LAND APPLICATION OF WASTEWATER AND ITS EFFECT ON GROUND-WATER QUALITY IN THE LIVERMORE-AMADOR VALLEY, ALAMEDA COUNTY, CALIFORNIA

By Marc A. Sylvester

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 82-4100

Prepared in cooperation with the

ALAMEDA COUNTY FLOOD CONTROL AND

WATER CONSERVATION DISTRICT, ZONE 7

3006-05

March 1983

UNITED STATES DEPARTMENT OF THE INTERIOR

JAMES G. WATT, SECRETARY

GEOLOGICAL SURVEY

Dallas L. Peck, Director

For additional information, write to:

District Chief
Water Resources Division
U.S. Geological Survey
2800 Cottage Way, Room W-2235
Sacramento, Calif. 95825

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ILLUSTRATIONS

[Plates are in pocket]

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CONVERSION FACTORS

For readers who may prefer to use 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
acres	4047	m^2 (square meters)
ft (feet)	0.3048	m (meters)
gal/d (gallons per day)	0.003785	m^3/d (cubic meters per day)
inches	25.4	mm (millimeters)
Mgal/d (million gallons per day)	3785	m^3/d (cubic meters per day)
mi (miles)	1.609	km (kilometers)
mi^2 (square miles)	2.59	km^2 (square kilometers)
μmho/cm (micromhos per centimeter)	1	μS (microsiemens per centimeter)

Other abbreviations used:

MCL (maximum contaminant levels)
mg/L (milligrams per liter)

Degrees Celsius (°C) are converted to degrees Fahrenheit (°F) by using the formula:

$$\text{Temp °F} = (\text{temp °C} \times 1.8) + 32$$

ALTITUDE DATUM

National Geodetic Vertical Datum of 1929 (NGVD of 1929): A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called mean sea level.

DEFINITION OF WATER YEAR

Water year is a 12-month period ending September 30 and is designated by the year in which it ends.

TRADE NAME DISCLAIMER

The use of brand names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

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By Marc A. Sylvester

ABSTRACT

Ground-water quality, ground-water level, and rainfall data collected from 1975 through the 1980 water year were analyzed to determine the effects of land application of effluent from wastewater treatment plants on ground-water quality in the Livermore-Amador Valley. Annual rainfall varied markedly during the study: 1976 and 1977 water years had less than one-half the normal rainfall; 1978 and 1980 water years had greater than normal rainfall; and 1975 and 1979 water years had nearly normal rainfall. The directions of ground-water movement in the valley are generally the same as the directions of surface-water flow.

Median concentrations of dissolved nitrate as N were greater than 10 milligrams per liter in most wells sampled in the Livermore wastewater application area near the Livermore Municipal Airport and in that part of the Pleasanton wastewater application area downgradient from and north of the percolation ponds. Median concentrations of dissolved nitrate as N were less than 8.0 milligrams per liter in most wells in areas not receiving wastewater applications.

In the Castlewood, Pleasanton, and Veterans Administration Hospital wastewater application areas and in the upper aquifer in the Livermore wastewater application areas, values of specific conductance, pH, dissolved solids, and dissolved chloride were very similar to those characteristic of effluent from wastewater treatment plants in the Livermore-Amador Valley. In the Dublin-San Ramon and Camp Parks Military Reservation wastewater application area, values of specific conductance, dissolved solids, and dissolved chloride were about 3 to 4 times those characteristic of effluent from wastewater treatment plants in the Livermore-Amador Valley.

An area-by-area assessment of areal and temporal variations in ground-water quality and ground-water levels in wastewater application areas showed that rainfall, soil, and geology appeared to be the main determinants of ground-water quality in the Castlewood wastewater application area and in the Dublin-San Ramon and Camp Parks Military Reservation wastewater application area. Wastewater application appeared to be the main determinant of ground-water quality in the wastewater application area near the Livermore Municipal Airport and in the Pleasanton and Veterans Administration Hospital wastewater application areas.

Comparison of ground-water quality in wastewater application areas with water-quality objectives for ground water in the Livermore-Amador Valley showed impaired ground-water quality in all wastewater application areas.

Next page is 3

INTRODUCTION

Background

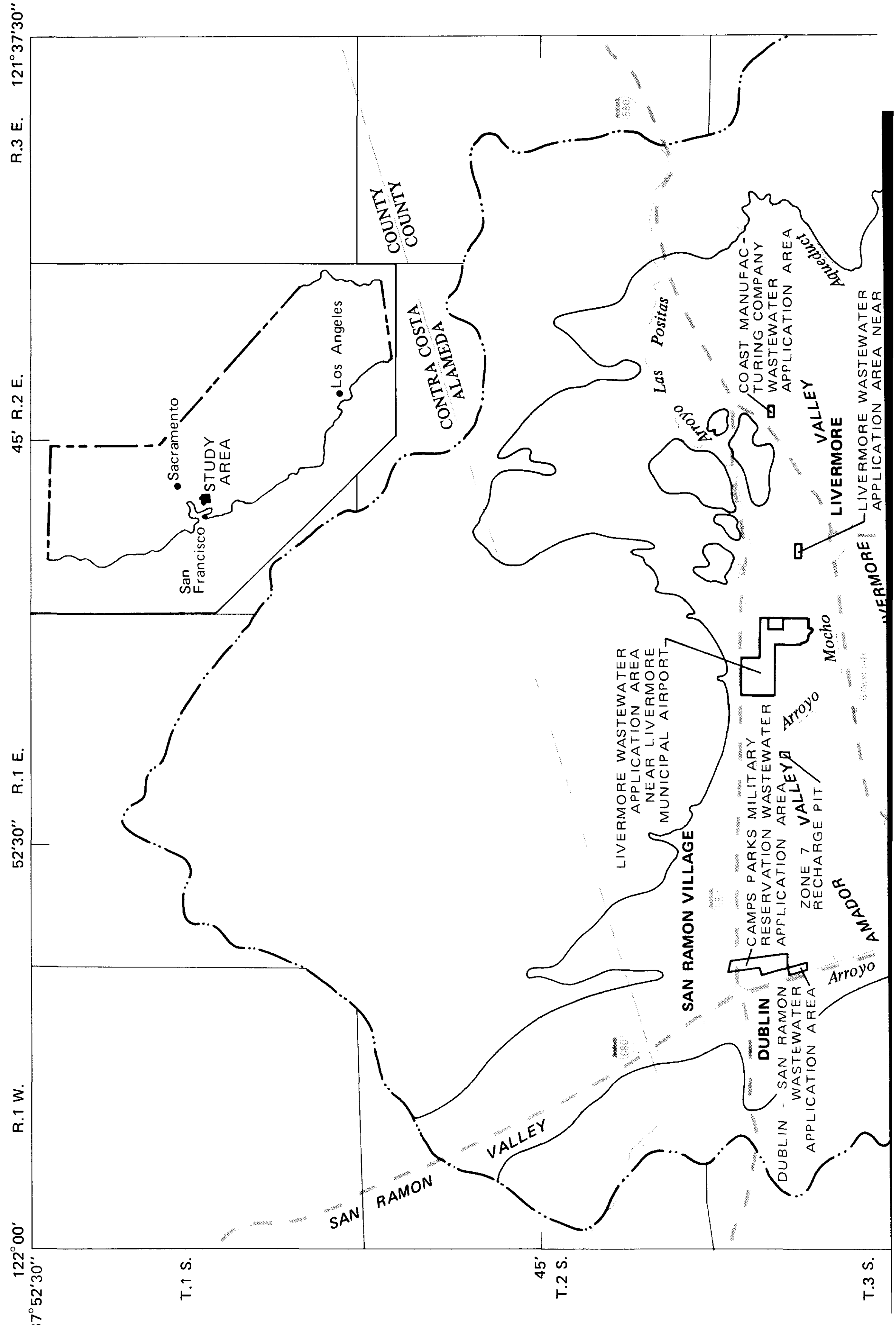
The study area includes Livermore and Amador Valleys and parts of San Ramon and Sunol Valleys (fig. 1). Ground-water and surface-water use in the Livermore-Amador Valley has increased as a result of population growth and, as a consequence, the amount of wastewater produced has also increased. Prior to 1980, most of the effluent from wastewater treatment plants was discharged to ponds for percolation and evaporation, applied to agricultural land and golf courses, and released to streams. In all cases, application was on the surface of alluvium, which contains the major aquifer in the valley. Local water-resources managers and planners are concerned about possible effects of this effluent on ground-water quality, and this concern prompted the construction of a pipeline to export most of this effluent from the valley. Although the pipeline was completed in January 1980, the Livermore Wastewater Treatment Plant, Dublin-San Ramon Services District, Veterans Administration Hospital, and Castlewood Wastewater Treatment Plant continue land application of effluent.

The Alameda County Flood Control and Water Conservation District, Zone 7 (hereinafter referred to as Zone 7), is the lead agency responsible for management of ground water in the Livermore-Amador Valley. In 1975, Zone 7 established a network of observation wells to define and assess changes in water levels and ground-water quality. Since then, the network has been expanded by drilling and monitoring additional wells. As part of a cooperative program, the U.S. Geological Survey assisted Zone 7 in designing the network, drilling observation wells, and collecting, analyzing, and reviewing water-quality data. In addition, the California Department of Water Resources has collected water-level and water-quality data in the valley for about 20 years.

Purpose and Scope

This report describes the effect of land application of effluent from wastewater treatment plants on ground-water quality in the Livermore-Amador Valley. The report focuses on five wastewater application areas contiguous to or near the following wastewater treatment plants:

(1) Livermore;
(2) Pleasanton;
(3) Dublin-San Ramon Services District (was Valley Community Services District);
(4) Castlewood Corporation; and
(5) Veterans Administration Hospital.



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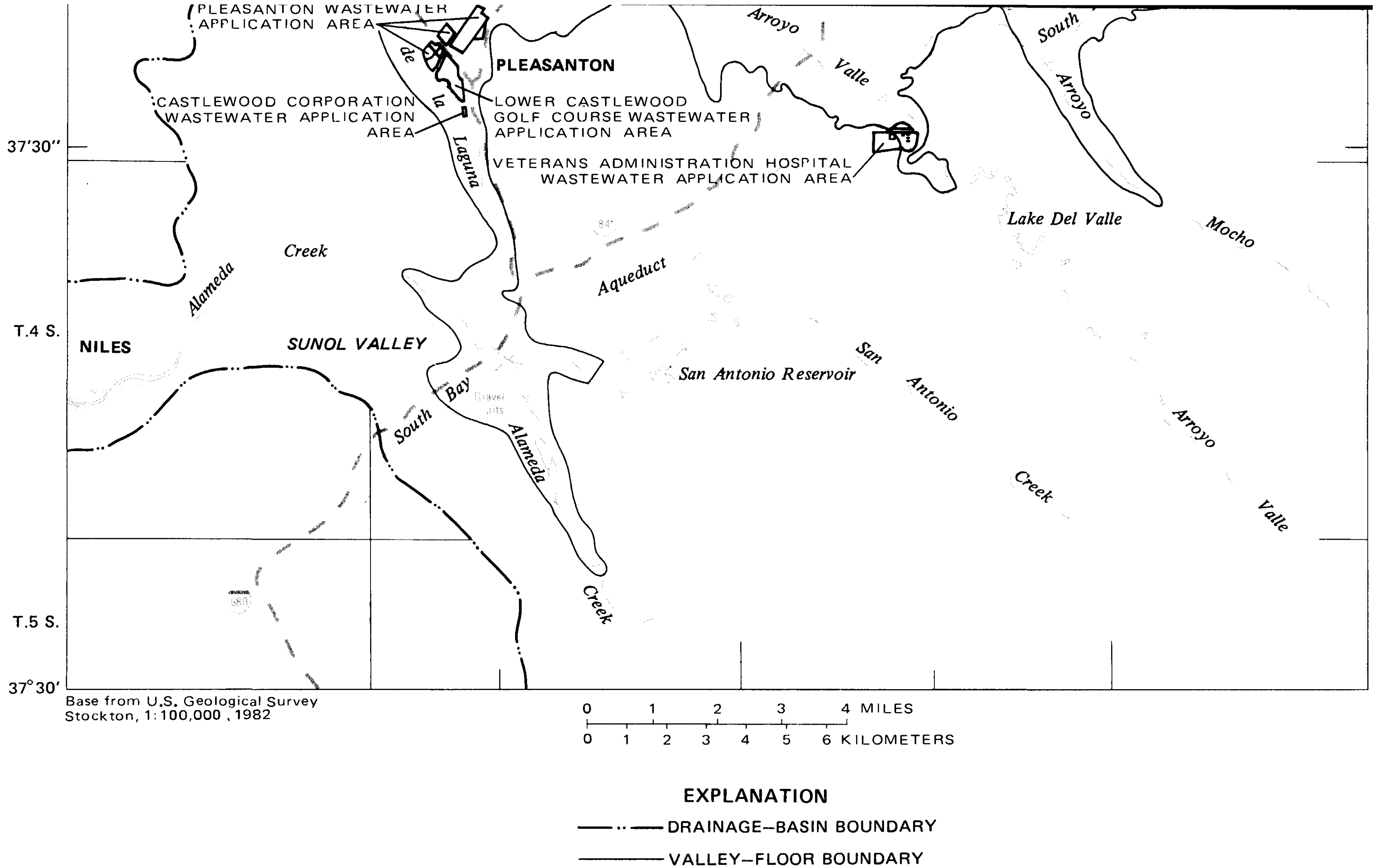


FIGURE 1. – Location of study area and wastewater application areas.

In the Areawide Assessment section of this report, water-level data from wells throughout the study area were used to determine the general directions of ground-water movement in the valley. Nitrate data from wells throughout the study area were used to compare the quality of the ground water in areas that receive wastewater applications to those that do not. Water-quality data from wells in wastewater application areas (selected wells in table 1) were used to compare ground-water quality in wastewater application areas with the quality of effluent from wastewater treatment plants in the valley.

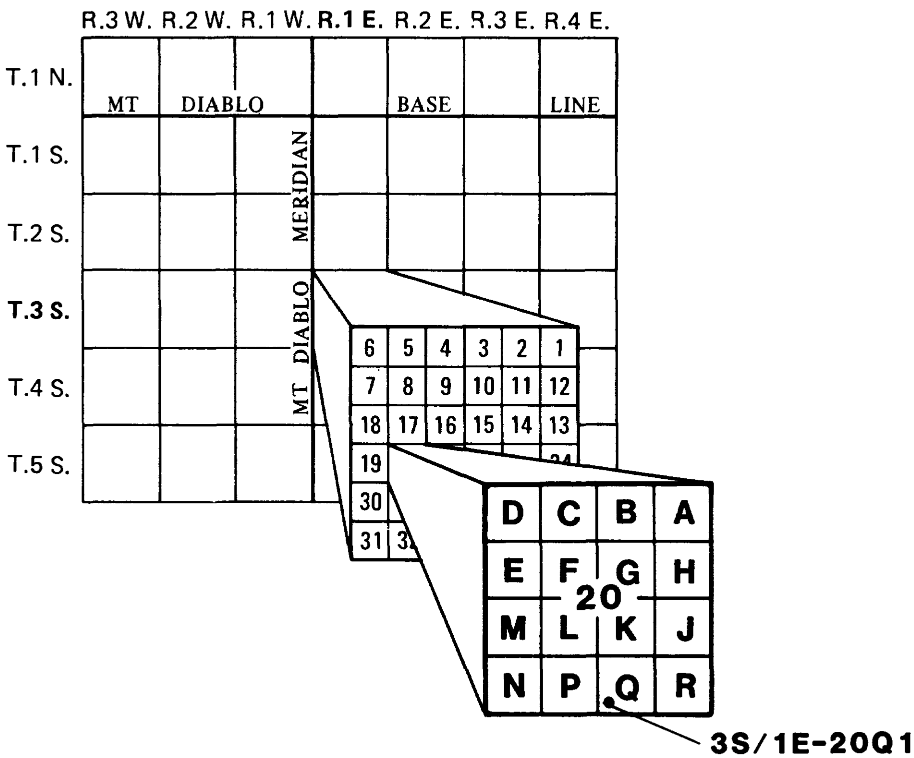
Results in the Site-Specific Assessment section of this report are based on water-level and water-quality data from wells in or near wastewater application areas (table 1). Information about these wells is from well logs and the U.S. Geological Survey WATSTORE computer file. To avoid invalid results, analysis of water-quality and water-level data generally was restricted to those wells in table 1 that met the following criteria:

1. Well casing is perforated below the upper clay confining bed and in the upper alluvial aquifer;
2. Sufficient water-quality and water-level data are available to obtain reliable results from statistical and other analytical procedures; and
3. Location of wells is critical for providing adequate spatial coverage of wastewater application areas (for example, wells that are in, upgradient from, and downgradient from application areas were included).

Wells selected for analysis are shown in the last column of table 1. Where two or more wells located close together met the criteria, only the well with the longer record of water-quality and water-level data was selected (for example, well 3S/1E-20Q1 was selected instead of 3S/1E-20Q2 because the period of water-quality and water-level record is longer at 3S/1E-20Q1). Sometimes all the wells in a particular part of a wastewater application area did not meet one or more of the criteria. To insure adequate spatial coverage of a wastewater application area, some of these wells were selected for analysis based on the remaining criteria; such wells are indicated by a question mark (?) in the last column of table 1. The first criterion was not applied to wells in the Veterans Administration Hospital wastewater application area because these wells are in the Livermore Formation or stream-channel deposits. Wells indicated by a checkmark (√) were used only for a comparison of water quality between upper and lower alluvial aquifers and for comparison with water-quality objectives.

Well-Numbering System

The well-numbering system used by the U.S. Geological Survey in California indicates the location of wells according to the rectangular system for the subdivision of public land. For example, in the well 3S/1E-20Q1, the first two segments designate the township (T. 3 S.) and the range (R. 1 E.); the third number gives the section (sec. 20); and the letter indicates the 40-acre subdivision of the section, as shown in the accompanying diagram. A final digit is a serial for wells in each 40-acre subdivision (3S/1E-20Q1).



Acknowledgments

The author gratefully acknowledges the following agencies for their assistance with the data-collection program: Alameda County Flood Control and Water Conservation District, Zone 7; Alameda County Water District; California Regional Water Quality Control Board, San Francisco Bay Region; Livermore-Amador Valley Water Management Agency; Dublin-San Ramon Services District; and the City of Livermore Wastewater Treatment Plant.

