STATE OF CALIFORNIA
The Resources Agency

Department of Water Resources

in cooperation with
Alameda County Flood Control and
Water Conservation District, Zone 7

BULLETIN No. 118-2

EVALUATION OF GROUND WATER RESOURCES: LIVERMORE AND SUNOL VALLEYS

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DEPARTMENT OF WATER RESOURCES
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Sacramento, California 95802
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JUNE 1974

BULLETIN NO. 118 SERIES

The Bulletin No. 118 Series is published by the Department of Water Resources for the use of all interested agencies and the general public. Bulletins included in this series are:

Bulletin No. 118-1 — Evaluation of Ground Water Resources, South Bay

- Appendix A: Geology, August 1967
- Volume I: Fremont Study Area, August 1968
- Volume II: Additional Fremont Area Study, July 1973
- Volume III: North Santa Clara County, in progress

Bulletin No. 118-2 — Evaluation of Ground Water Resources, Livermore and Sunol Valleys, Appendix A: Geology, August 1966

Bulletin No. 118-3 — Evaluation of Ground Water Resources, Sacramento County, in progress

Bulletin No. 118-4 — Evaluation of Ground Water Resources, Sonoma County, in progress

FOREWORD

The ground water basins of Livermore and Sunol Valleys have played an important role in the water supply of the San Francisco Bay Area since the late 1800's. In the late 1940's and in the 1950's, ground water extractions exceeded recharge and caused a reduction of ground water in storage, cessation of subsurface outflow, and degradation of water quality in portions of the Livermore and Sunol Valleys ground water basins. During the 1960's additional water was imported to Livermore Valley through the State Water Project and water levels have been stabilized.

This Bulletin reports the results of the first phase of a study by the Department of Water Resources in cooperation with Alameda County Flood Control and Water Conservation District, Zone 7, to evaluate the ground water resources of Livermore and Sunol Valleys. A general discussion of the geology of the area was published in August 1966 in Appendix A to this Bulletin. The present bulletin includes additional detailed geologic studies and a hydrologic inventory of the ground water resources for the period 1961-1970.

The report concludes that a verified mathematical model of the Livermore Valley ground water basin has been achieved and recommends that additional studies evaluate how ground water can be used along with other water sources to meet future water demands. Also recommended are studies to evaluate water quality changes that could occur in response to changes in pumping and recharge. In addition, modifications of water quality and measurement programs are suggested. The results of operations-economics studies recommended will be of significant use to local government in making decisions on conservation, development and use of the County's water resources.

John R Teerink

John R. Teerink, Director
Department of Water Resources
The Resources Agency
State of California
April 25, 1974

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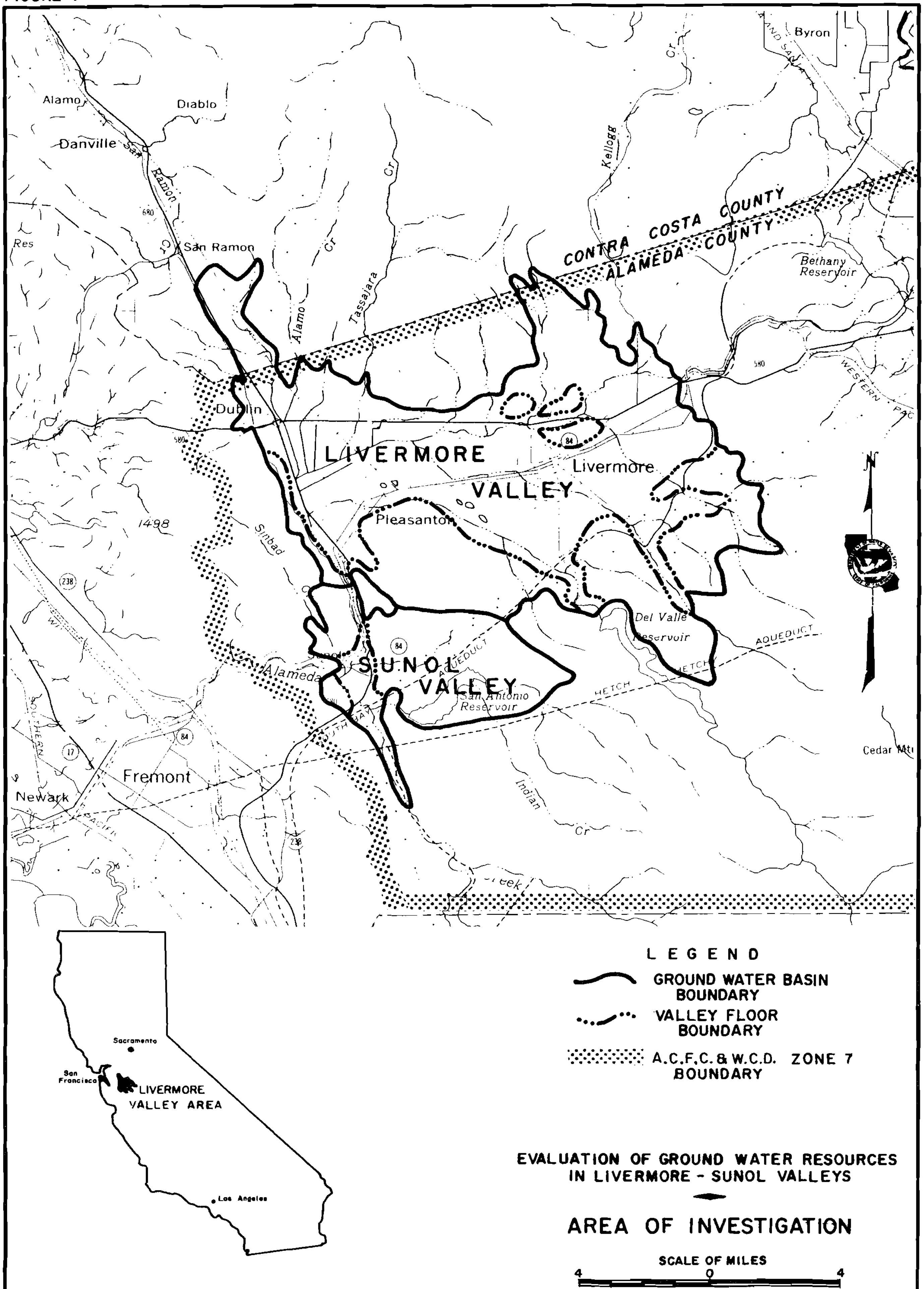
ABSTRACT

Livermore and Sunol Valleys are located in central Alameda County midway between the southern part of San Francisco Bay and the San Joaquin Valley. In the late 1940's and during the 1950's, water demand exceeded supply and ground water levels declined. This trend has been stopped by the availability of a new water supply to the area as a result of the construction of Del Valle Reservoir on the southern edge of Livermore Valley as a unit of the State Water Project.

A general geologic study of Livermore and Sunol Valleys was made in the early 1960's and the results were published in August 1966 as Appendix A to Bulletin 118-2.

This report contains the results of a cooperative study by the Department of Water Resources and the Alameda County Flood Control and Water Conservation District, Zone 7, of geologic and hydrologic conditions affecting the occurrence and movement of ground water and the relation between recharge to and withdrawals from the ground water system.

FIGURE 1



EVALUATION OF GROUND WATER RESOURCES IN LIVERMORE - SUNOL VALLEYS

AREA OF INVESTIGATION

CHAPTER I. SUMMARY AND RECOMMENDATIONS

Livermore and Sunol Valleys are part of the rapidly urbanizing metropolitan region surrounding San Francisco Bay. These two valleys contain three basic resources: land, gravel, and water. The land, a significant portion of which is devoted to viticulture, rapidly is becoming urbanized; the gravel is being extracted; and surface and ground waters are being utilized extensively. All of these factors have combined to create a great demand for water. Because of this demand, the California Department of Water Resources and Zone 7 of the Alameda County Flood Control and Water Conservation District have conducted a cooperative study to develop a better understanding of the ground water resources of the area. The study will lead to the development and testing of alternative plans for conjunctive use of the surface, ground, and waste waters which are available in the area. In addition, the large-scale extraction of gravel competes with use of these gravels in situ for storage of ground water. The purpose of this bulletin is to report on the geology and hydrology of the study area in sufficient detail so that planning for use of the ground water may be undertaken by local agencies.

History of Development

The earliest recorded homesteading in Livermore Valley occurred when Robert Livermore became cograntee of Rancho las Positas in 1839. The subsequent gold rush years greatly stimulated agricultural growth in the valley, and since the turn of the century, much of the valley has been under cultivation of grapes and other crops. In 1960 the population of the Livermore Valley area was 29,587. At that time urban growth from the San Francisco Bay Area was encroaching into Livermore Valley, utilizing land formerly devoted to agriculture. Ten years later, urbanization had reached a population level of 77,655 in the valley, which represented an increase of nearly 5,000 people per year.

Surface waters in areas tributary to Livermore and Sunol Valleys first were developed in 1888. In 1898, Spring Valley Water Company completed a group of water wells at the Bernal Well Field in the southwest portion of Livermore Valley. Water from these wells, which originally were artesian, was conveyed by pipeline to the Sunol Filter Galleries, from which it was piped to San Francisco along with water from Alameda and San Antonio Creeks. To augment supplies from the Bernal Well Field, Spring Valley Water Company constructed, in 1924, Calaveras Dam and Reservoir on Calaveras Creek, located just above its confluence with Alameda Creek.

In 1930, the City of San Francisco purchased Spring Valley Water Company. The Hetch Hetchy Aqueduct, which imported Tuolumne River water to San Francisco, was completed by the City in 1934. At that time, export of ground water from Livermore Valley ended. During 1948 and 1949, while the second barrel of the Hetch Hetchy Aqueduct was under construction, ground water again was exported from the Bernal Well Field to San Francisco. With the construction in 1964 of James H. Turner Dam and San Antonio Reservoir, on San Antonio Creek, the San Francisco water development plan in the area was completed.

In the early 1900's, most of the agricultural and domestic water demands of Livermore Valley were met from ground water, augmented by minor amounts of diversions from local streams. In 1962 the first deliveries of imported water were made through the South Bay Aqueduct of the State Water Project. Del Valle Dam and Reservoir, a unit of the State Water Project, were completed in 1969, and provide additional water supplies through storage and regulation of imported South Bay Aqueduct water and conservation of runoff on Arroyo del Valle.

