# WATER-QUALITY CONDITIONS AND AN EVALUATION OF GROUND- AND SURFACE-WATER SAMPLING PROGRAMS IN THE LIVERMORE-AMADOR VALLEY, CALIFORNIA

By Stephen K. Sorenson, Patricia V. Cascos, and Roy L. Glass

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[Plates are in pocket]



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# CONVERSION FACTORS

For readers who prefer to use the International System of units (SI) rather than inch-pound units, the conversion factors for the terms used in this report are listed below:

| Multiply | By | To obtain |
|---|---|---|
| acre | 0.4047 | square hectometer |
| acre-ft (acre-foot) | 1,233 | cubic meter |
| ft (foot) | 0.3048 | meter |
| $ft^2$ (square foot) | 0.09294 | square meter |
| gal/min (gallon per minute) | 0.2642 | liter per minute |
| mi (mile) | 1.609 | kilometer |
| $mi^2$ (square mile) | 2.590 | square kilometer |
| µmho/cm (micromho per centimeter) | 1.000 | microsiemens per centimeter |

Degree Fahrenheit is converted to degree Celsius by using the formula:

$$\text{Temp } ^\circ\text{C} = (\text{temp } ^\circ\text{F} - 32)/1.8$$

Explanation of abbreviations

| | |
|---|---|
| mg/L | Milligrams per liter |
| µg/L | Micrograms per liter |
| meq/L | Milliequivalents per liter |

Chemical concentrations in water are given in milligrams per liter (mg/L) or micrograms per liter (µg/L). Milligrams per liter is a unit expressing the solute per unit volume (liter) of water. One thousand micrograms per liter is equivalent to one milligram per liter.

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## ABSTRACT

A program to monitor the ground- and surface-water quality in the Livermore-Amador Valley has been operated since the 1976 water year. As of 1982, this monitoring network consisted of approximately 130 wells, about 100 of which were constructed specifically for this program, and 9 surface water stations. Increased demand on the ground water for municipal and industrial water supply has caused a decline in water levels in the past resulting in a closed ground-water basin with no outflow. The result has been a gradual buildup of salts from natural surface-water recharge and from land disposal of treated wastewater from several waste-treatment plants. Results of this study show that salt buildup in the ground water is the major problem with ground-water quality. Established water-quality objectives for dissolved solids were exceeded in 70 of 137 wells. Concentrations of dissolved nitrate in excess of basin objectives and health standards also were detected in several areas in the valley.

Water quality in both surface and ground water is highly variable areally. Magnesium to calcium magnesium bicarbonate ground water was detected in areas where most of the high volume municipal wells are located. Large areas of sodium bicarbonate water occurred in the northern part of the valley. Surface water was mostly mixed cation, bicarbonate water with the exception of the two stations on Arroyo Las Positas, which had sodium chloride water.

## INTRODUCTION

Water in the Livermore-Amador Valley is both a vital and scarce resource. The rapidly expanding urban population demands not only more water but means of treatment and disposal of wastewater. Water use in the Livermore-Amador Valley also has an impact on the water resources in the major ground-water basin near the end of Alameda Creek, the only stream draining the valley. Concerns for the quality and quantity of the limited water resources of this area have been the stimulus for scientific study, litigation, and formation of several private and governmental agencies since the early 1900's. This study is an outgrowth of recommendations and proposals from several of these previous studies, which indicated that a comprehensive monitoring network of both surface water and ground water was needed to document present conditions and to detect long-term trends in the valley's water resources.

### Purpose

The primary purpose of this report is to describe water-quality conditions in surface and ground water in the Livermore-Amador Valley. The basis for this description is the data collected, as a result of the cooperative monitoring program between the U.S. Geological Survey and the Alameda County Flood Control and Water Conservation District, Zone 7, from 1975 through 1982. An additional objective of the report is to evaluate the current monitoring program and to determine the frequency of sampling and type of analyses that will provide the best monitoring for future water-quality protection.

### Location and Description of Study Area

The study area includes Livermore and Amador Valleys and the southern part of San Ramon Valley. This area is 30-40 miles southeast of San Francisco (fig. 1). The ground-water basin covers about 63 $mi^2$. Pleasanton, Livermore, and Dublin are the major population centers.

### Previous Studies

Several studies of water-quality and water-resources development in the Livermore Valley have been done since the 1950's. A report by the California Department of Water Resources (1964) was the first large scale study of surface- and ground-water quality and hydrology in the area. The California Department of Water Resources (1974) discussed ground-water hydrology and water quality with an emphasis on hydrologic subbasins and also presented a ground-water-flow model for part of the Livermore Valley. One of the recommendations from that report was to install small-diameter, shallow- and medium-depth wells specifically for the purpose of monitoring water quality from known aquifers. That recommendation was the basis for the present monitoring program.

Two studies of ground and surface water in the Alameda Creek drainage basin have been published by the U.S. Geological Survey. Lopp (1981) made an appraisal of surface-water quality in the Alameda Creek basin for the period October 1974-June 1979. Sylvester (1983) studied land application of wastewater and its effect on ground-water quality in the Livermore-Amador Valley. Sylvester's report deals with ground-water quality in the wastewater-application areas in much greater detail than is covered in this report. That report also deals with time-trend variations in ground-water quality in the wastewater-application areas.

### Geologic Features

The valley ground-water basin is composed of alluvial deposits. The

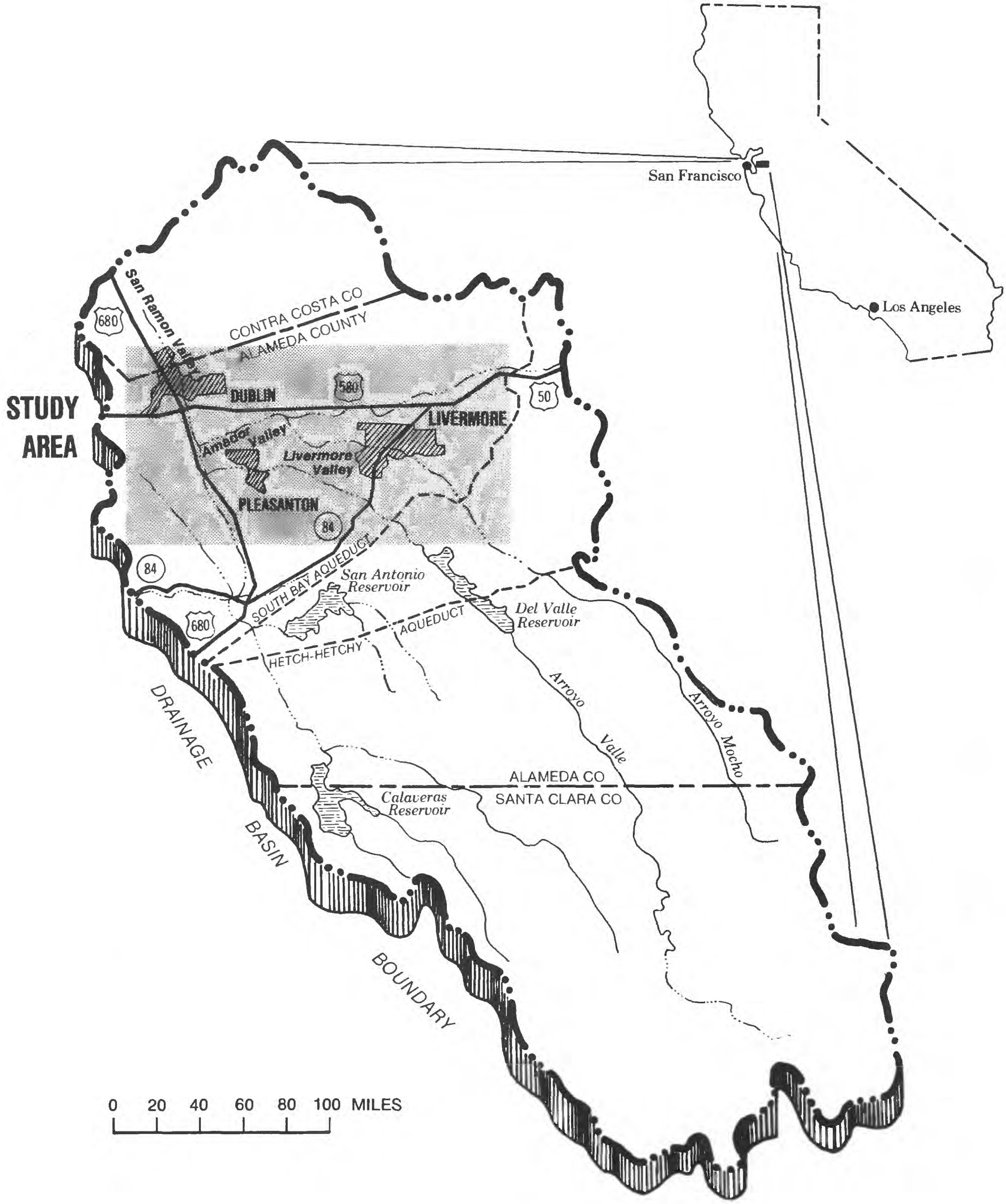



FIGURE 1. – Location of study area.

maximum depth of these deposits is less than 100 feet in the eastern part of Livermore Valley and increases to about 400 feet in the area east of Pleasanton. The water-bearing alluvium in the valley is composed of sand, gravel, and clay and is moderately to highly permeable. Confining beds of silty clays are found at various depths throughout the valley, and are extensive enough in some areas to define totally separate aquifers. The valley areas are underlain and are bordered on the south by the Pleistocene and Pliocene Livermore Formation (Clark, 1930), which consists of sand, gravel, and clay of moderate permeability. The Pliocene Tassajara Formation, bordering the valley to the north, is composed primarily of sandstone and claystone and is of low permeability. Both of these formations are from 4,000 to 5,000 feet thick, and although the formations are water bearing, wells completed in them are generally of low yield and produce moderately poor quality sodium bicarbonate water. Non-water-bearing formations composed mostly of marine sandstone, shale, siltstone, and conglomerate border the Amador and San Ramon Valleys on the west and the San Ramon Valley on the east.

A more detailed discussion of the geology of the study area is contained in publications by the California Department of Water Resources (1964 and 1974), and more recently in a series of geologic maps by Dibblee (1980a, 1980b, and 1980c). A generalized geologic map is presented by Sylvester (1983).

## Hydrologic Features

Four major streams drain the uplands surrounding the valley (pl. 1). Altamont Creek drains the northeastern part of the valley, originating where Altamont Creek joins Arroyo Seco, and the combined stream becomes Arroyo Las Positas, which continues westward to Arroyo Mocho north of Pleasanton. Arroyo Mocho drains the uplands to the southeast of the valley. After entering the valley it runs northwest and west until it joins Arroyo de la Laguna just north of Pleasanton. Arroyo Valle drains the uplands south of the valley. It is impounded about 1 mile upstream from the valley floor by Del Valle Dam, which is outside of the study area. Arroyo Valle flows generally west along the southern edge of the gravel pits, through the central part of Pleasanton, and joins Arroyo de la Laguna. South San Ramon Creek, which becomes Alamo Creek and then Alamo Canal, flows south out of San Ramon Valley and becomes Arroyo de la Laguna at the confluence with Arroyo Mocho. Arroyo de la Laguna, the only stream flowing out of the valley, connects with Alameda Creek. Other streams contribute flow to the valley only during the rainy season. These include Tassajara Creek, Cayetano Creek, Collier Canyon Creek, Arroyo Seco, and Dublin Creek. The South Bay aqueduct is located along the southeastern edge of the valley. Water is discharged from this aqueduct periodically at Altamont Creek (prior to 1982), Arroyo Mocho, and Arroyo Valle.

The Livermore, Amador, and San Ramon Valleys have been divided into 12 subbasins by the California Department of Water Resources (1974) (pl. 1). These subbasins were based on fault traces and hydrologic discontinuities. Mocho II, Amador, and Bernal are the most significant subbasins in terms of water capacity and usage.

## Past and Present Land Use

The Spanish, who arrived in the early 1800's, were the first western settlers in the Livermore-Amador Valley area. They established a large cattle industry that reached its peak in the 1850's when about 50,000 cattle were in the area. The first settlement, called Amador, was established in the early 1850's, and the 1860 census reported that 513 people lived in the valley. In the late 1850's and early 1860's, agriculture became the predominant industry in the valley. The most common crops in the early years were wheat, barley, and hay. In the 1880's, irrigated agriculture became established making it possible to grow such crops as hops, sugar beets, tomatoes, and grapes. Agriculture continues to be the predominant industry in the valley, but has declined in recent years because of the loss of farmland to urbanization and gravel-mining operations (Alameda County Flood Control and Water Conservation District, written commun., 1981).

## Water-Resources Development

Surface-water development in the Livermore-Amador Valley began in the late 1880's when small dams were constructed to divert water for irrigation. In 1898, the Spring Valley Water Co. constructed a group of wells in the Bernal well field west of Pleasanton. These wells were originally artesian. Water from these wells was discharged into Arroyo de la Laguna where it was carried to the Sunol filter galleries and then piped to San Francisco. The city of San Francisco purchased the Spring Valley Water Co. in 1930 and continued to pump water from the Bernal well field until 1934 when the Hetch Hetchy aqueduct was completed. Pumping by San Francisco was resumed for 2 years in 1948 when the second barrel of Hetch Hetchy aqueduct was under construction (Alameda County Flood Control and Water Conservation District, written commun., 1981).

Several private and governmental water purveyors and wholesalers have been established to provide water for domestic and industrial uses. These agencies include California Water Service Co., City of Livermore Water Service, City of Pleasanton Water District, Valley Community Services District (now called Dublin-San Ramon Services District), and Alameda County Flood Control and Water Conservation District, Zone 7 (hereinafter referred to as Zone 7).

Until 1962, most of the water used in the Livermore-Amador Valley was provided by ground water, with small quantities coming from local streams. This almost total dependence on ground water caused a serious overdraft in the valley, with water levels dropping 100 feet or more in some areas. In order to correct this overdraft situation, Zone 7 signed an agreement with the California State Water Project to provide water from the South Bay aqueduct starting in 1962. Zone 7 now operates two water-treatment plants in the Livermore Valley to directly treat the South Bay aqueduct water for domestic and industrial uses. Zone 7 also releases South Bay aqueduct water to Arroyo Mocho and Arroyo Valle for ground-water recharge. Currently (1983), Zone 7 has an annual entitlement of 46,000 acre-ft of South Bay aqueduct water.