TABLE 1. - Information about wells in or near wastewater application areas

[Well selected: √, Well was used only for a comparison of water quality between upper and lower alluvial aquifers and a comparison with water-quality objectives; x, Well met selection criteria; ?, If in Well Selected column, well did not meet one or more selection criteria but was used for analysis to provide adequate areal coverage. Otherwise, ? indicates the information used was insufficient to make a determination]

Application area and wells	Formation tapped	Type of material in perforation zone	Depth of well (ft)	Perforation depth (ft)	Location of perforation in relation to upper clay confining bed and upper alluvial aquifer	Location in relation to effluent application area	Period of water-quality record	Properties and constituents sampled, and sampling frequency	Period of water-level record	Well selected
Castlewood Corporation										
3S/1E-32K2	Alluvium	Yellow sand, blue clay, gravel, blue sandstone	150	40-130	Below/ In and below	Down-gradient	1961-1977	PMNT[1]/M[2]	1974-present	
3S/1E-32K4	Alluvium	Blue-gray sand, gravel, clay	44	20.5-42	? / In	Down-gradient	1976-1977	PMN/M	1976-present	
3S/1E-32G2	Alluvium	Sand with trace of gravel	40	30-35	Below/ In	In	1976-present	PMN/M	1975-present	x
Lower Castlewood Golf Course										
3S/1E-29P2	Alluvium	Sand, gravel	42	32-37	Below/ In	Down-gradient	1975-present	PMN/M-6	1961-present	x
Pleasanton										
3S/1E-29E3	Alluvium	Sand, gravel, blue clay, sand	155	37-107	Below/ In and below	Down-gradient	1960-present	PMNT/M-3	1961-present	
3S/1E-29M4	Alluvium	Sand, gravel	57	42-47	Below/ In	In	1975-present	PMN/M-6	1975-present	x
3S/1E-29D2	Alluvium	Sand, gravel	61	46-51	Below/ In	In	1975-present	PMN/M-6	1975-present	x
3S/1E-20Q2	Alluvium	Silt, sand, gravel	65	45-53	Below/ In	In	1976-1977	PMN/M-6	1976-present	
3S/1E-20Q1	Alluvium	Loose gravel	52	41-51	Below/ In	In	1977-present	PMN/M-6	1961-present	x
3S/1E-20J1	Alluvium	Sandy gravel	42	37-42	Below/ In	In	1976-present	PMN/M-6	1976-1979	
3S-1E-20J4	Alluvium	Clayey sand, gravel	72	62-67	Below/ In	In	1975-present	PMN/M-6	1975-present	x
3S/1E-29A1	Alluvium	Gravel, yellow clay	105	58-83	Below/ In	Upgradient	1976-1977	PMN/M-6	1976-present	x
3S/1E-30G3	Alluvium	Clayey and sandy silt	61.3	51.3-56.3	In/ Below	Upgradient	1976-present	PMN/M-4	1976-present	
3S/1E-30A9	Alluvium	Sand, gravel	73	63-68	Below/ In	In	1975-present	PMN/M-6	1975-present	x
3S/1E-30A8	Alluvium	Sand, gravel, clay	61	46-56	Below/ In	Down-gradient	1975-present	PMN/M-6	1975-present	x
3S/1E-30A11	Alluvium	Clay, gravel	30	20-25	In/ Above	Down-gradient	1975-1977	PMN/M	1975-present	
3S/1E-20M11	Alluvium	Gravel with silt	71	61-66	Below/ In	Down-gradient	1978-present	PMN/M-6	1977-present	x
3S/1E-20F5	Alluvium	Silty sand, gravel	46	36-41	Below/ In	Down-gradient	1975-present	PMN/M-2	1975-present	x
3S/1E-20E7	Alluvium	Sand, gravel, clay	47	37-42	? / In	Down-gradient	1975-1977	PMN/M	1975-1977	
Dublin-San Ramon and Camp Parks Military Reservation										
3S/1W-12J1	Alluvium	Clayey sand	62	52-57	Below/ In	Down-gradient	1975-present	PMN/M-6	1975-present	x
3S/1E-7M2	Alluvium	Sandy clay, gravel, blue clay	85	70-71 78-85	Below/ ?	In	1979-present	PMN/2-4	1979-present	
3S/1W-12H2	Alluvium	Clay	49	39-44	? / ?	In	1975-present	PMN/M-3	1975-1979	?
3S/1E-7F1	Alluvium	Clayey gravel	75	64-69	Below/ In	Down-gradient	1978-present	PMN/4-5	1977-1980	x
3S/1E-6F3	Alluvium	Sand, clayey silt	37	27-32	? / Above	Upgradient	1976-present	PMN/4	1976-1980	?
3S/1W-1B5	Alluvium	Blue sandy clay, gravel	112	97-102	Below/ Below	Upgradient	1979-present	PMN/4	1979-present	

See footnotes at end of table.

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TABLE 1. - Information about wells in or near wastewater application areas--Continued

Application area and wells	Formation tapped	Type of material in perforation zone	Depth of well (ft)	Perforation depth (ft)	Location of perforation in relation to upper clay confining bed and upper alluvial aquifer	Location in relation to effluent application area	Period of water-quality record	Properties and constituents sampled, and sampling frequency	Period of water-level record	Well selected
Dublin-San Ramon and Camp Parks--Continued										
3S/1W-1B4	Alluvium	Sand, clayey silt	25.6	15.6-20.6	? / Above	Upgradient	1976-1979	PMN/4	1976-1979	?
3S/1W-2A2	Alluvium	Clayey silt	47	37-42	? / Above	Upgradient	1976-present	PMN/4	1976-1980	
3S/1W-2A1	Alluvium	Yellow clay, sand, gravel	200	40-200	Below/ Below	Upgradient	1976-1977	PMN/2-3	1969-present	
3S/1W-1L1	Alluvium	No well log	60	No well log	No well log	Upgradient	1976-present	PMN/4	1961-present	
2S/1W-36E3	Alluvium	Sandy clay, some gravel	60	50-55	? / ?	Upgradient	1978-present	PMN/4	1976-1979	?
Veterans Administration Hospital										
3S/2E-33K1	Livermore[3]	Boulders, sand, siltstone	15	7-12	Not related	Downgradient	1975-present	PMN/M-4	1976-present	x
3S/2E-33L1	Livermore[3]	Gravel, some clay	16	11-16	Not related	Upgradient	1977-present	PMN/M-5	1977-1979	x
3S/2E-33G1	Alluvium	Sand, gravel, boulders	17	9-14	Not related	Downgradient	1975-present	PMN/M-4	1976-present	x
3S/2E-33G2	Livermore[3]	Sand, gravel, clay	15	8-13	Not related	In	1977-present	PMN/M-5	1977-present	x
3S/2E-33G3	Alluvium	Gravel, clay	14	9-14	Not related	Downgradient	1977-present	PMN/M-3	1977-present	x
Livermore Plant near Pine Street and Rincon Avenue										
3S/2E-8H2	Alluvium	Sand, gravel, silt	46	36-41	? / In	Upgradient	1976-present	PMN/3-4	1976-present	x
3S/2E-8F1	Alluvium	Clay, gravel	576	143-433	Below/ Below	Upgradient	1978-1979 present	PMN/1-2	1977-	√
3S/2E-8K2	Alluvium	Gravel, sandy clay	74	64-69	Below/ In	Upgradient	1977-present	PMN/4	1977-present	x
3S/2E-8N2	Alluvium	Clay, sandy clay, gravel	526	150-175	Below/ Below	?	1976	PMN/3	1976-present	√
3S/2E-7C2	Alluvium	Gravel with clay, sand	49	39-44	Below/ In	Downgradient	1978-present	PMN/4	1977-present	x
3S/2E-6P1	Alluvium	Yellow clay, gravel, sand	147	6-46 101-146	In and below/ In and below	Downgradient	1976-1980	PMN/4	1958-present	
3S/2E-7N1	Alluvium	Gravel, sandy clay	136	76-88 92-95 127-130	Below/ ?	Downgradient	1979-present	PMN/4	1979-present	
Livermore Plant near Livermore Municipal Airport										
3S/1E-1H3	Alluvium	Clay, sand, gravel	80	70-75	Below/ In or below	Upgradient	1977-present	PMN/4	1977-present	x
3S/1E-1R1	Alluvium	Clay, sand	31.5	21.5-26.5	? / ?	Upgradient	1975-present	PMN/M-6	1975-present	
3S/1E-12H1	Alluvium	Gravel	342	94-120 157-172	Below/ Below	In	1979-present	PMN/2-3	1958-present	√
3S/1E-12G1	Alluvium	Gravel, sand	73	65-70	Below/ In	In	1975-present	PMN/M-6	1975-present	x
3S/1E-12F1	Alluvium	Gravel	240	5 perforations from 115-234	Below/ Below	Downgradient	1959-present	PMNT/M-4	1969-present	√
3S/1E-11J1	Alluvium	Gravel	207	104-128 162-180 190-198	Below/ Below	Downgradient	1959-present	PMNT/M-3	1949-present	√
3S/1E-12A2	Alluvium	Clay	68.7	63.7-68.7	? / Below	In	1975-present	PMN/M-2	1976-present	
3S/1E-12D2	Alluvium	Sand, gravel	46	36-41	Below/ In	In	1975-present	PMN/M-6	1976-present	x

See footnote at end of table.

TABLE 1. - Information about wells in or near wastewater application areas--Continued

Application area and wells	Formation tapped	Type of material in perforation zone	Depth of well (ft)	Perforation depth (ft)	Location of perforation in relation to upper clay confining bed and upper alluvial aquifer	Location in relation to effluent application area	Period of water-quality record	Properties and constituents sampled, and sampling frequency	Period of water-level record	Well selected
Livermore Plant near Livermore Municipal Airport--Continued										
3S/1E-11B1	Alluvium	Sand	43	33-38	Below/ In	In	1975-present	PMN/M-6	1976-present	x
3S/1E-12C1	Alluvium	Gravel	268	133-158 213-217 248-259	Below/ Below	In	1977-present	PMN/1-4	1959-present	√
3S/1E-1P2	Alluvium	Sand, clay	50	40-45	Below/ In and below	Upgradient	1975-present	PMN/M-4	1975-present	x
3S/1E-2R1	Alluvium	Sand, clay	33	21-26	? / ?	In	1975-present	PMN/M-6	1975-present	
3S/1E-2N3	Alluvium	Gravel	316	157-167 301-311	Below/ Below	Down-gradient	1976-present	PMN/4	1976-present	√
3S/1E-2N2	Alluvium	No well log	80	No well log	No well log	Down-gradient	1978-present	PMN/3-4	1959-present	
3S/1E-10A2	Alluvium	Gravel	88	70-80	Below/ In	Down-gradient	1979-present	PMN/4	1979-present	?
Zone 7 Recharge Pit										
3S/1E-10G2	Alluvium	Not known	207	Not known	Not known	Down-gradient	1977-present	PMN/2-4	1970-present	?

[1]P = physical properties, M = mineral constituents, N = nutrient constituents, T = trace elements.
[2]M = monthly, M-# = monthly to indicated number of times per year, # = indicated number of times per year.
[3]Livermore Formation of Clark, 1930.

LOCATION AND DESCRIPTION OF STUDY AREA

The study area (fig. 1) comprises about 63 mi^2 and includes the Livermore and Amador Valleys, the southern part of the San Ramon Valley, and the northern part of the Sunol Valley. The major population centers are Livermore, Pleasanton, Dublin, and San Ramon Village.

Hydrologic and Geologic Features

The principal surface-water features are Alameda Creek, Arroyo de la Laguna, Arroyo Valle, Arroyo Mocho, Arroyo Las Positas, the South Bay Aqueduct, Lake Del Valle, San Antonio Reservoir, and the gravel excavation ponds along Arroyo Valle and Arroyo Mocho. The valley areas are generally flat (less than 5 percent slope) but are surrounded by steep uplands (generally 30 percent slope or more). Land-surface altitudes range from 300 to 500 feet in the valley areas to about 3,000 feet in the uplands. Streams that drain the uplands bordering the Livermore and Amador Valleys flow toward valley margins and then westward, following the east-to-west land slope, until they join Arroyo de la Laguna, which flows southward. Streams that drain the uplands bordering San Ramon Valley flow to valley margins and then southeastward following the northwest-to-southeast land slope of this part of the study area.

The ground-water basin of the Livermore, Amador, and San Ramon Valleys is composed of alluvial deposits (fig. 2). The California Department of Water

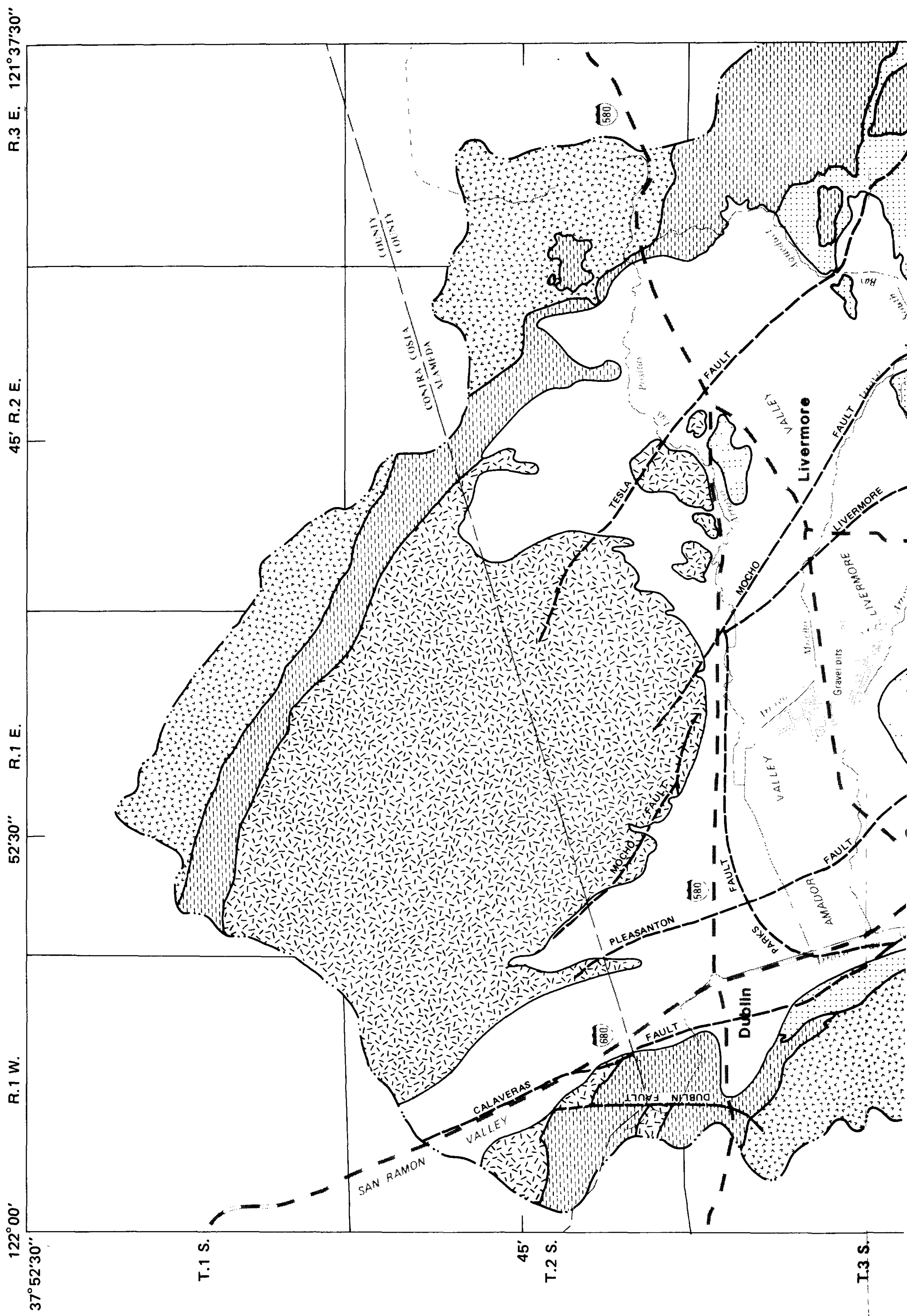
Resources (1974) has divided the basin into 12 subbasins. In terms of water storage and usage, the principal subbasins are Amador, Bernal, and Mocho. The Amador subbasin, comprising 10,790 acres, is bounded by the Pleasanton fault on the west, the Parks fault on the north, and the Livermore fault on the east. The boundaries of the Bernal subbasin, which contains 2,711 acres, are the Calaveras fault on the west, the Parks fault on the north, and the Pleasanton fault on the east. The Mocho subbasin, comprising 9,181 acres, is bounded by the Livermore fault on the west and the Tesla fault on the east (California Department of Water Resources, 1974). The wastewater application areas are all within these three subbasins.

Water-bearing, alluvial deposits of sand, gravel, and clay underlie the valleys. These deposits are moderately to highly permeable, as much as 700 feet thick, and contain the principal aquifers in the study area. The top of the upper aquifer is generally between 10 and 50 feet below land surface, and the thickness ranges from 25 to 100 feet. A confining bed of silty clay separates this aquifer from lower alluvial aquifers. The Livermore and Amador Valleys are bordered to the south by the Livermore Formation of Clark (1930), which consists primarily of permeable sand, gravel, and clay, and to the north by the Tassajara Formation, which consists primarily of sandstone and claystone of low permeability. Both formations are water bearing and are about 4,000 to 5,000 feet thick. The Livermore Formation provides quantities of water sufficient for irrigation, industrial, and municipal uses, and the Tassajara Formation provides quantities of water adequate only for domestic, stock, and limited irrigation uses. The formations bordering the Livermore Valley on the east and the San Ramon Valley on the west consist primarily of marine sandstone, shale, siltstone, and conglomerate, which are not water bearing. The uplands south of the Livermore Formation are composed mostly of the Knoxville Formation and Franciscan Complex, which also are not water bearing but which comprise a major part of the Arroyo Valle and Arroyo Mocho drainages.

Wastewater Application Areas

Livermore

Prior to 1959, wastewater from the Livermore area (fig. 3) was treated at a wastewater treatment plant located near the intersection of Pine Street and Rincon Avenue. This plant used an Imhoff tank, which discharged effluent to percolation beds near the plant. In 1957 the percolation beds had a surface area of 11 acres. The soil of the percolation beds is gravelly loam, slightly acid to mildly alkaline, and moderately to slowly permeable. This plant ceased operation in 1959 after construction of a new plant southeast of and adjacent to, the Livermore Municipal Airport. The new plant was designed to process average flows of 2.5 Mgal/d and used high-rate, trickling filters followed by aeration in 37 acres of oxidation ponds to achieve secondary treatment of wastewater. Effluent from the oxidation ponds was discharged to Arroyo Las Positas. In 1967, this plant was converted to an activated-sludge treatment process and enlarged to handle 5 Mgal/d. Oxidation ponds were converted to emergency holding basins. Effluent was used to irrigate about 120 acres of adjacent farmland and about 140 acres of airport and golf-course land (fig. 3). Soils in this area are silty, clayey, or gravelly, mildly to moderately alkaline, and moderately permeable. Eighty-five to ninety-five percent of the effluent was discharged directly to Arroyo Las Positas. Some of this effluent percolated to ground water and some left the valley as streamflow. Zone 7 operated a ground-water recharge pit (fig. 1) from 1962 to 1974. Water from Arroyo Las Positas was used for recharge. This water was a mixture of natural runoff, South Bay Aqueduct releases, and, after 1966, effluent from the Livermore Wastewater Treatment Plant.