Ground water levels in the central portion of Livermore Valley dropped from an average elevation of about 280 feet to 250 feet from the late 1950's to the early 1960's. During the 1960's, levels remained about the same, but in 1970 they began to rise. The rise in water levels may be attributed to importation of water, conservation of surface water, and retention of waste water. The continued rise in water levels may, under certain conditions, result in excessively high ground water levels in portions of Livermore Valley.

The presence of naturally occurring poor quality ground water is a restraint to complete utilization of the ground water basins. Furthermore, the quantity of waste water produced in Livermore Valley is increasing rapidly and will require development of disposal methods to protect the quality of ground water in the valley.

Description of Study Area

The area covered by this bulletin is shown on Figure 1. It consists of that part of the Alameda Creek watershed above Sunol Dam, at the head of Niles Canyon, and occupies parts of Contra Costa, Alameda, and Santa Clara Counties. It is an elongated area of some 582 square miles, oriented northwest-southeast, and lies within the Diablo Range. The area is located about 40 miles southeast of San Francisco and 30 miles southwest of Stockton. The area of investigation includes Livermore Valley, Sunol Valley, and the watersheds tributary to both valleys.

A brief description of the features in the study area, the ground water geology, the movement and quality of ground water, and the development of the mathematical model is contained in this chapter. Detailed descriptions of ground water conditions in each subbasin in Livermore and Sunol Valleys are contained in a succeeding chapter. Detailed discussions of the ground water geology and water quality of Livermore and Sunol Valleys are contained in appendixes at the end of this bulletin.

Cities, Towns, and Districts

There are two incorporated cities in Livermore Valley: Livermore, located in the east central portion of the valley; and Pleasanton, located in the southwestern portion of the valley. In addition, there is a major unincorporated residential community, the San Ramon Village-Dublin area, which is located in the northwestern portion of Livermore Valley. Sunol Valley is almost entirely rural, with few residences outside of the unincorporated town of Sunol.

Zone 7 of the Alameda County Flood Control and Water Conservation District wholesales treated water to municipal water agencies and companies and retails untreated water to individuals for agricultural uses. The boundaries of Zone 7 include all of eastern Alameda County and are shown on Figure 1.

Zone 7, under a contract with the State, purchases imported water to supplement the local water supply within the Zone. It takes delivery of the imported water through the South Bay Aqueduct of the State Water Project shown on Figure 2. The Zone also extracts ground water from several locations, including a well field along Hopyard Road.

There are four major retail water service agencies in Livermore Valley and one in Sunol Valley. The areas served and principal imported water facilities are shown on Figure 2. California Water Service Company is a privately owned public utility serving the urban area of Livermore and vicinity. This utility obtains its water from Zone 7, as well as from wells. The City of Pleasanton Water Department is a publicly owned and operated system which serves water in the Pleasanton area entirely from wells. Valley Community Services District, located in the San Ramon-Dublin area, provides water from wells to customers in the Alameda County portion of its district and provides sewage treatment for customers in both the Alameda County and Contra Costa County portions of the district. Water service to customers in the Contra Costa County portion of the district is provided by the East Bay Municipal Utility District. The City of Livermore Water Department serves treated water purchased from Zone 7 to the area east and north of the California Water Service Company service area.

The City of San Francisco Water Department serves the community of Sunol, as well as irrigated lands in Sunol Valley and the Lawrence Livermore Laboratory.

Previous Investigations

"Alameda County Investigation", Bulletin 13, published by the Department of Water Resources in March 1963, is a report of a general water resource investigation conducted by the former Division of Water Resources. (A preliminary report of this investigation was published in 1955.) The report contains information of surface and subsurface supplies, projected water demands, and alternate plans for surface water development.

"Alameda Creek Watershed Above Niles: Chemical Quality of Surface Water, Waste Discharges, and Ground Water", a federal-state cooperative water quality investigation published by the Department of Water Resources in January 1964, contains information on the effects of waste water discharges on the surface and ground waters of Livermore and Sunol Valley.

"Evaluation of Ground Water Resources, Livermore and Sunol Valleys, Appendix A: Geology", Bulletin 118-2, Appendix A, was published by the Department of Water Resources in August 1966. The report contains an evaluation of the geology as it affects ground water occurrence and movement in Livermore and Sunol Valleys.

"Water Quality Management Plan for the Alameda Creek Watershed Above Niles", was published in September 1972 by Brown and Caldwell, Consulting Engineers, for Zone 7 of the Alameda County Flood Control and Water Conservation District, City of Pleasanton, City of Livermore, and Valley Community Service District. The report describes various plans for treating and disposal of waste water of Livermore Valley.

Physiography

The Livermore Valley portion of the study area occupies the northern and eastern portion of the Alameda Creek watershed. The valley is approximately 13 miles long in an east-west direction, and approximately 4 miles wide; it is completely surrounded by hills of the Diablo Range. The principal streams in the area are Arroyo Valle, Arroyo las Positas, Arroyo Mocho, Alamo Creek, South San Ramon Creek, and Tassajara Creek. Arroyo Valle and Arroyo Mocho are the largest streams and have the largest watersheds. All of the streams converge in the southwestern portion of Livermore Valley to form Arroyo de la Laguna. This stream then flows southerly to Sunol Valley, where it joins Alameda Creek.

The Livermore Valley area has been divided into six physiographic areas, which are shown on Figure 3. Named from north to south, they are the Tassajara Upland, the Dublin Upland, the Altamont Upland, Livermore Valley, the Livermore Upland, and the Livermore Highland. Valley lands and certain upland areas are water-bearing and thus receive and transmit ground water in varying degrees. In contrast, other uplands and the steeper highlands are nonwater-bearing and consequently are of little importance to ground water.

The Sunol Valley portion of the study area occupies the southwestern portion of the Alameda Creek watershed; it also is completely surrounded by the Diablo Range. Streams in the area include Smith Creek, Isabel Creek, Arroyo Hondo, Alameda Creek, Calaveras Creek, Indian Creek, San Antonio Creek, and Vallecitos Creek. The main tributary streams are Arroyo Hondo and Calaveras Creek. All the streams are tributary to Alameda Creek, which flows northward through Sunol Valley.

The Sunol Valley area has been divided into six physiographic areas, as shown on Figure 3. These are, from north to south, the Sinbad Upland, Sunol Valley, Vallecitos Valley, La Costa Valley, the Sunol Upland, and the Sunol Highland. Detailed descriptions of these various physiographic areas of Livermore and Sunol Valleys are contained in Bulletin 118-2, "Evaluation of Ground Water Resources, Livermore and Sunol Valleys, Appendix A: Geology".

Geology

Bulletin 118-2, "Evaluation of Ground Water Resources, Livermore and Sunol Valleys, Appendix A: Geology", was published by the Department of Water Resources in August 1966. The bulletin contains a description of the physiography, areal geology, and geologic structure of the two valleys. During the investigation following publication of Appendix A, it was found necessary to develop additional information on geology for use as a base for hydrologic studies of Livermore Valley.

A detailed study was made using existing aerial photographs, well log data, and water quality data; in addition, a seismic survey was made to provide additional subsurface data. Although results of the present investigation did not materially change the basic concepts of the geology of the Livermore Valley that were presented in the earlier bulletin, they revealed additional information regarding the areal and subsurface geology. These, in turn, resulted in modification of previous concepts of ground water movement.

Two of the modifications to the geologic description of the basin were the inclusion of the Livermore Formation within the ground water basins and the redefinition of the fault system affecting the movement of ground water. These two modifications resulted in a change of subbasin boundaries. The areal extent of the two ground water basins and their respective subbasins is shown on Figure 3; the names and areas of the subbasins are listed on Table 1. The areal geology of the two valleys is shown on the various sheets of Figure 4; geologic cross sections are shown on Figure 5. The stratigraphy and water-bearing characteristics of the geologic materials are shown on Table 2.

Livermore and Sunol Valleys have two major sources of ground water: (1) the alluvial deposits, which make up the valley floor, and (2) the Livermore Formation, which is adjacent to and underlies the valley floor. Livermore Valley and Sunol Valley ground water basins encompass the surface exposures of both the alluvium and the Livermore Formation. A third water-producing unit, the Tassajara Formation, underlies the northern portion of Livermore Valley and has a large area of exposure to the north of the valley. This formation was excluded from the ground water basin because of the relatively low yields of wells tapping it and the low degree of continuity between it and the alluvial materials.

Nonwater-Bearing Series

Rocks of the nonwater-bearing series are exposed throughout the Diablo Range. They are composed principally of marine sediments and range in age from Jura-Cretaceous to mid-Tertiary. Nonwater-bearing rocks occur beneath the valley floors at depths ranging to over 1,000 feet near the axis of Livermore Valley and to several hundred feet in Sunol Valley. Under certain conditions, the rocks of this series may yield small quantities of ground water to wells and springs. The quality of the water frequently is poor and may be unsuitable for most beneficial uses. The areal extent of the nonwater-bearing series adjacent to Livermore and Sunol Valleys is shown on Figure 4.

Water-Bearing Series

Materials of the water-bearing series make up the entire valley floor of Livermore and Sunol Valleys, as well as the lower portions of La Costa and Vallecitos Valleys. They also occur to the west, south, and north of Livermore Valley; they are exposed to the east of Sunol Valley, with lesser areas also occurring to the north and west. Under most conditions, these materials yield adequate quantities of ground water to all types of wells. The quality of the water produced ranges from poor to excellent, with most waters in the good to excellent range.

The areal extent of the various members of the water-bearing series is presented on Figure 4; their subsurface configuration is shown on Figure 5. The more important members of the water-bearing series are briefly discussed below; the stratigraphy and water-bearing characteristics are summarized on Table 2. A detailed description of each member is contained in Appendix A-1 of this bulletin.

The oldest water-bearing formation in the study area is the Tassajara Formation. This formation is of Pliocene age and occurs north of Livermore Valley and also beneath the central portion of the valley at depths which range from 200 feet to 750 feet. Postdepositional deformation has folded and tilted the beds of the Tassajara Formation into a number of northwest-southeast trending anticlines and synclines. These beds are composed of sandstone, siltstone, shale, conglomerate, and limestone. The sandstones ordinarily would be expected to have a fair degree of permeability. However, the presence of tuff and clay particles reduces its overall permeability, and wells tapping the Tassajara Formation yield only sufficient water for domestic, stock, or limited irrigation purposes. Ground water contained in this formation is of sodium bicarbonate character of moderately good quality.