In 1969, Del Valle Dam and Reservoir were completed, providing storage of South Bay aqueduct water and runoff from Arroyo Valle. This 77,000 acre-ft reservoir is operated by the California Department of Water Resources. Releases from the reservoir are used for ground-water recharge and municipal supply.

## Wastewater Treatment

Wastewater in the valley has historically been treated at various treatment plants and either applied to the ground surface by spray irrigation or discharged to percolation ponds and then released to streams for disposal.

In the Livermore area prior to 1959, wastewater was treated at a plant located near the intersection of Pine Street and Rincon Avenue and then disposed into percolation beds. In 1959, the present (1983) wastewater-treatment plant, east of the Livermore Municipal Airport, was put into service. This plant used percolation ponds, spray irrigation at the airport, nearby golf course and farmlands, and Arroyo Las Positas for effluent disposal. The Pleasanton wastewater-treatment plant has operated since 1910. Until 1949, this plant consisted of a large septic tank. After 1949, effluent was discharged to leach fields, used for spray irrigation, or released to percolation ponds until 1980 when the facility was closed. The Dublin-San Ramon Services District has operated a sewage-treatment plant northwest of Pleasanton since 1961. Sludge from this plant was discharged to drying beds on the property, and effluent was discharged to Alamo Canal. From 1940 to 1961, wastewater from Camp Parks was treated on site and discharged to surface water in the 1940's, and to oxidation ponds from 1950 to 1961. Other smaller, wastewater-treatment plants are located at Castlewood Country Club southwest of Pleasanton, the Veterans Administration Hospital along Arroyo Valle, and Coast Manufacturing Co. in Livermore. Since January 1980, most effluent from the three major plants in the valley has been exported to San Francisco Bay via a pipeline.

## DESIGN AND IMPLEMENTATION OF THE MONITORING NETWORK

The monitoring program operated jointly by the U.S. Geological Survey and Alameda County Flood Control and Water Conservation District, Zone 7 began in 1975. The original design of the ground-water-monitoring network called for drilling a number of wells specifically for water-quality monitoring and included four types of wells:

1. Q wells--shallow wells (20 to 80 feet) located in or near wastewater disposal areas.
2. S wells--other shallow wells in areas between wastewater-disposal sites.
3. M wells--medium depth wells (80 to 200 feet) in various locations through the valley.
4. D wells--deep wells (200 to 600 feet) in various locations throughout the valley.

The Q and S wells were designed to monitor the shallow aquifer and were expected to be the first to show indications of water-quality degradation from wastewater or other surface sources. M and D wells were designed for monitoring the deeper aquifers, to determine if there were substantial differences in piezometric head and water quality at different depths.

In 1975, the first 30 wells (Q wells) were constructed using a hollow stem auger. The casings were 2.5-inch PVC pipe having a 5-foot perforated section, between 5 and 10 feet from the bottom of the well. Water-quality sampling began in 1975 when the new Q wells and about 30 existing wells were sampled.

Because of the high construction cost of the proposed M and D wells, and the likelihood of long delays before the wells could be drilled, the decision was made to substitute existing wells for the deeper wells needed for the monitoring network. Zone 7 made an extensive survey of existing wells and chose wells that came closest to fulfilling the objective of monitoring deeper aquifers. Initially, about 30 existing wells (designated E wells) were sampled. This list of E wells was revised periodically when better monitoring wells were located.

In 1976, 27 S wells were drilled using the same construction techniques and casings as the Q wells. Twenty-two additional S wells were drilled in 1978, and 14 more in 1980, to complete the monitoring network. The last 14 wells were drilled using the cable tool method and have 4-inch PVC casings. During the course of the study, several wells were destroyed, replaced, or otherwise determined as unsuitable for sampling. The use of existing wells as deep monitoring wells was a compromise because most existing wells are perforated at several depths or continuously perforated from near the water table to the bottom. This results in a monitoring well that draws water from several depths and possibly from two or more aquifers. The S and Q wells, on the other hand, were constructed such that the sample water is drawn from a confined depth range, resulting in a sample that is more representative of the aquifer. The wells currently (1982) included in the ground-water-monitoring program are given in table 1.

TABLE 1.--Wells used for water-quality analyses

[Abbreviation: USGS, U.S. Geological Survey. USGS well identification number: First six digits are latitude, next seven digits are longitude, and final two digits are sequence number to uniquely identify each site. --, no data available. Type of well: C, well constructed for this study; E, existing well]

| Well No. | USGS well identification No. | Depth of well, in feet | Type of well | Perforation interval, in feet | Period of water-quality record (water year) |
|---|---|---|---|---|---|
| 2S/1E-32N1 | 374242121533101 | 45 | C | 35-40 | 1976-83 |
| 2S/1W-14N1 | 374512121565201 | 48 | C | 38.5-43.5 | 1976-83 |
| 15B1 | 374557121573701 | 821 | E | 21 perforations from 50-710 | 1978-83 |
| 15F1 | 374544121572501 | 60 | C | 50.3-55.3 | 1976-83 |
| 26C2 | 374418121563201 | 50 | C | 40-45 | 1976-83 |
| 36E3 | 374307121554601 | 60 | C | 50-55 | 1978-83 |
| 2S/2E-21L4 | 374439121454501 | 214 | E | 85-157 | 1976-83 |
| 27C2 | 374406121444201 | 108 | E | 41-45, 52-56 | 1976-83 |
| 27P2 | 374326121442801 | 68 | C | 35-45, 58-63 | 1979-83 |
| 28D2 | 374416121455801 | 55 | C | 45-50 | 1976-83 |
| 28Q1 | 374325121452501 | 28 | C | 17.6-22.6 | 1976-83 |
| 32K2 | 374253121463601 | 48 | C | 33-38 | 1977-83 |
| 34E1 | 374258121445801 | 49 | C | 40-45 | 1977-83 |
| 3S/1E-1H3 | 374207121482101 | 80 | C | 70-75 | 1977-83 |
| 1P2 | 374147121485401 | 50 | C | 40-45 | 1975-83 |
| 1R2 | 374143121481801 | 56 | C | 49-54 | 1981-83 |
| 2K2 | 374203121493801 | 46.5 | C | 36.5-41.5 | 1975-83 |
| 2N2 | 374154121501801 | 80 | C | 70-75 | 1978-83 |
| 2N3 | 374143121501601 | 316 | E | 157-167, 301-311 | 1976-83 |
| 2R1 | 374148121492301 | 33 | C | 21-26 | 1975-83 |
| 3G2 | 374214121505801 | 50 | C | 40-45 | 1978-83 |
| 4J4 | 374208121515801 | 107 | C | 96-101 | 1979-83 |
| 4Q2 | 374143121515101 | 90 | C | 80-85 | 1978-83 |
| 5F2 | 374209121532501 | 150 | C | 143-147 | 1979-83 |
| 5J2 | 374204121523901 | 100 | C | 90-95 | 1978-83 |
| 5M1 | 374155121533101 | 93 | E | -- | 1977-83 |
| 5R2 | 374146121523701 | 230 | E | 190-220 | 1976-83 |
| 6F3 | 374211121542701 | 37 | C | 27-32 | 1976-83 |
| 6R2 | 374134121535201 | 74 | C | 64-69 | 1978-83 |
| 7B2 | 374137121541301 | 150 | C | 143-149 | 1979-83 |
| 7F1 | 374126121543201 | 75 | C | 64-69 | 1978-83 |
| 7M2 | 374118121544401 | 85 | C | 70-71, 78-85 | 1979-83 |
| 8B1 | 374133121530901 | 148 | C | 55-60, 74-82 | 1979-83 |

TABLE 1.--Wells used for water quality analyses--Continued

| Well No. | USGS well identification No. | Depth of well, in feet | Type of well | Perforation interval, in feet | Period of water-quality record (water year) |
|---|---|---|---|---|---|
| 3S/1E-8H2 | 374118121523801 | 205 | E | 124-139, 148-165 | 1981-83 |
| 8K1 | 374108121530701 | 99 | C | 89-94 | 1978-83 |
| 8N1 | 374054121533201 | 72.1 | C | 62-67 | 1976-83 |
| 9G1 | 374116121520001 | 160 | E | 77-149 | 1975-83 |
| 9P5 | 374058121520101 | 105 | C | 95-100 | 1978-83 |
| 9Q1 | 374052121515501 | 232 | E | 140-153, 170-211 | 1977-83 |
| 10A2 | 374130121502701 | 88 | C | 70-80 | 1979-83 |
| 10E1 | 374117121512201 | 195 | E | -- | 1980-83 |
| 10G2 | 374117121505101 | 207 | E | -- | 1977-83 |
| 10Q5 | 374054121505601 | 300 | E | 243-295 | 1975-83 |
| 11B1 | 374130121494201 | 43 | C | 33-38 | 1975-83 |
| 12A2 | 374132121483201 | 68.7 | C | 63.7-68.7 | 1975-83 |
| 12D2 | 374131121490701 | 46 | C | 36-41 | 1975-83 |
| 12F1 | 374112121485001 | 240 | E | 5 perforations from 115-234 | 1959-83 |
| 12G1 | 374113121484601 | 73 | C | 63-38 | 1975-83 |
| 12H1 | 374117121483301 | 342 | E | 94-120, 157-172 | 1979-83 |
| 12N1 | 374056121491301 | 304 | E | 7 perforations from 112-295 | 1980-83 |
| 12P1 | 374056121485001 | 348 | E | 262-290, 315-236 | 1959-83 |
| 13E1 | 374033121490901 | 100 | C | 75-97 | 1976-83 |
| 13N1 | 374003121491301 | 498 | E | -- | 1980-83 |
| 13P2 | 373956121485501 | 400 | E | -- | 1977-83 |
| 14A2 | 374039121493401 | 210 | E | 135-160, 170-205 | 1980-83 |
| 14F1 | 374026121500101 | 269 | E | -- | 1977-83 |
| 14G1 | 374027121495201 | 500 | E | 150-500 | 1979-83 |
| 14K2 | 374012121494301 | 508 | E | 8 perforations from 120-480 | 1980-83 |
| 15F3 | 374027121510601 | 640 | E | 7 perforations from 195-615 | 1978-83 |
| 16E4 | 374024121523201 | 105 | C | 95-100 | 1978-83 |
| 16H2 | 374028121514001 | 94 | C | 82-92 | 1979-83 |
| 16L7 | 374037121534801 | 647 | E | 165-365, 371-647 | 1965-83 |
| 16P5 | 373955121521801 | 75 | C | 64-69 | 1978-83 |
| 17B4 | 374037121525601 | 248 | E | -- | 1977-83 |
| 17Q4 | 373957121530601 | 84 | C | 74-79 | 1978-83 |
| 18A5 | 374037121534801 | 454 | E | 120-440 | 1967-83 |
| 18E4 | 374037121543201 | 83 | C | 69-79 | 1979-83 |
| 18J1 | 374011121535401 | 325 | E | -- | 1980-83 |
| 18J2 | 374012121540201 | 71 | C | 61-66 | 1980-83 |
| 19A5 | 373942121534501 | 220 | E | -- | 1946-83 |
| 19C4 | 373943121541901 | 78 | C | 68-73 | 1979-83 |
| 19K1 | 373921121540701 | 57.6 | C | 47.6-52.6 | 1975-83 |
| 20B2 | 373946121525601 | 500 | E | 218-500 | 1970-83 |
| 20F5 | 373931121531901 | 46 | C | 36-41 | 1975-83 |
| 20J1 | 373919121525101 | 42 | C | 32-37 | 1976-83 |
| 20J4 | 373928121524901 | 72 | C | 62-67 | 1975-83 |
| 20M11 | 373919121532701 | 71 | C | 61-66 | 1978-83 |
| 20Q1 | 373906121525601 | 52 | E | 41-51 | 1977-83 |
| 22D2 | 373953121511601 | 72 | C | 62-67 | 1976-83 |
| 24K1 | 373924121484901 | 80 | C | 70-75 | 1978-83 |
| 29D2 | 373856121532801 | 64 | C | 54-59 | 1975-83 |
| 29E3 | 373840121532901 | 155 | E | 37-107 | 1960-83 |
| 29M4 | 373834121534301 | 57 | C | 47-52 | 1975-83 |
| 29P2 | 373817121531301 | 42 | C | 32-37 | 1975-83 |
| 30A8 | 373859121534801 | 61 | C | 51-56 | 1975-83 |
| 30A9 | 373843121535201 | 73 | C | 63-68 | 1979-83 |
| 30G3 | 373841121535801 | 61.3 | C | 51.3-56.3 | 1976-83 |
| 32G2 | 373756121530601 | 40 | C | 30-35 | 1976-83 |