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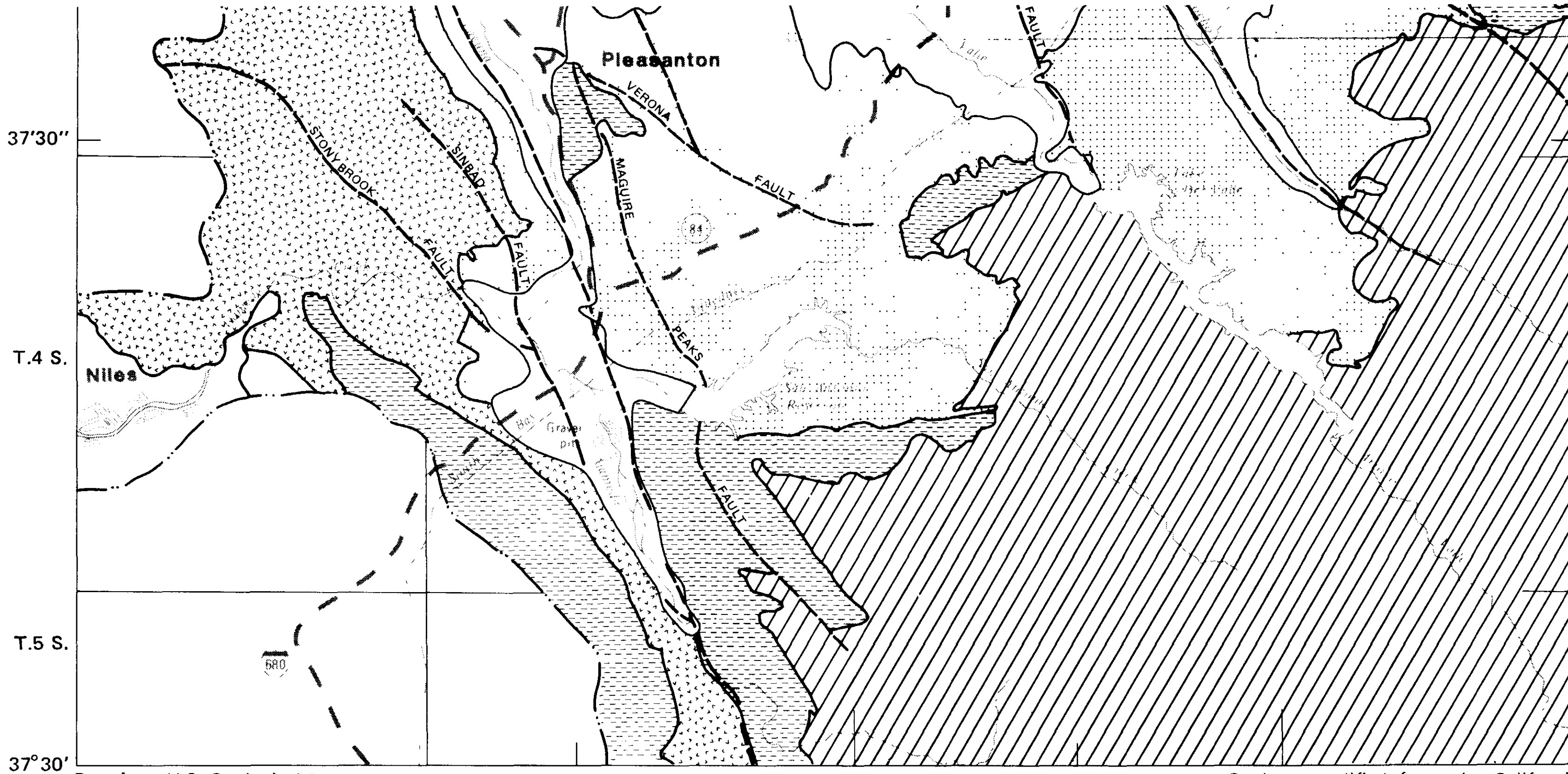


Base from U.S. Geological Survey
Stockton, 1:100,000, 1982

0 1 2 3 4 MILES
0 1 2 3 4 5 6 KILOMETERS

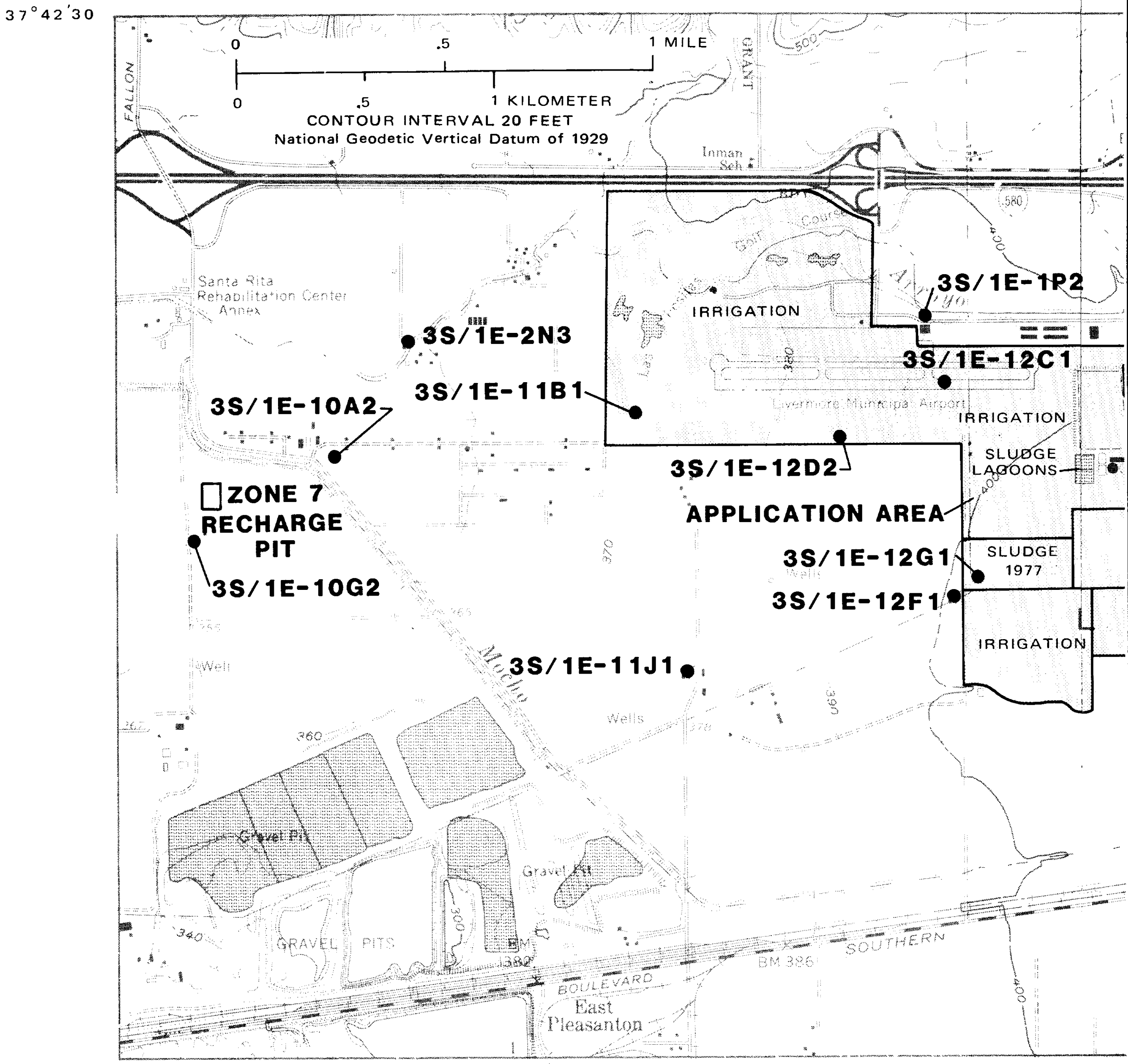
Geology modified from the California
Department of Water Resources, 1966

EXPLANATION

- Alluvial deposits of unconsolidated gravel, sand, silt, and clay of Quaternary age
- Undifferentiated partly consolidated formations of gravel, sand, and clay with some tuff of Tertiary and Quaternary age. Includes gravels of Livermore Formation of Clark, 1930 and Santa Clara Formation
- Undifferentiated partly consolidated formations of conglomerate, sandstone, claystone, tuff, and some limestone lentils, many cemented, of Pliocene age. Includes Tassajara Formation
- Undifferentiated partly consolidated formations of marine sandstone, shale, conglomerate, and some tuff, commonly fossiliferous, of Miocene age
- Undifferentiated formations of marine sandstone, siltstone, shale, and conglomerate of Cretaceous age
- Undifferentiated Knoxville Formation and Franciscan Complex generally of marine sandstone, shale, and chert of Jurassic and Cretaceous age

- Contact
- Fault — Approximately located
- DRAINAGE–BASIN BOUNDARY
- VALLEY–FLOOR BOUNDARY

FIGURE 2. — Generalized geology.



Base from U.S. Geological Survey
Livermore, 1973

121° 50'

FIGURE 3. — Livermore

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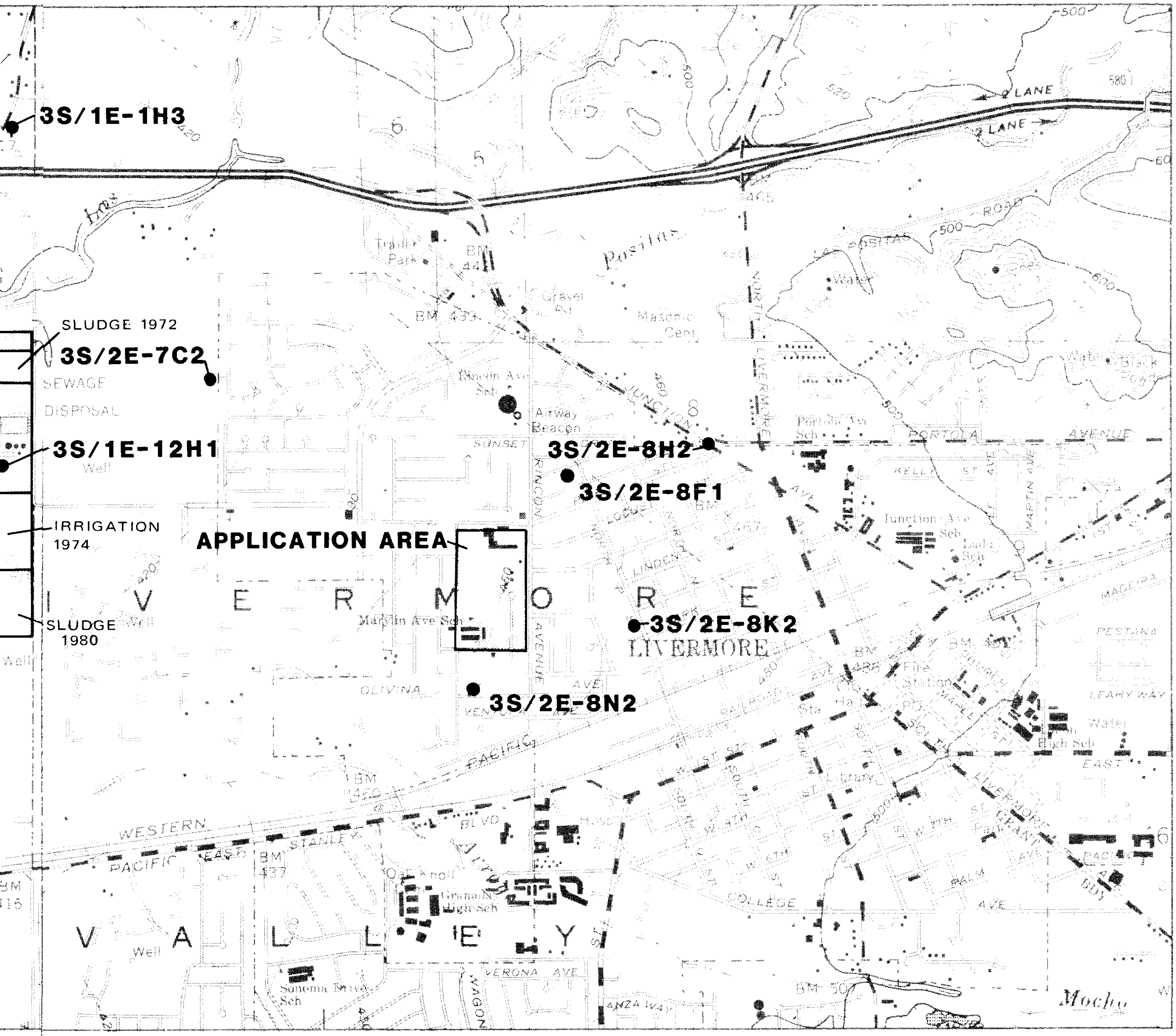


wastewater application area.

Sludge has been applied in the following locations: (1) sludge lagoons; (2) farmland adjacent to and north of oxidation ponds during 1972; (3) farmland southwest of the treatment plant during 1977; and (4) farmland south of the treatment plant during 1980. During other years sludge solids were disposed at a sanitary landfill on Vasco Road, 7 miles northeast of the treatment plant (Alameda County Flood Control and Water Conservation District, Zone 7, written commun., 1979, and W. A. Adams, Superintendent, City of Livermore Water Reclamation Plant, written commun., 1980).

Pleasanton

Wastewater from Pleasanton has been treated at the Sunol Wastewater Treatment Plant (fig. 4). From 1910 to 1949 this plant consisted of a septic tank. Effluent was discharged to a leach field until 1940, when 10-acre percolation ponds immediately south of the treatment plant began operation. In 1949, secondary treatment and sludge digestion were added. Effluent was discharged to a 20-acre field adjacent to the plant and to the 10 acres of percolation ponds. Beginning in 1954, pasture land southwest of the treatment plant was spray irrigated with effluent pumped from the 10 acres of percolation ponds (fig. 4). The spray-irrigation area had increased to 184 acres by September 1980, when the treatment plant was connected to the export pipeline. Plant capacity was increased to 1.7 Mgal/d in 1960. An 11-acre evaporation and percolation pond (Lake Monaco) was built in 1974 for surface runoff from spray irrigation areas. Since November 1975, sludge from the treatment plant has been applied to a 1.5-acre drying bed west of Interstate 680 (Alameda County Flood Control and Water Conservation District, Zone 7, written commun., 1979, and A. N. Monaco, City of Pleasanton Public Works Field Superintendent, written commun., 1980). Soils in this area are clayey, silty, or gravelly, moderately alkaline, and slowly to moderately permeable (U.S. Department of Agriculture, Soil Conservation Service, 1966).

Castlewood

Wastewater from the Castlewood Country Club has been treated at the Castlewood Wastewater Treatment Plant since 1952 (fig. 4). Effluent and sludge from the treatment plant are disposed to percolation ponds just south of the plant. Since 1956, water pumped from Arroyo de la Laguna has been used to irrigate Lower Castlewood Golf Course (R. J. Lavine, Castlewood Golf Course Superintendent, written commun., 1980). This water probably contained treated wastewater discharged upstream (Ralph Johnson, Alameda County Flood Control and Water Conservation District, Zone 7, oral commun., 1980). Soils in this area are loam, in some places with a silty texture, mildly to moderately alkaline, and moderately slow to moderate in permeability (U.S. Department of Agriculture, Soil Conservation Service, 1966).

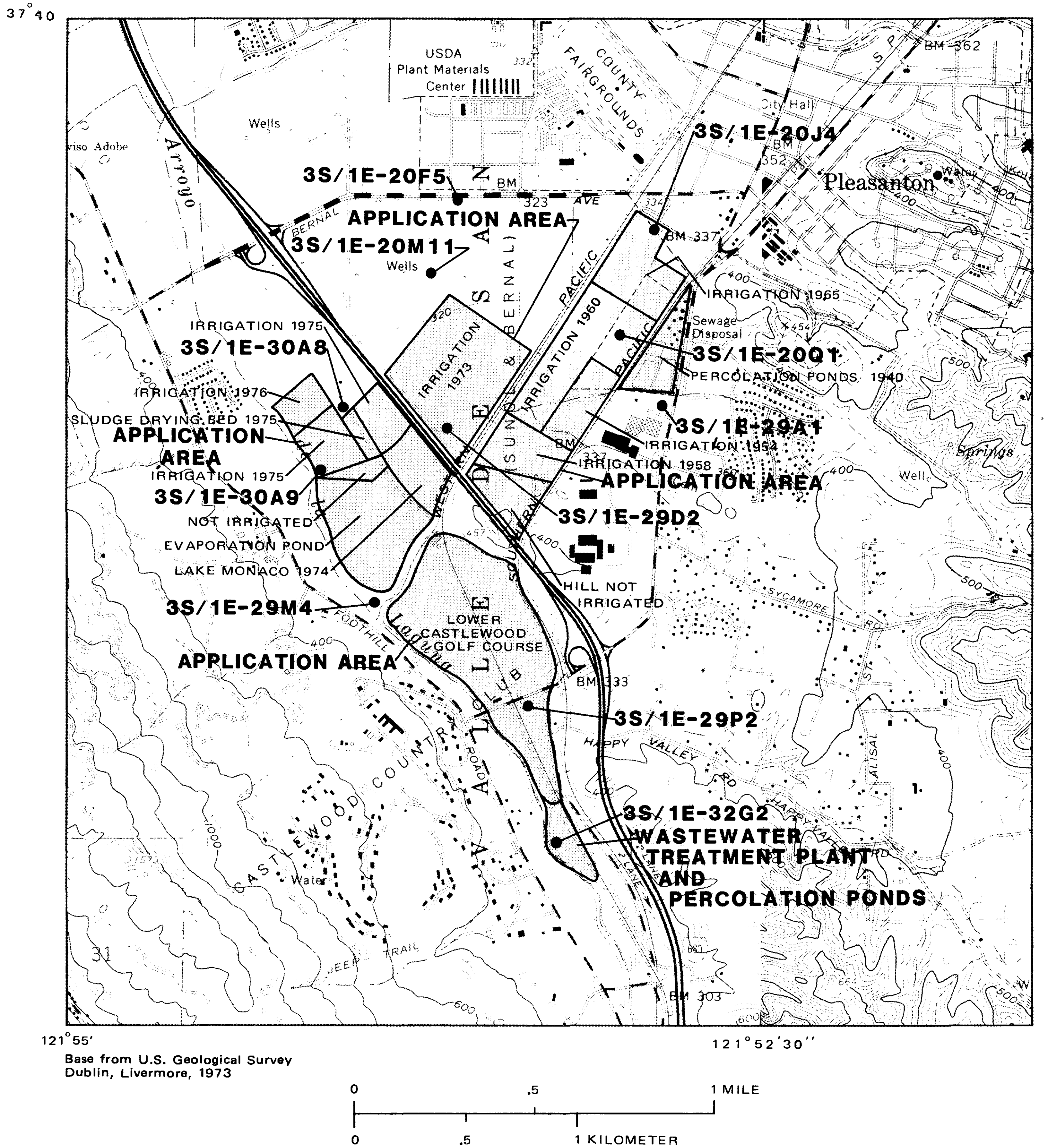


FIGURE 4. — Castlewood and Pleasanton wastewater application areas.

Dublin-San Ramon and Camp Parks Military Reservation

Since 1961, wastewater from the Dublin-San Ramon area and the Camp Parks Military Reservation has been treated at the Dublin-San Ramon Services District Wastewater Treatment Plant (fig. 5). Effluent has been discharged to Alamo Creek, and sludge to drying beds (now sludge lagoons) located on the premises. Soil at the sludge-drying beds is clay, slightly acid to moderately alkaline, and slowly permeable. One of the drying beds was dredged in 1980, and dredged material was deposited at the Camp Parks Military Reservation. Since January 1980, liquid effluent has been discharged to the export pipeline (R. S. Swanson, Valley Community Services District Wastewater Treatment Plant Superintendent, written commun., 1980). From 1940 to 1961, wastewater from Camp Parks Military Reservation was treated onsite in a 3.5-Mgal/d primary treatment plant. Effluent was discharged to Alamo Creek during the 1940's and to about 100 acres of oxidation ponds from 1950 to 1961. Soil at the oxidation ponds is clay, slightly acid to moderately alkaline, and very slowly permeable (U.S. Department of Agriculture, Soil Conservation Service, 1966).

Veterans Administration Hospital

From 1924 to 1951 wastewater from the Veterans Administration Hospital (fig. 6) was treated onsite with an Imhoff tank. Since 1951, secondary treatment by trickling filter has been used. Effluent has been discharged to percolation ponds just east of the hospital and since 1976 has been spray-irrigated on 35 acres of farmland adjacent to and north of the hospital. Sludge has been applied to drying beds and then disposed of on the premises (Charlie Stout, Supervisor, Veterans Administration Hospital, Livermore, written commun., 1980). Soils in this area range from very gravelly, coarse-sandy loam to gravelly loam, are slightly acid to neutral, and are highly permeable (U.S. Department of Agriculture, Soil Conservation Service, 1966).

Coast Manufacturing Company

Wastewater from the Coast Manufacturing Company (Hexcel) (fig. 1) was treated onsite until March 1980, when its wastewater treatment plant was connected to the Livermore Wastewater Treatment Plant. Effluent from onsite treatment was discharged to a percolation area east of the plant. This plant treated and discharged small quantities of wastewater, compared to the other facilities mentioned previously; it is not considered a principal wastewater treatment facility in the study area and hence is not discussed further in this report.