Because of the regional dip of the beds in the Tassajara Formation, and also because of the presence of fine-grained materials which act as confining beds, there is little, if any, hydrologic continuity between ground water in the Tassajara Formation and that in the overlying materials.

The next youngest geologic unit in Livermore Valley is the Livermore Formation, which is of Plio-Pleistocene age and is exposed over broad regions south of Livermore Valley and east of Sunol Valley. Limited exposures occur on the north and west side of Livermore Valley, as well as to the west of Sunol Valley. The Livermore Formation also occurs beneath the floors of Livermore and Sunol Valleys, occurring at depths ranging from a few tens of feet to over 400 feet. Surface and subsurface contours on the upper surface of the Livermore Formation are presented on Figure 6.

The Livermore Formation occurs generally as beds of clayey gravel in a sandy clay matrix. To the south of Livermore Valley these beds dip toward the north. They are nearly flat under the valley, and they dip gently to the south along the north edge of the valley where they lap onto the Tassajara Formation. This formation is a significant water-bearing formation in the Livermore Valley area. All of the deep wells in the eastern half of the valley produce from this formation. Yields to wells are adequate for most irrigation, industrial, or municipal purposes. Like the underlying Tassajara Formation, ground water in the Livermore Formation is of sodium bicarbonate character and of good quality.

The surficial valley-fill materials overlie the Tassajara and Livermore Formations and range in thickness from a few feet to nearly 400 feet. An idea of this thickness can be obtained by comparing land surface elevation contours with contours of the buried surfaces of the Livermore and Tassajara Formations shown on Figure 6.

The valley-fill materials are composed of unconsolidated sand, gravel, silt, and clay, all of Holocene age. Wells located in these materials yield both confined and unconfined ground water. Figure 7 identifies wells tapping confined and unconfined ground water in Livermore Valley. Yields from properly designed wells tapping the valley-fill materials are sufficient for any type of high capacity use. Figure 8 shows the specific capacity of wells in Livermore Valley. All of the high-producing wells shown on this figure produce from the valley-fill materials. These materials generally produce an excellent quality sodium, calcium, and magnesium bicarbonate water. Exceptions are local areas containing significant quantities of chloride or nitrate ions.

Occurrence and Movement of Ground Water

The water-bearing series in Livermore and Sunol Valleys can be described as multi-layered systems having an unconfined upper aquifer over a sequence of leaky or semiconfined aquifers. One of the problems encountered with this type of system is obtaining sufficient water level data in the upper aquifer and forebay areas to determine annual changes of ground water in storage in the entire system. Furthermore, changes in storage in the lower portion of the series, the Livermore Formation, are probably of lesser magnitude than those in the upper portion. However, this is more difficult to determine because the individual beds of the formation are separated from each other in areas where storage changes probably take place.

Ground water in Livermore Valley moves downslope toward the longitudinal axis of the valley. It then moves in a generally westerly direction toward the Bernal Subbasin. Here the various ground waters of the basin commingle and move in a southerly direction across the Verona Fault zone and into Sunol ground water basin. The central and western portions of Livermore Valley contain the greatest amount of valley fill materials and produce the largest quantities of water. The approximate depths of the valley fill materials, the nature of the underlying materials, and the general slope of the potentiometric surface are indicated in Table 3.

Faults and lateral variations in thickness and permeability of aquifer materials cause restrictions to the horizontal movement of ground water. Restrictions to the vertical movement of ground water are due to separations between the two water-bearing units, the valley fill materials, and the Livermore Formation, each of which has different permeabilities and internal stratification within each unit. Hydraulic continuity between the two water-bearing units is limited to areas where the Livermore Formation is in direct contact with overlying stream channel deposits along the courses of Arroyo Valle and Arroyo Mocho. In addition, there are many wells which penetrate both the valley fill materials and the Livermore Formation and thus allow some degree of interconnection to exist. The degree of hydraulic continuity between subbasins is mainly controlled by faulting. Table 4 indicates the subsurface flow conditions at the subbasin boundaries.

Water Quality

Water quality characteristics are an important tool in the interpretation of flow of ground waters of differing characteristics. The mineral quality of both surface and ground water in Livermore and Sunol Valleys varies considerably in location, but it is generally suitable for most beneficial uses.

The chemical character of ground water in the valley-fill materials ranges from an excellent quality sodium, magnesium, or calcium bicarbonate water to a poor quality sodium chloride water. Figure 9 presents the geochemistry of ground water in Livermore Valley, illustrating the areal extent of the various types of ground water occurring in the valley.

Water quality conditions in the individual subbasins are discussed in Chapter II, entitled, "Ground Water in the Subbasins". A detailed discussion of water quality in Livermore and Sunol Valley appears in Appendix B to this Bulletin.

The quality of ground water is generally a reflection of the surface water available for replenishment. The central and southern portions of Livermore Valley are replenished principally by good quality surface waters from Arroyo Valle and Arroyo Mocho. Figure 9 shows the extent of influence of the good quality calcium bicarbonate waters of Arroyo Valle and the magnesium bicarbonate waters of Arroyo Mocho. Sodium bicarbonate ground water originates as runoff or subsurface flow from upland areas composed of Tassajara and Livermore Formations.

Poor quality ground water occurs in the eastern part of the valley. A major source of the poor quality water is from recharge of sodium chloride waters from Altamont Creek. Another area of poor quality water of sodium chloride and sodium sulfate character occurs in the central part of Livermore Valley southeast of Dublin. Here the poor quality ground water is related to clays rich in crystallized salts which are believed to have been derived from playa or sink deposits. Some of this poor quality water may also be related to the adjacent waste disposal ponds which are shown on Figure 10.

Ground water quality problems in the Livermore Valley are associated largely with the occurrence of excessive concentrations of nitrate, boron, and total dissolved solids. Excessive nitrate occurs locally, possibly resulting from infiltration of waste water and/or from fertilizers applied to croplands. Hardness concentrations frequently are undesirable for domestic or industrial uses. Excessive boron concentrations in ground water are derived from surface flow from areas of marine sediments. Variations of electrical conductivity and chloride concentrations in ground water in Livermore Valley are shown on Figure 11. Areas of ground water having high nitrate concentrations are shown on Figure 12, and areas of high boron and fluoride concentrations are shown on Figure 13.

In Sunol Valley, the quality of ground water generally is suitable for irrigation purposes. Nitrate in some shallow wells exceeds 44 ppm, indicating degradation, possibly from surface sources.

Hydrologic Inventory

An inventory of recharge to and withdrawals from a ground water basin over a given base period provides information on the relative importance of various sources and uses. Annual inventories determine the effect of changing culture on the ground water basin. When the results of an annual inventory agree with historical water level changes, the parameters used to develop the inventory are considered verified.

For the Livermore Valley ground water basin, the 9-year period from 1961-62 through 1969-70 was selected as the study period because, as shown on Figure 14, it contains a mixture of wet and dry years approximating long-term climatic conditions. During the study period, data are available to calculate the items of the hydrologic inventory, either directly or indirectly. An example of the available data is the land use survey for 1970 shown on Figure 15.

To develop and verify the hydrology, inventories of water supply and use were made for the combined surface and subsurface hydrologic system as well as for the ground water system by itself. The hydrologic systems are shown on Figure 16. The various items developed for the inventory are discussed in detail in Chapter III and summarized below. The adjusted inventory is shown in Table 5.

The amount of precipitation and applied water recharged to the ground water basin was computed by comparing water available for plant growth with the ability of the vegetation to use water. Flow in streams was computed by developing precipitation-runoff curves for tributary hill areas and by estimating surface runoff from valley lands. Amounts of streamflow becoming recharge were based on the differences between estimated and gaged flows at several points in the valley. Pumpage was obtained from records for urban use and computed from land use and water requirements for agricultural use.

The net amount of water added to or withdrawn from the ground water system should over a period of years be equivalent to the change in the amount of water in storage as computed from water levels and specific yields of the saturated subsurface materials. The differences between net recharge computed by hydrologic inventory and change in storage computed by water levels are listed in Table 5 and shown on Figure 18.

Over the study period, stream runoff appears to have been the major source of recharge. Agricultural pumpage has represented the largest amount of withdrawal and appears to have remained fairly constant. However, pumpage for urban use has increased and now exceeds agricultural pumpage. Calculations of net recharge by hydrologic inventory and review of water levels indicate that the average annual pumpage from the valley-fill materials was about 19,400 acre-feet for the period 1961 through 1970. For this same period the average annual recharge of ground water has been 23,900 acre-feet.

Mathematical Model

For the ground water system inventory, the nodal boundaries for the mathematical model, shown in Figure 17, were developed and programmed for a digital computer analysis for the study period. The valley-fill materials were considered to contain the main ground water system and transfers from underlying water-bearing formations, both the Livermore and Tassajara Formations, were computed as subsurface flow. In developing the nodal configuration for the model, subbasin boundaries and differences in water quality characteristics and soil permeabilities were taken into account.

The process used in verifying the model was a three-step approach. The first step was adjusting the transmissivity between nodes so the water would flow from the areas where computed water levels were higher than the historic water level to the areas where the computed water levels were too low. This adjustment was done until the best agreement between the computed and historical water levels was obtained.

The next step in getting the water levels to agree was adjusting the net recharge for each node within the level of accuracy of the data. The total net recharge for all the nodes remained the same, but increments were shifted from one node to another. The last step was to reevaluate the historical water levels in nodes where historic and computed water levels did not match. Figure 15 shows the first and final verification run of the model for node 38.

The mathematical model is considered verified for the major portion of the area because water levels obtained as model results are in general agreement with reliable historic water levels. In two areas of the model (Figure 17), nodes 1 through 9 in the northwest, and nodes 43 through 45 in the east, the model cannot be considered verified due to inadequate historic water levels. However this deficiency does not significantly impair the use of the mathematical model as a planning tool.

Recommendations

Completion of the geohydrology phase of the study and development of a verified mathematical model of Livermore Valley provides the opportunity to obtain an evaluation of the effects of future actions relating to water resources. It is recommended that additional studies be made to:

1. Determine what portion of the area's future water demands can be met by ground water when used conjunctively with surface, imported, and reclaimed water sources in a variety of alternative operation plans.

