. The deep zone is untapped, and it may contain water of poor quality.

Development of ground-water supplies in storage units I and II has been primarily for municipal use. During 1975, pumpage totaled 449 acre-ft; however, the preceding 24-year average (1951-74) was 1,755 acre-ft (Owen, 1976, p. 3.9), which approximates the lower limit of estimated perennial yield of the basin. Muir (1968, p. A23) estimated the perennial yield of the basin to be between 1,700 and 2,000 acre-ft/yr. Currently, five active municipal supply wells in the city have pumping capacities ranging from 420 to 750 gal/min. Total pumping capacity of the five wells is just over 2 Mgal/d, which represents 2,200 acre-ft/yr. The wells pump water from zones that are 72 to 700 ft below land surface. At least one additional production well is proposed.

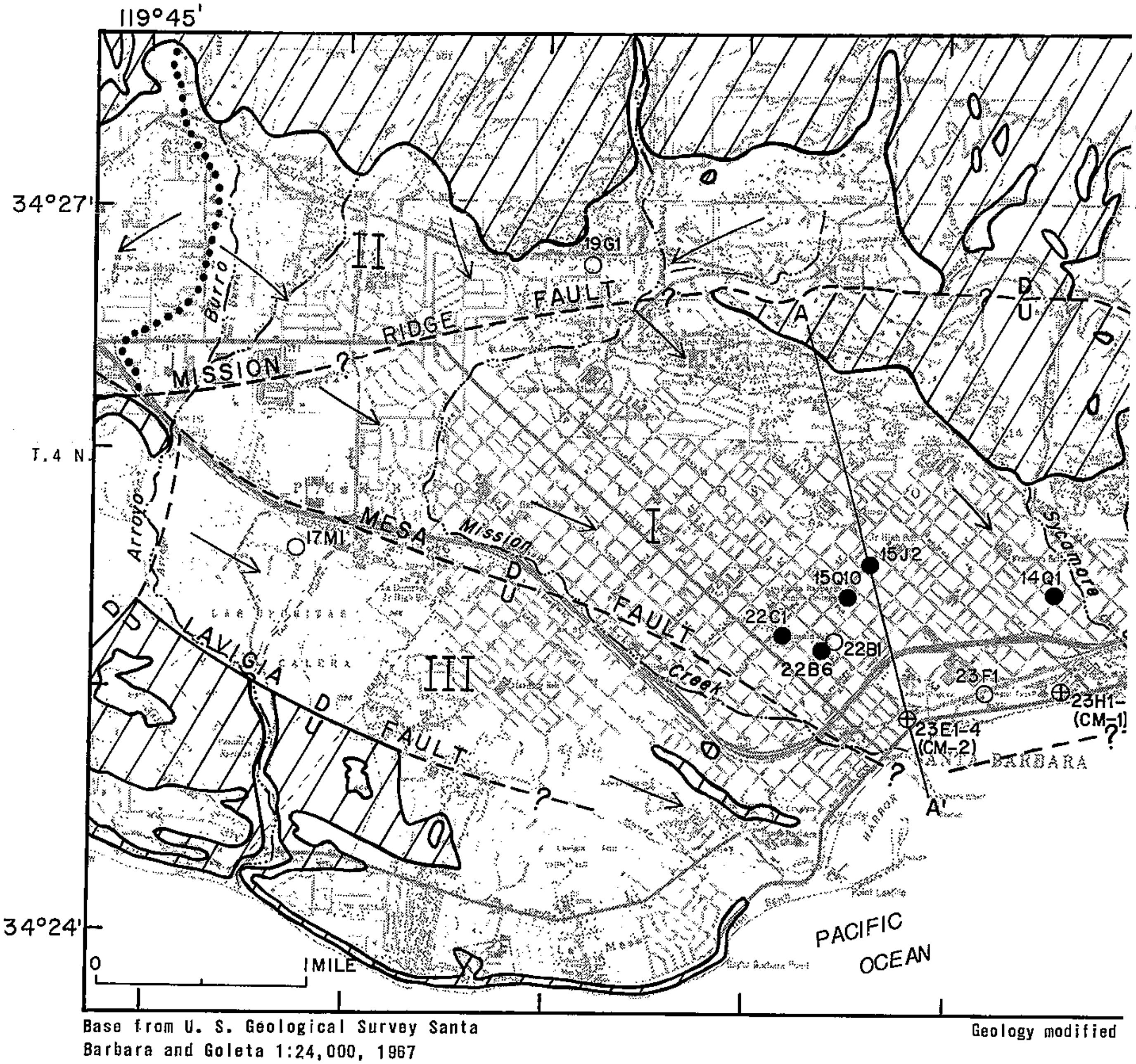
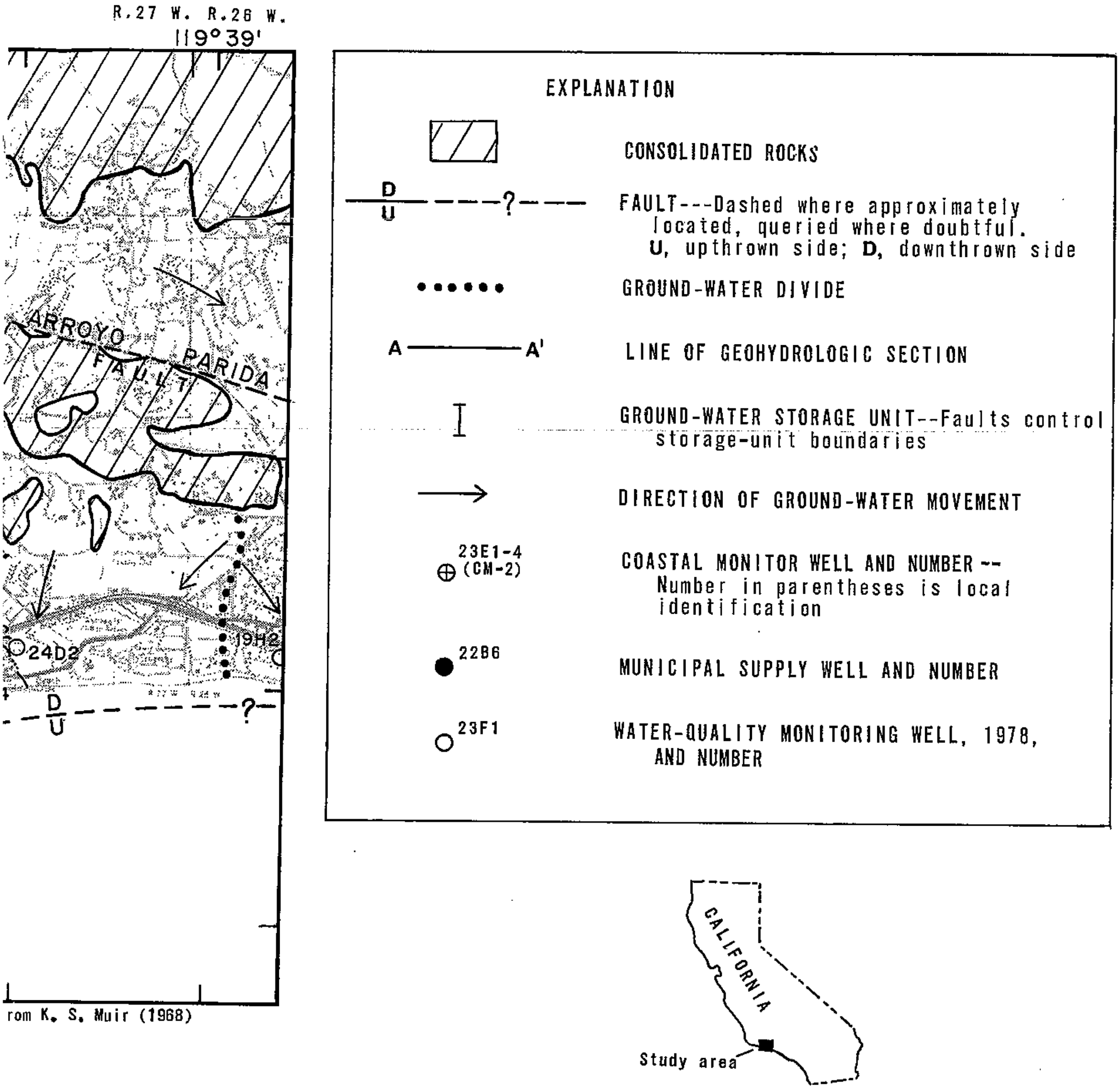