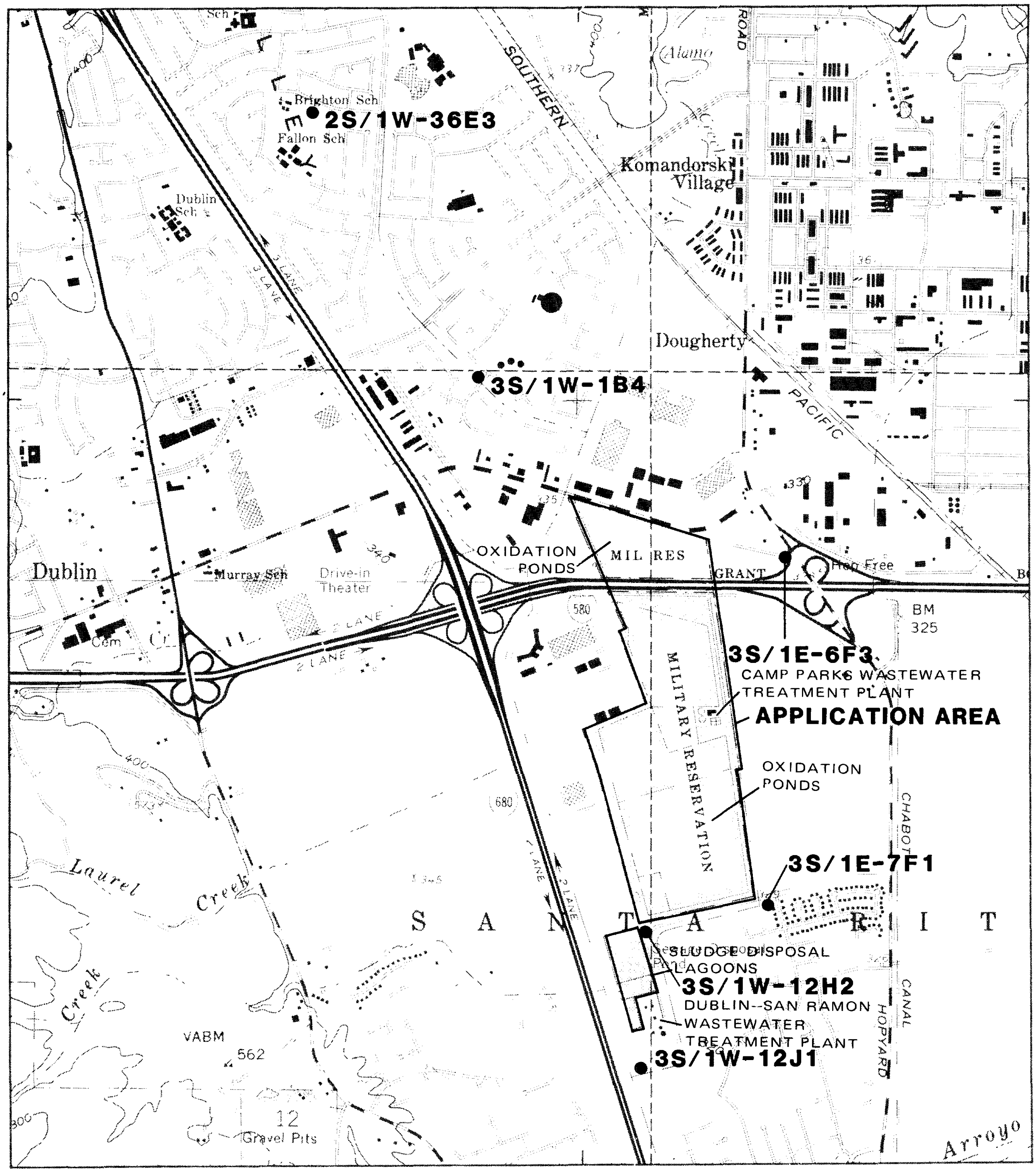


FIGURE 5. — Dublin-San Ramon and Camp Parks Military Reservation wastewater application areas.

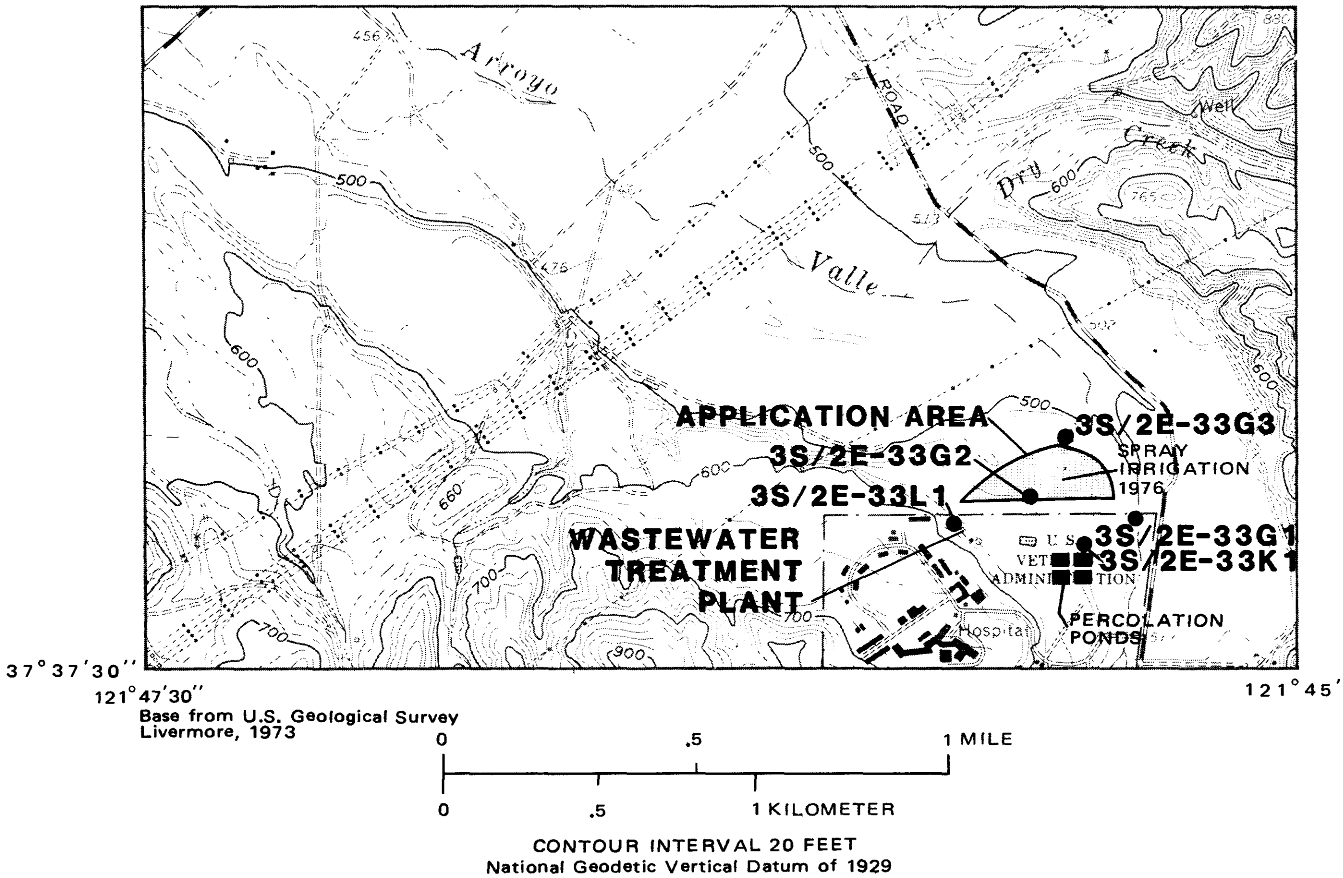
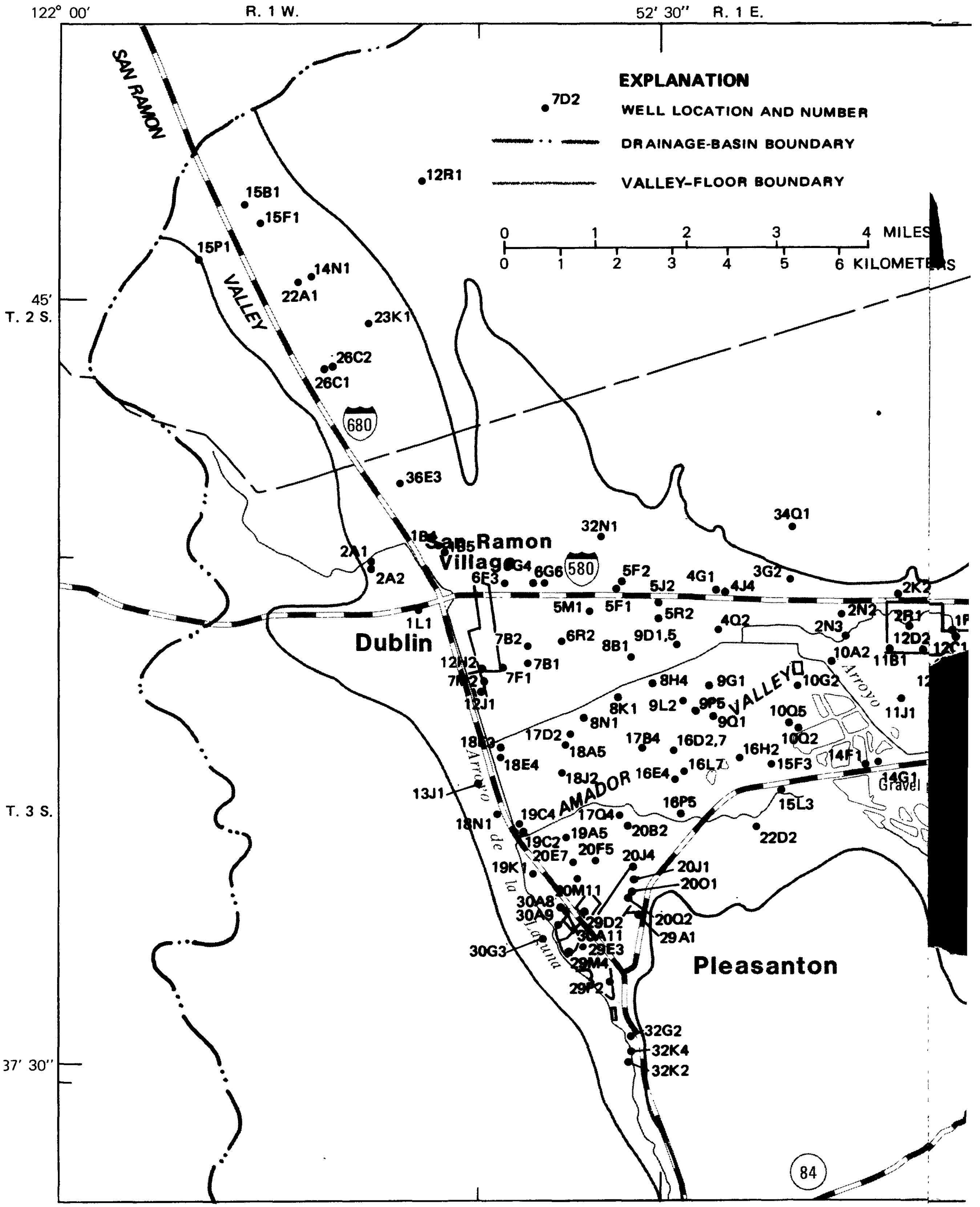


FIGURE 6. — Veterans Administration Hospital wastewater application area.

Figure 7 shows the ground-water wells in the study area from which water-quality samples have been collected. Of the 179 wells sampled, 44 existed before the beginning of this study. The California Department of Water Resources began sampling at some of these wells in the early 1950's and 1960's. In 1975, Zone 7 and the Geological Survey drilled additional wells, and in November and December of that year began sampling the 44 existing wells and 27 of the newly drilled wells. In 1976, more wells were drilled for the sampling program, which now uses about 130 wells.

Samples for the following dissolved constituents were collected at all wells: calcium, magnesium, sodium, potassium, bicarbonate, chloride, sulfate, silica, nitrite, nitrate, phosphorus, iron, manganese, boron, and fluoride. Dissolved-solids sums were calculated from the values for these constituents and compared to results from samples collected at all wells for dissolved residue at 180°C. Hardness from calcium and magnesium values, and percent sodium and sodium-adsorption ratios were calculated. Samples for chemical oxygen demand (COD) and total organic carbon (TOC) were collected at most wells. Samples for trace elements (arsenic, silver, aluminum, barium, cadmium, chromium, copper, mercury, lead, selenium, and zinc) were collected at a few wells. Field determinations were made of water temperature, specific conductance, and pH, and water-level measurements were made at each well at the time of sampling. Samples were collected after the wells had been pumped for a period long enough that water temperature, specific conductance, and pH did not change. At most wells, the sampling frequency ranged generally from monthly to four times per year for nitrite, nitrate, chloride, and dissolved-solids residue at 180°C. Samples for other constituents were collected only once or twice a year. Some wells were sampled less than four times per year. Wells in wastewater-application areas were sampled monthly prior to the 1977 water year, at which time the sampling frequency was changed to six times per year.

Mercury-filled thermometers, used to measure water temperature, were checked to be accurate to ±0.5°C. Portable meters were used to make field pH and conductivity measurements. After collection, samples for dissolved minerals, nutrients (nitrite, nitrate, phosphorus), and trace elements were immediately filtered through membrane filters with 0.45-micrometer pore size to remove suspended material. Immediately after filtration, cation samples were preserved with nitric acid, COD samples with sulfuric acid, and nutrient and TOC samples were chilled to less than 4°C. Samples were sent to the Geological Survey's Central Laboratory, located in Salt Lake City, Utah, prior to 1977 and in Denver, Colo., thereafter. Prior to 1979, laboratory analyses for dissolved minerals, trace elements, nutrients, and COD were done using methods given in Brown, Skougstad, and Fishman (1970). Beginning in 1979, the methods given in Skougstad and others (1979) were used. TOC samples were analyzed by the method given in Goerlitz and Brown (1972, p. 4-6).



Base from U.S.Geological Survey
Stockton, 1982

Figure 7.– Location of wells where

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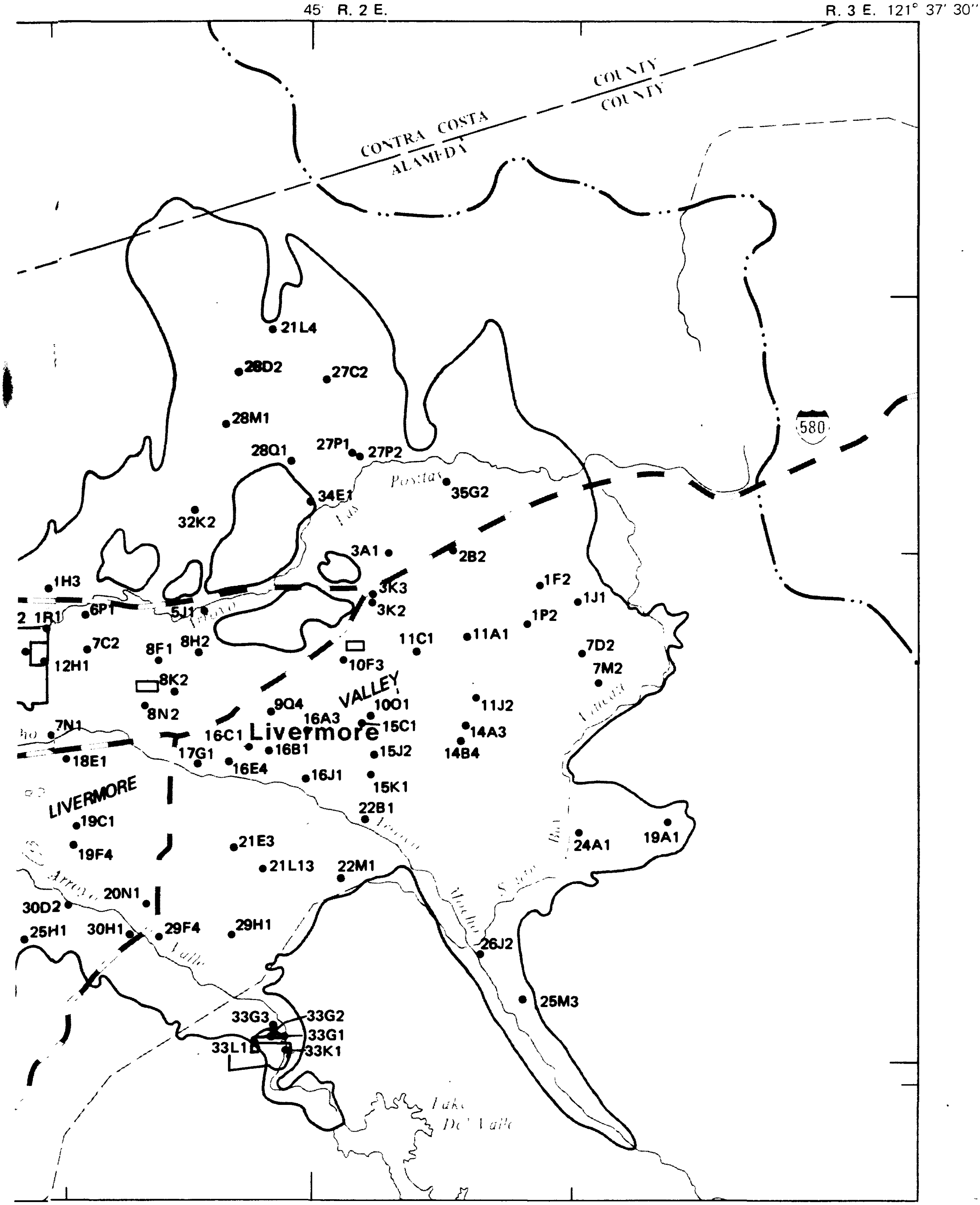


water–quality samples were collected.

Areawide Assessment

Rainfall

Annual precipitation during the study period varied markedly (fig. 8). Precipitation during water years 1976 and 1977 was less than one-half the normal precipitation, whereas precipitation during water years 1975 and 1979 was near normal. The 1978 water year, following the drought, had above normal precipitation. The 1980 water year also had above normal precipitation.