TABLE 1.--Wells used for water-quality analyses--Continued

| Well No. | USGS well identification No. | Depth of well, in feet | Type of well | Perforation interval, in feet | Period of water-quality record (water year) |
|---|---|---|---|---|---|
| 3S/1W-1B5 | 374234121552001 | 108 | C | 98-103 | 1979-83 |
| 1L1 | 374156121553301 | 60 | E | -- | 1976-83 |
| 2A2 | 374223121561001 | 47 | C | 37-42 | 1976-83 |
| 12J1 | 374105121545101 | 62 | C | 52-57 | 1975-83 |
| 13J1 | 374013121544901 | 49 | C | 39-44 | 1976-83 |
| 3S/2E-1F2 | 374215121422801 | 69 | C | 59-64 | 1977-83 |
| 1P2 | 374152121423001 | 144 | E | 10-43 | 1980-83 |
| 3A1 | 374222121430501 | 54 | C | 44-49 | 1977-83 |
| 3K3 | 374202121442201 | 60 | C | 50-55 | 1977-83 |
| 5J1 | 374153121462101 | 49.2 | C | 39.2-44.2 | 1976-83 |
| 7C1 | 374127121480301 | 280 | E | -- | 1980-83 |
| 7C2 | 374136121474901 | 49 | C | 39-44 | 1978-83 |
| 7N1 | 374058121481601 | 136 | C | 76-88, 92-95 127-130 | 1979-83 |
| 7P3 | 374100121474901 | 520 | E | 300-320, 430-490 | 1977-83 |
| 8N2 | 374058121470401 | 530 | E | -- | 1958-83 |
| 8H2 | 374126121462201 | 46 | C | 36-41 | 1976-83 |
| 8K2 | 374103121463801 | 74 | C | 64-69 | 1977-83 |
| 9Q4 | 374054121453201 | 80 | C | 70-75 | 1978-83 |
| 10F3 | 374123121443601 | 45 | C | 35-40 | 1978-83 |
| 10Q1 | 374049121442001 | 43.5 | C | 33.5-38.5 | 1976-83 |
| 11A1 | 374142121430401 | 64.7 | C | 54.7-59.7 | 1976-83 |
| 11C1 | 374130121434101 | 66.2 | C | 56.2-61.2 | 1976-83 |
| 11J2 | 374103121430201 | 110 | C | 90-92, 102-108 | 1979-83 |
| 14A3 | 374044121430901 | 110 | C | 100-105 | 1978-83 |
| 14B4 | 374035121430701 | 260 | E | 5 perforations from 143-250 | 1976-83 |
| 15J2 | 374015121440101 | 186 | E | 76-81, 111-123, 123-134 | 1976-83 |
| 16A3 | 374043121451001 | 240 | E | 91-121, 145-240 | 1978-83 |
| 16B1 | 374034121453401 | 410 | E | 7 perforations from 140-390 | 1945-83 |
| 16C1 | 374037121454601 | 584 | E | 5 perforations from 288-523 | 1958-83 |
| 16E4 | 374031121460101 | 45 | C | 35-40 | 1978-83 |
| 16J1 | 374016121450801 | 501 | E | 5 perforations from 233-496 | 1977-83 |
| 18E1 | 374035121480301 | 133.8 | C | 123.8-128.8 | 1977-83 |
| 19C1 | 373950121475301 | 355 | E | 236-238, 272-285 327-331 | 1976-83 |
| 19D4 | 373949121481301 | 245 | E | 185-205, 225-245 | 1980-83 |
| 19D6 | 373957121481401 | 180 | E | -- | 1980-83 |
| 19F4 | 373941121475701 | 164 | E | 100-160 | 1976-83 |
| 20N1 | 373907121465901 | 214 | E | 70-80, 110-125 150-208 | 1977-83 |
| 22B1 | 373954121442501 | 55 | C | 45-50 | 1976-83 |
| 24A1 | 373943121414501 | 46.3 | C | 36.3-41.3 | 1976-83 |
| 26J2 | 373837121425701 | 44 | C | 34-39 | 1977-83 |
| 29F4 | 373842121465301 | 36 | C | 26-31 | 1976-83 |
| 30D2 | 373856121475701 | 44 | C | 24-29, 34-39 | 1979-83 |
| 33G1 | 373747121452501 | 17 | C | 9-14 | 1975-83 |
| 33G2 | 373748121453301 | 15 | C | 8-13 | 1977-83 |
| 33G3 | 373754121452801 | 14 | C | 9-14 | 1977-83 |
| 33K1 | 373744121453001 | 15 | C | 7-12 | 1975-83 |
| 33L1 | 373745121454201 | 25 | C | 11-16 | 1977-83 |
| 3S/3E-7D2 | 374136121414401 | 74 | C | 64-69 | 1976-83 |
| 7M2 | 374112121414001 | 199 | E | 171-188 | 1976-83 |

The surface-water-monitoring network was started in 1979, superseding an earlier network operated from 1974 to 1979. The earlier network was operated by a cooperative program between the Alameda County Water District, Livermore-Amador Valley Water Management Agency, Zone 7, and U.S. Geological Survey. The program was designed to find the sources of the increasing amounts of dissolved solids in the streams. Increasing dissolved-solids concentrations were having a deleterious effect on the quality of water in Alameda Creek, which recharges the Niles Cone ground-water basin. Lopp (1981) reported the results of the 1974-79 network program.

With the establishment of a treated wastewater-export pipeline in January 1980, treated wastewater releases to streams ended. As a result, the surface-water-quality-monitoring network was modified to determine water quality since the pipeline began operation. The network consisted of nine gaging stations, eight of which were equipped with continuous specific conductance monitors (table 2 and pl. 8).

## FIELD AND LABORATORY METHODS

Water samples from all 2.5-inch wells constructed for this program were taken using a 2-inch diameter air squeeze pump developed by the U.S. Geological Survey in Menlo Park, Calif., in 1975. This pump is driven with compressed nitrogen and is capable of pumping at a rate of about 1 gal/min. The pump is designed so that the water never comes in contact with nitrogen gas or air before it is discharged from the sampler hose. Samples from the existing wells and larger constructed wells were taken using a portable, electric submersible pump or using the pump already installed at the well. Prior to sampling, water was pumped from all wells until stable temperature, specific conductance, and pH readings were obtained.

TABLE 2.--Surface-water sampling stations

[Specific conductance and water discharge monitored continuously for dates given. --, no data available]

| Station No. | Station name | Drainage area ($mi^2$) | Period of record: Physical and chemical constituents | Period of record: Specific conductance | Period of record: Water discharge |
|---|---|---|---|---|---|
| 11174600 | Alamo Canal near Pleasanton | 40.8 | 10/74-10/81 | 10/79-10/81 | 10/79-10/81 |
| 11176000 | Arroyo Mocho near Livermore | 38.2 | 12/79-10/81 | 1/79-10/81 | 1912-30; 10/63-10/81 |
| 11176145 | Arroyo Las Positas at Livermore | -- | 3/81-10/81 | 8/80-10/81 | 8/80-10/80 |
| 11176180 | Arroyo Las Positas at El Charro Rd., near Pleasanton | 75.0 | 12/79-10/81 | 12/78-10/81 | 10/77-10/81 |
| 11176200 | Arroyo Mocho near Pleasanton | 142 | 11/70-3/71; 3/81-10/81 | 10/78-10/81 | 9/62-10/81 |
| 11176300 | Tassajara Creek near Pleasanton | 26.8 | 11/80-10/81 | 3/79-10/81 | 1914-19; 1921-30; 10/78-10/81 |
| 11176500 | Arroyo Valle near Livermore | 147 | 11/60-5/67; 3/81- 10/81; 3/81-10/81 | none | [1]1912-30; 10/57-10/81 |
| 11176600 | Arroyo Valle at Pleasanton | 171 | 1/75-10/75; 1/77 to 10/81 | 12/74-10/81 | 10/57-10/81 |
| 11177000 | Arroyo de la Laguna near Pleasanton | 405 | 7/79-10/81 | 8/79-10/81 | [1]1912-30; 10/69-10/81 |

[1]Monthly discharge only.

Samples for the following dissolved constituents were collected at all wells: Ca, Mg, Na, K, $HCO_3$, Cl, $SO_4$, $NO_3$, P, and Fe. Hardness was calculated from Ca and Mg values. Samples for total organic carbon and chemical oxygen demand were collected at most wells. Water temperature, specific conductance, pH, and water levels were determined at each well when sampled. Most wells were sampled either monthly or quarterly for $NO_2$, $NO_3$, Cl, and dissolved-solids residue at 180°C. Samples for other constituents were usually collected once or twice a year. Wells in wastewater-disposal areas were sampled monthly prior to the 1977 water year, and bimonthly after that.

The major ions and residue on evaporation at 180°C were sampled to assess the general quality of the water and to determine areas of similar water types. Nitrate, chloride, total organic carbon, and chemical oxygen demand were sampled as possible tracers of areas affected by wastewater discharge.

Samples for dissolved constituents were filtered immediately after collection through a 0.45-micrometer membrane filter to remove suspended material. Cation samples were preserved with nitric acid, chemical oxygen demand samples with sulfuric acid, and nutrient and total organic carbon samples were chilled to 4°C. The samples were sent for analyses to either the U.S. Geological Survey Central Laboratory in Denver, Colo., or the California Department of Water Resources Laboratory in Bryte, Calif. Prior to 1979, laboratory analyses were done by methods given in Brown and others (1970). Beginning in 1979, the methods given in Skougstad and others (1979) were used. Total organic carbon samples were analyzed by the method given in Goerlitz and Brown (1972).

Surface-water samples were taken over a wide range of hydrologic conditions with an emphasis on winter storm sampling. Grab samples were taken at midstream 4 to 12 times a year at the surface-water stations. Samples were processed and analyzed using the same methods as the ground-water samples. Samples were analyzed for major ions, B, Fe, Mn, and dissolved solids. About three to six times per year samples were collected and analyzed for nutrient species ($NO_2$ + $NO_3$, organic nitrogen, $NH_4$, and $PO_4$). In addition, field determinations of pH, specific conductance, and water temperature were made.

## WATER LEVELS AND GROUND-WATER MOVEMENT

Ground-water-level contours in the valley in the spring of 1980 are shown on plate 2. This map was based on a large number of wells, many of which were not in the monitoring network. Ground-water movement is in the general direction of the gravel pits (pl. 2). The gravel operations pump large quantities of water from the pits to facilitate gravel mining, thus creating a large artificial depression in the valley ground-water system. The gravel pit operators also back fill some of the pits with silt and clay to minimize further recharge and ground-water movement in the area.

The extensive gravel mining has greatly altered the historical ground-water-flow regime. Originally the ground-water gradients were from east to west with outflow from the valley along Arroyo de la Laguna. This outflow of ground water has stopped due to pumping for municipal and agricultural purposes in the Pleasanton area. The directions of flow were later altered by gravel excavation activities.

In most of the valley, vertical flow is minimal because of the many clay layers that tend to separate parts of the permeable aquifer material (California Department of Water Resources,

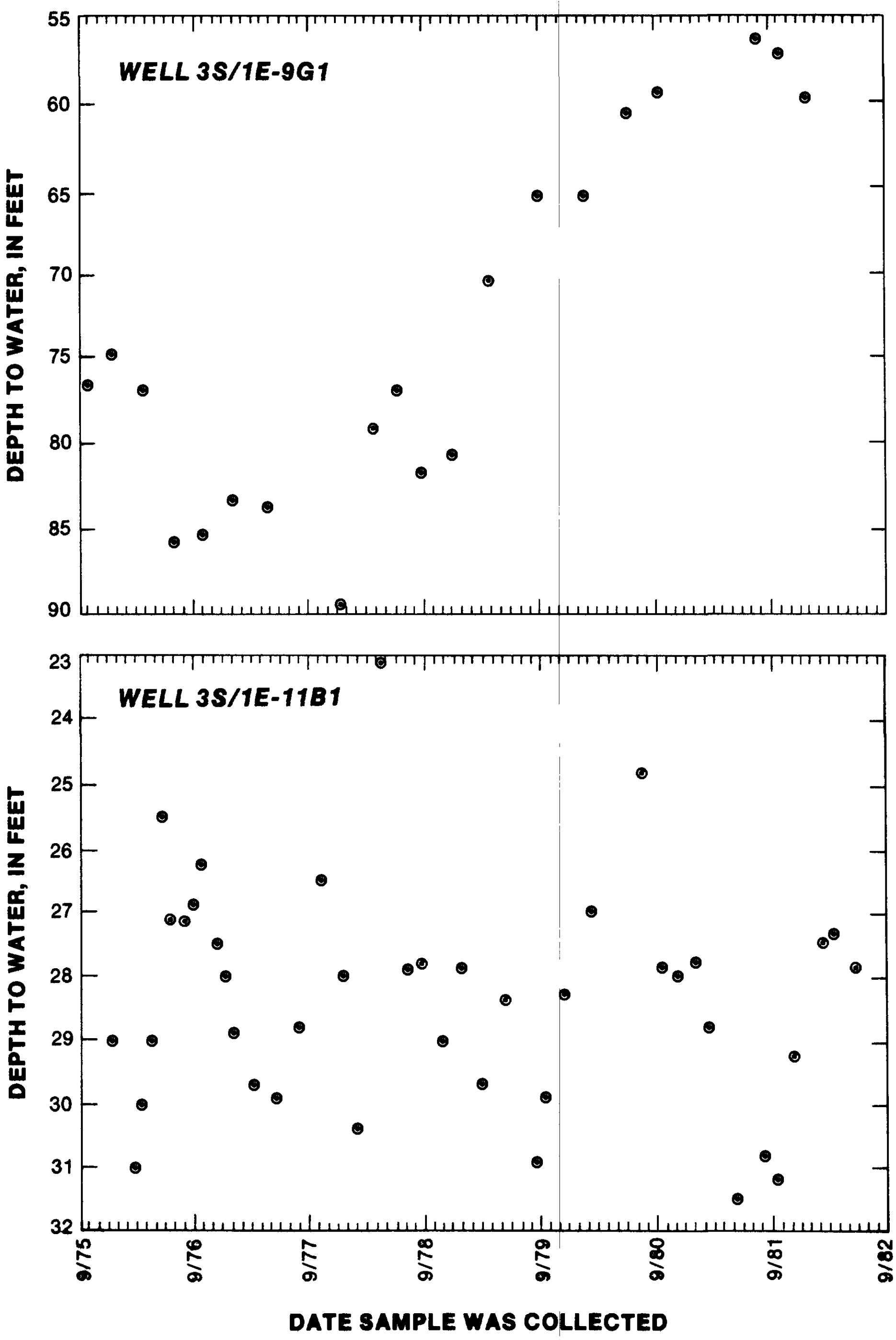



FIGURE 2. — Water levels at four wells over their period of record.