2. Determine the effects of possible combinations of pumping and recharge modifications on the movement or containment of areas of poor water quality.

There is a need to improve the mathematical model by extending the area verified to the entire Livermore Valley, and a related need to modify the existing ground water quality and measurement monitoring systems to provide more accuracy in annual changes in water quality, trends in water quality changes and changes in the amount of ground water in storage. It is recommended that these needs be met by:

1. Developing a ground water data system that monitors all portions of the ground water basin.

2. Increase the number of data points of moderate depth and reduce the number of deep ones. This may require the installation of small diameter piezometers for the sole purpose of data collection.

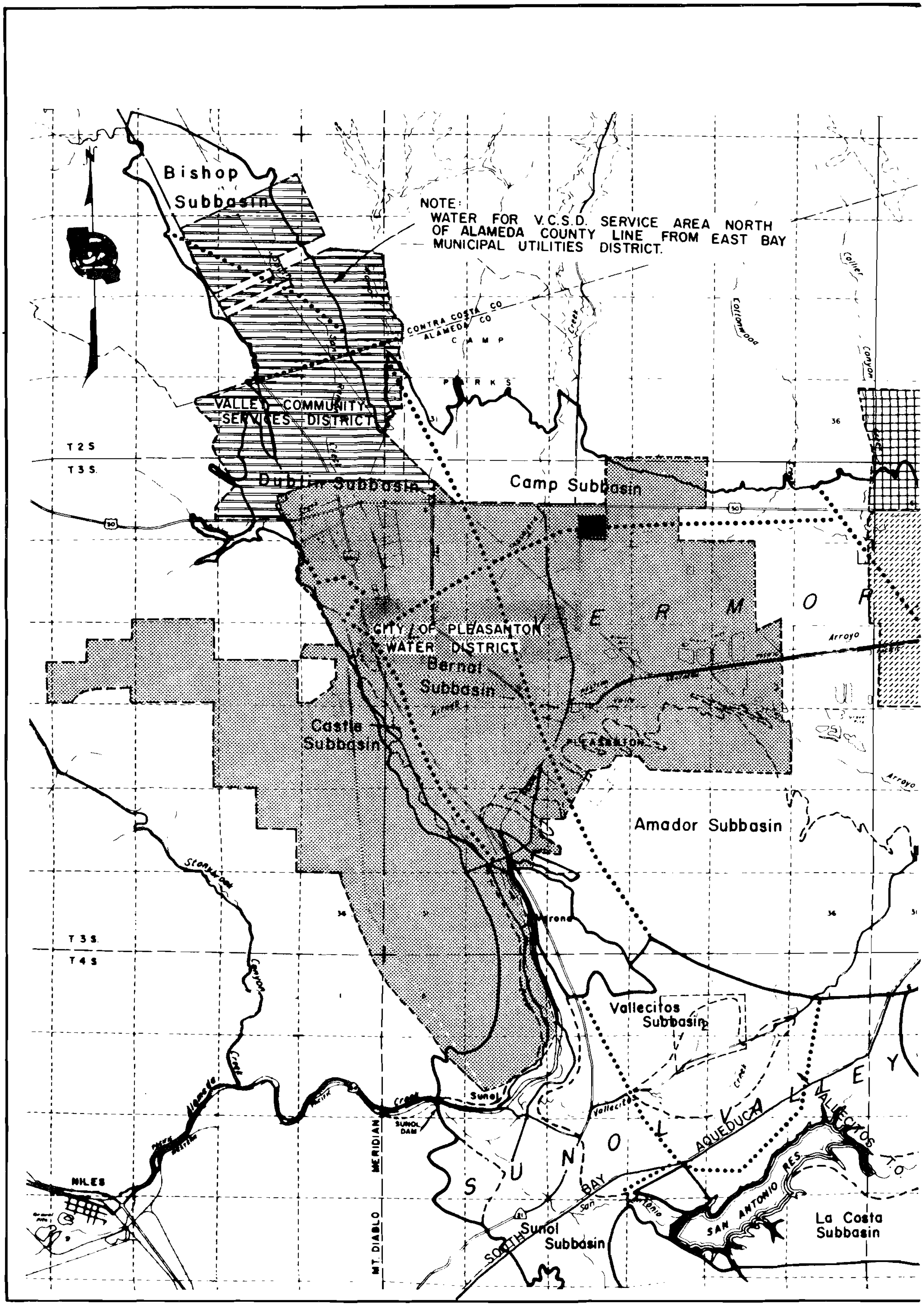
3. Increase the number of data points in the vicinity of ground water areas having high concentrations of nitrate, chloride, boron, or fluoride to develop a more accurate description of both depth and areal extent of areas of poor water quality.

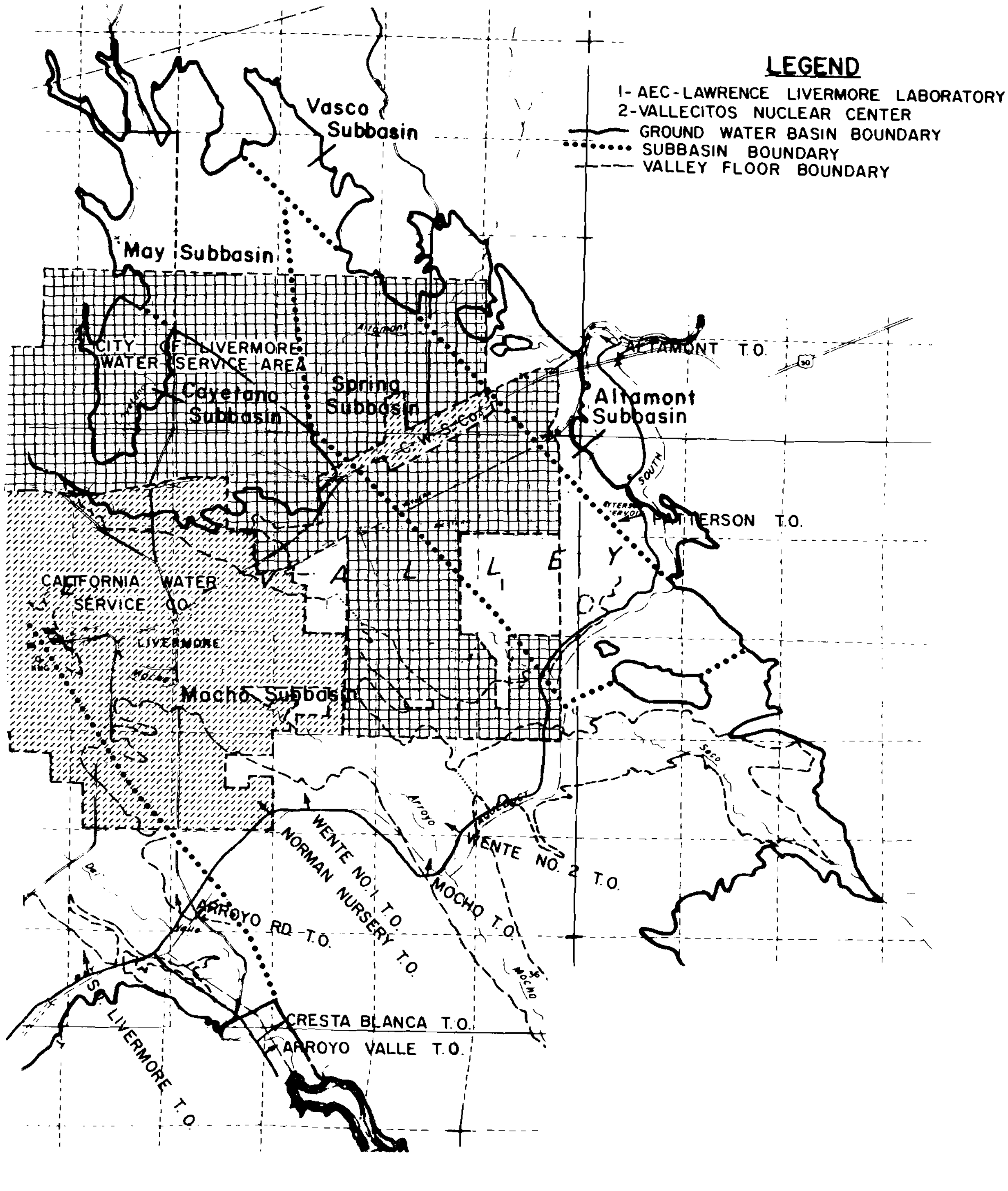
4. Adopt the objective that a well or piezometer is not an acceptable data point unless the formation being monitored can be identified. This would require logs and construction information for most of the data points.

TABLE 1

AREAS OF GROUND WATER BASINS AND SUBBASINS
(in acres)

Subbasin Name	Valley Floor	Uplands	Total
LIVERMORE VALLEY GROUND WATER BASIN			
Bishop	1,666	--	1,666
Dublin	4,957	--	4,957
Castle	361	544	905
Bernal	2,711	895	3,606
Camp	2,858	--	2,858
Amador	10,790	7,571	18,361
Mocho	9,181	13,946	23,127
Mocho I	2,935		
Mocho II	6,246		
Cayetano	562	--	562
May	2,433	--	2,433
Spring	4,097	682	4,779
Vasco	568	--	568
Altamont	1,476	--	1,476
Basin Total	41,660	23,638	65,298
SUNOL VALLEY GROUND WATER BASIN			
Sunol	3,395	1,894	5,289
Vallecitos	912	3,278	4,190
La Costa	710	4,230	4,940
Basin Total	5,017	9,402	14,419


Bishop Subbasin
NOTE:
WATER FOR V.C.S.D. SERVICE AREA NORTH OF ALAMEDA COUNTY LINE FROM EAST BAY MUNICIPAL UTILITIES DISTRICT.
CONTRA COSTA CO
ALAMEDA CO
CAMP
PARKS
VALLEY COMMUNITY SERVICES DISTRICT
T 2 S
T 3 S
Dublin Subbasin
Camp Subbasin
CITY OF PLEASANTON WATER DISTRICT
Bernal Subbasin
Castle Subbasin
PLEASANTON
Amador Subbasin
L E R M O R
Arroyo
T 3 S
T 4 S
Vallecitos Subbasin
S U N O L V A L L E Y
SOUTH BAY AQUEDUCT
SAN ANTONIO RES
La Costa Subbasin
Sunol Subbasin
Sunol
SUNOL DAM
MT. DIABLO MERIDIAN
NILES
Alameda Creek
Stonybrook
Vallecitos
Collier
Cottonwood
Canyon
Creek
N