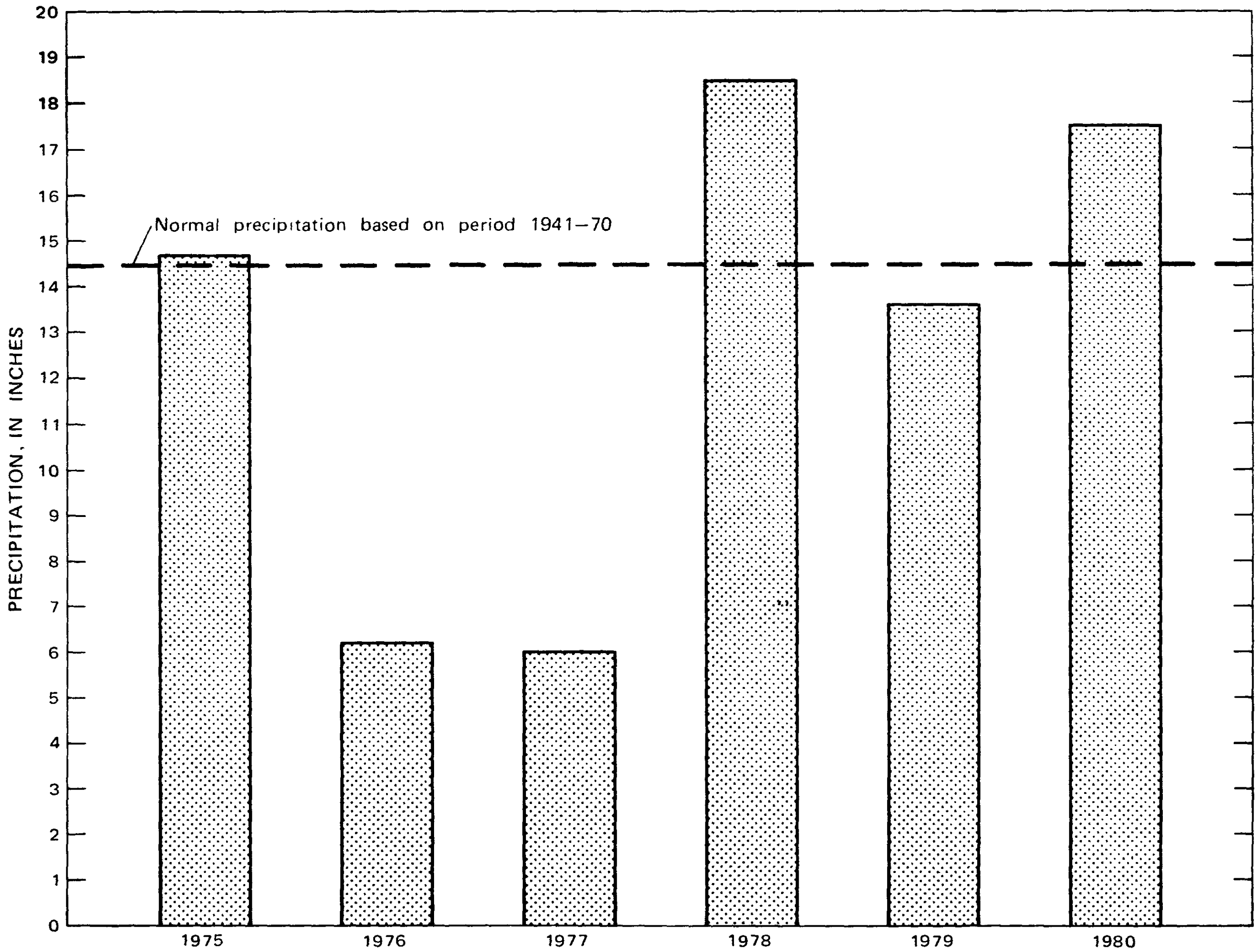


Figure 8.– Annual precipitation at the Livermore County Fire Department for the water-years 1975–80. (Compiled from U.S. Department of Commerce, National Oceanic and Atmospheric Administration, 1974–80)

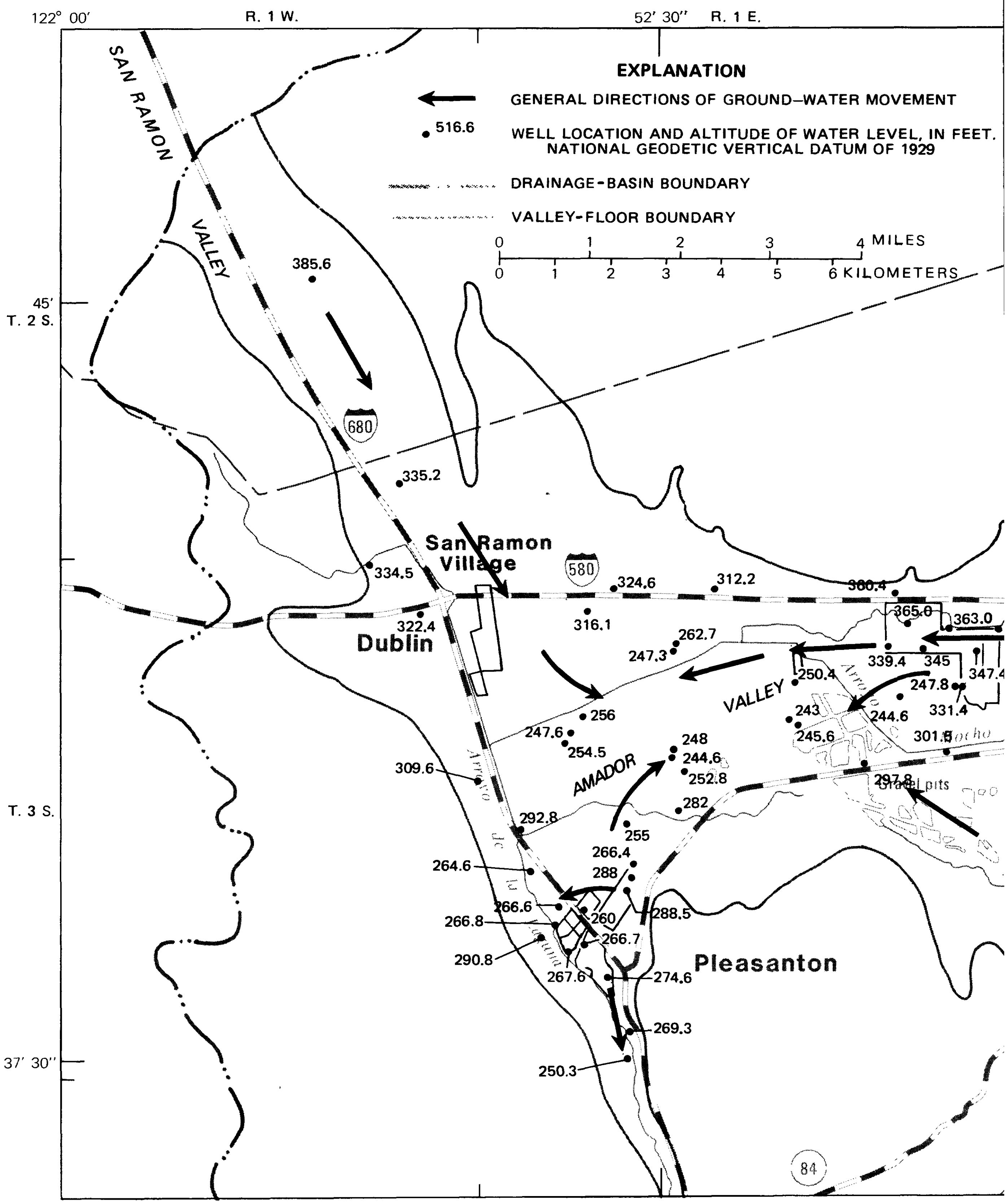
Ground-Water Movement

Water-level data from wells throughout the study area (fig. 7) were used to determine the general directions of ground-water movement in the valley. Median ground-water levels were plotted for a period of low ground-water levels during September and October 1977 and for a period of near normal rainfall and higher ground-water levels during March and April 1979 (figs. 9 and 10). Annual variations in precipitation appeared to influence water levels greatly but did not alter the general directions of ground-water movement. The gradients of ground-water levels show that the directions of ground-water movement follow land slope. Water levels are high near valley margins and are lower toward the central axis of the Livermore-Amador Valley; levels decline from east to west. Ground-water levels are generally lowest in the central part of the Amador Valley. The directions of ground-water movement in wastewater application areas are as follows:

1. Livermore--westward and southwestward;
2. Veterans Administration Hospital--towards Arroyo Valle;
3. Pleasanton--north towards Arroyo Valle and Arroyo Mocho and west towards Arroyo de la Laguna;
4. Lower Castlewood Golf Course and Castlewood percolation ponds--southward; and
5. Dublin-San Ramon Services District and Camp Parks Military Reservation--southeastward following the southeast trend of San Ramon Valley.

In summary, the directions of ground-water movement in the valley are generally the same as the directions of surface-water flow except in the Pleasanton wastewater application area, where the direction of ground-water movement near the percolation ponds is northward.

An estimate of the rate of ground-water movement was attempted by examining ground-water concentrations of tritium and nitrate in the study area. Tritium and nitrate can be useful tracers of ground-water movement because they generally are stable in ground-water systems and tend to be transported with ground-water flow. Effluent from the Livermore Wastewater Treatment Plant contains tritium because this plant receives wastewater containing low levels of tritium from the Lawrence Livermore Laboratory (Silver and others, 1978, 1979, and 1980). Available data were insufficient to determine the rate of ground-water movement in the study area, though the general directions of ground-water movement were confirmed.



Base from U.S.Geological Survey
Stockton, 1982

Figure 9.– Median water levels and general directions of

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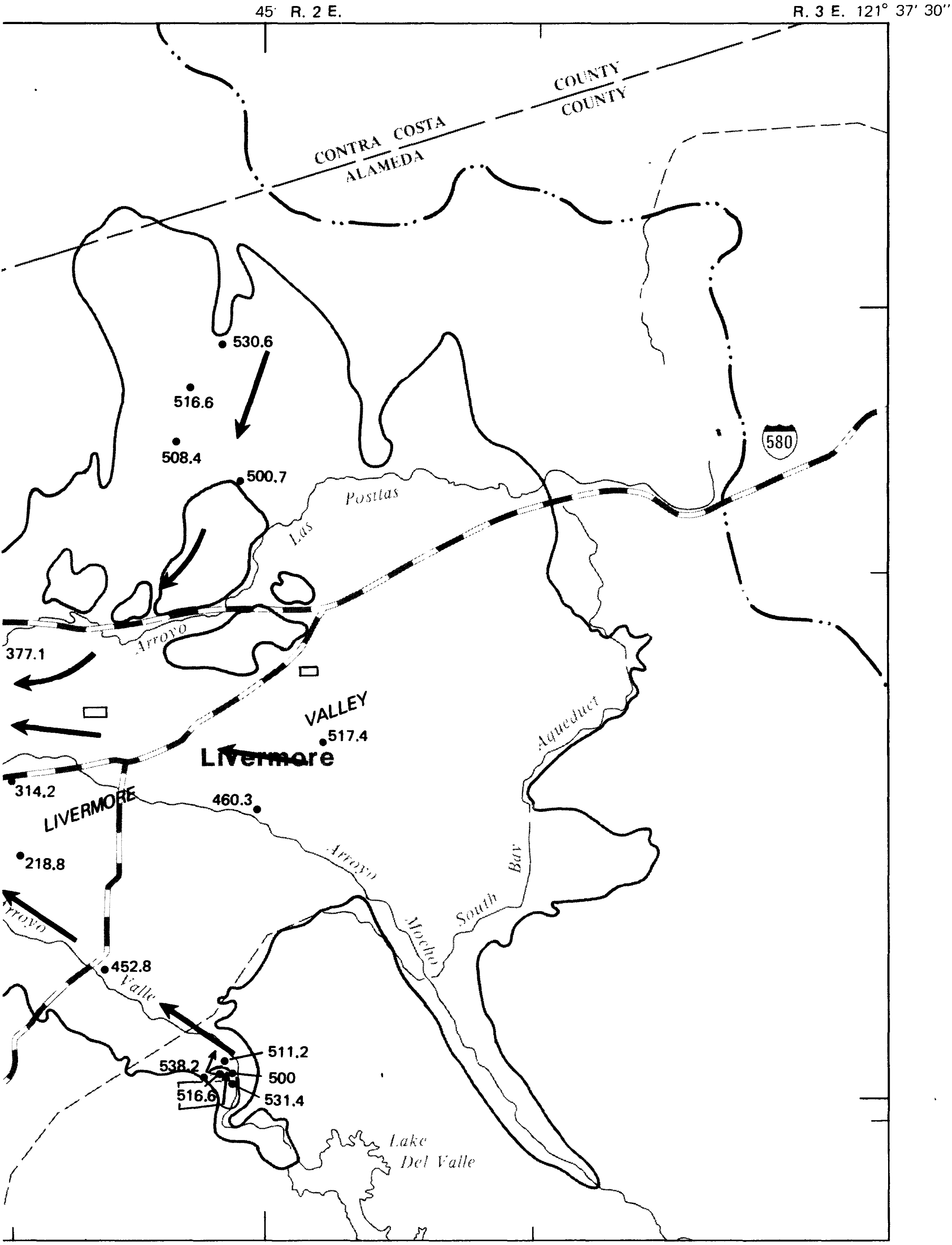
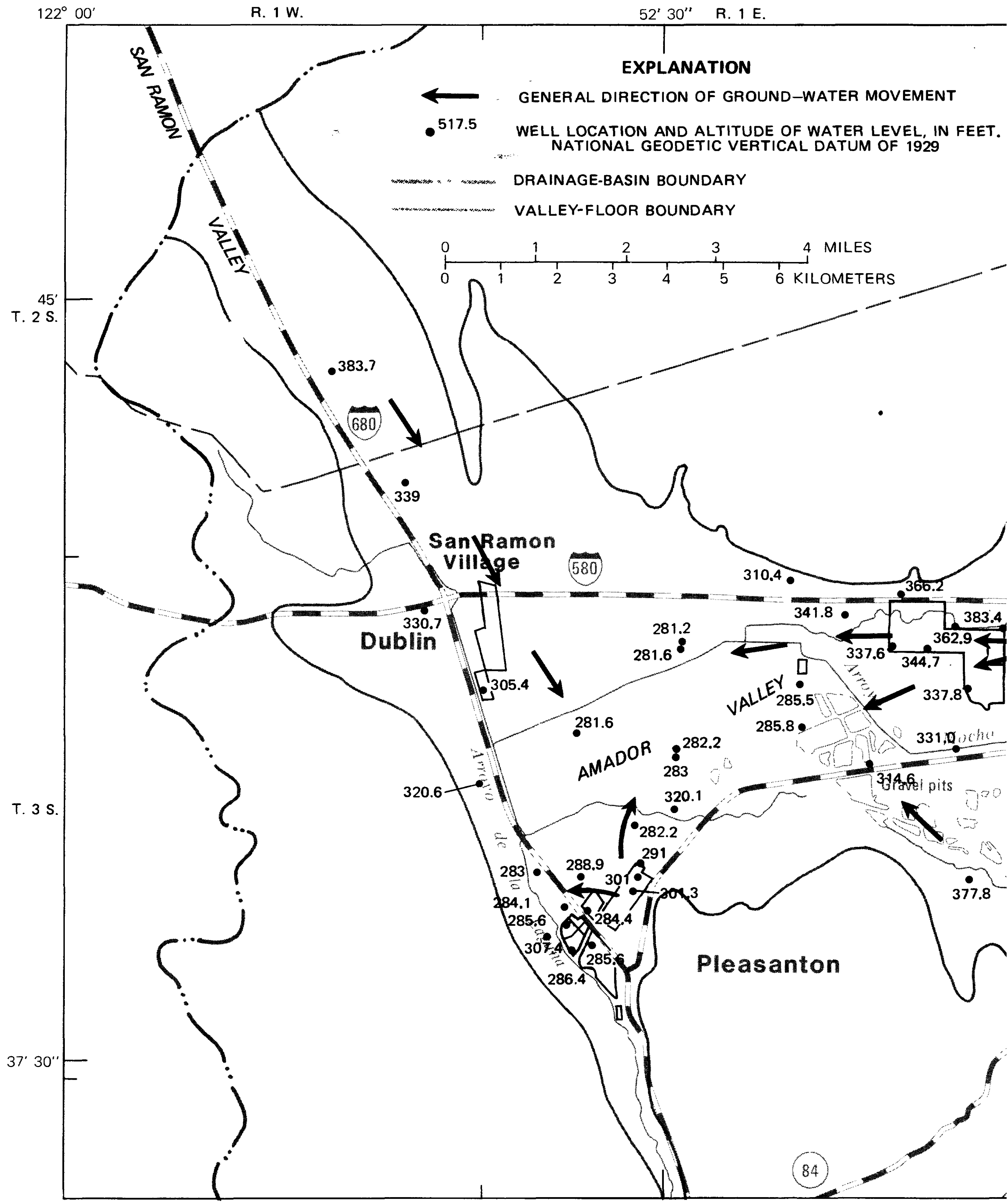


ground–water movement, September and October 1977.



Base from U.S.Geological Survey
Stockton, 1982

Figure 10.– Median water levels and general directions

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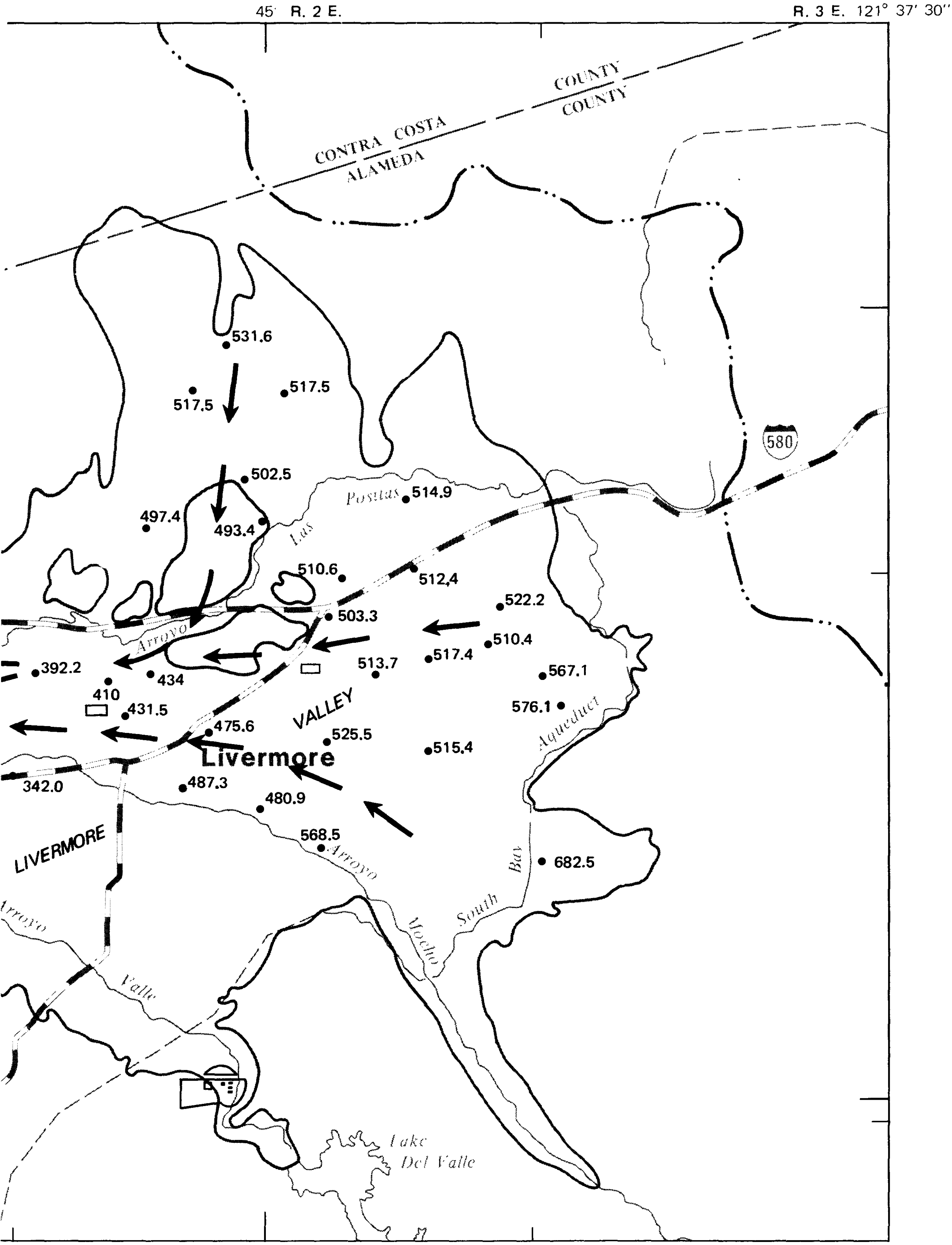


of ground–water movement, March and April 1979.

Ground-Water Quality

A comparison of water quality throughout the study area is not within the scope of this report, but it is necessary to understand how water quality in areas that do not receive wastewater applications compares with areas that do. To provide this comparison, median concentrations of dissolved nitrate in wells throughout the study area were plotted for the 1976 and 1980 water years (figs. 11 and 12). Nitrate was used because ground-water concentrations of this constituent are probably more affected by wastewater applications than other water-quality properties and constituents measured or analyzed in this study. For wells having one or no nitrate values for the periods plotted, no median value could be calculated and, hence, no median value appears for these wells in figures 11 and 12.

The 1976 and 1980 water-year plots show that the dissolved-nitrate concentrations in ground water were highest at the following locations:

1. In the Livermore wastewater application area near the Livermore Municipal Airport;
2. In that part of the Pleasanton wastewater application area downgradient from and north of the percolation ponds;
3. In an area east of the City of Livermore between Arroyo Seco and Arroyo Mocho; and
4. In a small area just east of the gravel pits along Arroyo Valle.