FIGURE 1.--Ground-water storage units, directions of ground-water movement,




enters of pumping, and coastal monitor wells, Santa Barbara ground-water basin.

## 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 4N/27W-14Q1, the part of the number preceding the slash indicates the township (T. 4 N.); the number following the slash indicates the range (R. 27 W.); the number following the hyphen indicates the section (sec. 14); the letter following the section number indicates the 40-acre subdivision according to the lettered diagram below. The final digit is a serial number for wells in each 40-acre subdivision.

| | | | |
|---|---|---|---|
| D | C | B | A |
| E | F | G | H |
| M | L | K | J |
| N | P | Q | R |

# COASTAL MONITOR WELLS

## Selecting the Well Sites

The coastal monitor wells are intended to provide an early warning of saltwater intrusion into the freshwater aquifer of storage unit I underlying the city of Santa Barbara; therefore, the wells were located near the shoreline to be between the ocean and the center of pumping (fig. 2). If the wells had been intended to monitor the extent of saltwater intrusion, they would have been located along a line from the pumping center to the coast. At each site, wells were installed in the shallow zone, the upper producing zone, the lower producing zone, and the deep zone to permit determination of the vertical distribution of water levels and water quality. The well sites are shown in figure 1.

Well site CM-1 (coastal monitor 1) is about 1 mi east of the pumping center and 300 ft from the ocean. The site was selected on the basis of its proximity to the ocean and the unnamed offshore fault. It is in an area where water levels would be below sea level in an overdraft situation simulated by a mathematical model (Brown and Caldwell, 1973, fig. 7-3).