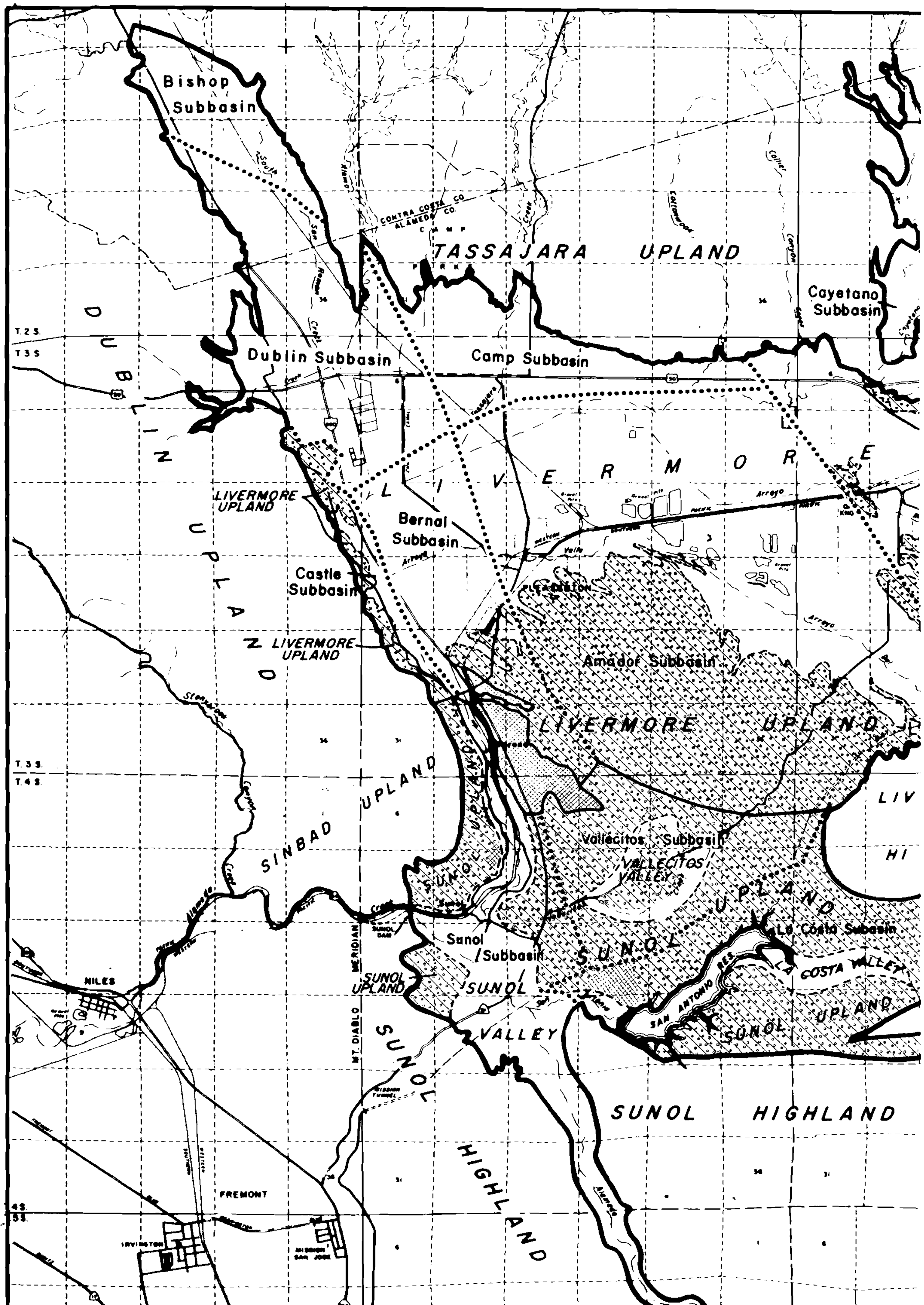


NOTE:
LAWRENCE LIVERMORE LAB, VALLECITOS NUCLEAR CENTER AND SUNOL ARE SERVED BY THE SAN FRANCISCO WATER DEPARTMENT.

SOME AREAS OUTSIDE THE WATER SERVICE AREAS PURCHASE WATER FROM ZONE 7.

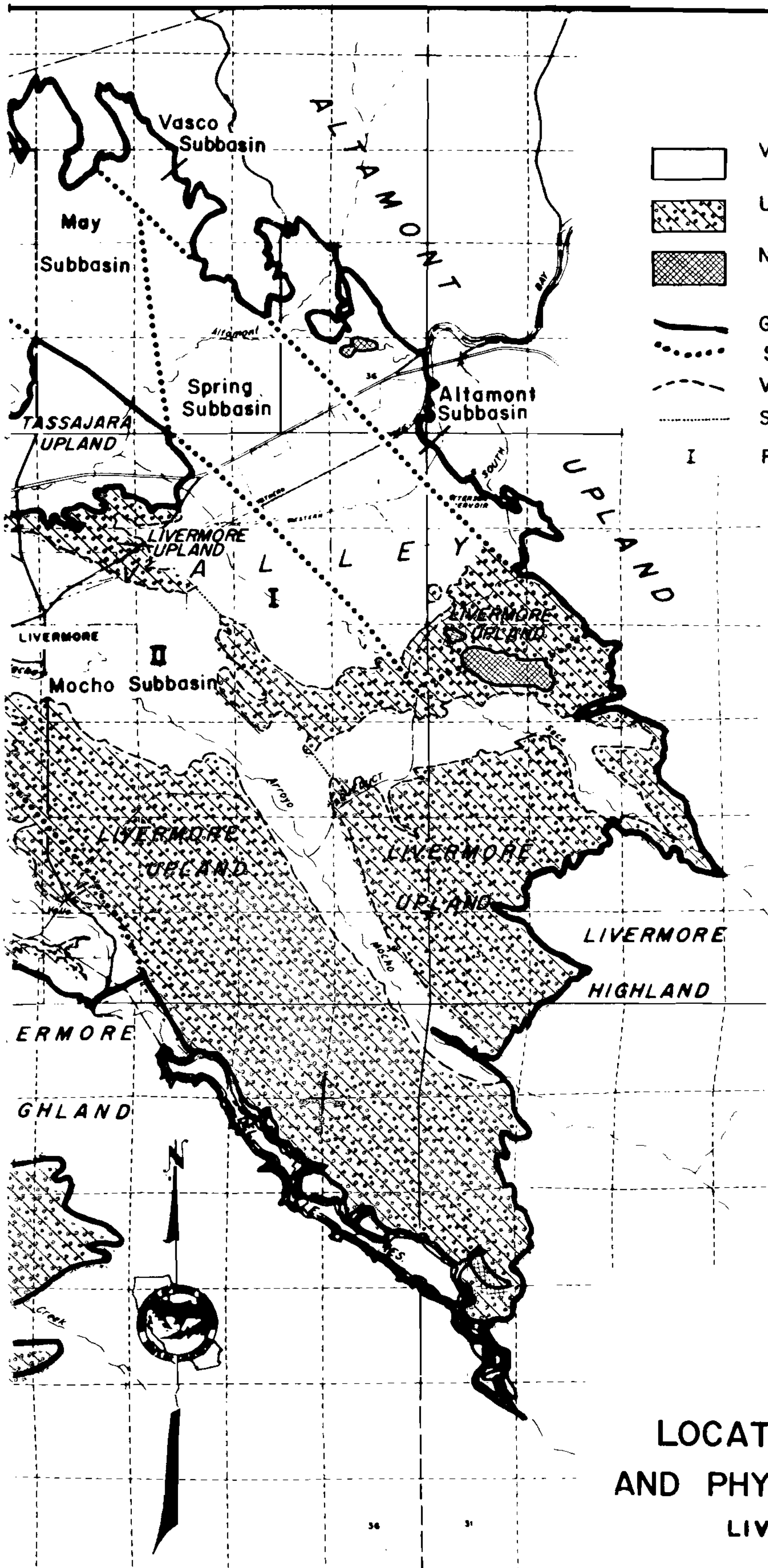
WATER SERVICE AREAS
LIVERMORE VALLEY

SCALE OF FEET
4000 0 4000 8000 12000



Bishop Subbasin
TASSAJARA UPLAND
Cayetano Subbasin
CONTRA COSTA CO.
ALAMEDA CO.
CAMP PARKS
DUBLIN UPLAND
Dublin Subbasin
Camp Subbasin
LIVERMORE
LIVERMORE UPLAND
Bernal Subbasin
Castle Subbasin
LIVERMORE UPLAND
Amador Subbasin
LIVERMORE UPLAND
SINBAD UPLAND
SUNOL UPLAND
Vallecitos Subbasin
VALLECITOS VALLEY
SUNOL UPLAND
La Costa Subbasin
LA COSTA VALLEY
Sunol Subbasin
SUNOL UPLAND
SUNOL VALLEY
SUNOL UPLAND
SAN ANTONIO RES.
SUNOL HIGHLAND
SUNOL HIGHLAND
MT. DIABLO MERIDIAN
NILES
FREMONT
IRVINGTON
MISSION SAN JOSE
PLEASANTON
T.2 S.
T.3 S.
T.3 S.
T.4 S.
4 S.
5 S.