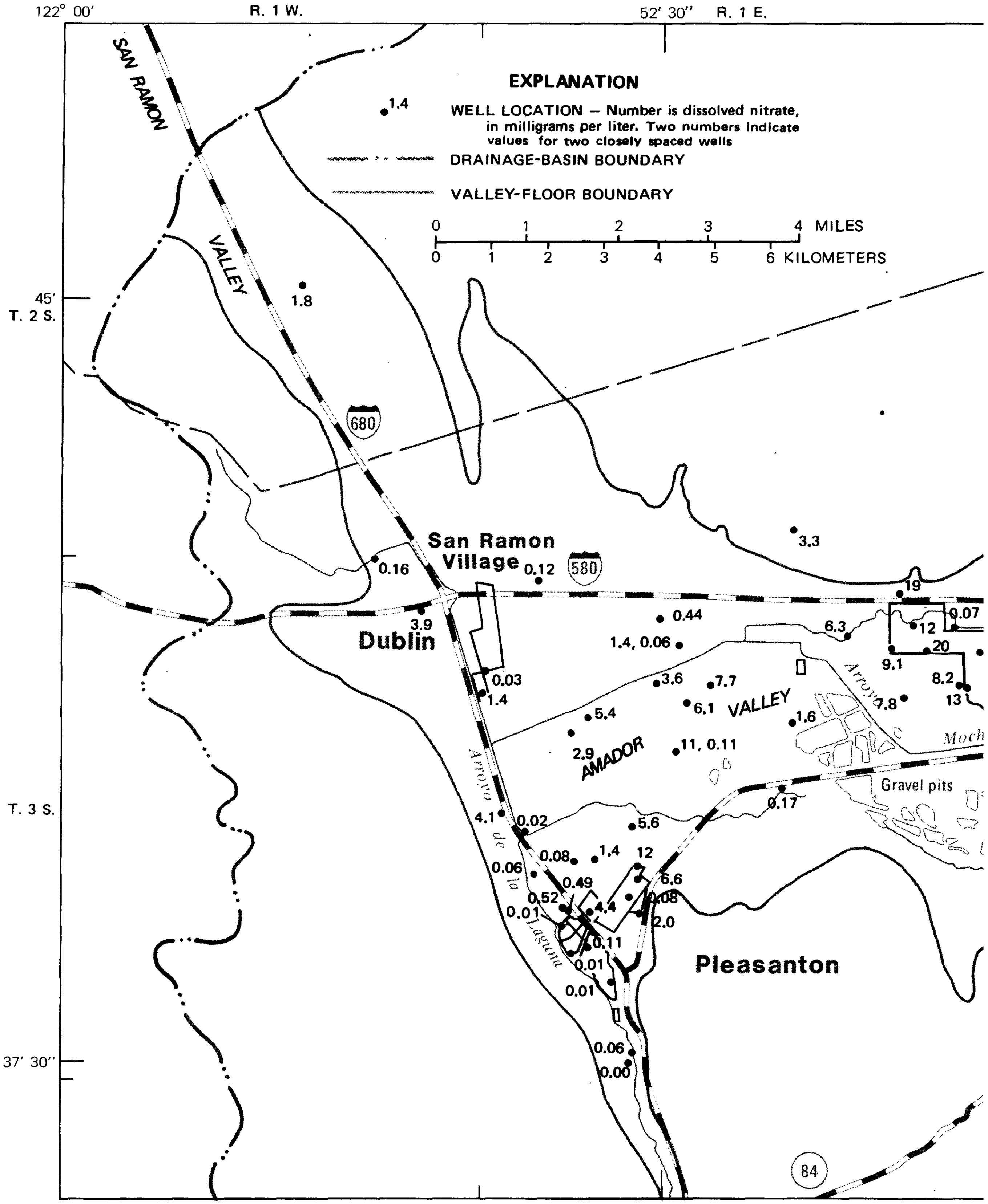
Median concentrations of dissolved nitrate as N in most wells sampled at locations 1-4 described above were greater than 10 mg/L (figs. 11 and 12). Except for locations 3 and 4, median concentrations of dissolved nitrate as N were less than 8.0 mg/L in most wells in areas not receiving wastewater applications. The cause of the high concentrations of dissolved nitrate at locations 3 and 4 is not known but may be related to agricultural practices or, at location 3, to a community along Buena Vista Avenue that uses individual septic tank systems for wastewater treatment. Median concentrations of dissolved nitrate as N in wells upgradient from and to the northeast of and downgradient from the Livermore wastewater application area near the Livermore Municipal Airport were lower than median concentrations of dissolved nitrate as N in wells in this application area.

From 1976 to 1980, median concentrations of dissolved nitrate as N: (1) Decreased at most wells in the Livermore wastewater application area near the Livermore Municipal Airport; (2) increased at most wells in that part of the Pleasanton wastewater application area downgradient from and north of the percolation ponds; and (3) increased in the Dublin-San Ramon and Veterans Administration Hospital wastewater application areas. At location 3 mentioned above, the median concentration of dissolved nitrate as N in the only well sampled during both the 1976 and 1980 water years increased from 22 mg/L to 24 mg/L. At location 4, the median concentration of dissolved nitrate as N increased from 7.8 mg/L in 1976 to 11 mg/L in 1980 in one well, but decreased from 14 mg/L in 1976 to 7.8 mg/L in 1980 in another well.

Comparison of ground-water quality in wastewater application areas (table 2) with the quality of effluent from wastewater treatment plants in the Livermore-Amador Valley (table 3) may help to show which of these areas have been affected by wastewater applications. Wastewater applications appear to have affected the water quality of the upper and lower aquifers in the Livermore wastewater application areas. Median concentrations of dissolved nitrate as N were 12 mg/L in the upper aquifer and 8.1 mg/L in the lower aquifer in the Livermore application areas, whereas in other wastewater application areas, they were less than 5 mg/L. Although the median concentration of dissolved nitrate as N in the Livermore wastewater application areas were less than in effluent from the Dublin-San Ramon Services District wastewater treatment plant (26 mg/L) and in effluent from the Livermore wastewater treatment plant near the Livermore Municipal Airport (20 mg/L), concentrations in the Livermore wastewater application areas were greater than they were in most wells in areas not receiving wastewater applications (median less than 8.0 mg/L--see previous discussion in this report).

Although median concentrations of dissolved nitrate as N in the Castlewood, Pleasanton, and Veterans Administration Hospital wastewater application areas were only about 5 percent of what they were in effluent from wastewater treatment plants in the Livermore-Amador Valley, wastewater applications may have also affected ground-water quality in these areas. In these areas and in the upper aquifer in the Livermore wastewater application areas, values of specific conductance, pH, dissolved solids, and dissolved chloride were very similar to those characteristic of effluent from wastewater treatment plants in the Livermore-Amador Valley. In these wastewater application areas, the median value of specific conductance ranged from 1,250 to 1,540 μmho at 25°C, the median concentration of dissolved solids ranged from 746 to 810 mg/L, the median pH value ranged from 6.9 to 7.3, and the median concentration of dissolved chloride ranged from 120 to 210 mg/L. In effluent from the Dublin-San Ramon Services District wastewater treatment plant, the median value of specific conductance was 1,420 μmho at 25°C, the median concentration of dissolved solids was 878 mg/L, the median pH value was 7.0, and the median concentration of dissolved chloride was 180 mg/L. In effluent from the Livermore wastewater treatment plant near the Livermore Municipal Airport, the median specific conductance value was 1,310 μmho at 25°C, the median dissolved solids concentration was 776 mg/L, the median pH value was 7.0, and the median concentration of dissolved chloride was 190 mg/L.

Ground-water quality in the Dublin-San Ramon and Camp Parks Military Reservation wastewater application area appears to be determined by factors other than wastewater applications. In this wastewater application area, the median value of specific conductance was 3,780 μmho at 25°C, the median concentration of dissolved solids was 3,530 mg/L, the median pH value was 7.2, the median concentration of dissolved chloride was 510 mg/L, and the median concentration of dissolved nitrate as N was 4.8 mg/L. Thus, values of specific conductance and concentrations of dissolved solids and dissolved chloride were about 3 to 4 times and concentrations of dissolved nitrate were about a fifth of those characteristic of effluent from wastewater treatment plants in the Livermore-Amador Valley. The major source of mineralization of ground water in the Dublin-San Ramon and Camp Parks Military Reservation wastewater application areas is believed to be soil salts, which are dissolved and transported by surface water percolating to the ground water (California Department of Water Resources, 1974, p. 147 and 148).



Base from U.S.Geological Survey
Stockton, 1982

FIGURE 11.–Median concentrations of

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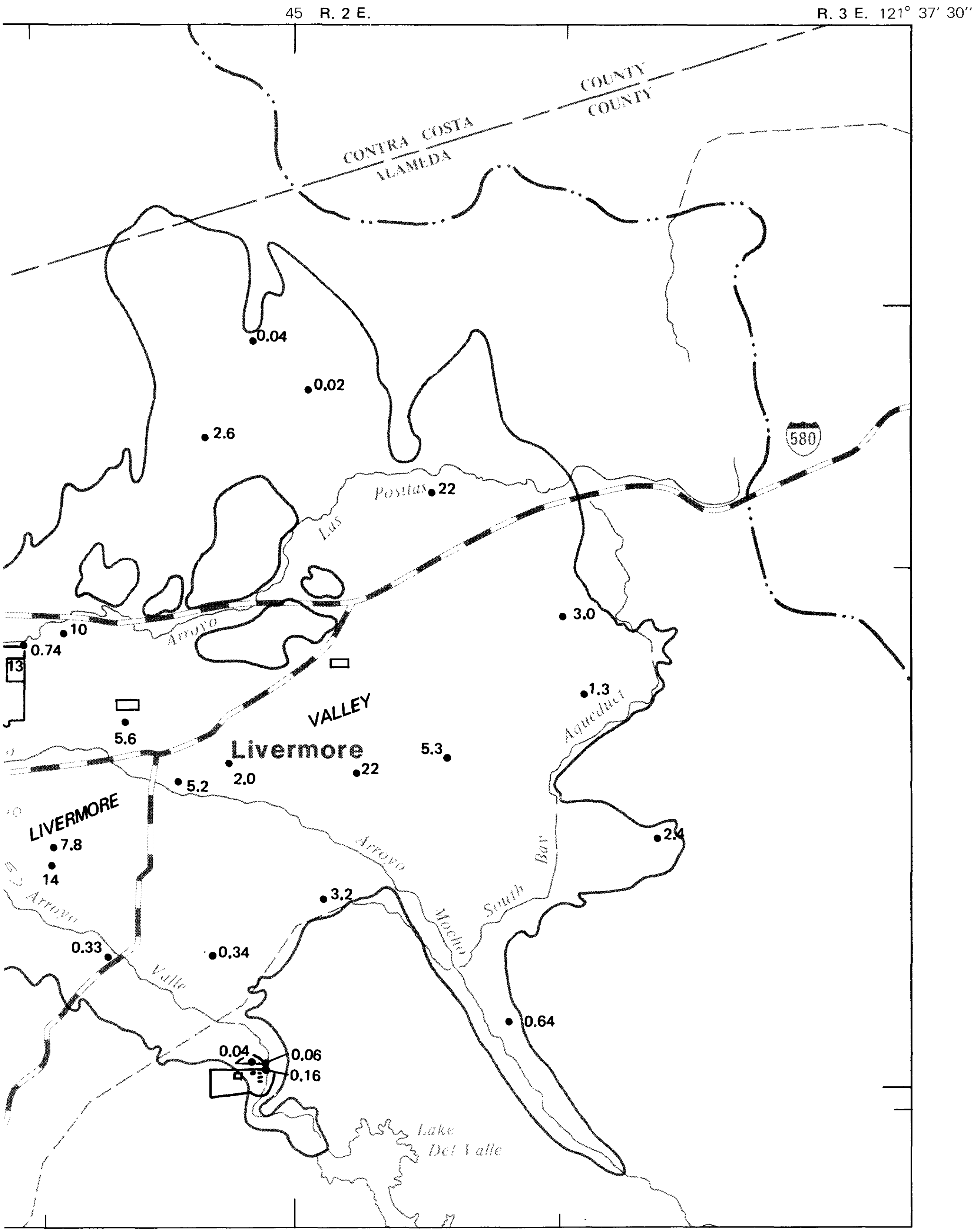
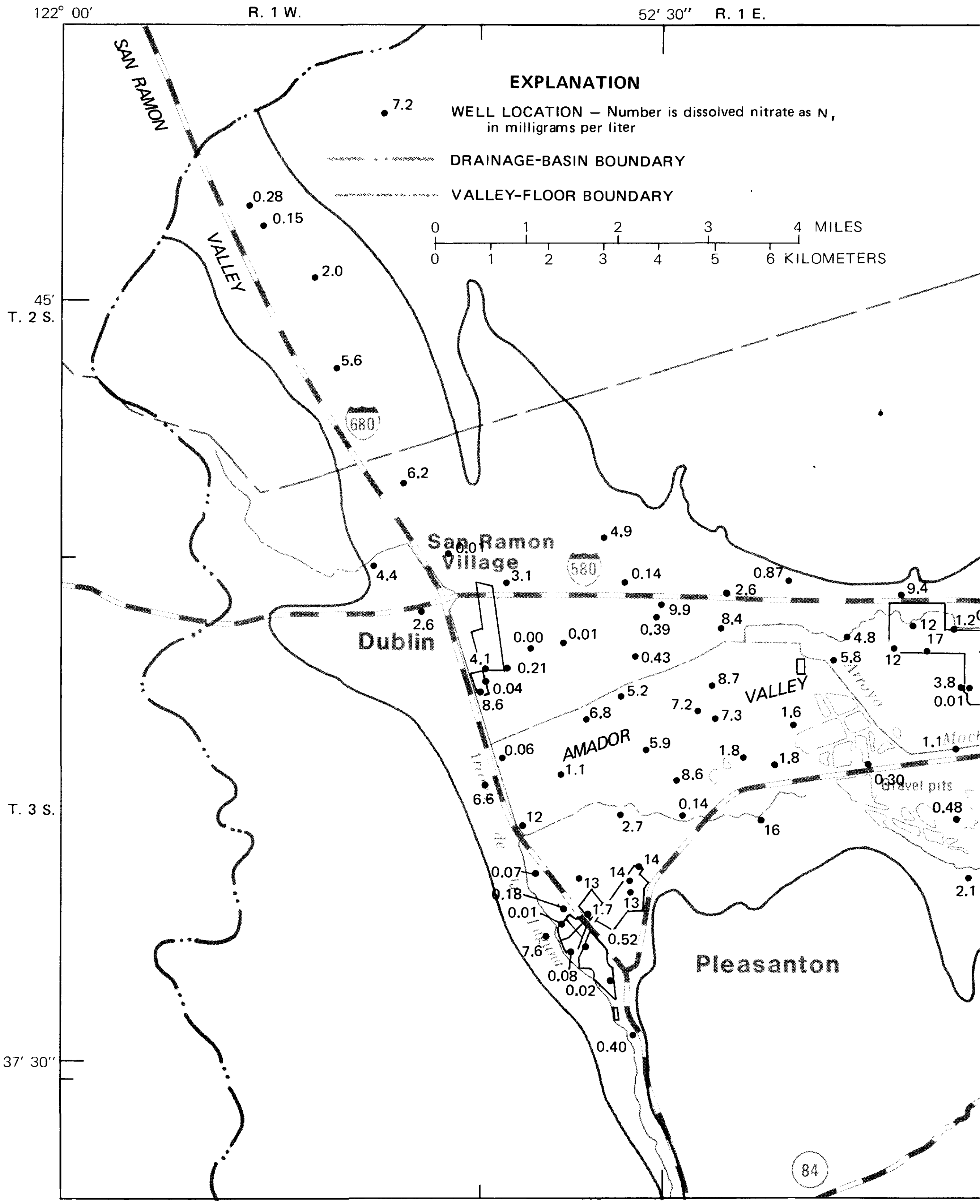
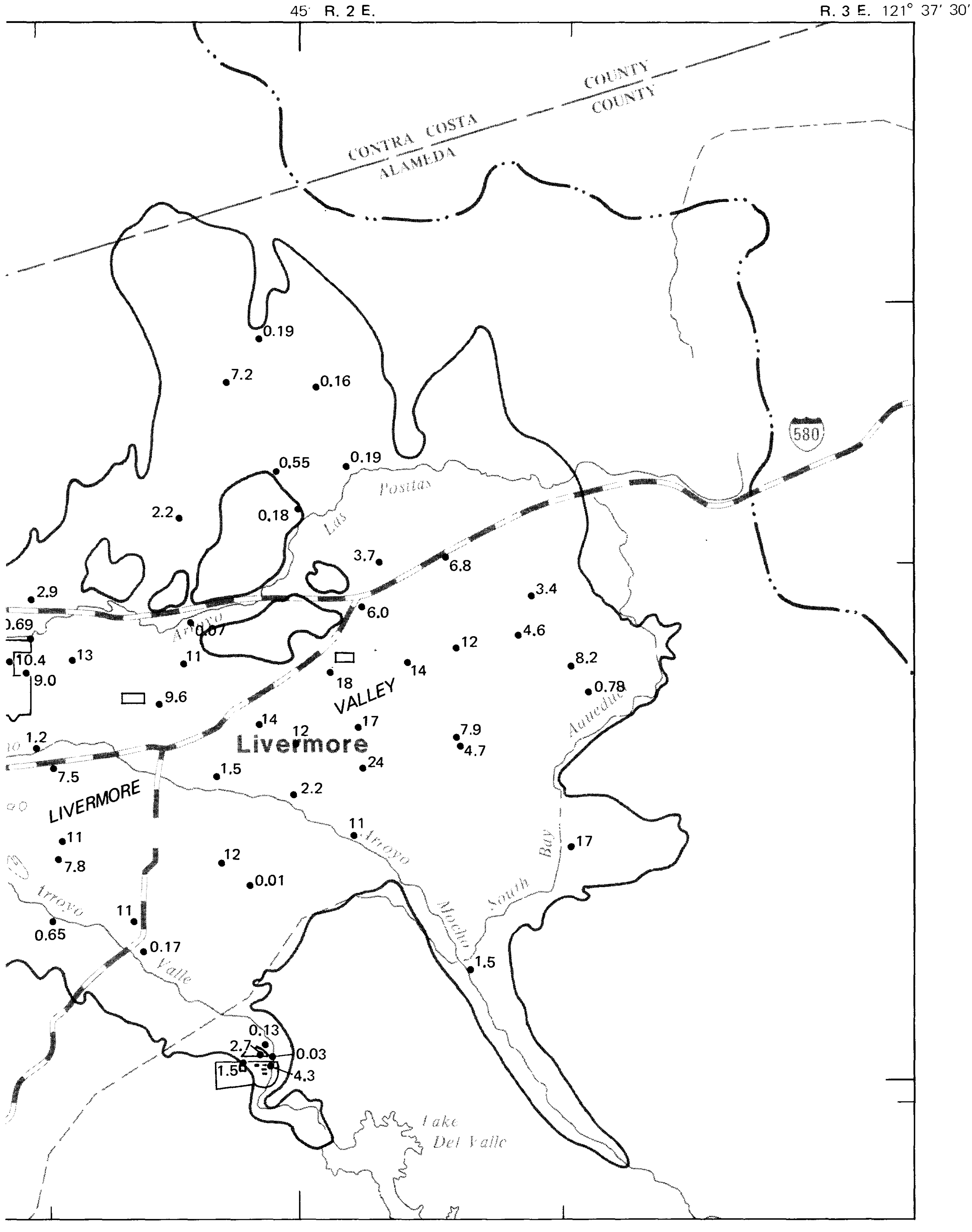


dissolved nitrate as N, for 1976 water year.



Base from U.S.Geological Survey
Stockton,1982

FIGURE 12.–Median concentrations of



dissolved nitrate as N, for 1980 water year.