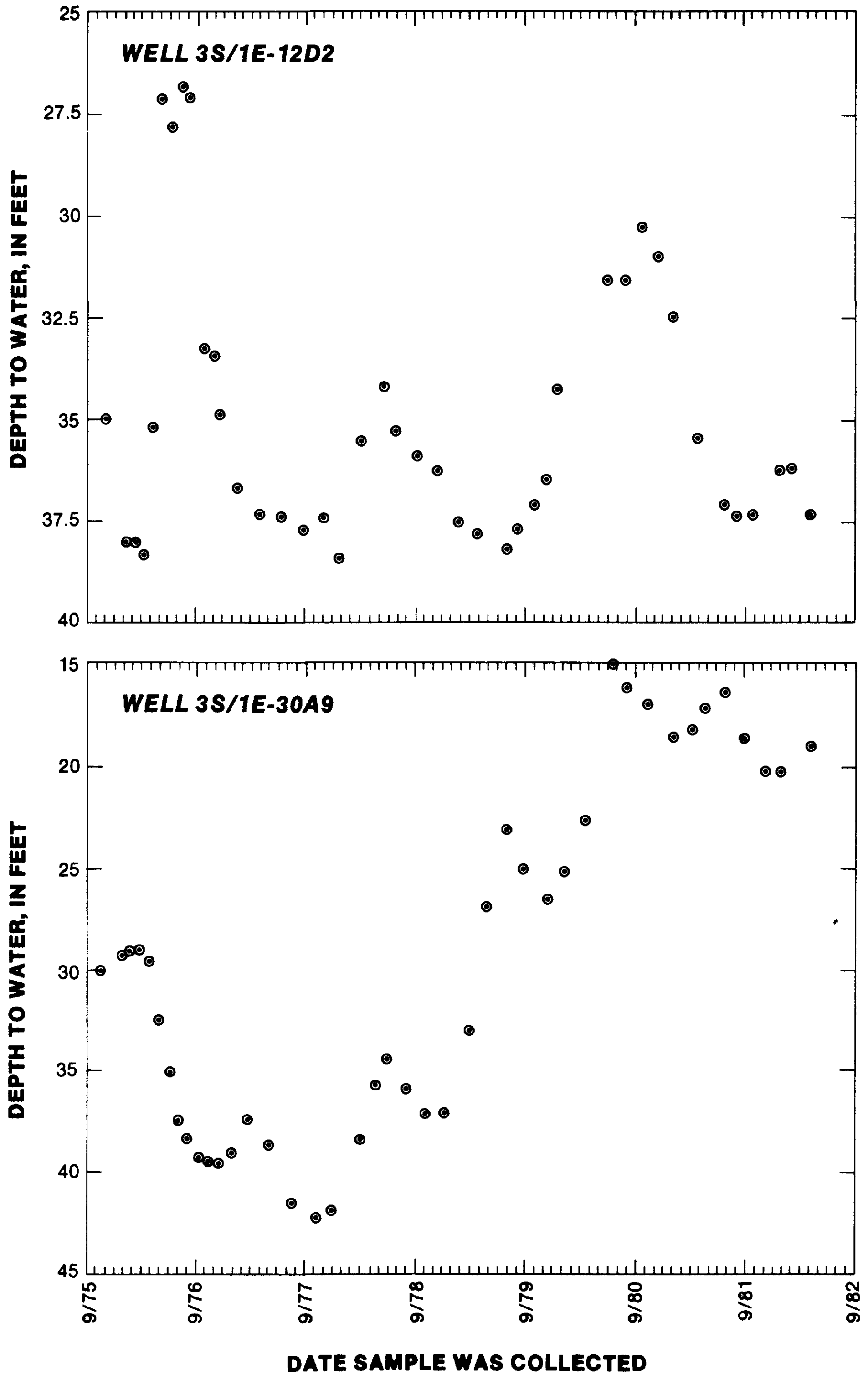



FIGURE 2. — Continued.

1964). The clay layers are not continuous, however, and some vertical flow does occur. In much of the southern parts of the Amador and Mocho II subbasins, the clay layers are less extensive and vertical flow is more apparent from water-quality measurements.

Water levels in the valley have generally increased in most parts of the valley from 1975 to 1982. The hydrograph of well 3S/1E-9G1 (fig. 2) is typical of many wells throughout the valley. It shows a substantial increase in water level over the period of study. Some wells (particularly in the Mocho II and Amador subbasin) had water levels that fluctuated somewhat but showed no upward or downward trend over the monitoring period. An example of this is the hydrograph from 3S/1E-11B1 (fig. 2). Of the wells in the network that have been monitored for more than 3 years, only six wells have had a steady decline in water level. These include 3S/1E-1P2 and 3S/1E-2N2, located northwest of the Livermore sewage-treatment plant, and 3S/1E-16H2, located in the western gravel pit area. Three other wells with declining water levels during the study period are 3S/2E-7N1, 3S/2E-8H2, and 3S/2E-24A1.

The hydrographs of some wells indicate a decline in water levels, corresponding to the 1977 drought. The wells southwest of the Pleasanton sewage-treatment plant showed this effect particularly well (fig. 2, hydrograph of 3S/1E-30A9). Water levels in many of the wells in the valley, while generally showing increases, were highly variable during the period of record. Much of this variability could be attributed to seasonal wet-dry cycles; however, some of the wells, particularly around the Livermore airport, had water levels that varied but not on a seasonal basis (fig. 2 hydrograph of 3S/1E-12D2). This is most likely due to on-land wastewater-application practices that are somewhat independent of seasonal cycles.

The five wells around the Veterans Administration Hospital are considered anomalous to the rest of the valley's ground-water system. They are shallow wells (14 to 25 feet) and, except for 3S/2E-33G1, are primarily affected by the nearby percolation ponds. Well 3S/2E-33G1 is near Arroyo Valle, but it is so shallow that it is probably not representative of ground-water conditions in that area. For these reasons, the hospital wells were not used when making the contour maps, but specific reference to these wells is made where appropriate. The range in water levels during the period of record was generally greatest around the gravel pits, the northern part of Pleasanton, and around the Pleasanton wastewater-disposal area. The range in depth to water in these areas was typically greater than 30 feet during the study period. The depth to water in these areas tended to vary more in the deeper wells than in the shallow wells. Much of the variability in the deeper wells is probably due to greater pumping of those wells, or nearby wells, than would occur in the shallow wells constructed for this study.

## GROUND-WATER QUALITY

The areal distribution of selected water-quality properties and constituents of ground water are presented on plates 3-7. The maps were constructed using mean values for each well for the period of record. This approach ignores the possible variability of the data over the period of record, and since the period of record is different at different wells, there is some uncertainty as to the location of the contour lines. The contours near the margins of the valley also contain some uncertainty because of the lack of data for some areas and are thus represented by dashed lines. In some areas there was a considerable difference in water quality between deep and shallow wells in the same general area. In these areas, the mean value for the shallower wells was generally used. The mean value for wells that were anomalous to the contour area are indicated on the plates.

Three program wells, located in San Ramon Valley, north of San Ramon Village, are not on any of the maps because of restrictions in map size. Reference to these wells are made in appropriate sections.

## Specific Conductance

The lowest values of specific conductance were detected in wells along and near Arroyo Valle and Arroyo Mocho (pl. 3). These are the principal recharge areas for the ground-water basin, and the low specific conductance is indicative of the quality of the recharge water carried by these two streams. The highest specific conductance occurred in the northwest part of the Amador Valley and the northeast corner of Livermore Valley where it was more than 2,000 μmho in some wells. The source of this high specific conductance water is probably the marine sediments that border the valley. In the northeast corner of Livermore Valley, high specific conductance occurred in both shallow wells (3S/2E-1F2) and deep wells (3S/2E-1P2). The high specific conductance in the military reservation area north of Pleasanton was confined to the shallow aquifer. In this area, there is an extensive water-bearing confining bed consisting of the clay and sandy clay that extends to a depth of about 120 to 140 feet below land surface. Wells completed below the confining bed in the area (3S/1E-7B2 and 3S/1E-5R2) had a specific conductance value of less than 1,000 μmho. The clay layer probably is not continuous or of constant thickness over this entire area. It seems that the clay layer may be a series of smaller clay lenses that together form an effective confining bed with little hydrologic connection to the lower aquifer. Smaller areas of high conductivity water, probably associated with these clay layers, were detected in the shallow aquifer to the south (3S/1E-18J2). Overall there was a general decrease in specific conductance from the military reservation south to Pleasanton primarily due to recharge from Arroyo Mocho and Arroyo Valle. The high specific conductance in wells near and west of the Livermore airport probably is the result of high conductivity recharge water from Arroyo Las Positas. The three wells in the San Ramon Valley that are not shown on the contour maps had a mean specific conductance of between 950 and 1,080 μmho. The wells near the Veterans Administration Hospital had mean specific conductance ranging from 726 μmho in 3S/2E-33G1 to 2,420 μmho in 3S/2E-33G3 and therefore, were higher in specific conductance than other wells in their contour area.

## Water Types

The water-type map shows areas based on the predominant cation (pl. 4). These cationic water types were based on the percentage of each cation in the sample. For example, a magnesium-type water is one in which 50 percent or more of the cations (in milliequivalents) are magnesium. When a single cation does not make up at least 50 percent of the total, the water type is designated as a combination of the two cations that contribute the largest percentage of the total.

A large area of sodium water was detected along the north edge of the valley, except in the San Ramon Valley. The source of this water type is probably recharge from the local streams draining the Tassajara Formation, and underground recharge from these areas. The large area of magnesium water was generally the area that is recharged by Arroyo Mocho.

Water in the area along Arroyo Valle was a calcium magnesium or magnesium calcium cationic type. An exception to this is the area around the Veterans Administration Hospital. These wells yielded sodium chloride water that is probably the result of localized geology or percolation from the sewage-treatment ponds, and does not represent water recharged from Arroyo Valle. The three wells in the San Ramon Valley that are not shown on the map yielded calcium or calcium sodium water.

Water from most of the wells in the study area contained bicarbonate as the predominant anion. Those wells from which samples had anything other than bicarbonate as the predominant anion are given in table 3. Most of these wells contain water that was predominant either in chloride or a combination of chloride and bicarbonate, and are located in the areas where sodium is the predominant cation.

TABLE 3.--Wells with anionic water types that are not bicarbonate

| Water type | | | |
|---|---|---|---|
| Bicarbonate chloride or Chloride bicarbonate | Chloride | Bicarbonate sulfate | Sulfate chloride |
| 3S/1E-4Q2 | 3S/1E-7F1 | 3S/1W-12J1 | 3S/1E-6R2 |
| 2N2 | 7M2 | 3S/2E-33G1 | |
| 2R1 | 22D2 | | |
| 8B1 | 3S/1W-1B5 | | |
| 3S/2E-11C1 | 2S/1E-32N1 | | |
| 24A1 | 2S/2E-27P2 | | |
| 33G3 | 3S/2E-1F2 | | |
| 33L1 | | | |
| 33K1 | | | |
| 2S/2E-28D2 | | | |
| 34E1 | | | |

## Chloride

Water having high chloride concentrations (pl. 5) generally corresponded to water having high specific conductance (pl. 3). The highest mean chloride concentration (3,070 mg/L) occurred at 3S/1E-7F1, east of the Dublin-San Ramon Services District Sewage Treatment Plant. The three wells in the San Ramon Valley that are not on the map had mean chloride concentrations ranging from 61 to 134 mg/L.

Chloride is generally considered to be a good tracer of the movement of a particular water through an aquifer because it is not absorbed appreciably by soil or organic particles. Waste discharges which are high in chloride will increase chloride concentrations in ground-water areas downgradient from effluent discharge if the effluent reaches the aquifers. Most of the valley had a percentage chloride of less than 30 (pl. 5). The source of the increased percentage chloride west of Livermore's wastewater-treatment plant is very likely effluent from the plant that was discharged to Arroyo Las Positas and used for spray irrigation near the Livermore airport. Another area with high percentage chloride water was in the northeast part of the valley. This area is recharged by high chloride water from local surface water. The percentage chloride in the area around the Pleasanton wastewater-treatment plant was not as high as that around the Livermore plant. It is very difficult, from the chloride data available, to trace effluent contributions to the ground water from the Pleasanton plant.

## Nitrate

Water with nitrate concentrations greater than the drinking water standard (U.S. Environmental Protection Agency, 1977) of 10 mg/L as N was detected in three parts of the study area (pl. 6). The largest area covers much of Livermore and south to the valley margin. The highest concentrations of nitrate were in the Buena Vista Road area where samples from well 3S/2E-15J2 had a mean nitrate concentration of 20 mg/L. Water from the wells around the Livermore airport and the Pleasanton wastewater-treatment plant generally had nitrate concentrations greater than 10 mg/L.

High nitrate concentrations in water has long been recognized as a primary water-quality problem in Livermore Valley. Sylvester (1983) gives a detailed discussion of nitrate in the sewage-disposal areas, and Camp, Dresser, and McKee Inc. (1982) discussed the presence of high nitrate concentrations in unsewered areas such as Buena Vista.

The wells around the Veterans Administration Hospital had mean nitrate concentrations ranging from 0.09 to 3.1 mg/L.

## Boron

Concentrations of boron in ground water in the Livermore-Amador Valley were generally low (less than 1,000 µg/L and usually less than 500 µg/L) (pl. 7). Notable exceptions were the northeast part of Livermore Valley where mean boron concentrations were as much as 16,000 µg/L in water from well 2S/2E-27P2, and the area west of the Livermore wastewater-treatment plant. Wells that yielded boron concentrations greater than 2,000 µg/L are all shallow (the deepest well is 2S/2E-27C2 at 108 feet). Boron in these areas is probably from the marine sediments adjacent to these areas. The three San Ramon Valley wells not shown on the map had mean boron concentrations ranging from 160 to 216 µg/L. Water from the Veterans Administration Hospital wells all had mean boron concentrations greater than 1,000 µg/L except in well 3S/2E-33G1, which had 533 µg/L. Water from the other four wells had mean boron concentrations ranging from 1,800 to 6,350 µg/L.

## Total Organic Carbon

Samples were analyzed for total organic carbon (TOC) at least once from all the network wells to trace areas that were high in organic carbon. Such samples might indicate possible areas of organic pollution. Analysis of the data showed TOC values ranging from less than detection (0.5 mg/L) to 23 mg/L. General background concentrations of TOC appeared to be between 2 and 5 mg/L. Water with TOC greater than the background level were detected in various areas throughout the valley, but were not necessarily associated with the wastewater-disposal areas. Further analysis of these data showed that in wells where several TOC analyses were made, the fluctuation in TOC concentrations was much greater than could reasonably be expected considering the reported values of other constituents. The large fluctuations were probably attributed to sampling and analytical error and not to actual fluctuations in TOC concentrations. Because of the variability of the analyses, it was impossible to draw an accurate map of TOC concentrations in ground water; however, it seems clear that high TOC concentrations are not associated with the wastewater-disposal areas, and cannot be used as a tracer of organic contamination in the valley's aquifers.