FIGURE 3



LEGEND

[box]	VALLEY LANDS Underlain by Holocene sediments
[hatched box]	UPLANDS Underlain by the Livermore Formation
[cross-hatched box]	NONWATER-BEARING ROCKS Exposed within Ground Water Basin
[heavy line]	GROUND WATER BASIN BOUNDARY
[dotted line]	SUBBASIN BOUNDARY
[dashed line]	VALLEY FLOOR BOUNDARY
[fine dotted line]	SUBBASIN INTERIOR BOUNDARY
I	REGION WITHIN SUBBASIN

LOCATION OF SUBBASINS AND PHYSIOGRAPHIC FEATURES

LIVERMORE VALLEY

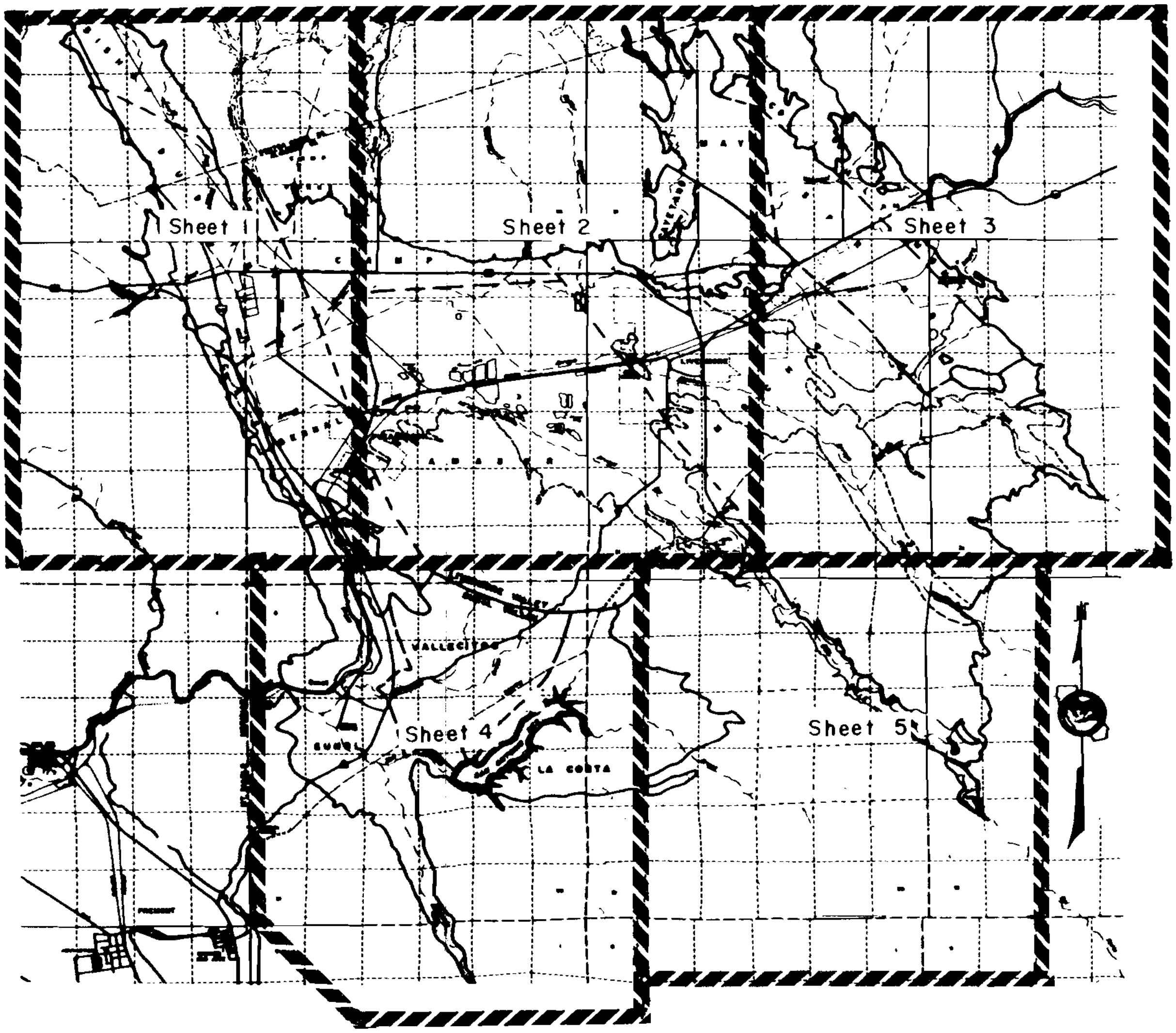
SCALE OF FEET
4000 0 4000 8000 12000

TABLE 2

GEOLOGIC UNITS OF THE
LIVERMORE VALLEY-SUNOL VALLEY AREA

Geologic Age	Map Symbol	Geologic Unit	Thickness (feet)	General Character	Water-Bearing Properties
Holocene	gp	Gravel Pits	Up to 150' deep	Location of gravel extraction operations.	May be source area for ground water recharge.
		Valley Fill Materials:			
	Qsc	Stream Channel Deposits	0-20	Loose deposits of sand, gravel and boulders along active streams.	Highly permeable but limited in thickness. Act as forebay for ground water recharge.
	Qb	Basin Deposits	0-50	Unconsolidated deposits of silt and clay.	Essentially impermeable. Subject to ponding. Not a source of ground water.
	Qal	Alluvium	0-200	Unconsolidated deposits of clay, silt, sand, and gravel.	Where not over 100' thick provides ground water sufficient for domestic needs. Thicker sections provide large quantities of ground water to wells.
	Qfg	Alluvial Fan Deposits, Gravel Facies	0-150	Semiconsolidated deposits of sand and gravel in matrix of clayey sand.	Permeable; provides adequate supplies of ground water to wells for most purposes.
	Qfc	Alluvial Fan Deposits, Clay Facies	0-150	Stratified deposits of clay, silt, and sand in north part of Livermore Valley.	Of moderate permeability. Provides low yields of ground water to domestic wells.
	Qt	Terrace Deposits	0-75	Poorly bedded deposits of clay, silt, sand, and boulders adjacent to stream channels.	Permeability ranges from high to low. Highly permeable materials usually elevated and thus are drained. Not a consistently good source for ground water.
Plio-Pleistocene	TQl	Livermore Formation	4,000	Massive beds of rounded gravel cemented by an iron-rich sandy clay matrix.	Permeable. Provides ground water to deep wells in quantities adequate for most irrigation, industrial and municipal purposes.
	TQlc	Clay Facies	500(?)	Beds of claystone with few lenses of gravel. Exposed only in eastern part of Livermore Valley.	Of low permeability; provides moderate amounts of ground water to wells.
Pliocene	Tp	Tassajara Formation	5,000+	Bedded deposits of sandstone, tuffaceous sandstone, tuff, and shale.	Of low permeability; yields water to wells in quantities sufficient only for domestic, stock, and limited irrigation purposes.
pre-Pliocene	Tm	Tertiary Marine Sediments	4,000+	Shale, sandstone, conglomerate, and chert.	Nonwater-bearing.
pre-Tertiary	JK	Jura-Cretaceous Marine Sediments	8,000+	Sandstone, shale, conglomerate, greenstone, and chert.	Nonwater-bearing.

Index Sheet FIGURE 4



SYMBOLS

GEOLOGIC CONTACT, DASHED WHERE INFERRED.

U D FAULT, DASHED WHERE INFERRED, DOTTED WHERE CONCEALED. U DENOTES UPTHROWN SIDE; D DENOTES DOWNTHROWN SIDE.