TABLE 2. - Comparison of water quality among wastewater application areas

[Principal cations and anions listed in order of greatest contribution to total milliequivalents of dissolved ionic constituents, except where "&" symbol is used, which indicates that cations or anions listed contribute equally. Minimum, median, and maximum values are medians for area based on rankings of minimum, median, and maximum values for selected wells (see table 1) in each area. Specific conductance values are in micromhos per centimeter at 25°C, pH in units, and constituent values in milligrams per liter]

Application area	Principal cations and anions	Properties and constituents																	
		Specific conductance			Dissolved solids at 180°C			pH			Dissolved chloride			Dissolved nitrate as N			Dissolved phosphorus		
		Min	Med	Max	Min	Med	Max	Min	Med	Max	Min	Med	Max	Min	Med	Max	Min	Med	Max
Castlewood and Pleasanton	Ca, Na, Mg, HCO_3	1070	1250	1490	546	746	936	6.6	6.9	7.4	71	120	150	0	1.2	4.0	0	0.03	0.14
Dublin-San Ramon and Camp Parks Military Reservation	Na, Ca, SO_4, HCO_3, Cl	2850	3780	5150	2030	3530	4060	7.0	7.2	7.7	330	510	680	.38	4.8	6.8	.12	.16	.24
Veterans Administration Hospital	Na, Ca, HCO_3, Cl, SO_4	1090	1540	2060	664	778	1190	6.9	7.3	7.8	150	210	380	0	1.0	6.3	.04	.08	.25
Livermore[1]--Upper aquifer	Na & Mg, HCO_3	1190	1400	1600	695	810	996	6.8	7.2	7.4	100	180	220	4.5	12	14	.06	.08	.14
Livermore[1]--Lower aquifers	Mg, HCO_3	813	950	1020	453	544	633	7.2	7.4	7.6	53	79	94	4.8	8.1	12	.02	.05	.08

[1]Values combined from the following wastewater application areas: Livermore Plant near Pine Street and Rincon Avenue; Livermore Plant near Livermore Municipal Airport; and Zone 7 Recharge Pit (see table 1).

TABLE 3. - Quality of effluent from wastewater treatment plants in the Livermore-Amador Valley

[Values shown are medians for data collected at the wasteway from October 1974 to June 1979. N = number of observations]

Wastewater treatment plant[1]	Property or constituent				
	Specific conductance (μmho/cm at 25°C)	pH (units)	Dissolved solids at 180°C (mg/L)	Dissolved chloride (mg/L)	Dissolved nitrate as N (mg/L)
Dublin-San Ramon Services District	1420 N=273	7.0 N=27	878 N=281	180 N=282	26 N=12
Livermore plant near Livermore Municipal Airport	1310 N=332	7.0 N=215	776 N=332	190 N=332	20 N=16

[1]Values are not known for Pleasanton, Castlewood Corporation, and Veterans Administration Hospital wastewater treatment plants.

Site-Specific Assessment

So far, this report has given areawide information. Water-quality and water-level data, however, can be further assessed on a site-specific (area-by-area) basis. The effects of wastewater on ground water in each application area were investigated in two ways:

1. Data from selected wells within each application area were compared to determine where wastewater affected the quality of ground water.

2. Time-series plots of water levels and water quality in selected wells within each application area were made to determine when wastewater affected the ground water.

By a process of elimination, the two approaches can also help to show the effects of such other factors as geology and climate on the ground water of each application area.

Areal Variations in Ground-Water Quality in Wastewater Application Areas

Comparisons of ground-water quality among sampling sites in each wastewater application area were done by making box plots (pl. 1) and using a nonparametric statistical procedure, Kruskal-Wallis (Chi-square approximation) test, to determine if values of properties and constituents from selected wells in wastewater application areas are alike or not. The Kruskal-Wallis test is an extension of the Wilcoxon rank-sum test (equivalent to Mann-Whitney U-test) from a two-sample to a k-sample situation. A nonparametric test was used, rather than a parametric test, because many of the data distributions tested did not conform to the normal distribution assumed for parametric tests. Thus, nonparametric test results would likely be more reliable than parametric test results for the data used. Box plots were prepared from information computed using the UNIVARIATE procedure in a computerized statistical analysis system called SAS (Helwig and Council, 1979). Box plots show distributions of values for properties and constituents compared among wells. The Kruskal-Wallis procedure tests whether or not these distributions are alike. For this report, a 95-percent confidence level was used. Kruskal-Wallis tests were made using the NPARIWAY procedure in SAS (Helwig and Council, 1979).

Castlewood and Pleasanton wastewater application areas.--Specific conductance values varied markedly from well to well in the Castlewood and Pleasanton areas (pl. 1A). The only wells having like values were 3S/1E-29D2, which is in the spray irrigation area, and 3S/1E-30A8, which is downgradient from that area. Specific conductance values were lowest at well 3S/1E-30A9, which is in the spray irrigation area, and at well 3S/1E-29A1, which is upgradient from the percolation ponds at the Pleasanton wastewater treatment plant. Specific conductance values were highest at well 3S/1E-32G2, which is in the vicinity of the Castlewood Corporation percolation ponds. In the spray irrigation area, well 3S/1E-20Q1 had the highest specific conductance values. Well 3S/1E-20Q1 is the closest downgradient well to the Pleasanton percolation ponds and is in the first area used for spray irrigation. Specific conductance values progressively decreased north and west of well 3S/1E-20Q1; the lowest values in the Pleasanton wastewater application area occurred at wells 3S/1E-20F5 and 3S/1E-30A9.

The pattern of dissolved chloride values among wells in the Castlewood and Pleasanton areas is similar to that for specific conductance. The variation in pH values among wells in these areas was much less than that for specific conductance. Wells upgradient from, in, and downgradient from the percolation ponds and adjacent spray irrigation area all had like pH values (group A wells on pl. 1A). Generally, the lowest pH values occurred at wells 3S/1E-29M4 and 29D2, which are in the spray irrigation area. The highest pH values were observed at wells 3S/1E-32G2, 29P2, and 30A9. Well 3S/1E-32G2 is in the vicinity of the Castlewood Corporation percolation ponds, 3S/1E-29P2 is upgradient from these ponds but downgradient from the Lower Castlewood Golf Course, and 3S/1E-30A9 is in the spray irrigation area west of Interstate 680.

The pattern of dissolved nitrate values among wells in the vicinity of the Pleasanton percolation ponds is similar to that for specific conductance and chloride. In other places the pattern is different. Generally, the lowest dissolved nitrate values were observed at wells in the spray irrigation area west of Interstate 680 and south of the Lower Castlewood Golf Course. The highest nitrate values were observed at wells in and downgradient from the spray irrigation area adjacent to and northwest of the Pleasanton percolation ponds.

The most significant and consistent pattern shown by plate 1A is the large increase in property and constituent values between wells 3S/1E-29A1 (upgradient from the Pleasanton wastewater treatment plant percolation ponds) and 3S/1E-20Q1 (immediately downgradient from these ponds) and the progressive decrease in these values downgradient from and north of well 3S/1E-20Q1. These observations clearly show that wastewater applications have affected ground-water quality in this area. High specific conductance and chloride values at well 3S/1E-32G2 are probably primarily caused by connate water from adjacent marine sediments seeping into the alluvial aquifer in this area (California Department of Water Resources, 1974, p. 64).

Dublin-San Ramon and Camp Parks Military Reservation wastewater application area.--Specific conductance values were markedly dissimilar among wells in the Dublin-San Ramon and Camp Parks area (pl. 1B). The highest specific conductance values were observed at wells 3S/1W-12H2 and 3S/1E-7F1, which are downgradient from oxidation ponds used from the late 1950's to mid-1960's at Camp Parks. Much lower specific conductance values occurred at other wells in this area. Values for pH were fairly similar in all wells located in this area. Dissolved-chloride values follow a pattern similar to specific conductance values, except that well 3S/1E-7F1 had the highest chloride values. The pattern for dissolved nitrate is different. The lowest nitrate values occurred at wells 3S/1W-12H2 and 3S/1E-7F1, which are downgradient from Camp Parks. The highest nitrate values observed were from well 3S/1W-1B4, which is upgradient from Camp Parks. Moderately high nitrate values were observed from wells 3S/1W-12J1, 3S/1E-6F3, and 2S/1W-36E3. The first well is downgradient from Camp Parks and near wastewater sludge lagoons, and the other two wells are upgradient from Camp Parks.

The lack of a consistent pattern of water quality in this area and the large variations in property and constituent values from well to well are most likely due to an areal variation in soil salt concentrations. The major source of mineralization of ground water in this area is believed to be soil salts which are dissolved and transported by surface water percolating to the ground water (California Department of Water Resources, 1974, p. 147 and 148).

Veterans Administration Hospital wastewater application area.--Specific conductance values varied greatly from well to well in the Veterans Administration Hospital area (pl. 1C). The lowest values were observed at well 3S/2E-33G1, which is downgradient from the percolation ponds but adjacent to Arroyo Valle. The highest values were from well 3S/2E-33G3, which is downgradient from the spray irrigation area and farther from Arroyo Valle than is well 3S/2E-33G1. Values of pH were similar at all wells except 3S/2E-33K1, which is adjacent to and north of the percolation ponds. The pattern of dissolved-chloride values among wells is very similar to that for specific conductance. The pattern of nitrate values is different. The lowest nitrate values were from well 3S/2E-33G1, and the highest values were from wells 3S/2E-33L1 and 3S/2E-33G2; well 3S/2E-33L1 is directly downgradient from the wastewater treatment plant and well 3S/2E-33G2 is in the spray irrigation area.

Wastewater apparently influenced the patterns of water-quality values shown on plate 1C. Wells directly downgradient from the wastewater percolation ponds (3S/2E-33K1), in or directly downgradient from the wastewater spray irrigation area (3S/2E-33G2 and 33G3), and directly downgradient from the wastewater treatment plant (3S/2E-33L1) had much greater nitrate, specific conductance, and chloride values than well 3S/2E-33G1, which is adjacent to Arroyo Valle. The water quality of well 3S/2E-33G1 appears to have been primarily affected by Arroyo Valle, not by wastewater applications.

Livermore wastewater application areas.--Wastewater application has occurred in three areas in the vicinity of the city of Livermore (table 1) (figs. 1 and 3). In the area near the intersection of Pine Street and Rincon Avenue, ground-water quality was analyzed using results from three wells: (1) 3S/2E-8H2, upgradient from and northeast of the application area; (2) 3S/2E-8K2, upgradient from and east of the application area; and (3) 3S/2E-7C2, downgradient from and northwest of the application area. Given the general west and southwest direction of ground-water movement in the vicinity of this application area, well 3S/2E-7C2 is not ideal for assessing the effects of wastewater applications on ground-water quality downgradient from this area, but it is the best available well (table 1 and fig. 7). Comparison of water-quality values from these wells shows that wells 3S/2E-8H2 and 3S/2E-7C2 had similar values for pH, dissolved chloride, and dissolved nitrate. Well 3S/2E-8K2 had lower specific conductance, dissolved chloride, and dissolved nitrate values but greater pH values than wells 3S/2E-8H2 and 3S/2E-7C2 (pl. 1D). This pattern of water quality among these wells may indicate that wastewater applications have affected ground-water quality, but because there are no ideally located wells to assess the water quality downgradient from this application area, and because water-quality values were similar for wells 3S/2E-8H2 and 3S/2E-7C2, no firm conclusion can be drawn from the available data.

In the wastewater application area near the Livermore Municipal Airport and in the Zone 7 recharge pit area, ground-water quality was assessed using wells: 3S/1E-1H3 and 3S/1E-1P2, upgradient from the wastewater application areas; 3S/1E-12G1, 3S/1E-12D2, and 3S/1E-11B1, in the application area near the Livermore Municipal Airport; 3S/1E-10A2, upgradient from the Zone 7 recharge pit area; and 3S/1E-10G2, downgradient from the Zone 7 recharge pit area. There are no upgradient wells to the east of the wastewater application area near the Livermore Municipal Airport that are suitable for comparison with wells in this application area. The only such well is well 3S/2E-7C2, which may be affected by wastewater application from the area near the intersection of Pine Street and Rincon Avenue. Also, the Livermore fault is adjacently east of the wastewater application area near the Livermore Municipal Airport, and this fault apparently restricts the westward movement of ground water (California Department of Water Resources, 1974, p. 68). Wells 3S/1E-1H3 and 3S/1E-1P2 are the best available upgradient wells (table 1). Generally, the highest specific-conductance values were observed at well 3S/1E-10A2 and the lowest at wells 3S/1E-12G1 and 3S/1E-10G2 (pl. 1D). Specific-conductance values at other wells in the wastewater application area were like those of upgradient wells. The pattern of dissolved-chloride values among wells is similar to that for specific conductance. Values of pH were alike at all wells in these areas. For dissolved-nitrate values, the pattern is different. The lowest dissolved-nitrate values were observed at wells upgradient from the wastewater application areas. Generally, nitrate values were highest at wells in the wastewater application area near the Livermore Municipal Airport, and the values appeared to decrease downgradient from this area. This indicates that wastewater applications have significantly increased nitrate concentrations in the ground water in the wastewater application area near the Livermore Municipal Airport. Specific conductance, pH, and dissolved chloride values in this area do not appear to have been affected by wastewater applications.

Temporal Variations in Ground-Water Quality in Wastewater Application Areas

Time-series plots (pl. 2) of water levels, specific conductance, pH, dissolved chloride, and dissolved nitrate were used to assess changes in water level and water quality at wells selected for analysis (table 1). In months in which two or more measurements were made or samples taken, a median value was calculated and plotted. Wastewater application and rainfall were the primary factors considered in interpreting the patterns shown in the time series plots. Increasing values of specific conductance, dissolved chloride, and dissolved nitrate were attributed to wastewater applications unless other factors were evident. Decreasing values of specific conductance, dissolved chloride, and dissolved nitrate, when accompanied by increased water levels, were attributed to dilution caused by increased rainfall after the drought or during rainy seasons. In areas having alkaline soil, changes in pH values should also be related to rainfall because water percolating through the soil in these areas should transport the alkaline material in the soil to the ground water. Hence, in these areas, pH values should generally increase after the drought and during rainy seasons.

Castlewood wastewater application area.--Changes in water level and water quality in the Castlewood area were related primarily to annual rainfall (pl. 2A). Increased rainfall during post-drought years resulted in higher water levels and decreased specific-conductance and dissolved-chloride values during the 1979 and 1980 water years. Increased dissolved-nitrate values during the 1978 water year at well 3S/1E-32G2 (pl. 2A) were probably also related to increased rainfall. A possible explanation for the increased nitrate values is that material from wastewater applications accumulated in and on the soil during the drought and was dissolved and transported to the aquifer by increased rainfall during the 1978 water year. Such a process may also explain the increased specific-conductance and dissolved-chloride values at wells 3S/1E-32G2 and 3S/1E-29P2 during the 1978 water year. Greater pH values after the drought were probably related to increased rainfall, because the soils in this area are alkaline. Greater amounts of rainfall after the drought increased water levels almost immediately. Water levels also followed a seasonal pattern, increasing during the rainy season (October to May) and decreasing during the summer dry season (May to October). The magnitude of seasonal fluctuations in water levels was less during the drought than afterwards.

Pleasanton wastewater application area.--Changes in water level and water quality in the Pleasanton area are shown by time-series plots for four wells (pl. 2A). Plots for other selected wells (table 1) are not shown because they showed either the same patterns of change as those shown on plate 2A, or no discernible patterns because of the lack of either drought or post-drought data at these wells. The patterns of change in property and constituent values at wells 3S/1E-29M4 and 3S/1E-29D2 are similar. The main increase in specific-conductance and dissolved-chloride values started in July 1977 and continued into the 1978 water year. Dissolved-nitrate values either decreased or remained the same during the drought, but they increased markedly after the drought. Values of pH decreased slightly during the drought and increased after the drought. Water levels fell substantially during the drought and rose acutely afterwards. Seasonal fluctuations in water levels are also apparent. Water levels increased during the rainy season and decreased during the summer dry season. These patterns are similar to those in the Castlewood area and are explainable in the same way.

The patterns of change in property and constituent values are similar at wells 3S/1E-30A8 and 3S/1E-20J4. Specific-conductance values were variable and followed no explainable pattern. Dissolved-chloride and pH values increased after the drought. During the drought, dissolved-nitrate values decreased at well 3S/1E-30A8 but increased at well 3S/1E-20J4. After the drought, dissolved-nitrate values decreased at both wells during the 1978 water year but increased during subsequent water years. The pattern of change in dissolved-nitrate values at well 3S/1E-20J4 was probably caused by wastewater applications and perhaps by increased rainfall during the 1978 water year. Dissolved-chloride values at well 3S/1E-30A8 appear to be related to water level and hence to rainfall. Increases in pH values at wells 3S/1E-30A8 and 3S/1E-20J4 were probably related to rainfall, because soils in this area are alkaline. Changes in water level corresponded to changes in rainfall. The causes of the other patterns shown on plate 2A are not known.

Dublin-San Ramon and Camp Parks Military Reservation wastewater application area.--Time-series plots for wells 3S/1E-7F1 and 2S/1W-36E3 were not used because no drought data were collected at these wells, and the same patterns of change in water quality are indicated as shown at other wells in the Dublin-San Ramon and Camp Parks area. In time-series plots for the remaining wells (pl. 2B), the most significant patterns shown are the increase in dissolved-nitrate values at well 3S/1W-12J1 and the increase in dissolved-chloride values at well 3S/1W-12H2. The cause of the latter is not known but appears to be related to higher water levels, and hence to increased rainfall, after the drought. Well 3S/1E-12J1 is adjacent to sludge lagoons at the Dublin-San Ramon Services District wastewater treatment plant and to Alamo Creek, into which effluent was discharged from the wastewater treatment plant. Wastewater discharges and sludge application appear to have been the primary causes of the increased dissolved-nitrate concentrations in well 3S/1W-12J1 because dissolved-nitrate concentrations decreased at wells 3S/1W-1B4 and 3S/1E-6F3, which are upgradient of the Dublin-San Ramon Services District wastewater treatment plant. Greater amounts of rainfall and higher water levels after the drought retarded the rate of increase in dissolved-nitrate values at well 3S/1W-12J1.

Water levels fell at all wells during the drought and rose at all wells after the drought. The magnitude of seasonal fluctuations in water levels increased and pH values became higher at all wells after the drought. The patterns of change in water levels and pH values corresponded to changes in rainfall.

Veterans Administration Hospital wastewater application area.--Except for wells 3S/2E-33L1 and 3S/2E-33G2, patterns of water-level and water-quality changes differed for each well sampled in the Veterans Administration Hospital area (plots for well 3S/2E-33L1 are not shown because they are essentially the same as those for 3S/2E-33G2). For wells 3S/2E-33L1 and 3S/2E-33G2, the general decrease and seasonal fluctuation in specific-conductance, pH, and dissolved-chloride values were inversely related to the pattern of change in water levels (pl. 2C). This indicates that rainfall was the primary determinant of water-level and water-quality changes in this part of the wastewater application area. However, concentrations of dissolved nitrate as N increased from nearly zero in October 1977 to about 5 mg/L in February 1978. After returning to nearly zero in October 1978, concentrations of dissolved nitrate as N increased to about 10 mg/L in February 1979. These patterns indicate that nitrate accumulated in the soil during the summer dry period and was dissolved and transported to ground water during the rainy season. Spray irrigation of wastewater was the likely source of the accumulated nitrate in the soil. Values of pH decreased with increased rainfall because soils in this area are slightly acid to neutral and highly permeable.

Rainfall does not appear to be the controlling influence on water quality at well 3S/2E-33K1, because there was no relation between changes in water level and water quality (pl. 2C). The increases in specific conductance, dissolved chloride, and dissolved nitrate during and after the drought indicate that wastewater applications were affecting the water quality of this well, which is located immediately downgradient from percolation ponds that receive effluent from the wastewater-treatment plant.

The patterns of change in water quality at well 3S/2E-33G3 are also unrelated to water levels (pl. 2C). Increased rainfall after the drought should have resulted in decreased specific-conductance values owing to dilution of ground waters with water of low dissolved-solids content. Instead, specific-conductance values increased. Wastewater applications probably caused the increase in specific conductance. The acute increase in specific conductance, dissolved chloride, and dissolved nitrate during the rainy season of the 1978 water year may have been the result of an accumulation of salts in the soil during the drought. Rainfall may have dissolved and transported these salts to the ground water in this area. The source of accumulated salts is most likely the spray irrigation area just upgradient from well 3S/2E-33G3. Water levels did follow the seasonal rainfall pattern.

Rainfall appears to be the primary determinant of water quality at well 3S/2E-33G1 (pl. 2C). During the drought, specific conductance and dissolved chloride increased, and after the drought they decreased, a predictable pattern provided that salts have not accumulated in the soil and rainfall has an influence on ground-water quality. The pattern of water levels generally followed the pattern of rainfall.