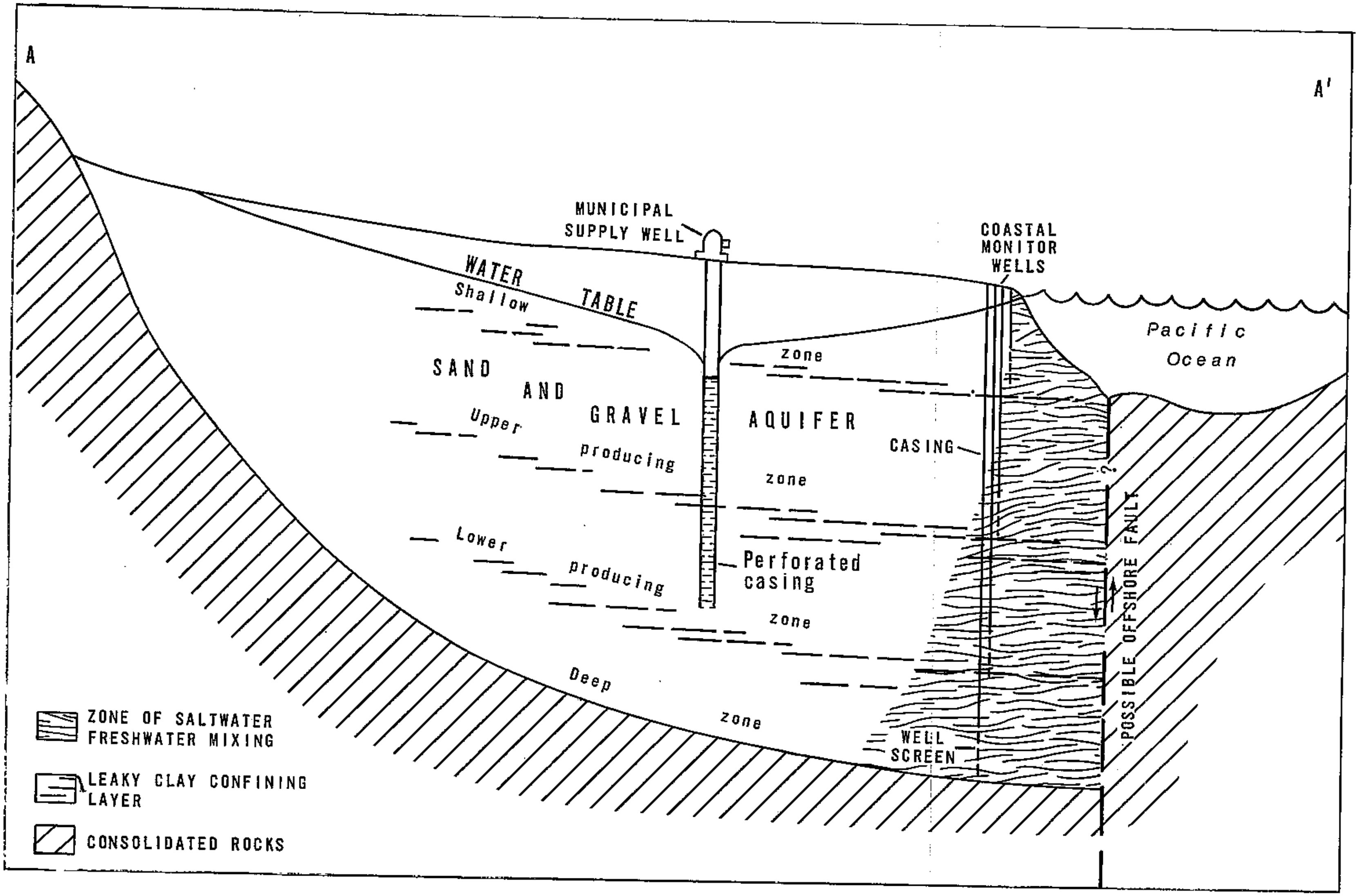



FIGURE 2.--Diagrammatic geohydrologic section through the Santa Barbara ground-water basin. See figure 1 for location of section.

Well site CM-2 (coastal monitor 2), near the west boundary of storage unit I, is about 500 ft from the coast and half a mile south of the pumping center. This site was selected on the basis of its proximity to both the Mesa fault and the unnamed offshore fault that parallels the coast. It is in an area of maximum potential drawdown predicted along the coast in a mathematical model simulating overdraft conditions in the basin (Brown and Caldwell, 1973, fig. 7-3).

Because the well sites are within 3,000 ft of the Pacific Ocean, construction permits were required from the California Coastal Commission. Construction permits were also issued by the city of Santa Barbara, Public Works Department. Local gas, electric, water, and telephone companies were notified of the intent to drill holes near the roadside.

## Technical Drilling Specifications

A set of technical drilling specifications, or compilation of work orders, was prepared for the purpose of controlling drilling, logging, installation, and development of the coastal monitor wells. The specifications, filed with the Santa Barbara Public Works Department, formed the basis for contractual bidding by well-drilling companies.

## Well Logs

A lithologic log of each well was compiled from analysis of drill cuttings. Electric logs and gamma-ray or caliper logs were correlated with the lithologic logs to determine the depths for setting the well screens and cement plugs. The lithologic logs are presented in table 1. Logging methods are pictured in figure 3.

Lithologies of both test holes consist of interbedded sand and clay, generally becoming finer grained with depth. At site CM-1 the electric log indicates four sand zones (70-110, 185-345, 380-650, 675-850 ft) separated by distinct clay layers (fig. 4); hence, selection of monitoring zones was relatively straightforward. At site CM-2 identification of the four principal zones was difficult because of the presence of many sand and clay layers.

TABLE 1.--Lithologic logs of monitor wells

| Depth below land surface (ft) | Lithology |
|---|---|
| Site CM-1; Well 4N/27W-23H1; total depth, 850 ft; altitude of land surface, 7 ft. Drilled by Valley Pump and Supply Co., July 1978. | |
| 0-50 | Sand, very fine to fine, clayey, yellowish-brown. |
| 50-70 | Sand, fine, with clayey gravel, yellowish-brown. |
| 70-95 | Sand, fine, yellowish-brown with clean gravel. |
| 95-110 | Sand, very fine to fine, yellowish-brown. |
| 110-185 | Clay, sandy, with grains ranging from very fine to coarse, some gravel, hard drilling 145-148 ft; intermittent hard and soft drilling 155-170 ft. |
| 185-215 | Sand, very fine, occasional very coarse grains, clayey (45 percent), yellowish-brown. |
| 215-230 | Sand, very fine, clayey (40 percent), very coarse sand, yellowish-brown, and gravel (20 percent). |
| 230-260 | Sand, very fine, clayey (50 percent), yellowish-brown. |
| 260-345 | Sand, very fine to fine, silty, gravel and cobbles of various rock types (sandstone, quartz, chert, serpentine), pine needles, and wood fragments, yellowish-brown to olive-gray. |
| 345-380 | Clay, silty with subangular gravel, yellowish-brown to olive-gray. |
| 380-390 | Sand, fine to medium, with subangular to angular gravel, olive-brown. |
| 390-455 | Sand, fine to medium, clayey, with subangular gravel, olive-brown. |

TABLE 1.- Lithologic logs of monitor wells--Continued

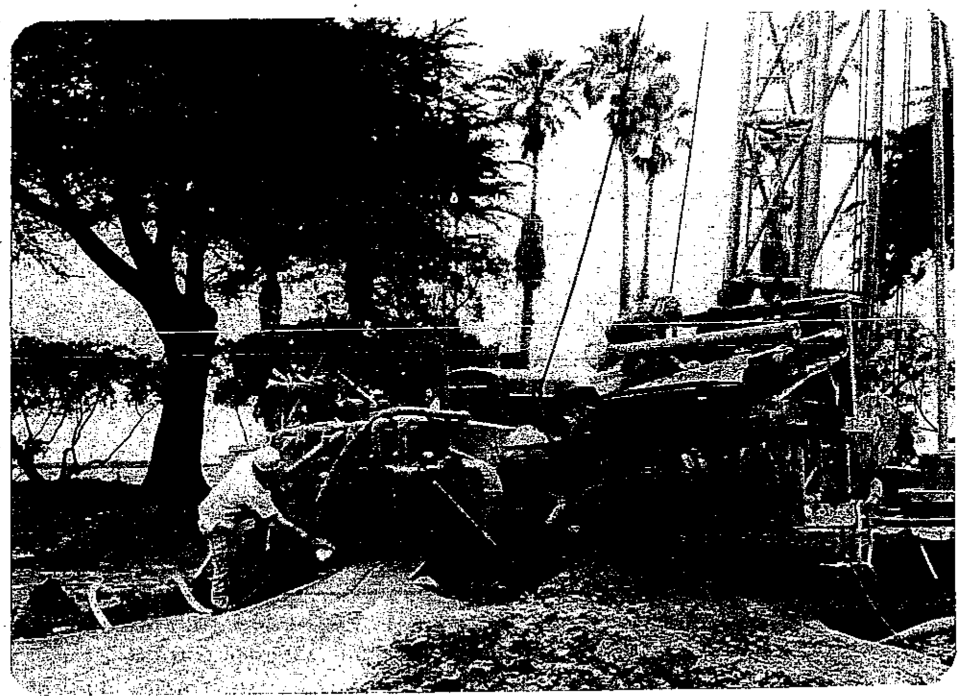
| Depth below land surface (ft) | Lithology |
|---|---|
| | Site CM-1--Continued |
| 455-540 | Sand, fine to coarse, clayey, with small gravel. Change in formation color ranges from light olive gray (salt and pepper) for the sand to darker olive gray for the clay. |
| 540-570 | Clay, sandy, with subangular to subrounded gravel, olive-gray. |
| 570-650 | Sand, very coarse, slightly clayey, some gravel, olive-brown to olive-gray. |
| 650-675 | Clay, sandy, silty (10 percent), occasional coarse grains, olive-brown to olive-gray. |
| 675-850 | Sand, medium to coarse, silty, clayey, some small gravel and shell and wood fragments, olive-gray sand and clay. |
| | Site CM-2; Well 4N/27W-23E1; total depth, 850 ft; altitude of land surface, 7.5 ft. Drilled by Valley Pump and Supply Co., August 1978. |
| 0-25 | Sand, fine to coarse, subrounded to rounded, some gravel, clayey, olive-gray. |
| 25-35 | Clay, sandy, with grains ranging from silt size to small gravel, gravel subrounded to rounded, olive-gray. |
| 35-60 | Sand, medium to coarse, subrounded to rounded, predominantly quartz grains, wood fragments and chips (to 50 percent), some evidence of mollusks, plant fibers (5 percent), olive-gray to black. |
| 60-85 | Clay, sandy, very fine to medium sand (40 percent), well rounded, some gravel, subrounded to rounded, olive-gray. |