## Differences in Water Quality Between Shallow and Deep Wells

The sampling network was designed to provide data from deep and shallow wells near each other in various locations in the valley. This should show if there are any chemical differences in ground water of the shallow and deep aquifers, and if those differences are stable over time. Some of the paired wells used for these comparisons are not close enough together to make ideal comparisons but an attempt was made to provide a deep-shallow comparison in several areas. Comparisons between data distributions of water-quality properties and constituents were made using the Kruskal-Wallis (Chi-square approximation) test. This nonparametric statistical procedure was necessary because many of the data distributions were not normal. Normal distribution of data is a condition assumed for most parametric tests. The Kruskal-Wallis tests were made using the NPAR1WAY procedure in SAS (Helwig and Council, 1979). Schematic boxplots (fig. 3) were constructed for several water-quality properties and constituents using the SPLOT procedure from SAS. These plots are useful in visualizing the data distributions and central tendencies. All the statistical tests and schematic plots for each well pair were made using data covering the same time period and approximately the same number of samples from each pair of wells.

<u>3S/2E-14A3 (110 feet) and 3S/2E-14B4 (260 feet)</u>.--These two wells are located near the corner of Grant Street and Las Positas Avenue east of Livermore. The shallower well had significantly higher specific conductance and concentrations of all the major dissolved constituents except sulfate (fig. 3). Water types were similar for both wells. Mean water levels were not significantly different at the 0.05 level. Well 3S/2E-11J2, about a quarter of a mile north of well 14A3, is also 110 feet deep. The differences in water chemistry between wells 14A3 and 11J2 were much greater than the differences between wells 14A3 and 14B4. Water in well 11J2 was lower in specific conductance than either of the other two wells and was also lower in all major dissolved constituents sampled. This indicates that in this part of the valley, differences in water quality are more likely to be caused by the location of the well than by the depth of the well.

<u>3S/2E-29F4 (36 feet) and 3S/2E-20N1 (214 feet)</u>.--These two wells are located in the southeastern part of the Amador subbasin near Arroyo Valle. They have very similar water quality in terms of major dissolved constituents except nitrate concentrations, which were significantly different at the 0.05 level (fig. 3). The shallow well had a mean nitrate concentration of 1.0 mg/L, the deeper well had mean nitrate concentration of 9.5 mg/L. Temporal variability of all the major constituents is much greater in the shallow well and seems to be linked closely to changes in water quality in nearby Arroyo Valle. The deeper well has a mean water level about 36 feet lower than in the shallow well. This indicates a possible perched ground-water area.

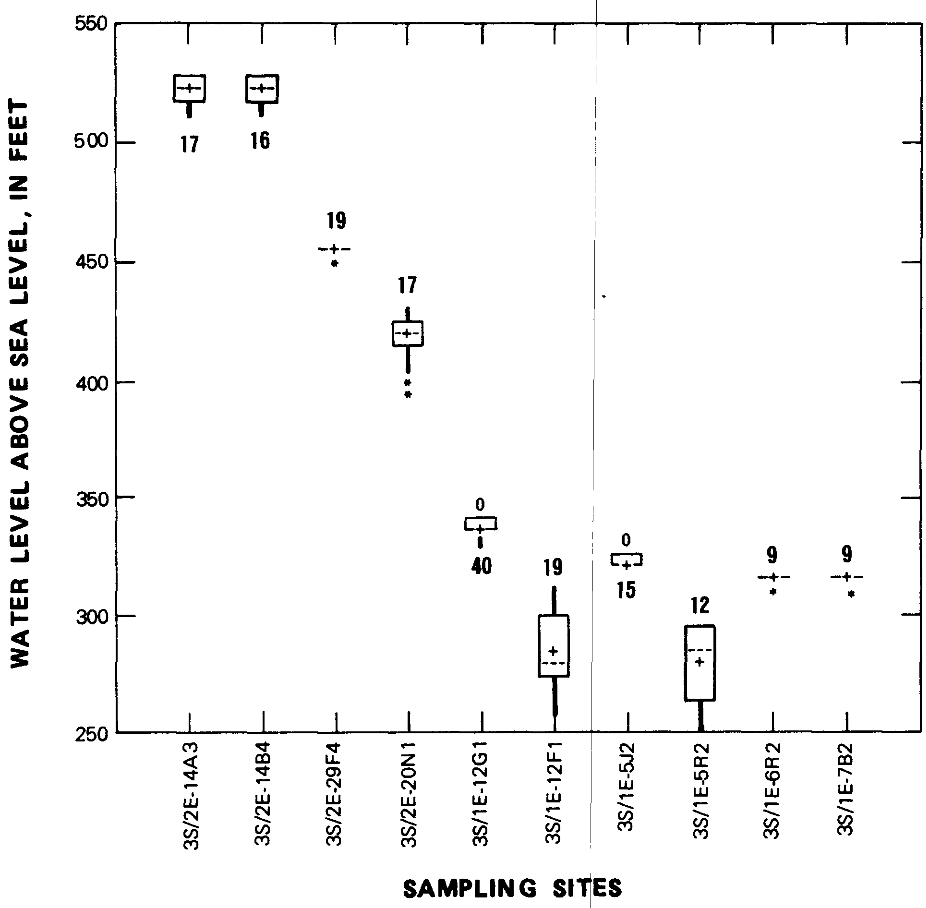
<u>3S/1E-12G1 (73 feet) and 3S/1E-12F1 (240 feet)</u>.--These two wells are located within 150 feet of one another, about a quarter of a mile southwest of the Livermore wastewater-treatment plant. The specific conductance and the concentrations of major dissolved constituents in samples from the shallow well were significantly greater than in the deeper well. Variability of the data also is generally greater in these wells than others used in the deep-shallow comparisons. The water types of the two wells were similar, but the mean percentage bicarbonate in the deeper well is 68 compared to 55 in the shallow well. The percentage sodium was 26 in the shallow well compared to 19 in the deeper well. Water levels averaged about 55 feet lower in the deep well, indicating a multiple aquifer system in this area. These wells are adjacent to the wastewater-application area near the Livermore wastewater-treatment plants. This probably accounts for the high nitrate concentrations and higher percentage of sodium detected in the shallow well.

<u>3S/1E-5J2 (100 feet) and 3S/1E-5R2 (230 feet)</u>.--These wells are located about a quarter of a mile south of the Santa Rita Rehabilitation Center and along Tassajara Creek. Water in the shallow well had a specific conductance nearly twice that of the deeper well. Concentrations of major dissolved constituents also were about twice as high in the shallower well. Variability in these data is much less than in most of the other deep-shallow

comparison wells. Variability in water depth was much greater in the deeper well even though the depth to water is much greater. This is most likely due to its location near a major ground-water pumping area. Fluctuations, seasonal or otherwise, in pumping in this area probably influences ground-water levels in the deeper aquifer. The water types of these two wells were very similar. These two wells show that there are apparently two distinct aquifers in this area with similar water types but very different concentrations of dissolved constituents.

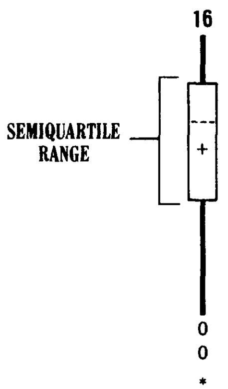
3S/1E-6R2 (74 feet) and 3S/1E-7B2 (150 feet).--These wells are located east of Hopyard Road and south of Interstate 580. The differences in water quality between these wells are typical of the differences in this area between the upper aquifer with poor water quality, and the deeper aquifer with better water quality. In this clay layer area, concentrations of all major dissolved constituents, except nitrate, were much greater in the shallow well. Nitrate was less than 0.2 mg/L in both wells (fig. 3). Water types were very different with the deep well having a sodium (82 percent) bicarbonate type similar to wells north of this area, and the shallow well having a mixed sodium magnesium, sulfate chloride water similar to other wells that were finished in and above the confining clay layer in this area. Water levels in the two wells were nearly identical.

In most of the Bernal, Amador (except the southeastern part along Arroyo Valle), and Mocho subbasins, the shallow wells generally were higher in dissolved constituents than the deeper wells. In some areas west of Livermore, this is most likely caused by wastewater application to the land surface and to the percolation ponds. In the area northwest of Pleasanton the buildup of salts in the shallow aquifer is probably due to the historical runoff pattern in the valley which caused water to pond in this low spot and evaporate, leaving behind the salt and fine clay that now makes up the thick confining bed. In the Mocho subbasin where clay layers are less extensive and shallow and deep ground water can mix more readily, the differences in water quality at different depths becomes much less defined.




## EXPLANATION

SCHEMATIC PLOTS (Tukey, 1977)




16 NUMBER OF SAMPLES

--- MEDIAN

\+ MEAN

0 OUTSIDE VALUE

* FAROUT VALUE

Vertical lines from rectangle are the range of the data

Upper and lower limits of rectangle are 25th and 75th percentiles (50 percent of samples located between limits)

**Outside values** are between 1 and 1.5 times the **semiquartile range** from the top or bottom of the rectangle

**Far out values** are more than 1.5 times the **semiquartile range** from the top or bottom of the rectangle

FIGURE 3. – Schematic plots showing variations in water level, specific conductance, calcium, magnesium, sodium, alkalinity, sulfate, chloride, and nitrate at paired shallow-deep wells.

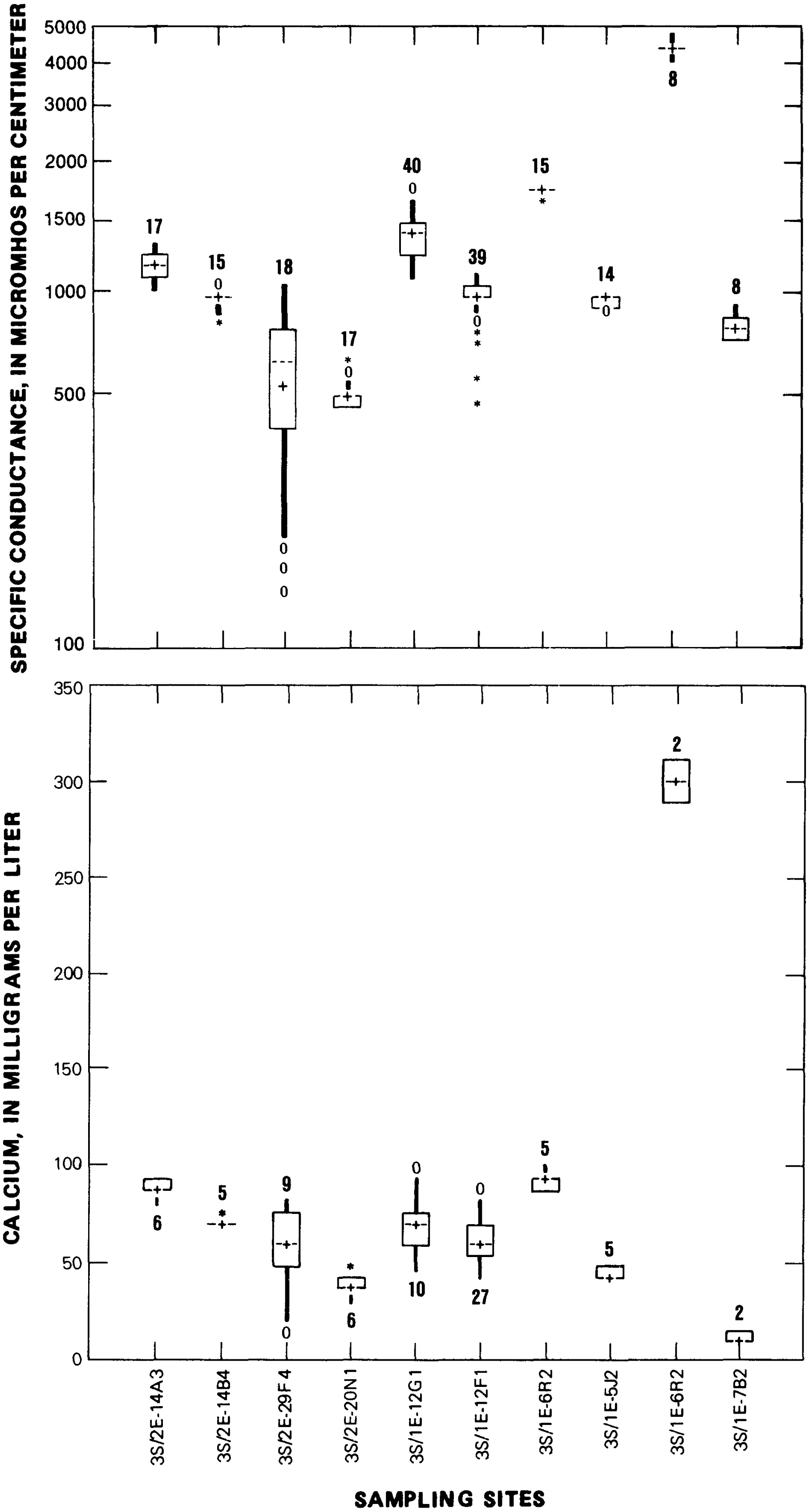



FIGURE 3. – Continued.