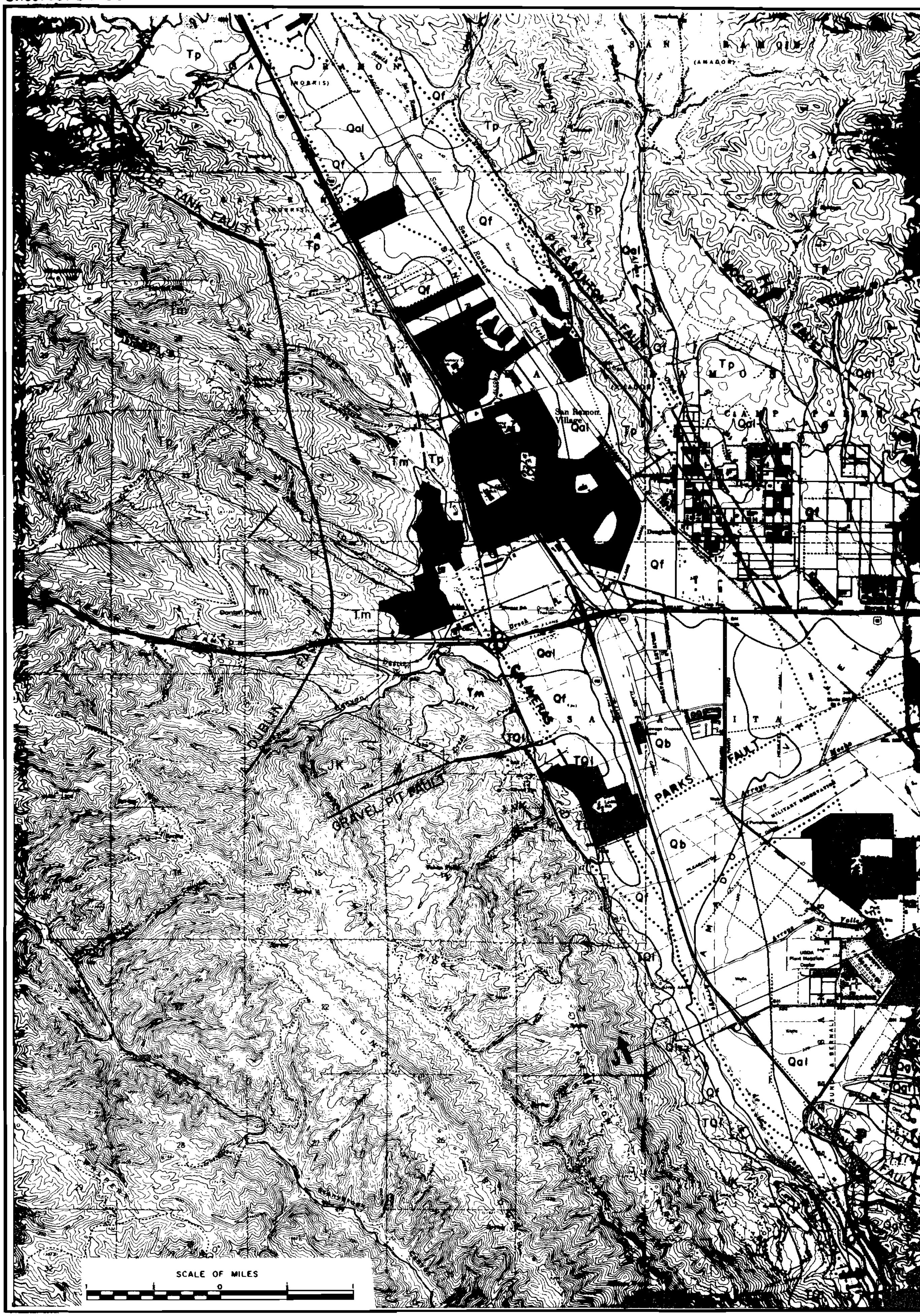
4 ATTITUDE OF BEDDING

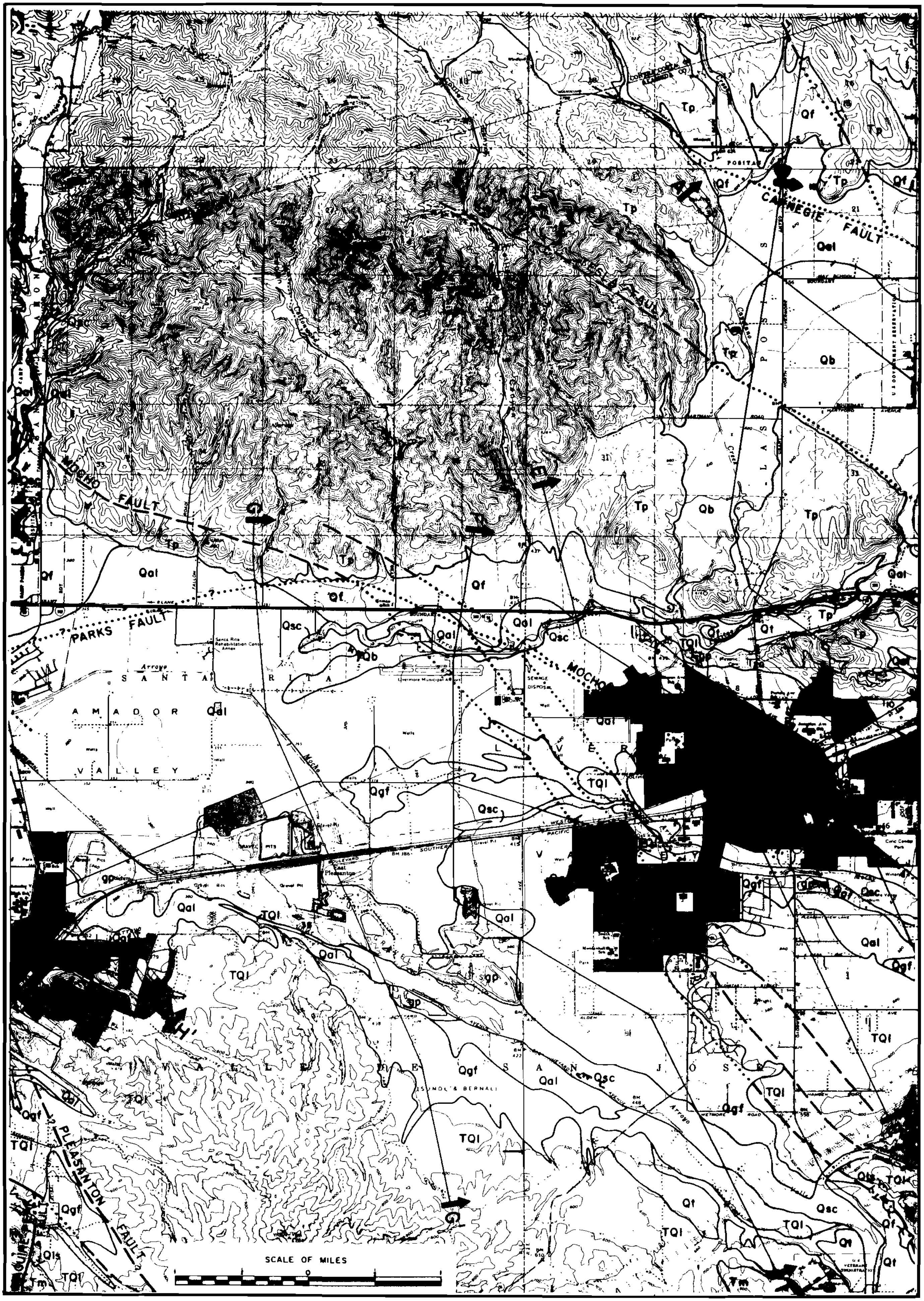
L LOCATION OF GEOLOGIC SECTION.

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
CENTRAL DISTRICT

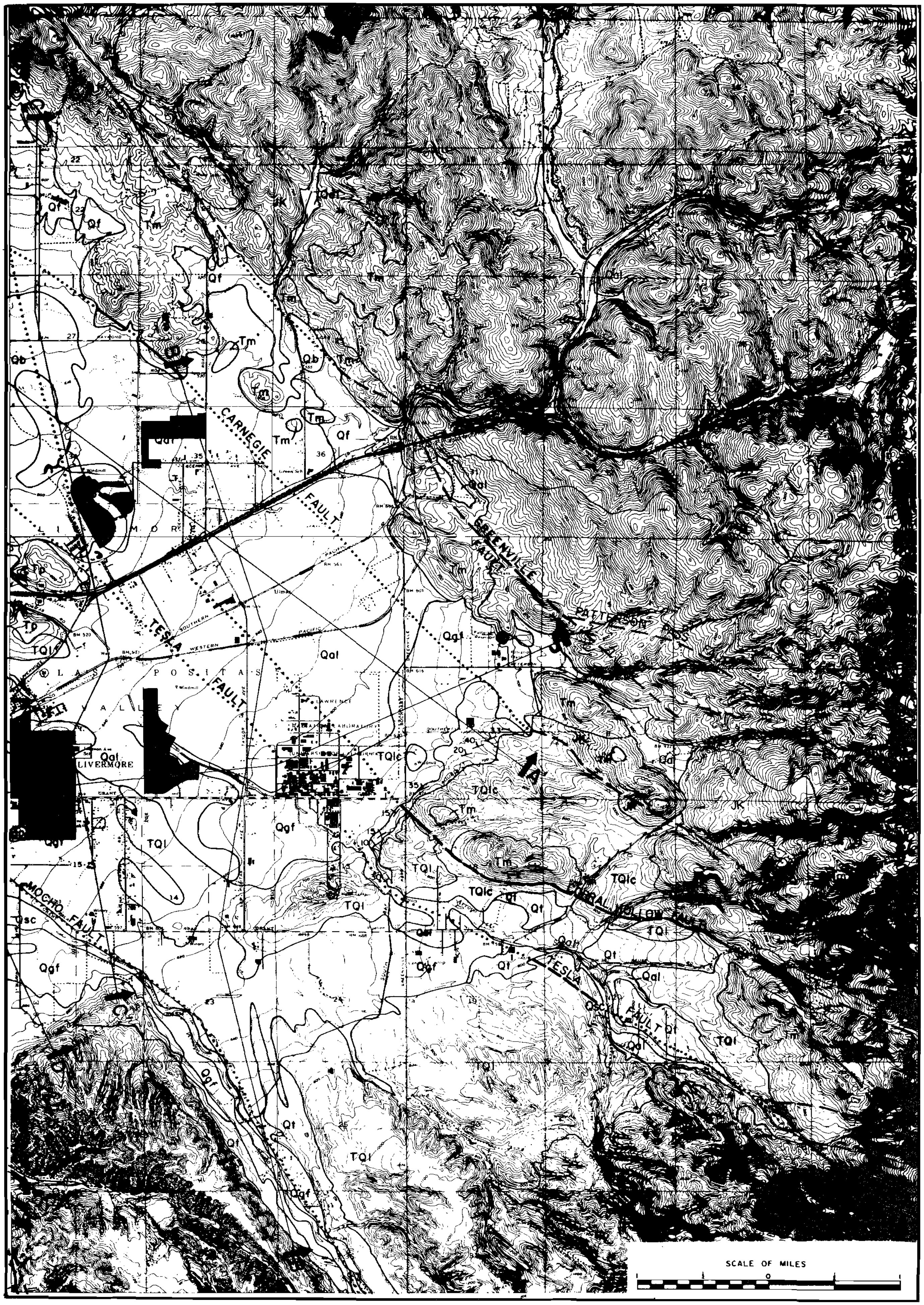
EVALUATION OF GROUND WATER RESOURCES
IN LIVERMORE — SUNOL VALLEYS