TABLE 1.- Lithologic logs of monitor wells--Continued

| Depth below land surface (ft) | Lithology |
| --- | --- |
| | Site CM-2--Continued |
| 85-95 | Clay, sandy, with inclusions or stringers of very fine sand, sand, and gravel (20 percent), olive-gray. |
| 95-105 | Clay, sandy, sand, and sandstone gravel (20 percent), subrounded to rounded, olive-gray. |
| 105-140 | Clay, sandy, with fine to medium sand (10 percent), few pebbles, probably formation change, mixture of colors, olive-brown and grayish-olive. |
| 140-160 | Sand, medium, subrounded to rounded, predominantly quartz with few small pebbles, clay, grayish-olive and olive-brown. |
| 160-180 | Sand, medium to coarse, subangular, some gravel and small pebbles, few plant fibers, olive-brown. |
| 180-190 | Sand, medium to coarse, well sorted, subrounded to rounded, slightly clayey, olive-brown. |
| 190-200 | Clay, sandy, subangular to angular gravel, some rock chips and plant fibers, olive-brown to olive-gray. |
| 200-255 | Sand, very fine to very coarse, silt and gravel, subangular to rounded, some pebbles, sample poorly sorted, very clayey (40 percent), olive-brown. |
| 255-290 | Sand, very fine to very coarse, poorly sorted, subangular, gravel composed of sandstone, chert, serpentine, and shale, clayey, olive-brown. |
| 290-340 | Clay, sandy, subangular to rounded sand and gravel (15 percent), some plant fibers, olive-gray to yellowish-brown. |
| 340-390 | Sand, medium to coarse, some gravel, subangular to subrounded, clayey, olive-gray. |

TABLE 1.- Lithologic logs of monitor wells--Continued

| Depth below land surface (ft) | Lithology |
|---|---|
| | Site CM-2--Continued |
| 390-450 | Clay, sandy, medium to coarse (40 percent), subrounded, olive-gray. |
| 450-475 | Gravel, sandy, with chert, sandstone, and serpentine pebbles, subangular to subrounded, clayey, olive-gray. |
| 475-510 | Clay, sandy, medium to coarse, subrounded, some gravel, olive-gray. |
| 510-565 | Sand, very coarse, with gravel and pebbles, angular to subrounded, clayey, shell fragments, olive-gray. |
| 565-590 | Sand, very fine to coarse, clayey (40 percent), shell fragments (5 percent), olive-gray. |
| 590-605 | Sand, very fine to coarse, clayey (20 percent), shell fragments (15 percent), olive-gray. |
| 605-620 | Sand, very fine to coarse, clayey (40 percent), shell fragments (5 percent), olive-gray. |
| 620-660 | Clay, sand, very fine to coarse sand (40 percent), shell fragments (5 percent), olive-gray. |
| 660-740 | Clay, sandy, silt to coarse sand (15 percent), olive-gray. |
| 740-800 | Sand, medium to coarse, clayey (30 percent), some shell fragments, olive-gray. |
| 800-850 | Clay, sandy, fine to medium sand (15 percent), olive-gray. |



A. Lithologic logs were made from formation samples mechanically separated from the drilling fluid. Gravel and clay balls are removed as fluid passes through a shaker screen (right); then sand is removed by centrifugal desanding cones (left).

B. Geophysical logs, consisting of electric and gamma-ray or caliper logs, were run in the open borehole.

FIGURE 3.--Logging methods utilized for the coastal monitor wells.

## Well Construction

A generalized construction diagram of the completed coastal monitor wells is shown in figure 4. Small-diameter screens were placed opposite sand and gravel zones selected on the electric logs.

At each site, three 2-inch wells and one 4-inch well were arranged so that zones above, within, and below the 200- to 600-foot producing zones can be monitored for water levels and water quality. The 4-inch well was completed in the upper producing zone to allow for placement of continuous-recording equipment in that zone if it is deemed necessary.

At each site a 15-inch test hole was drilled, by the rotary method, to a depth of 850 ft. Casings and screens were placed at selected depths; in turn, the wells were gravel packed and cement-grout seals placed opposite confining layers above and below each producing zone to prevent vertical movement of water in the borehole. Because the wells were not intended for production, the screen-slot size and gravel-pack size were determined from analyses of the lithology of nearby test holes (Brown and Caldwell, 1973, appendix B) rather than from actual well cuttings. The wells were developed by the air-surge method, test pumped to determine yield, and finally completed as coastal monitor wells (table 2 and fig. 5).

The technical drilling specifications called for use of an organic-polymer drilling fluid rather than a conventional bentonite mud. The organic polymer breaks down by bacterial action, whereas bentonite forms a cake on the borehole wall that must be removed during development of the well. The organic polymer was specified because of anticipated problems arising through development of the 15-inch borehole through the 2-inch or 4-inch well screens. Halfway through the gravel packing of the wells at site CM-1 the hole collapsed, probably as a result of breakdown of the polymer fluid. The upper three casings were pulled and reinstalled in a new hole, 50 ft to the west, that was drilled with bentonite mud. The deep-zone monitor was left in the collapsed hole. Bentonite mud was also used to drill the test hole at site CM-2. The seven wells installed in holes drilled with bentonite mud yielded 2 gal/min or more, but the well drilled with the organic polymer fluid produced only 0.3 gal/min.