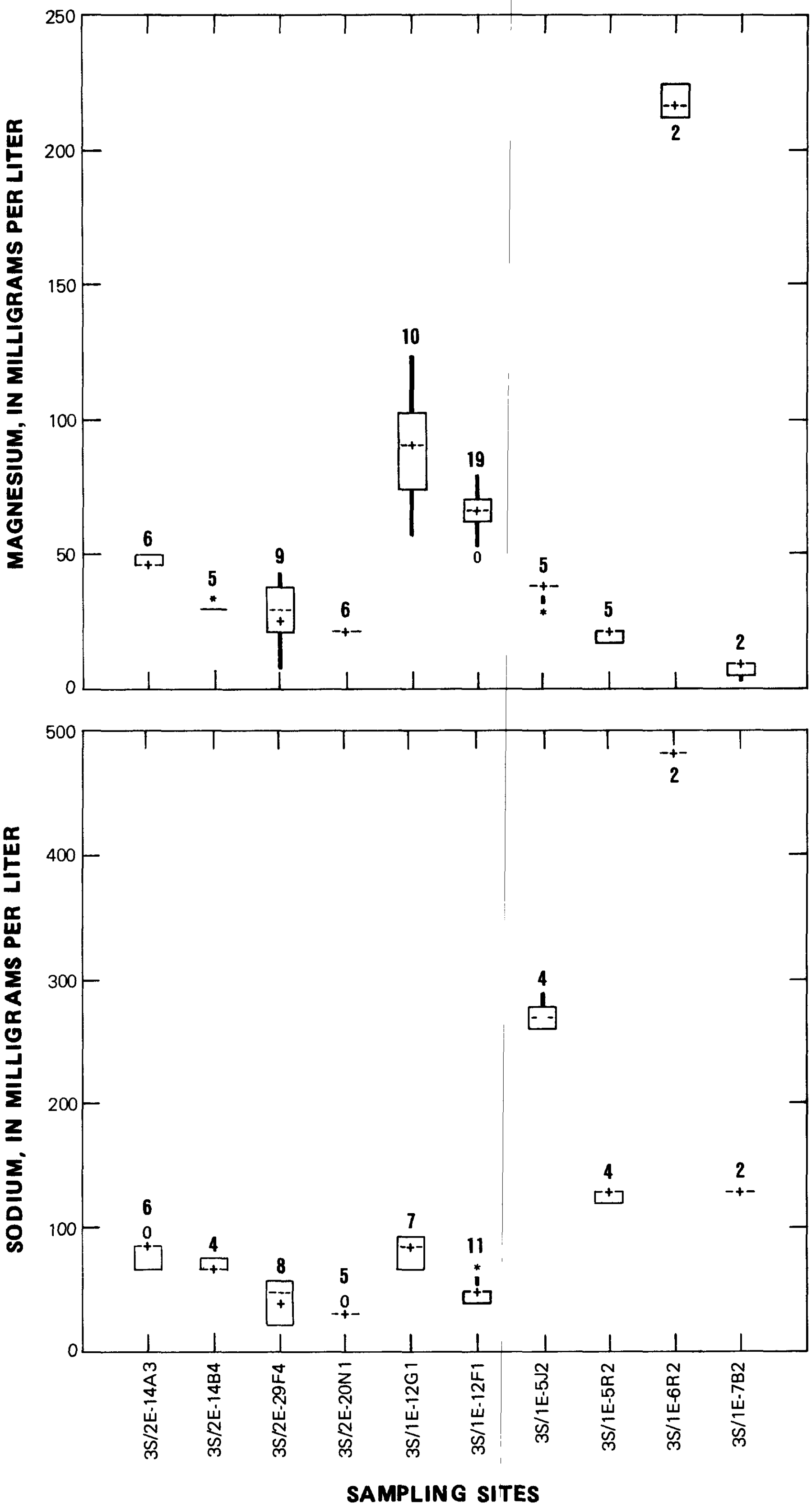



FIGURE 3. — Continued.

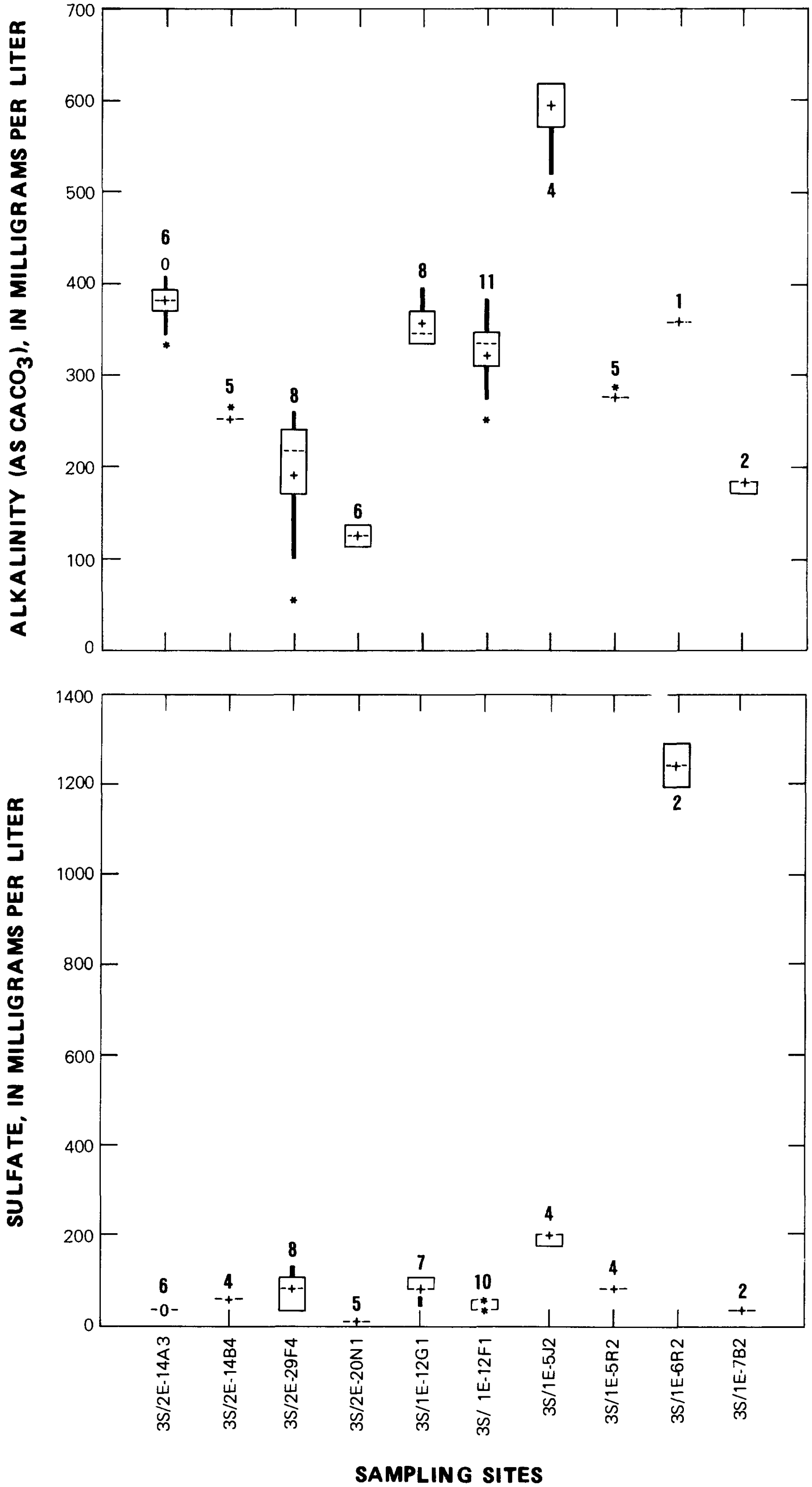



FIGURE 3. – Continued.

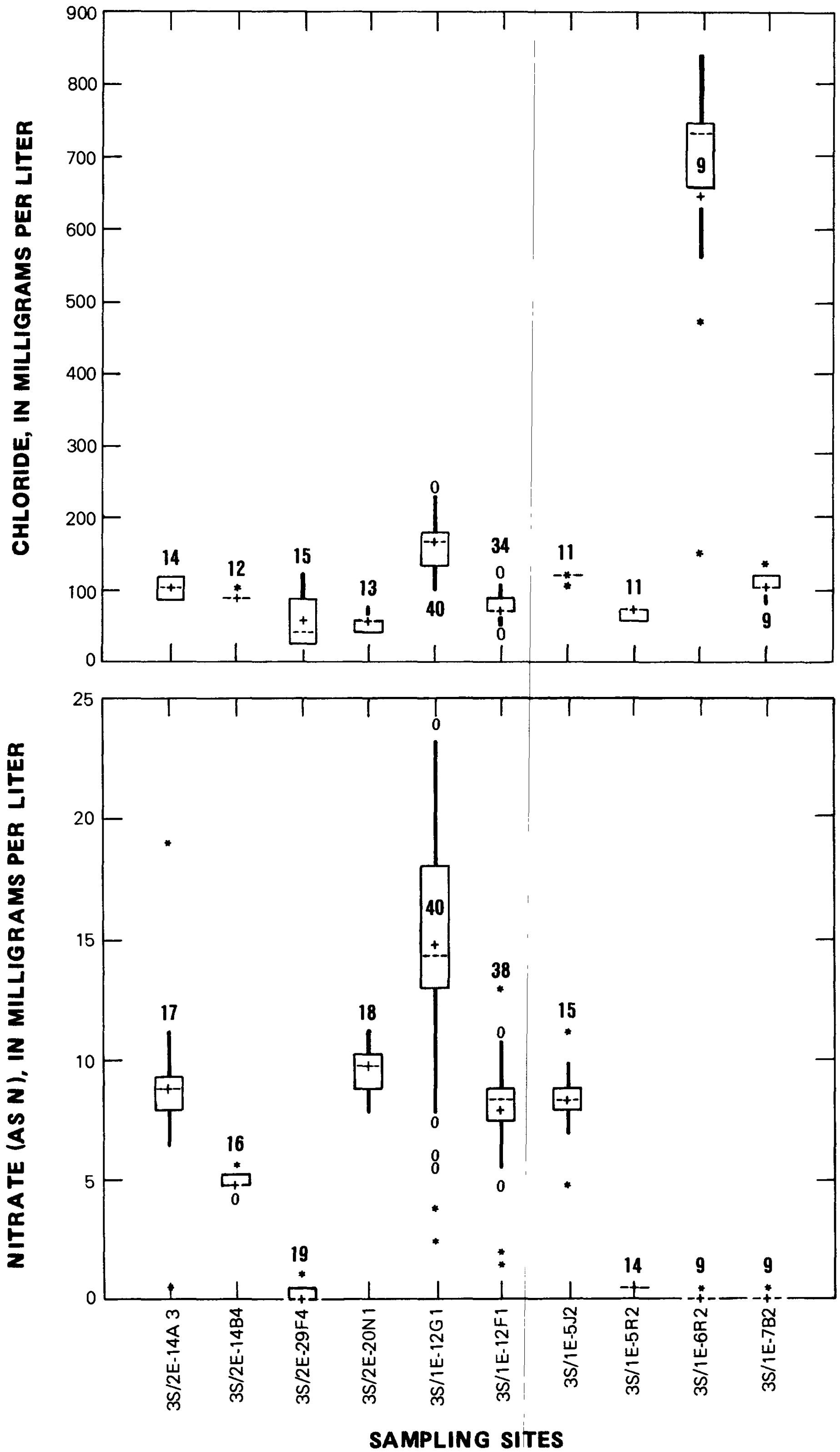



FIGURE 3. – Continued.

## STREAMFLOW

Streamflow in the Livermore Valley is highly seasonal with most of the runoff occurring during the winter from December through April. Natural flow ceases in most streams during summer and autumn in all but the wettest years. Hydrographs of mean monthly discharge at the nine surface-water network stations are exhibited on plate 8. Most of the hydrographs include data from the pre-1980 period before treated sewage water was exported and the 1980-81 water years after this export started. Close comparisons between hydrographs were hindered by the limited number of years of records available at most of the stations. Because these are small basins, the discharge each year is highly dependent on seasonal rainfall and there is little base flow in most of the streams. In addition, many artificial situations affect discharge such as the release of approximately 8,000 acre-ft of water from the South Bay aqueduct to Arroyo Mocho and Arroyo Valle for purposes of ground-water recharge, and the discharge of 6,000 to 7,000 acre-ft/yr ground water in Arroyo Valle from the dewatering operations at the gravel pits. The release of water from Del Valle Reservoir for downstream recharge in Niles Cone, accounted for the increases in flow for the June through August period at Arroyo Valle near Livermore and at Pleasanton and Arroyo de la Laguna. Although the 1981 water year was a near normal rainfall year, large storms in February caused discharge peaks at all the stations. However, at these same stations, the March, April, and May mean discharge was at or below the mean for the previous years of record.

## SURFACE-WATER QUALITY

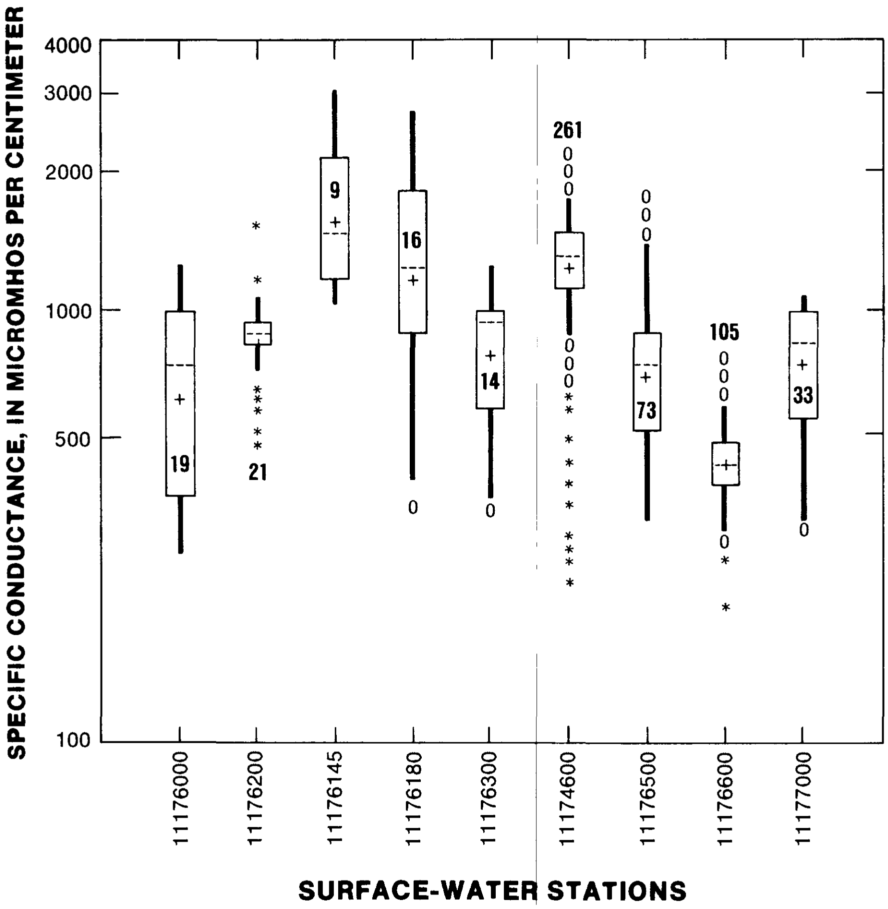
### Specific Conductance

The quality of the surface water, like the flow, is highly dependent on local hydrologic and climatic conditions. The distributions of specific conductance at surface-water stations over the period of record are shown in figure 4. Because specific conductance is an indirect measurement of dissolved solids, this figure relates to dissolved solids as well as specific conductance. The highest specific conductance occurred at Arroyo Las Positas at Livermore. This water is mostly natural discharge from a watershed that is composed primarily of marine sediments, which contributes large amounts of dissolved material. Downstream from this station at Arroyo Las Positas at El Charro Road near Pleasanton, the specific conductance was generally lower and the variability greater indicating some dilutions from other sources. In Arroyo Mocho, the upstream station (11176000 near Livermore) has generally lower specific conductance than the downstream station (11176200 near Pleasanton). The downstream Arroyo Valle station (11176600 at Pleasanton) has much lower specific conductance than the upstream station (11176500 near Livermore). This indicates that much of the flow that reaches the lower station at Pleasanton is not the same water that naturally occurs in the upper part of the basin stored in the Del Valle Reservoir, or the same water released from the South Bay aqueduct.