Livermore wastewater application areas.--Time-series plots for wells 3S/1E-8K2 and 3S/1E-7C2 are used to show changes in water level and water quality in the Livermore area, near the intersection of Pine Street and Rincon Avenue, (pl. 2D). Time-series plots for well 3S/1E-8H2 are not included because they showed no trends in water quality or water level, and the only evident pattern was a seasonal fluctuation in values related to the seasonal rainfall cycle. The marked increase in specific conductance and dissolved chloride at well 3S/1E-7C2, in contrast to the slight increase at well 3S/1E-8K2, indicates that wastewater applied in the area near the intersection of Pine Street and Rincon Avenue from the late 1800's to 1959 may still be affecting ground-water quality. The apparent decrease in dissolved nitrate at well 3S/1E-7C2, on the other hand, may reflect the discontinuance of wastewater applications near the intersection of Pine Street and Rincon Avenue after 1959. Water levels rose after the drought and followed the seasonal rainfall pattern.

In the area near the Livermore Municipal Airport, the patterns of water-level and water-quality changes were different for each selected well (pl. 2D). Trends in water quality were not apparent at well 3S/1E-1H3, which is upgradient from the wastewater application area (pl. 2D). Water levels did show a rising trend and appeared to follow the seasonal pattern of rainfall.

For well 3S/1E-1P2, which is also upgradient from the wastewater application area, values of specific conductance, dissolved chloride, and dissolved nitrate tended to increase after the drought (pl. 2D). During the drought, values showed a slight increase or no trend. Water levels followed the seasonal pattern of rainfall and did not show a trend. Well 3S/1E-1P2 is adjacent to Arroyo Las Positas, which is known to drain an area contributing water high in dissolved solids (California Department of Water Resources, 1974, p. 72-78 and 146, and Consoer-Bechtel, 1972, p. 9-15). Reduced natural surface flow in this drainage during the drought, followed by more normal flows after the drought, may have caused the patterns of specific-conductance, dissolved-chloride, and dissolved-nitrate values observed at this well.

At well 3S/1E-12G1, which is in the wastewater application area, lowered water levels during the drought may have contributed to the increased values of specific conductance, dissolved chloride, and dissolved nitrate (pl. 2D). However, the main cause of these increased values during the drought was probably wastewater application. Specific conductance, dissolved chloride, and dissolved nitrate increased abruptly from June through September 1976 during a substantial rise in water levels that probably resulted from a large application of effluent from the wastewater treatment plant. Sludge disposal in this area was probably the cause of the marked increase in specific conductance, dissolved chloride, and dissolved nitrate during the 1977 water year (pl. 2D). After the drought, rainfall appears to be the most important determinant of water-level and water-quality changes because water levels and pH values rose markedly after increased rainfall, and values of specific conductance, dissolved chloride, and dissolved nitrate decreased despite wastewater applications. The reason for the abrupt increase in specific conductance, dissolved chloride, and dissolved nitrate during the rainy season of the 1980 water year is not known.

The patterns of water-quality changes during the drought were complex at well 3S/1E-12D2, which is also in the wastewater application area, (pl. 2D). As water levels rose steeply from May through September 1976, dissolved-chloride and dissolved-nitrate values increased, but specific-conductance and pH values decreased. During the rest of the drought, specific-conductance and pH values generally increased, dissolved-chloride and dissolved-nitrate values generally remained at the increased level, and water levels declined. The increase in dissolved-nitrate and chloride values accompanying the rise in water levels during the drought is similar to that at well 3S/1E-12G1 and is probably explainable in the same way. To explain the decrease in specific-conductance values, however, detailed information would be needed about wastewater applications during this part of the drought. After the drought, changes in specific-conductance and dissolved-chloride values were similar to those at well 3S/1E-1P2. Water in Arroyo Las Positas after the drought may have influenced the quality of water in well 3S/1E-12D2, which is downgradient from nearby well 3S/1E-1P2. Wastewater applications may also have influenced the quality of water in well 3S/1E-12D2 after the drought, because these applications had high concentrations of dissolved solids and dissolved chloride. The decrease in dissolved-nitrate concentrations and the increase in pH values after the drought probably resulted from greater rainfall.

At well 3S/1E-11B1, the patterns of water-quality changes were much different from other wells in the wastewater application area (pl. 2D). Here, water quality during the drought appeared to improve because of wastewater applications: specific conductance, dissolved chloride, and dissolved nitrate decreased as the water level rose. Increases in water level during each summer (May to October) of the 1976-77 drought were most likely due to wastewater applications. Postdrought changes in values of water-quality properties and constituents are not explainable, partly because the relation of water levels to water-quality values is inconsistent and partly because consistent trends in water-quality values are not apparent.

Well 3S/1E-10A2, for which sampling began in 1979, did not provide enough data to show any trends in water level or water quality.

At well 3S/1E-10G2, which is downgradient from the Zone 7 recharge pit, specific conductance, dissolved chloride, and dissolved nitrate generally decreased, and pH increased after the drought as the water level rose sharply (pl. 2D). Such patterns are expected for a period of increased rainfall. Water levels also reflected the seasonal rainfall cycle.

Areas and Times of Water-Quality Impairment

The previous sections of this report have shown where and when wastewater applications have affected ground-water quality and ground-water levels in the Livermore-Amador Valley. One way of showing the significance of such effects is to compare ground-water quality to water-quality objectives that were established to maintain water suitable for present and potential beneficial uses.

The California Regional Water Quality Control Board, San Francisco Bay Region, is presently updating its Basin Plan, which includes a review of beneficial water-use designations and water-quality objectives. The Basin Plan presently identifies the existing and potential beneficial water uses applicable to the Livermore-Amador ground-water basin as municipal supply, industrial process water supply, and agricultural use. Maximum contaminant levels (MCL's) given in California Administrative Code Title 22, Chapter 15, Articles 4 and 8, and Sections 64435 and 64473 are being considered as objectives for ground waters used for domestic and municipal purposes. Except for pH, MCL's for the principal water-quality properties and constituents sampled in the area covered by this report are given in table 4. Maximum contaminant levels for pH are not given in the California Administration Code. Existing objectives for ground water do not limit values for specific conductance, dissolved solids, and dissolved chloride. They do set a limit of 10 mg/L for dissolved nitrate as N (California State Water Resources Control Board, 1975), which is the same as that given in table 4.

For the reasons stated previously, the values given in table 4 are used in this report to determine areas and times of impairment of ground-water quality. Because this report focuses on wells in or near wastewater application areas, only water quality at selected wells (table 1) in these areas was compared to values in table 4.

Wells that are in or near wastewater application areas and have water that exceeded MCL's for specific conductance, dissolved solids at 180°C, dissolved chloride, or dissolved nitrate, are shown in table 5, which also lists the number of times that MCL's were exceeded. Periods of water-quality impairment were ascertained by applying MCL's to time-series plots for wells discussed in the previous section of this report, though not for all wells listed in table 5. Because time-series plots were not prepared for dissolved solids, the occasions on which this constituent exceeded its MCL were not determined and thus are not shown in table 5. Because MCL's for dissolved solids and specific conductance are exceeded with similar frequency, and because values of specific conductance and dissolved solids are usually correlated, occasions on which MCL's for dissolved solids were exceeded probably correspond to those for specific conductance. If MCL's for a water-quality property or constituent were exceeded at all, or nearly all, times during the study--for example, specific conductance for well 3S/1E-29M4 was 31/34--occasions on which objectives were exceeded are not given.

TABLE 4. - Maximum contamination levels used for determining areas and times of water-quality impairment

[Concentrations in milligrams per liter and specific conductance in micromhos per centimeter at 25°C]

Property or constituent	Maximum contamination levels: Recommended value	Maximum contamination levels: Upper limit
Specific conductance	900	1,600
Dissolved solids at 180°C	500	1,000
Dissolved chloride	250	500
Dissolved nitrate as N	--	10

FUTURE SAMPLING PROGRAMS

The present sampling program is comprehensive, providing a good data base for statistical analysis in the preparation of this report. Although a few improvements could be made in the present program, it is well planned for sampling locations and frequency and the selection of water-quality properties and constituents to be measured. To help determine the present effect of wastewater applied prior to 1959 in the area near Pine Street and Rincon Avenue in Livermore, additional wells could be added downgradient and to the west and southwest. Not all the wells drilled for the sampling program were perforated at the correct depth to tap the aquifer desired for sampling (for example, 3S/1E-1R1 and 3S/1E-12A2--see table 1). Well logs are missing or the depth of perforated interval is not known for a few wells (table 1). For example, the perforated interval for well 3S/1E-10G2 is not known, and this well is in the most desirable location to determine effects of the Zone 7 recharge pit on ground-water quality.

The schedule of six samplings per year in wastewater application areas was not followed at a few wells (for example, 3S/1E-20F5, 3S/1W-12H2, and 3S/1E-12H1), and nonadherence to scheduled sampling could hinder areal and temporal analyses of data. Sampling six times per year at all wells selected for analysis in this report could be done to provide data more comparable than are existing data. Sampling in the Pleasanton area for dissolved organic nitrogen and ammonia may be desirable because nitrification of effluent was not performed at the Sunol Wastewater Treatment Plant. Samples could also be taken for other organics. Chlorinated effluent from wastewater-treatment plants is likely to contain trihalomethanes, and agricultural use of herbicides and pesticides may result in the contamination of the upper alluvial aquifer. Sampling for organics could be restricted to key wells such as one upgradient from, one in, and one downgradient from a wastewater application area. During the first year of sampling for organics, one sample at each key well would probably be sufficient to determine if a problem exists. In subsequent years, more frequent sampling may be necessary, depending on the magnitude of any identified problem. If the sampling program continues, with the above modifications it may be possible to determine what effect, if any, cessation of wastewater application in some areas and continuation of application in other areas are having on ground-water quality.

TABLE 5. - Wells having water that exceeded maximum contamination levels

[Explanation: first number is number of times objective was exceeded; second number is number of samples; dates are when objectives were exceeded]

Application area and well	Specific conductance: Recommended value	Specific conductance: Upper limit	Dissolved solids: Recommended value	Dissolved solids: Upper limit	Dissolved chloride: Recommended value	Dissolved chloride: Upper limit	Dissolved nitrate as N: Upper limit
Castlewood Corporation							
3S/1E-32G2	33/33	33/33	25/25	25/25	33/33	33/33	
Lower Castlewood Golf Course							
3S/1E-29P2	34/34	2/34 Dec. 75, Apr. 76	26/26	3/26			
Pleasanton							
3S/1E-29M4	31/34	1/34 Feb. 78	25/26				
3S/1E-29D2	34/34		25/26				
3S/1E-20Q1	19/19	11/19 July 77-Mar. 78 July 78-July 79	11/11	3/11			16/17
3S/1E-20J4	35/35		27/27	1/27			32/32
3S/1E-29A1							
3S/1E-30A9							
3S/1E-30A8	35/35		27/27				
3S/1E-20M11	17/17	7/17 Mar.-July 78 Oct. 78 Mar.-June 79	12/12				14/15
3S/1E-20F5	18/18		17/17				
Dublin-San Ramon and Camp Parks Military Reservation							
3S/1W-12J1	34/34	34/34	26/26	26/26	1/34 Aug. 76		
3S/1W-12H2	28/28	28/28	20/20	20/20	29/29	29/29	
3S/1E-7F1	12/12	12/12	9/9	9/9	8/8	8/8	
3S/1E-6F3	17/17	17/17	13/13	13/13			
3S/1W-1B4	12/12	12/12	7/7	7/7	9/9	9/9	6/12 Sept. 76-Aug. 77 Feb. 78
2S/1W-36E3	1/13 Oct. 78		10/10				

Veterans Administration Hospital							
3S/2E-33K1	30/30	29/30	21/21	20/21	29/30		
3S/2E-33L1	18/18	9/18 Aug.-Dec. 77 May-Dec. 78 Nov. 79	8/8	2/8	6/18 May-Dec. 78 Nov. 79		1/17 Feb. 78
3S/2E-33G1	7/26 Jan.-Dec. 77		5/22				
3S/2E-33G2	17/18		7/8		1/18 Oct. 78		
3S/2E-33G3	14/14	14/14	6/6	6/6	12/14	3/14 Feb. 78 Feb.-May 80	
Livermore Plant near Pine and Rincon Streets							
3S/2E-8H2	13/14		10/10				12/13
3S/2E-8F1							
3S/2E-8K2	12/12		9/9				7/9 Dec. 77-July 79 May 80
3S/2E-8N2							
3S/2E-7C2	12/12		9/9				8/9
Livermore Plant near Livermore Municipal Airport							
3S/1E-1H3	13/13		8/9				
3S/1E-12H1	3/4		4/4				1/3
3S/1E-12G1	36/36	2/36 Sept. 76 May 80	26/26	3/26			28/34
3S/1E-12F1	30/48		29/41				2/37
3S/1E-11J1	50/53		35/38				6/35
3S/1E-12D2	33/33	14/33 May 78-Aug. 80	24/24	7/24	6/34 Oct. 78-July 79		30/31
3S/1E-11B1	33/33	16/33 Dec. 75, Mar. 76 Dec. 76, Apr. 77 May-Dec. 78 May-Aug. 79 Mar.-Aug. 80	23/23	5/23	5/33 Dec. 78 Mar.-Aug. 80		21/31 Dec. 75-Apr. 76 Oct. 76-Apr. 77 Dec. 77-Dec. 78 May 79-May 80 Aug. 80
3S/1E-12C1	6/10		8/9				2/9
3S/1E-1P2	32/32	2/32 July 79 May 80	23/23	1/23	3/33 Oct. 79-Feb. 80		
3S/1E-2N3	19/19		17/17				1/17
3S/1E-10A2	5/5	5/5	5/5	4/5			2/3 May-Nov. 79
3S/1E-10G2	11/11		9/9				1/9 Nov. 77

SUMMARY AND CONCLUSIONS

The effects of land application of effluent from wastewater treatment plants on ground-water quality in the Livermore-Amador Valley were determined by (1) an areawide assessment of rainfall, ground-water movement, and ground-water quality and (2) a site-specific assessment of ground-water levels and ground-water quality in wastewater application areas. Annual rainfall varied markedly in the Livermore-Amador Valley during the study: 1976 and 1977 water years had less than one-half the normal rainfall; 1978 and 1980 water years had greater than normal rainfall; and 1975 and 1979 water years had nearly normal rainfall. Analysis of ground-water levels throughout the Livermore-Amador Valley indicated that the directions of ground-water movement are generally the same as the directions of surface-water flow except in the Pleasanton wastewater application area, where the direction of ground-water movement near the percolation ponds is northward.

The areawide assessment of ground-water quality was limited to a comparison of dissolved-nitrate concentrations in wells throughout the Livermore-Amador Valley. This comparison showed that median concentrations of dissolved nitrate as N were highest (greater than 10 mg/L) at the following locations:

1. In the Livermore wastewater application area near the Livermore Municipal Airport;
2. In that part of the Pleasanton wastewater application area downgradient from and north of the percolation ponds;
3. In an area east of the city of Livermore between Arroyo Seco and Arroyo Mocho; and
4. In a small area just east of the gravel pits along Arroyo Valle.

Except for locations 3 and 4, median concentrations of dissolved nitrate as N were less than 8.0 mg/L in most wells in areas not receiving wastewater applications. The cause of the high concentrations of dissolved nitrate at locations 3 and 4 is not known but may be related to agricultural practices or, at location 3, to a community along Buena Vista Avenue that uses individual septic tank systems for wastewater treatment.

From 1976 to 1980, median concentrations of dissolved nitrate as N: (1) Decreased at most wells in the Livermore wastewater application area near the Livermore Municipal Airport; (2) increased at most wells in that part of the Pleasanton wastewater application area downgradient from and north of the percolation ponds; and (3) increased in the Dublin-San Ramon and Veterans Administration Hospital wastewater application areas.

Comparison of ground-water quality in wastewater application areas to the quality of effluent from wastewater treatment plants in the Livermore-Amador Valley showed that wastewater applications appear to have affected the water quality of the upper and lower aquifers in the Livermore wastewater application areas. Although median concentrations of dissolved nitrate as N in the Livermore wastewater-application areas (12 mg/L in the upper aquifer and 8.1 mg/L in the lower aquifer) were only about one-half of the median concentrations of dissolved nitrate as N in effluent from wastewater treatment plants in the Livermore-Amador Valley, they were greater than in most wells in areas not receiving wastewater applications (median less than 8.0 mg/L).

Although median concentrations of dissolved nitrate as N in the Castlewood, Pleasanton, and Veterans Administration Hospital wastewater application areas were only about 5 percent of what they were in effluent from wastewater treatment plants in the Livermore-Amador Valley, wastewater applications may have also affected ground-water quality in these areas. In these areas and in the upper aquifer in the Livermore wastewater application areas, values of specific conductance, pH, dissolved solids, and dissolved chloride were very similar to those characteristic of effluent from wastewater treatment plants in the Livermore-Amador Valley.

Ground-water quality in the Dublin-San Ramon and Camp Parks Military Reservation wastewater application area appears to be determined by factors other than wastewater applications. In this area, values of specific conductance and concentrations of dissolved solids and dissolved chloride were about three to four times and concentrations of dissolved nitrate were about a fifth of those characteristic of effluent from wastewater treatment plants in the Livermore-Amador Valley. The major source of mineralization of ground water in the Dublin-San Ramon and Camp Parks Military Reservation wastewater application area is believed to be soil salts, which are dissolved and transported by surface water percolating to the ground water.

Results from the site-specific assessment are summarized in table 6. Rainfall, soil, and geology appeared to be the main determinants of ground-water quality in the Castlewood and in the Dublin-San Ramon and Camp Parks Military Reservation wastewater application areas. Wastewater application appeared to be the main determinant of ground-water quality in the wastewater application area near the Livermore Municipal Airport and in the Pleasanton and Veterans Administration Hospital wastewater application areas. Ground-water levels in the wastewater application areas generally followed the pattern of rainfall. Comparison of ground-water quality in the wastewater application areas with water-quality objectives shows impaired water quality in all areas.

TABLE 6. - Summary of major findings from site-specific assessment of ground-water quality in wastewater application areas

Wastewater application area and well	Areal variation analysis				Temporal variation analysis			
	Wastewater impact indicated	Rainfall impact indicated	Soil impact indicated	Geologic impact indicated	Wastewater impact indicated	Rainfall impact indicated	Soil impact indicated	Geologic impact indicated
Castlewood Corporation								
3S/1E-32G2				x	x	x	x	
Lower Castlewood Golf Course								
3S/1E-29P2					x	x	x	
Pleasanton								
3S/1E-29M4						x	x	
3S/1E-29D2						x	x	
3S/1E-20Q1	x							
3S/1E-20J4	x				x	x	x	
3S/1E-29A1								
3S/1E-30A9								
3S/1E-30A8						x	x	
3S/1E-20M11	x							
3S/1E-20F5								
Dublin-San Ramon and Camp Parks Military Reservation								
3S/1W-12J1			x	x	x	x	x	
3S/1W-12H2			x	x		x	x	
3S/1E-7F1			x	x				
3S/1E-6F3			x	x			x	
3S/1W-1B4			x	x		x	x	
2S/1W-36E3			x	x				
Veterans Administration Hospital								
3S/2E-33K1	x				x			
3S/2E-33L1	x				x	x		
3S/2E-33G1						x		
3S/2E-33G2	x				x	x		
3S/2E-33G3	x				x	x		
Livermore Plant near Pine and Rincon Streets								
3S/2E-8H2						x		
3S/2E-8K2								
3S/2E-7C2					x			
Livermore Plant near Livermore Municipal Airport								
3S/1E-1H3								
3S/1E-12G1	x				x	x	x	
3S/1E-12D2	x				x	x	x	
3S/1E-11B1	x				x[1]			
3S/1E-1P2						x[2]		
3S/1E-10A2	x							
Zone 7 recharge								
3S/1E-10G2	x					x	x	

[1]Wastewater impacts at this well appear to improve water quality.
[2]Impact mainly due to rainfall affecting surface-water runoff in the Arroyo Las Positas drainage.

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☆U.S. GOVERNMENT PRINTING OFFICE: 1983 — 690-753/09