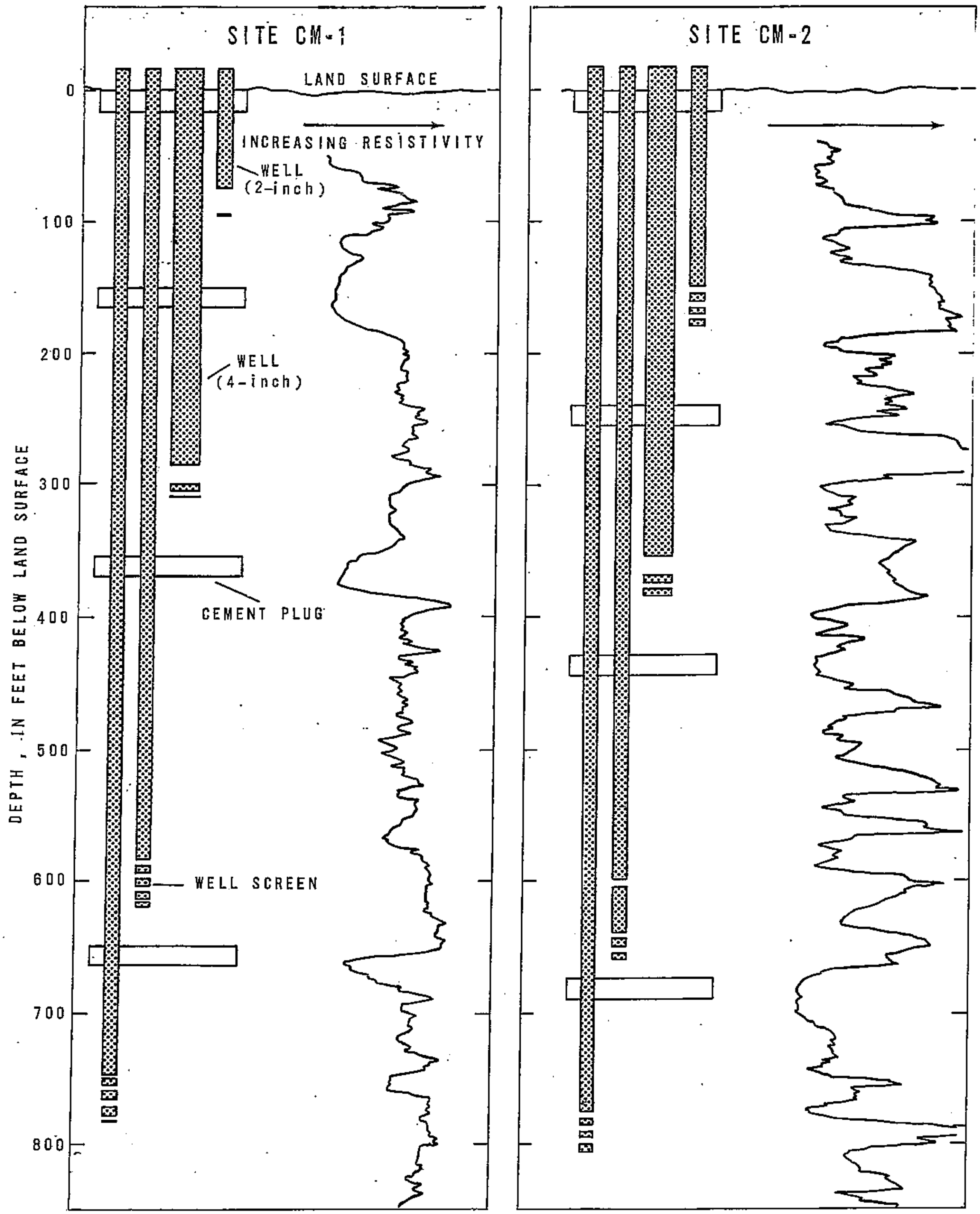
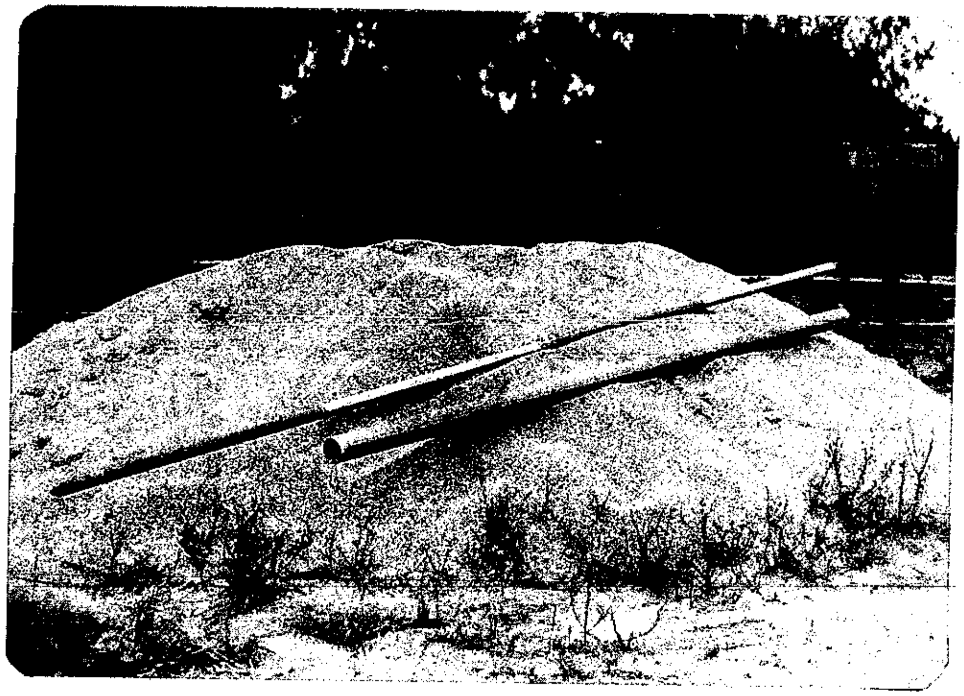



FIGURE 4.--Multiple-cased wells at the coastal monitor sites.