### Water Types

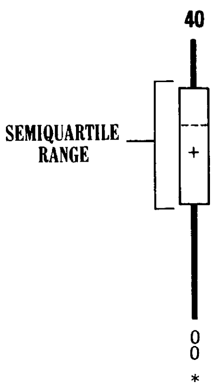
The water types at each station were calculated using data from water years 1980 through 1982 (pl. 9 and table 4).

Water in most of the streams sampled was on average a mixed cation, and mixed anion type. Exceptions to this were the two Arroyo Las Positas stations (11176180 and 11176145) and Arryo Mocho near Livermore (11176000). Water in Arroyo Las Positas at the two sampling stations was a sodium chloride type. These two stations also had the highest concentrations of




## EXPLANATION

SCHEMATIC PLOT (Tukey, 1977)




**40** NUMBER OF SAMPLES

--- MEDIAN

\+ MEAN

0 OUTSIDE VALUE

* FAROUT VALUE

Vertical lines from rectangle are the range of the data

Upper and lower limits of rectangle are 25th and 75th percentiles (50 percent of samples located between limits)

**Outside values** are between 1 and 1.5 times the **semiquartile range** from the top or bottom of the rectangle

**Far out values** are more than 1.5 times the **semiquartile range** from the top or bottom of the rectangle

FIGURE 4. – Schematic plot showing variability in specific conductance at the surface-water stations.

TABLE 4.--Percentage of each major anion and cation at surface-water stations, 1980-82 water years

| Station No. | Anions | | | | | | | | Total anions |
|---|---|---|---|---|---|---|---|---|---|
| | Alkalinity | | Chloride | | Sulfate | | Nitrate | | |
| | (meq/L) | (percent) | (meq/L) | (percent) | (meq/L) | (percent) | (meq/L) | (percent) | (meq/L) |
| 11174600 | 5.42 | 46.6 | 3.43 | 29.5 | 2.77 | 23.8 | 0.003 | <0.1 | 11.62 |
| 11176000 | 6.23 | 77.9 | .84 | 10.5 | .92 | 11.5 | .008 | .1 | 8.00 |
| 11176145 | 3.23 | 19.1 | 11.05 | 65.5 | 2.50 | 14.8 | .109 | .6 | 16.89 |
| 11176180 | 3.68 | 26.8 | 7.95 | 57.9 | 2.07 | 15.1 | .008 | .1 | 13.70 |
| 11176200 | 3.21 | 42.7 | 3.16 | 42.1 | 1.13 | 15.0 | .008 | .1 | 7.51 |
| 11176300 | 5.41 | 58.7 | 1.66 | 18.0 | 2.15 | 23.3 | .003 | <.1 | 9.22 |
| 11176500 | 2.44 | 39.1 | 1.51 | 24.2 | 2.29 | 36.7 | <.001 | <.1 | 6.24 |
| 11176600 | 2.38 | 54.7 | 1.10 | 25.3 | .87 | 20.0 | .001 | <.1 | 4.35 |
| 11177000 | 4.28 | 53.5 | 2.23 | 27.9 | 1.49 | 18.6 | .004 | .1 | 8.00 |
| South Bay aqueduct at Del Valle water-treatment plant. | 1.02 | 32.5 | 1.28 | 40.9 | .83 | 26.3 | .009 | .30 | 3.14 |

TABLE 4.--Percentage of each major anion and cation at surface-water stations, 1980-82 water years--Continued

| Stations | Cations | | | | | | | Total cations | Total ions |
|---|---|---|---|---|---|---|---|---|---|
| | Calcium | | Magnesium | | Sodium | Potassium | Potassium + sodium | | |
| | (meq/L) | (percent) | (meq/L) | (percent) | (meq/L) | (meq/L) | (percent) | (meq/L) | (meq/L) |
| 11174600 | 3.93 | 35.5 | 2.80 | 25.3 | 4.29 | 0.06 | 39.2 | 11.08 | 22.70 |
| 11176000 | 1.64 | 20.9 | 4.78 | 61.0 | 1.35 | .07 | 18.1 | 7.84 | 15.84 |
| 11176145 | 3.01 | 16.6 | 3.79 | 20.8 | 11.3 | .08 | 62.6 | 18.18 | 35.07 |
| 11176180 | 2.42 | 17.2 | 2.99 | 21.2 | 8.58 | .10 | 61.6 | 14.09 | 27.79 |
| 11176200 | 2.43 | 27.4 | 3.40 | 38.3 | 2.98 | .07 | 34.3 | 8.88 | 16.39 |
| 11176300 | 2.58 | 28.2 | 2.26 | 24.7 | 4.19 | .11 | 47.0 | 9.14 | 18.36 |
| 11176500 | 2.46 | 34.6 | 2.28 | 32.1 | 2.29 | .07 | 33.2 | 7.10 | 13.34 |
| 11176600 | 1.48 | 34.8 | 1.30 | 30.6 | 1.41 | <.06 | 34.6 | 4.25 | 8.60 |
| 11177000 | 2.40 | 32.1 | 2.40 | 32.1 | 2.57 | .10 | 35.7 | 7.47 | 15.47 |
| South Bay aqueduct at Del Valle water-treatment plant. | 1.13 | 30.5 | 0.88 | 23.8 | 1.62 | .07 | 45.7 | 3.70 | 6.84 |

dissolved ions of any of the program stations. Another exception was Arroyo Mocho near Livermore which had a strong magnesium bicarbonate water type. This water type is similar to that in the ground water in most of the Mocho II subbasin through which Arroyo Mocho flows. The water quality at Arroyo Mocho near Livermore (11176000) is not very representative of the water farther downstream during low flow periods. Water releases from the South Bay aqueduct, which enter the stream downstream from the sampling site, make up almost the entire flow of Arroyo Mocho during the dry months.

The water-quality sampling program was oriented to times of natural flow in the streams. Because most of the flow in Arroyo Valle and Arroyo Mocho is from South Bay aqueduct releases (97 percent of the time in Arroyo Valle in 1982), the diagram representing water quality in the South Bay aqueduct is more representative of water quality in these streams. Streams draining the Livermore Formation south of the valley had lower concentrations of dissolved ions than streams draining the marine and Tassajara Formations to the east and north.

## WATER-QUALITY OBJECTIVES

Water-quality objectives for ground and surface water in the San Francisco Bay area were established by the California Regional Water Quality Control Board, San Francisco Bay Region (1982) in 1982. This basin plan set objectives for several water-quality properties and constituents and in many cases set different objectives for municipal and agricultural uses. In addition to these objectives applicable for all surface and ground water in the San Francisco Bay area, separate and more specific objectives have been set for surface and ground water in the Alameda Creek basin above Niles (including Livermore-Amador Valley). The ground-water objectives are slightly different for two sections of the ground-water basin. The "central" ground-water basin consists of the Bernal, Amador, Mocho I, and Mocho II subbasins. These areas have the largest ground-water storage and are mostly used for municipal and domestic water supplies. The remaining subbasins, designated as "fringe" ground-water basins, have generally poorer, ambient water quality and are less important for most uses than the central basin. All water-quality objectives applicable to the study area, and for which data were obtained, are given in table 5 along with the number of wells that have mean concentrations that exceeded the objectives, and the surface-water stations that have had some samples that exceeded water-quality objectives. The individual wells that have mean values of properties and constituents greater than the objectives are given in table 6.

Because the sampling network wells are more numerous in areas of known or potential water-quality problems, there were probably a higher proportion of wells that exceeded objectives than would be detected if all the wells in the valley were sampled. In addition, most of the wells that exceeded objectives were shallow wells not used for public water supply. The existing large ground-water supplies all met water-quality objectives.

The dissolved-solids objective was exceeded in all but two of the wells in the Bernal subbasin and in all the wells along the northern part of the Amador subbasin. Only 3S/1E-1R2 exceeded the dissolved-solids objective in the Mocho subbasins. The areas in the central basin that have dissolved solids below the objectives are along Arroyo Mocho and Arroyo Valle, the principle recharge areas in the valley. All the wells that exceeded the nitrate objective in the central basin are located around the Livermore and Pleasanton wastewater-disposal areas with the exception of 3S/2E-19D6 and

TABLE 5.--Surface- and ground-water samples that exceeded water-quality objectives.
(Water-quality objectives set by San Francisco Bay Regional Water Quality Control Board, 1982)

[pH is in units. Specific conductance is in micromhos per centimeter at 25 degrees Celsius. All other properties and constituents are in milligrams per liter. Boron: Agricultural objective was used for evaluating ground- and surface-water samples]

| Properties and constituents | Objectives | | Number of wells with mean values in excess of municipal objective | Surface-water stations (Number of samples that exceeded objective/number of samples) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Municipal | Agricultural | | 11176145 | 11176180 | 11176000 | 11176200 | 11176300 | 11174600 | 11176500 | 11176600 | 11177000 |
| Dissolved solids | | | | | | | | | | | | |
| Ground water | | | | | | | | | | | | |
| Central subbasin-- | 500 | -- | 39 | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Fringe subbasin--- | 1,000 | -- | 13 | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Surface water, daily maximum----- | 500 | -- | -- | 9/9 | 12/16 | 5/19 | 12/21 | 10/14 | 238/261 | 24/38 | -- | 16/33 |
| pH------------------- | 6.5-8.5 | 4.5-9.0 | 0 | -- | [1]1/7 | -- | [1]1/11 | [1]1/7 | -- | [1]3/69 | [1]4/89 | -- |
| Specific conductance-- | 1,600 | 3,000 | 24 | 4/9 | 5/16 | -- | 1/21 | -- | 41/261 | 3/73 | -- | -- |
| Boron----------------- | -- | 2 | 16 | 9/11 | 8/16 | -- | 1/20 | -- | -- | 7/73 | -- | -- |
| Chloride | | | | | | | | | | | | |
| Ground water-------- | 500 | 355 | 5 | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Surface water, daily maximum----- | 250 | -- | -- | 7/11 | 7/16 | -- | 1/20 | -- | [2]27/260 | -- | -- | -- |
| Sulfate--------------- | 500 | -- | 2 | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Fluoride-------------- | 1.6 | 15 | 1 | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Nitrate plus nitrate-- | 10 | 30 | 16 | -- | -- | -- | -- | -- | 1/42 | -- | -- | 2/33 |
| Iron------------------ | 0.3 | 20 | 5 | -- | -- | -- | -- | 1/13 | -- | 1/10 | -- | 1/31 |
| Manganese------------- | 0.05 | 10 | 46 | 3/11 | 1/16 | -- | 2/20 | -- | 20/26 | 4/10 | 1/22 | 7/31 |

[1]Samples had pH greater than 8.5.
[2]Sample data was prior to 1978.

19F4. These two wells are in an unsewered area where septic tank leakage could cause nitrate in the ground water. The occurrence of high dissolved solids in ground water is most likely a natural phenomenon in the shallow aquifers in most of the valley that is away from Arroyo Mocho and Arroyo Valle. In addition, the waste-disposal practices at Livermore and Pleasanton probably have increased the dissolved solids and nitrate but the extent of these increases is not known. An example of an increase in dissolved solids is shown by comparing dissolved-solids concentrations at well 3S/2E-7C1, located just upgradient from the Livermore sewage-treatment plant, with wells downgradient. Water from well 3S/2E-7C1 was below the dissolved-solids and nitrate objectives, whereas, most of the water from wells downgradient from the sewage-treatment plant exceeded the objectives.

In several areas in the valley, dissolved iron and manganese were detectedin concentrations exceeding the recommended concentrations for public drinking water supplies (U.S. Environmental Protection Agency, 1977). The recommended maximum of 300 μg/L for iron and 50 μg/L for manganese is based on taste preference. Forty-six wells had mean manganese concentrations greater than 50 μg/L and five wells had mean iron concentrations greater than 300 μg/L (table 6). All the wells with high iron concentrations, except one (2S/2E-27C2), are located in the western edge of the valley. The highest mean concentration of iron (2,900 μg/L) was detected in well 3S/1E-30A9. Wells with high manganese concentrations (greater than 50 μg/L) were detected generally in the Dublin, Bernal, and Camp subbasins. The highest concentrations in these areas were generally associated with the clay layer north of Pleasanton.

Some violations of at least one of the water-quality objectives occurred at all of the surface-water stations. The dissolved-solids objective of 500 mg/L as a daily maximum was exceeded at every station except Arroyo Valle at Pleasanton. These violations are so widespread in both time and location that it is apparent the dissolved-solids objective cannot be met in most of the valley's surface water. Samples were too infrequent to evaluate the 90-day mean and 90-day, 90th-percentile objectives, but it seems that these objectives are regularly exceeded during much of the year. The specific-conductance objective was exceeded much less often than the dissolved-solids objective. This is because the 1,600-μmho specific conductance objective is approximately equivalent to a 1,000-mg/L dissolved-solids objective instead of the 500 mg/L that is currently (1983) set. The pH objective was exceeded (all greater than 8.5) at five stations, but so infrequently that a water-quality problem probably does not exist. Boron concentrations in excess of the objective was detected only at Arroyo Las Positas at Livermore and near Pleasanton, Arroyo Mocho near Pleasanton, and Arroyo Valle near Livermore. These boron concentrations are naturally occurring. Manganese concentrations in excess of the objective were common at most of the stations during low flow periods. These occurrences, like that of boron, are the result of upstream geology in the basin. The chloride objective was exceeded frequently at the Arroyo Las Positas stations because of the naturally occurring sodium chloride water in the stream. The 27 samples taken from Alamo Canal that exceeded the chloride objective were detected prior to February 1978. Most of these samples were taken during the 1976-77 drought when streamflow was generally less than normal in most streams. The chloride objective has not been exceeded in an Alamo Canal sample since the export of treated effluent began in 1980. Sampling was too infrequent to evaluate the 90-day mean and 90-day, 90th-percentile chloride objective.