Table 2.--Construction and yield characteristics of coastal monitor wells

| Monitor Well | State well identification/ location | Diameter (in) | Depth (ft) | Depth intervals of screens (ft) | Depth interval of cement (ft) | Altitude of land surface (ft) | Altitude of top of casing (ft) | Yield (gal/min) |
|---|---|---|---|---|---|---|---|---|
| CM-1.1 | 4N/27W-23H1 | 2 | 781 | 746.5-751.5, 756.7-761.7, 766.9-771.9, 777.5-781 | 655-670 | 7 | 7.91 | 0.3 |
| CM-1.2 | 4N/27W-23H2 | 2 | 620 | 585.5-590.5 595.7-600.7, 605.9-610.9, 616.5-620 | 355-370 | 7 | 7.67 | 3.7 |
| CM-1.3 | 4N/27W-23H3 | 4 | 310 | 284-299, 304.5-310 | 150-165 | 7 | 8.48 | 3.75 |
| CM-1.4 | 4N/27W-23H4 | 2 | 95 | 75.5-91, 91.5-95 | 0-15 | 7 | 7.60 | 6.6 |
| CM-2.1 | 4N/27W-23E1 | 2 | 800 | 775-780, 785-590, 795-800 | 675-690 | 7.5 | 8.40 | 8 |
| CM-2.2 | 4N/27W-23E2 | 2 | 655 | 600-605, 640-645, 650-655 | 430-445 | 7.5 | 8.46 | 4.8 |
| CM-2.3 | 4N/27W-23E3 | 4 | 380 | 355-370, 375-380 | 240-255 | 7.5 | 9.71 | 1.9 |
| CM-2.4 | 4N/27W-23E4 | 2 | 175 | 150-155, 160-165, 170-175 | 0-15 | 7.5 | 8.41 | 3 |



A. Two- and four-inch well screens were centered in the borehole at selected depths, then packed with 1/8- to 1/4-inch gravel.


B. The gravel pack was initially placed by washing it down through the drill stem, which was set at a desired depth. The gravel repeatedly bridged in the stem, so this method was abandoned in favor of shoveling in the gravel from the surface while circulating fluid through the drill stem to prevent bridging.

FIGURE 5.--Construction of the coastal monitor wells.

## MONITORING RESULTS AND SCHEDULE

### Water Levels

Currently (1978), the city of Santa Barbara measures water levels monthly in 17 observation wells scattered throughout the basin. One purpose of this network is to define areas where water levels are below sea level. Such areas are subject to intrusion by seawater when there is a reversal of the water-table gradient. The coastal monitor wells were added to the network in September 1978. Results of water-level monitoring will be included in the phase 2 report.

The initial water levels (table 3) in the coastal monitor wells reflect pumping of about 2 Mgal/d in the basin. Pumping had been continuous for 2 weeks. Where the water levels are below sea level, it may be assumed that the zone is influenced by pumping from the city's production wells and from other wells in the area. As anticipated, water levels in the producing zones at site CM-2, near the pumping center, are lower than those at the more distant site CM-1.

TABLE 3.--Water levels in the coastal monitor wells

| Monitor well | Date | Altitude of water level (ft) | Monitored zone |
|---|---|---|---|
| CM-1.1 | 9-29-78 | 0.92 | Deep |
| CM-1.2 | 9-29-78 | 4.06 | Lower producing |
| CM-1.3 | 9-29-78 | -3.53 | Upper producing |
| CM-1.4 | 9-29-78 | 4.95 | Shallow |
| CM-2.1 | 9-29-78 | -14.03 | Deep |
| CM-2.2 | 9-29-78 | -2.49 | Lower producing |
| CM-2.3 | 9-29-78 | -17.39 | Upper producing |
| CM-2.4 | 9-29-78 | 6.02 | Shallow |

## Water Quality

Currently, chemical analyses of common ions, nutrients, and trace metals are made semiannually on water in the city's five production wells. The coastal monitor wells will be added to this program. In addition, they will be sampled biweekly or monthly for chloride analysis and specific-conductance determination to ascertain trends in water quality that may relate to pumping from the production wells. The water-quality sampling technique is illustrated in figure 6.

A centrifugal pump is used to sample the coastal monitor wells. Enough water is withdrawn to displace twice the volume of water in the casing to ensure that a representative sample of formation water is collected. For the semiannual chemical analysis the water is immediately analyzed for specific conductance, temperature, and pH; samples are then filtered and preserved for shipment to the Geological Survey's National Water Quality Laboratory in Denver, Colo. Biweekly or monthly samples will be analyzed in the field for specific conductance and at the Santa Barbara Water Treatment Plant for chloride.

FIGURE 6.--Water-quality sampling technique.

Results of the initial sampling of the coastal monitor wells and municipal supply wells are compared by use of stiff diagrams in figure 7, and chemical analyses of water from four municipal supply wells, six privately owned wells, and the eight coastal monitor wells are presented in table 4. Water from the municipal supply wells has a calcium bicarbonate to calcium sulfate type of composition with dissolved-solids concentrations ranging from 455 to 986 mg/L, but the quality varies areally. The dissolved-solids concentration at the distant Voluntario well (4N/27W-14Q1) is about twice that measured at the other municipal supply wells which are clustered about 1 mi to the west. The Voluntario well is deeper and has a longer perforated interval than the other wells; hence, it may be drawing water of poor quality from shallow or deep zones. Water from the private wells generally is of poorer quality than water from the municipal supply wells. These wells primarily tap

TABLE 4.--Chemical analyses of water

[Constituents and hardness are in

| State well identification/location | Well name or owner | Date of sample | Well depth (ft) | Depth of first perforation (ft) | Specific conductance (µmho/cm at 25°C) | pH | Hardness as $CaCO_3$ | Calcium | Magnesium | Sodium |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | MUNICIPAL SUPPLY WELLS | | | | | | |
| 4N/27W-14Q1 | Voluntario well | 3-13-78 | 700 | 72 | 1,440 | 7.1 | 630 | 160 | 56 | 90 |
| 4N/27W-15Q10 | Corporation well | 3-13-78 | 655 | 195 | 780 | 7.3 | 330 | 89 | 27 | 21 |
| 4N/27W-22B6 | Vera Cruz Park well | 3-13-78 | 670 | 210 | 750 | 7.3 | 330 | 88 | 27 | 44 |
| 4N/27W-22C1 | City Hall well | 3-13-78 | 615 | 180 | 685 | 7.3 | 300 | 81 | 24 | 39 |
| | | | | PRIVATE WELLS | | | | | | |
| 4N/26W-19H2 | Biltmore Hotel | 6-08-78 | 150 | -- | 1,240 | 6.6 | 430 | 110 | 38 | 110 |
| 4N/27W-19G1 | Glendessary well | 3-16-78 | 273 | 179 | 1,170 | 6.5 | 470 | 95 | 57 | 77 |
| 4N/27W-17M1 | Las Positas Water Co. | 3-17-78 | 375 | 75 | 1,150 | 7.4 | 410 | 110 | 34 | 40 |
| 4N/27W-22B1 | Ambassador Laundry | 3-13-78 | -- | -- | 920 | 7.1 | 320 | 82 | 28 | 78 |
| 4N/27W-23F1 | Artesia Water Co. | 3-06-78 | 500 | -- | 690 | 7.0 | 260 | 64 | 25 | 55 |
| 4N/27W-24D2 | Murphy Park well | 3-15-78 | 473 | 131 | 6,700 | 6.9 | 2,600 | 580 | 290 | 370 |
| | | | | COASTAL MONITOR WELLS[1] | | | | | | |
| 4N/27W-23E1 | CM-2.1 | 9-29-78 | 800 | 775 | 2,430 | 7.4 | 880 | 240 | 69 | 170 |
| 4N/27W-23E2 | CM-2.2 | 9-28-78 | 655 | 600 | 8,500 | 6.8 | 3,400 | 910 | 280 | 430 |
| 4N/27W-23E3 | CM-2.3 | 9-28-78 | 380 | 355 | 705 | 7.0 | 280 | 79 | 21 | 48 |
| 4N/27W-23E4 | CM-2.4 | 9-28-78 | 175 | 150 | 630 | 8.5 | 200 | 62 | 12 | 57 |
| 4N/27W-23H1 | CM-1.1 | 9-30-78 | 781 | 746.5 | 3,750 | 7.2 | 630 | 170 | 130 | 130 |
| 4N/27W-23H2 | CM-1.2 | 9-30-78 | 620 | 585.5 | 1,680 | 7.1 | 560 | 150 | 45 | 100 |
| 4N/27W-23H3 | CM-1.3 | 9-30-78 | 310 | 284 | 7,250 | 6.7 | 3,300 | 810 | 320 | 11 |
| 4N/27W-23H4 | CM-1.4 | 9-29-78 | 95 | 75.5 | 2,660 | 6.9 | 980 | 290 | 62 | 130 |

[1]Monitored zone given in table 3.

the shallow zone and upper producing zone. At site CM-2 water in the shallow zone and upper producing zone has the same general ionic makeup as that from the municipal supply wells. In the lower producing zone and deep zone at site CM-2 and in all zones at site CM-1, the water is a calcium chloride type, has a considerably higher dissolved-solids concentration, and generally exceeds recommended levels of chloride and iron (National Academy of Sciences, National Academy of Engineering, 1972). The water from the deep zone at site CM-1 (4N/27W-23H1) apparently is contaminated with drilling fluid, as the concentration of dissolved potassium of 580 mg/L is about 100 times that observed in the other samples. Potassium chloride was added as a stabilizer to the organic-polymer drilling fluid during construction of the borehole. Future samples should show a decrease in the concentrations of potassium and chloride as the well is pumped and this drilling fluid is removed.

in the Santa Barbara ground-water basin

milligrams per liter except where noted]

| Potassium | Bicarbonate | Alkalinity as $CaCO_3$ | Sulfate | Chloride | Fluoride | Silica | Dissolved solids | Nitrite plus nitrate as N | Boron (μg/L) | Iron (μg/L) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | MUNICIPAL SUPPLY WELLS--Continued | | | | | | |
| 2 | 330 | 270 | 340 | 130 | 0.5 | 29 | 986 | 3.7 | 200 | 30 |
| 1 | 230 | 190 | 120 | 59 | .4 | 33 | 506 | 4.6 | 40 | 110 |
| 2 | 300 | 250 | 110 | 37 | .3 | 33 | 494 | 1.0 | 50 | 490 |
| 1 | 250 | 210 | 120 | 26 | .3 | 33 | 455 | 1.5 | 50 | 290 |
| | | | | PRIVATE WELLS--Continued | | | | | | |
| 2 | 280 | 230 | 130 | 180 | 0.5 | 30 | 782 | 9.9 | 340 | 20 |
| .8 | 170 | 140 | 340 | 98 | .2 | 27 | 796 | 3.8 | 250 | 70 |
| 3 | 400 | 330 | 140 | 140 | .7 | 24 | 783 | .85 | 390 | 200 |
| 1 | 230 | 190 | 100 | 93 | .5 | 35 | 589 | 13 | 40 | 40 |
| 2 | 230 | 190 | 120 | 37 | .6 | 36 | 453 | -- | 90 | 500 |
| 4 | 250 | 210 | 270 | 2,000 | .3 | 35 | 3,680 | .79 | 140 | 360 |
| | | | | COASTAL MONITOR WELLS--Continued | | | | | | |
| 4 | 300 | 250 | 180 | 580 | 0.3 | 33 | 1,610 | 0.04 | 130 | 680 |
| 8 | 190 | 160 | 350 | 2,800 | .1 | 36 | 6,290 | .03 | 80 | 4,800 |
| 2 | 290 | 240 | 95 | 35 | .5 | 43 | 470 | .02 | 100 | 290 |
| 3 | 190 | 160 | 95 | 53 | .7 | 58 | 450 | .66 | 170 | 110 |
| 580 | 560 | 460 | 110 | 870 | .4 | 25 | 2,360 | .07 | 2,600 | 5,600 |
| 3 | 230 | 190 | 110 | 350 | .1 | 33 | 1,080 | .07 | 220 | 8,200 |
| 5 | 220 | 180 | 21 | 2,200 | .2 | 31 | 4,360 | .02 | 160 | 5,900 |
| 4 | 300 | 250 | 190 | 620 | .2 | 33 | 1,700 | .67 | 170 | 680 |