TABLE 6.--Wells that have mean concentrations in excess of water-quality objectives

[--, mean observations that did not exceed water-quality objectives]

| Well No. | Specific conductance (umho) | Chloride, dissolved (mg/L) | Dissolved solids (mg/L) | Nitrate, dissolved (mg/L as N) | Boron, dissolved (ug/L) | Iron, dissolved (ug/L) | Manganese, dissolved (ug/L) |
|---|---|---|---|---|---|---|---|
| 2S/1W-14N1 | -- | -- | -- | -- | -- | -- | 520 |
| 15F1 | -- | -- | -- | -- | -- | -- | 1,200 |
| 36E3 | -- | -- | -- | -- | -- | -- | 450 |
| 2S/2E-21L4 | -- | -- | -- | -- | -- | -- | 220 |
| 27C2[1] | 3,040 | 780 | 1,710 | -- | 16,000 | 470 | 160 |
| 27P2[1] | 4,890 | 1,500 | 2,650 | -- | 38,000 | -- | 300 |
| 34E1 | -- | -- | -- | -- | -- | -- | 240 |
| 3S/1E-1H3 | -- | -- | 850 | -- | -- | -- | -- |
| 1P2 | -- | -- | 870 | -- | 2,600 | -- | -- |
| 1R2 | -- | -- | 539 | 11 | -- | -- | -- |
| 2K2[1] | 1,650 | -- | -- | 14 | 2,000 | -- | -- |
| 2N2[1] | -- | -- | 1,360 | 17 | -- | -- | 77 |
| 2N3 | -- | -- | 688 | -- | -- | -- | -- |
| 2R1 | -- | -- | -- | 13 | -- | -- | -- |
| 3G2 | -- | -- | -- | -- | -- | -- | 660 |
| 4J4 | -- | -- | -- | -- | -- | -- | 550 |
| 4Q2 | 1,600 | -- | -- | -- | 2,900 | -- | 50 |
| 5J2[1] | 1,780 | -- | 1,140 | -- | -- | -- | 917 |
| 5M1 | -- | -- | -- | -- | -- | -- | 590 |
| 6F3[1] | 2,250 | -- | 1,480 | -- | 5,600 | -- | 210 |
| 6R2[1] | 4,620 | 690 | 3,380 | -- | -- | -- | 1,800 |
| 7B2 | -- | -- | -- | -- | -- | -- | 60 |
| 7F1[1] | 9,930 | 3,000 | 6,550 | -- | -- | -- | 5,800 |
| 7M2[1] | 2,180 | -- | 1,350 | -- | -- | 2,100 | 1,200 |
| 8B1[1] | 1,950 | -- | 1,160 | -- | 2,300 | -- | 260 |
| 8H2 | -- | -- | 855 | -- | -- | -- | -- |
| 8K1 | -- | -- | 764 | -- | -- | -- | 70 |
| 8N1 | 1,670 | -- | 1,110 | -- | -- | -- | -- |
| 9G1 | -- | -- | 808 | -- | -- | -- | -- |
| 9P5 | -- | -- | 774 | -- | -- | -- | -- |
| 9Q1 | -- | -- | 721 | -- | -- | -- | -- |
| 10A2 | 1,730 | -- | 1,000 | -- | 3,000 | -- | -- |
| 10E1 | -- | -- | 522 | -- | -- | -- | -- |
| 10G2 | -- | -- | 794 | -- | -- | -- | -- |
| 11B1 | -- | -- | 949 | 11 | 2,900 | -- | -- |
| 12A2 | -- | -- | 688 | 12 | -- | -- | 57 |
| 12D2 | 1,620 | -- | 962 | 16 | -- | -- | -- |
| 12F1 | -- | -- | 529 | -- | -- | -- | 51 |
| 12G1 | -- | -- | 810 | 14 | -- | -- | -- |
| 12H1 | -- | -- | 577 | -- | -- | -- | -- |
| 16E4 | -- | -- | 604 | -- | -- | -- | -- |
| 17B4 | -- | -- | 652 | -- | -- | -- | -- |
| 18E4 | -- | -- | -- | -- | -- | -- | 660 |
| 18J1 | -- | -- | 564 | -- | -- | -- | -- |
| 18J2 | 2,350 | -- | 1,520 | -- | -- | -- | 1,800 |
| 19C4 | -- | -- | 648 | -- | -- | -- | 160 |
| 19K1 | -- | -- | 788 | -- | -- | -- | 2,500 |
| 20F5 | -- | -- | 665 | -- | -- | -- | -- |
| 20J1 | -- | -- | 861 | 11 | -- | -- | -- |
| 20J4 | -- | -- | 821 | 14 | -- | -- | 55 |
| 20M11 | -- | -- | 896 | 13 | -- | -- | -- |
| 20Q1 | 1,620 | -- | 932 | 14 | -- | -- | 180 |
| 22D2 | -- | -- | 776 | 15 | -- | -- | -- |
| 29D2 | -- | -- | 720 | -- | -- | -- | -- |
| 29E3 | -- | -- | 847 | -- | 2,300 | -- | 100 |
| 29M4 | -- | -- | -- | -- | -- | 670 | 200 |
| 29P2 | -- | -- | 848 | -- | -- | -- | 340 |

TABLE 6.--Wells that have mean concentrations in excess of water-quality objectives--Continued

| Well No. | Specific conductance (umho) | Chloride, dissolved (mg/L) | Dissolved solids (mg/L) | Nitrate, dissolved (mg/L as N) | Boron, dissolved (ug/L) | Iron, dissolved (ug/L) | Manganese, dissolved (ug/L) |
|---|---|---|---|---|---|---|---|
| 3S/1E-30A8 | -- | -- | 730 | -- | -- | -- | -- |
| 30A9 | -- | -- | -- | -- | -- | 2,900 | 510 |
| 32G2 | 2,140 | -- | 1,170 | -- | -- | -- | 470 |
| 3S/1W-1B5 | -- | -- | -- | -- | -- | -- | 435 |
| 1L1 | -- | -- | -- | -- | -- | 2,000 | 450 |
| 12J1[1] | 1,980 | -- | 1,330 | -- | -- | -- | 830 |
| 13J1 | -- | -- | -- | -- | -- | -- | 63 |
| 3S/2E-1F2[1] | 2,590 | 570 | 1,590 | -- | 6,600 | -- | -- |
| 1P2[1] | 2,040 | -- | 1,310 | -- | 5,400 | -- | -- |
| 3K3 | -- | -- | 560 | -- | -- | -- | -- |
| 5J1 | -- | -- | 762 | -- | 2,100 | -- | -- |
| 7C2 | -- | -- | 680 | 14 | -- | -- | -- |
| 7N1 | -- | -- | -- | -- | -- | -- | 67 |
| 8H2 | -- | -- | 638 | 15 | -- | -- | -- |
| 8K2 | -- | -- | 573 | 11 | -- | -- | -- |
| 9Q4 | -- | -- | 603 | 13 | -- | -- | -- |
| 10F3 | -- | -- | 749 | 15 | -- | -- | -- |
| 10Q1 | 1,640 | -- | 995 | 17 | -- | -- | -- |
| 11A1 | -- | -- | -- | 12 | -- | -- | -- |
| 11C1 | -- | -- | 628 | 10 | -- | -- | -- |
| 14A3 | -- | -- | 638 | -- | -- | -- | -- |
| 14B4 | -- | -- | 516 | -- | -- | -- | -- |
| 15J2 | -- | -- | 715 | 20 | -- | -- | -- |
| 16A3 | -- | -- | 502 | 11 | -- | -- | -- |
| 16J1 | -- | -- | -- | -- | -- | -- | 130 |
| 19D6 | -- | -- | -- | 10 | -- | -- | -- |
| 19F4 | -- | -- | -- | 10 | -- | -- | -- |
| 21L13 | -- | -- | -- | -- | -- | -- | 180 |
| 22B1 | -- | -- | 715 | 10 | -- | -- | -- |
| 24A1 | -- | -- | 865 | 18 | -- | -- | -- |
| 26J2 | -- | -- | 598 | -- | -- | -- | 310 |
| 29F4 | -- | -- | -- | -- | -- | -- | 160 |
| 30D2 | -- | -- | -- | -- | -- | -- | 160 |
| 33G2 | -- | -- | 656 | -- | -- | -- | 360 |
| 33G3 | 2,420 | -- | 1,450 | -- | 3,300 | -- | 640 |
| 33K1 | 2,110 | -- | 1,220 | -- | 6,400 | -- | -- |
| 33L1 | -- | -- | 778 | -- | -- | -- | 1,000 |
| 3S/3E-7D2[1] | 2,390 | -- | 1,490 | 11 | 7,000 | -- | -- |
| 7M2 | -- | -- | -- | -- | -- | -- | 63 |

[1] Well located in fringe subbasin.

## CHANGES IN THE EXISTING MONITORING NETWORK

Analysis of data for the present well network shows that variability of most water-quality constituents is high, and that many wells have seasonal or other periodic patterns to the variations found. Because of this variability, continued sampling is desirable for all wells that have less than 5 years of data on a quarterly basis until 5 years of data have been collected. Other wells could be sampled twice a year to establish long-term trends.

In addition to the twice-yearly sampling at most wells, a network of key wells at various locations and depths is proposed. These key wells would be sampled every 2 months and would be concentrated near areas of known ground-water contamination and major recharge areas. Sampling at these wells would monitor short-term variability in water quality. A list of suggested key wells is presented in table 7.

TABLE 7.--Proposed key wells

[U.S. Geological Survey identification well numbers are given in table 1. Type of well: C, wells constructed for this study; E, existing well]

| Well No. | Depth of well (feet) | Type of well | Perforation interval (feet) | Period of water quality record (water year) |
|---|---|---|---|---|
| 2S/1E-32N1 | 45 | C | 35-40 | 1976-83 |
| 2S/2E-27P2 | 68 | C | 35-45; 59-63 | 1979-83 |
| 3S/1E-1R2 | 56 | C | 49-54 | 1981-83 |
| 2R1 | 33 | C | 21-26 | 1975-83 |
| 5J2 | 100 | C | 90-95 | 1978-83 |
| 7B2 | 150 | C | 143-149 | 1979-83 |
| 8H2 | 205 | E | 124-139; 148-165 | 1981-83 |
| 10A2 | 88 | C | 70-80 | 1979-83 |
| 11B1 | 43 | C | 33-38 | 1975-83 |
| 12G1 | 73 | C | 63-68 | 1975-83 |
| 12N1 | 304 | E | 7 perforations from 112-295 | 1980-83 |
| 14G1 | 500 | E | 150-500 | 1979-83 |
| 16H2 | 94 | C | 82-92 | 1979-83 |
| 17Q4 | 84 | C | 74-79 | 1978-83 |
| 19C4 | 78 | C | 68-73 | 1979-83 |
| 20F5 | 46 | C | 36-41 | 1975-83 |
| 20Q1 | 52 | E | 41-51 | 1977-83 |
| 29D2 | 64 | C | 54-59 | 1975-83 |
| 29M4 | 57 | C | 47-52 | 1975-83 |
| 3S/1W-1B5 | 108 | C | 98-103 | 1979-83 |
| 12J1 | 62 | C | 52-57 | 1975-83 |
| 13J1 | 49 | C | 39-44 | 1976-83 |
| 3S/2E-8K2 | 74 | C | 64-69 | 1977-83 |
| 11J2 | 110 | C | 90-92; 102-108 | 1979-83 |
| 16E4 | 45 | C | 35-40 | 1978-83 |
| 19F4 | 164 | E | 100-160 | 1976-83 |
| 22B1 | 55 | C | 45-50 | 1976-83 |
| 30D2 | 44 | C | 24-29; 34-39 | 1979-83 |
| 3S/3E-7D2 | 74 | C | 64-69 | 1976-83 |

A complete analysis of major cations and anions, plus boron, silica, and manganese, would be collected once a year at all network wells. Key wells would have complete analyses taken every other bimonthly sample. Field measurements for pH, specific conductance, temperature, alkalinity, dissolved oxygen, and water level, and a nitrate and chloride sample would be taken at each well during each sampling. Dissolved oxygen would be measured on a reconnaissance basis the first year to determine if it can be a useful indicator of the presence of organic substances in ground water. Recent studies (Winograd and Robertson, 1982) have indicated that the presence of dissolved oxygen in significant concentrations in ground water may be much more common than widely believed.

The shallow, mostly unconfined aquifers in the Livermore Valley should have significant concentrations of oxygen, except in areas where soil and aquifer bacteria use organic material to consume the dissolved oxygen carried in the ground water by recharge.

Based on analysis of existing data, there is a consistent and reliable dissolved-solids to specific-conductance ratio in the network wells. This makes it possible to delete the dissolved-solids determination from the sampling schedules for all wells that have at least 5 years of data. Dissolved solids could be calculated routinely by use of the specific conductance and the dissolved-solids to specific-conductance ratio already established for that well. If a change in water type was detected at any one well, the ratio of dissolved solids to specific conductance would have to be verified by further sampling.

The determination of organic carbon content of the ground water is potentially useful means of determining areas of water-quality degradation. This study has shown that the use of TOC is unreliable because of sampling, analytical problems, and the uncertainty of what changes occur to the sample from the time of collection to analysis. A better method of sampling organic carbon is to analyze dissolved organic carbon (DOC). Since ground water is low in suspended material, the DOC determination would closely approximate actual TOC concentrations. In addition, the method used for filtering DOC samples (silver membrane filters) provides better sample preservation and assures minimal change in organic carbon content between the time of collection and analysis. A DOC sample collected twice at each key well during the next year could determine the reliability of this analysis.

Some changes in the surface-water monitoring network would be desirable in the future. Water-quality and discharge records at the two Arroyo Las Positas stations were very similar, indicating little recharge or inflow to the stream in this reach. Therefore, the station Arroyo Las Positas at Livermore (11176145), could be deleted with no effect on the monitoring network. Sampling of water-quality properties and constituents would continue as in the past with a frequency of no less than four times a year at each station. These samples would be taken at a variety of discharges.

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