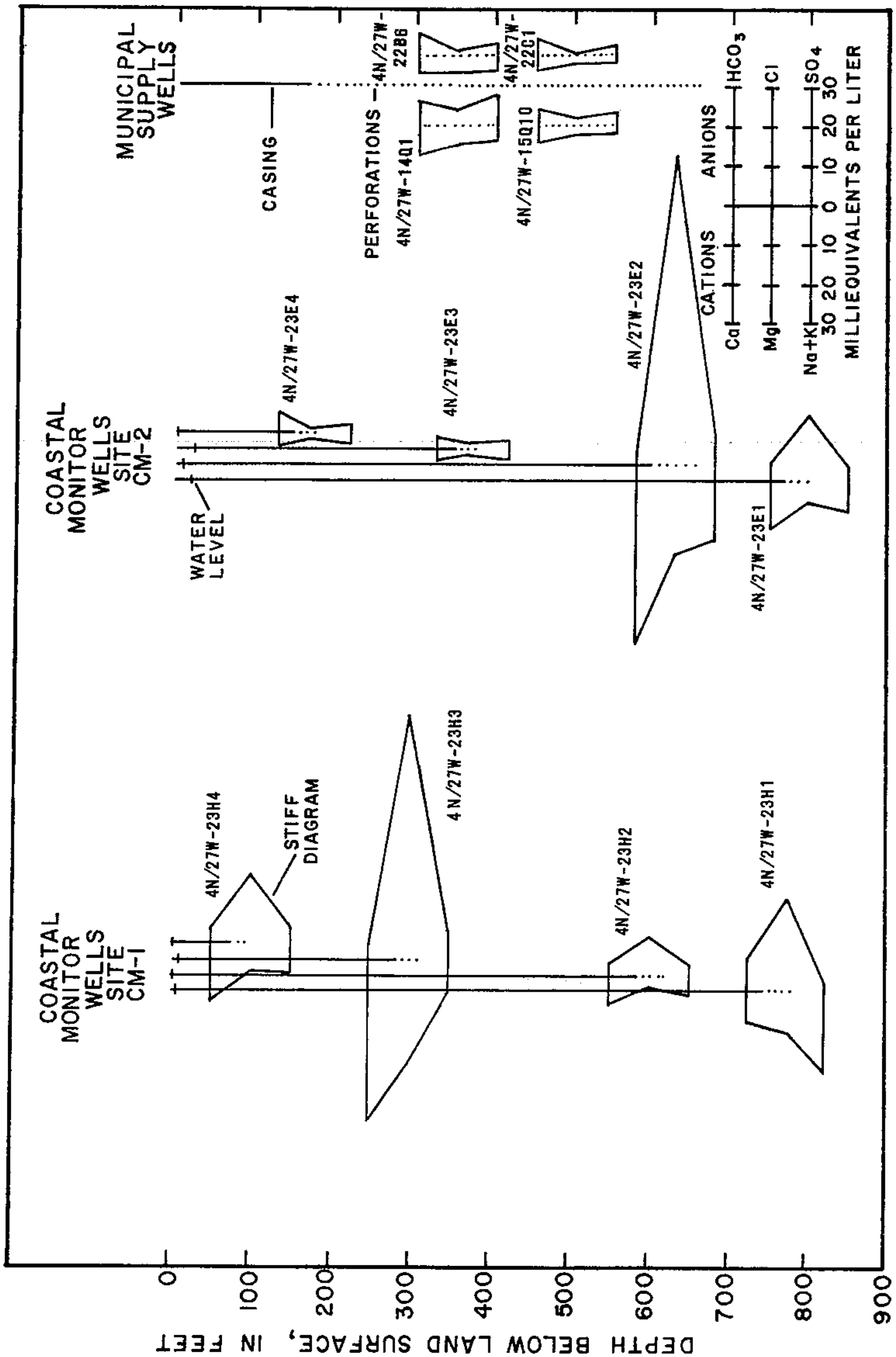



FIGURE 7.--Water levels and water quality in the coastal monitor wells.

Saltwater intrusion is a potentially serious problem in the Santa Barbara ground-water basin. It is important that the initial stages of saltwater intrusion be recognized so that steps can be taken to contain or reverse the situation.

Chloride is the major anion of seawater and is not readily sorbed to aquifer materials; therefore, it moves through the aquifer at about the same rate as the intruding water. Increases in chloride concentration in the aquifer are probably the first indication of saltwater intrusion. The chloride concentrations in samples collected from certain zones tapped by the coastal monitor wells (350-2,800 mg/L), significantly higher than background levels of chloride in the municipal supply wells (26-130 mg/L), indicate possible saltwater intrusion.

In a study of saltwater intrusion in the Torrance-Santa Monica area of southern California, about 75 mi south of Santa Barbara, Poland and others (1959, p. 3 and 222) determined that the contaminated water is not simply a mixture of the contaminant and native water but has been so greatly modified that the nature of the contaminant is obscure. Inasmuch as no known calcium chloride contaminant was known to exist, it was assumed that the contaminant was a sodium-chloride saline (seawater) chiefly modified by base exchange of calcium for sodium during blending with the native water. The similarity between water-quality characteristics at Santa Barbara and those at the Torrance-Santa Monica area, a known area of saltwater intrusion, suggests the possibility of saltwater intrusion into the freshwater aquifer at Santa Barbara. The only viable alternative would be the existence of connate water in the main producing zones. The rate of possible saltwater intrusion and the integrity of the offshore fault as a barrier to ground-water movement can only be evaluated through the long-term monitoring program.

## SUMMARY

This report presents the results of phase 1 of the Santa Barbara ground-water investigation; that is, to install coastal wells for the monitoring of water levels and water quality in multiple zones and, thereby, to detect possible saltwater intrusion into the freshwater aquifer.

Two 850-foot test holes were drilled 3/4 mi apart at the seaward edge of the Santa Barbara ground-water basin. Four small-diameter observation wells were installed at different depths at each site--one above, two within, and one below the producing zones tapped by municipal supply wells in the basin.

Initial water-level measurements were made and water-quality samples were collected in September 1978 during a pumping phase of the municipal supply wells. Zones having water levels below sea level or water of poor quality may be subject to saltwater intrusion. At site CM-1, about 1 mi from the pumping center, the well monitoring the upper producing zone was the only one whose water level was below sea level. At site CM-2, about half a mile from the pumping center, water levels in both producing zones and the deep zone were below sea level.

The quality of the ground water varies both horizontally and vertically. In the eight samples collected for the initial determination of water quality, dissolved-solids concentrations ranged from 450 to 6,290 mg/L and chloride concentrations ranged from 35 to 2,800 mg/L. The water of poorest quality at site CM-1 occurred in the upper producing zone and at site CM-2 in the lower producing zone. Water levels in these two zones were below sea level.

Water of poor quality occurs along the coast in zones tapped by the city's production wells. The source of this water, whether connate or underflow across the offshore fault, cannot be determined from a single sampling. The potential for saltwater intrusion into the freshwater aquifer can be truly evaluated only after careful analysis of long-term records. A program for collecting these data includes:

1. Monthly measurement of water levels in the eight wells.
2. Biweekly or monthly analysis of water from each well for specific conductance and chloride; semiannual analysis for common ions.

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