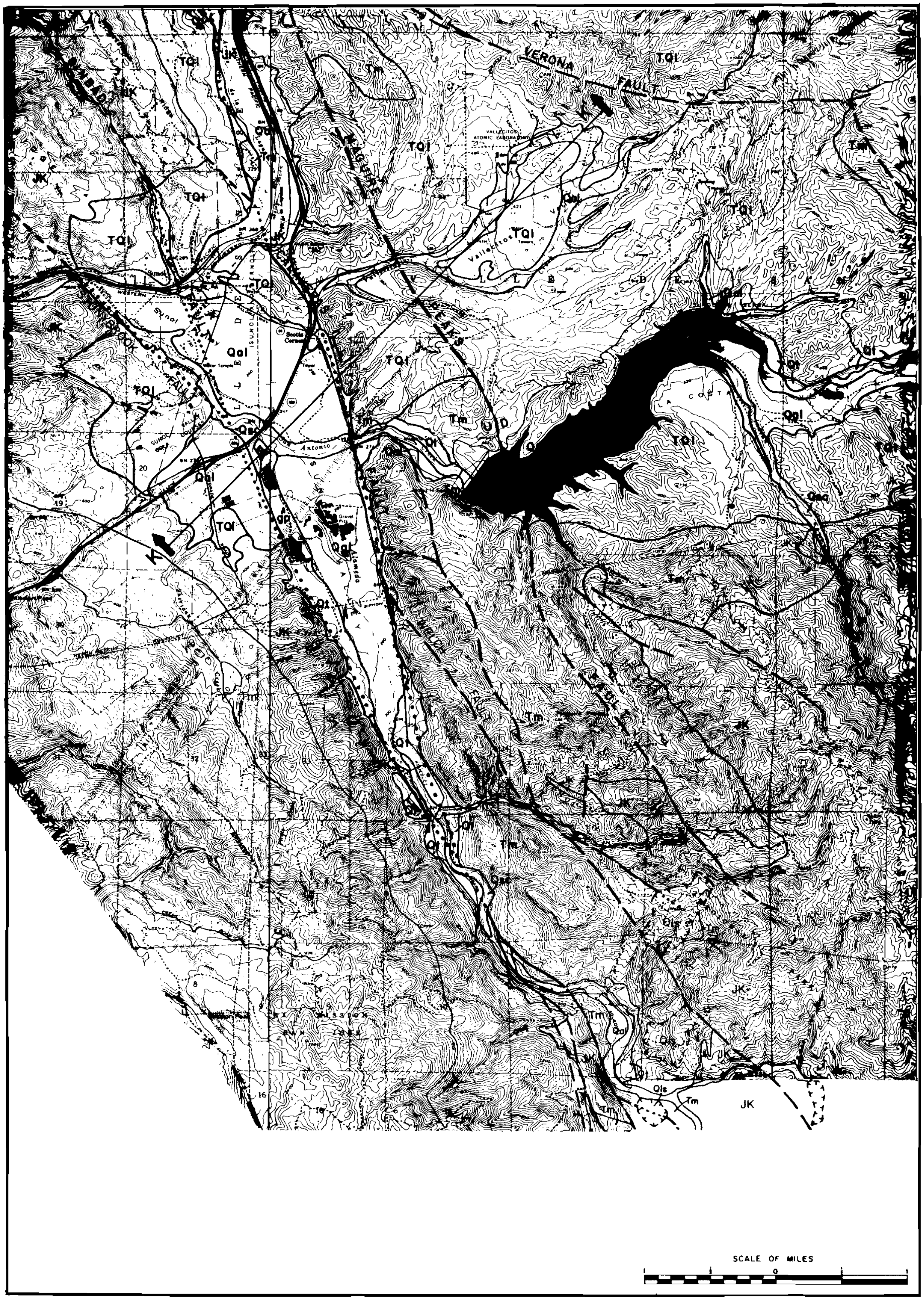
AREAL GEOLOGY

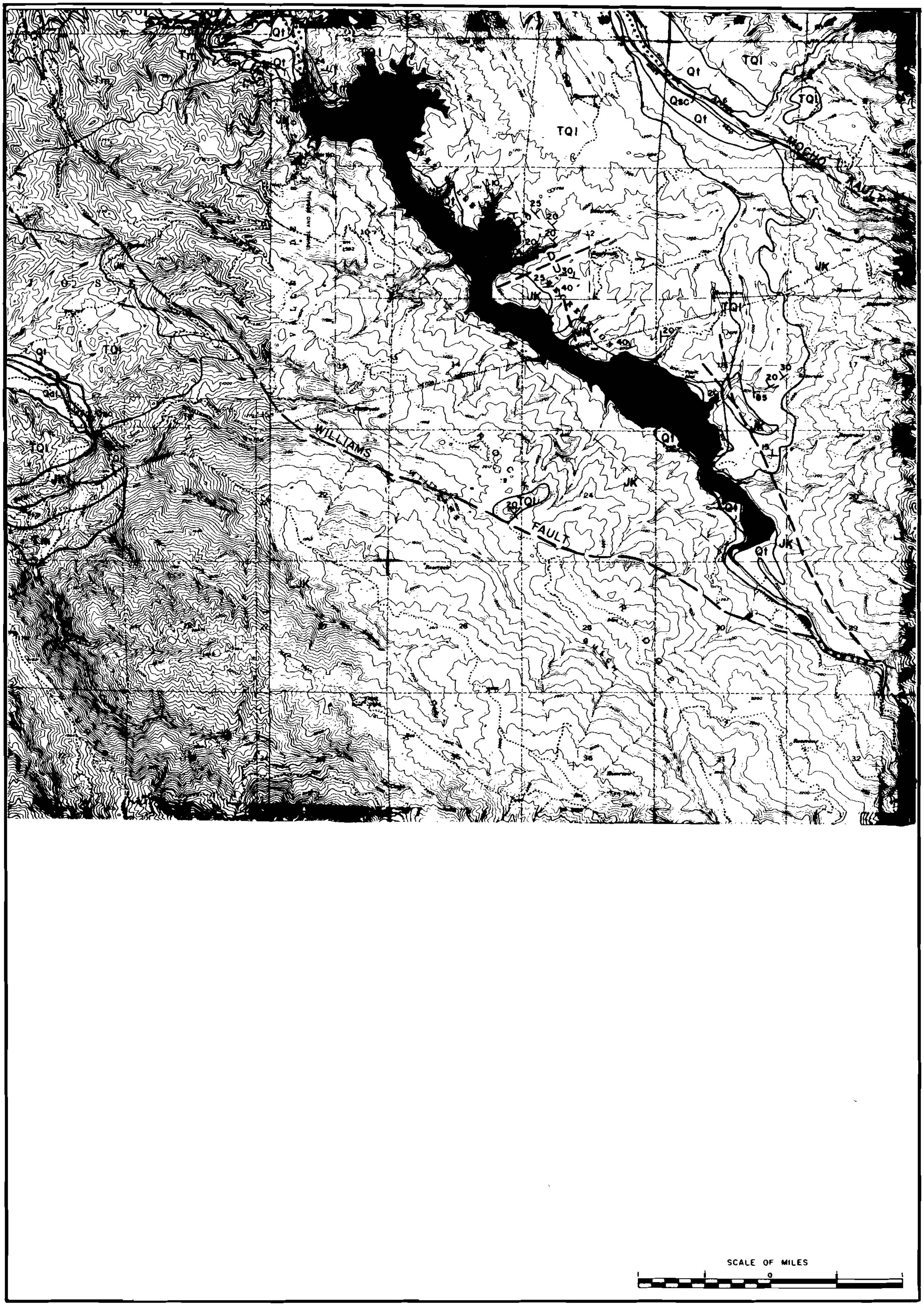

SCALE OF MILES
1
0
1
DUBLIN
GRAVEL PIT FAULT
CALAVERAS
PARKS
FAULT
Tp
Tm
Qal
Qf
Qb
San Ramon Village

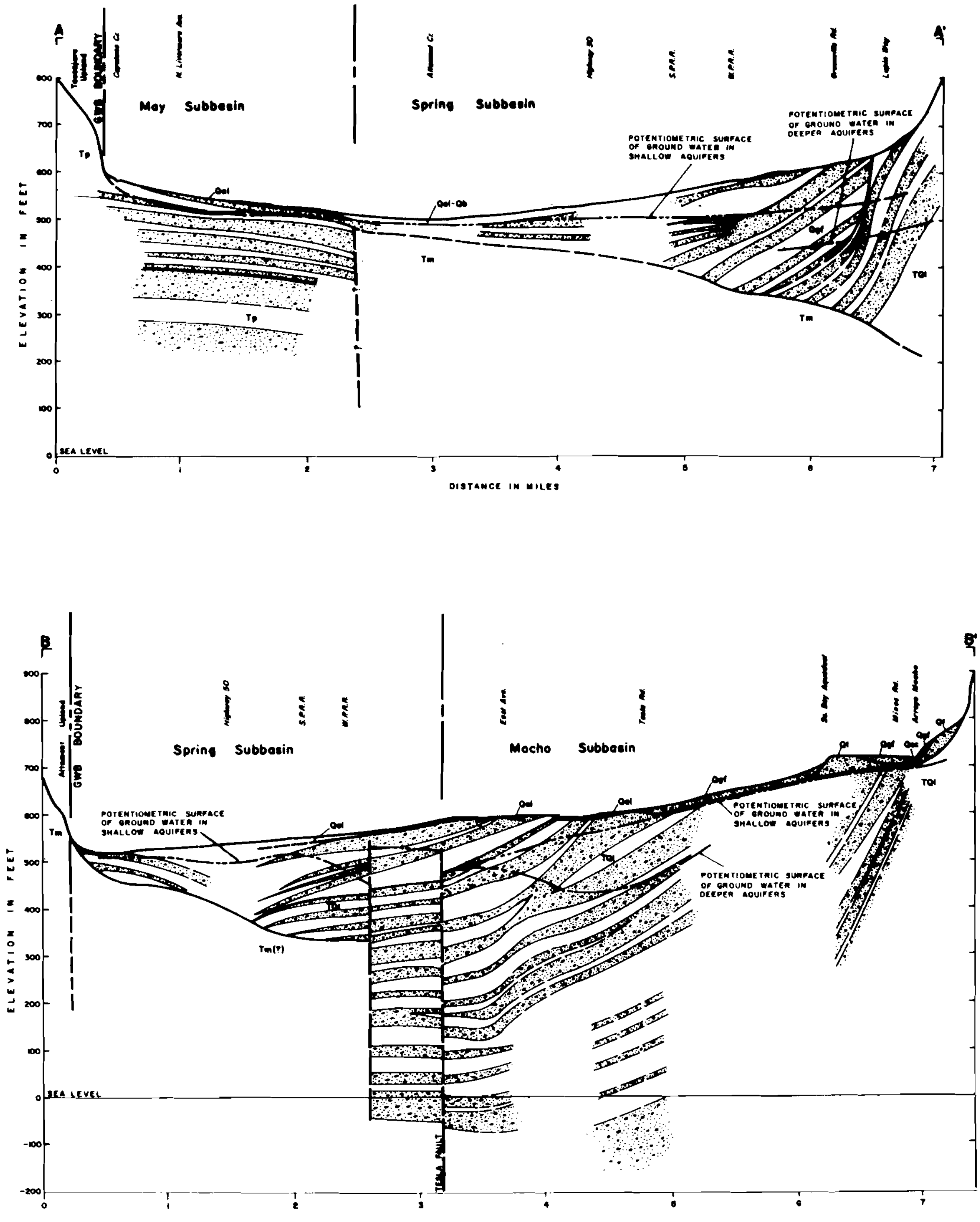

CARNEGIE FAULT
MOCHO FAULT
PARKS FAULT
PLEASANTON FAULT
SANTA RITA
AMADOR VALLEY
LIVERMORE VALLEY
VALLE DE SAN JOSE
LAS POSITAS
SCALE OF MILES
Tp
Qf
Qal
Qb
Qsc
QTb
Qgf
TQl
gp
Qls
Tm

Sheet 3 of 5 FIGURE 4




VERONA FAULT
TQl
Tm
JK
Qal
VALLECITOS ATOMIC LABORATORY
Sunol
Scotts Corner
Antonio
LA COSTA
Qls
SCALE OF MILES
0
1

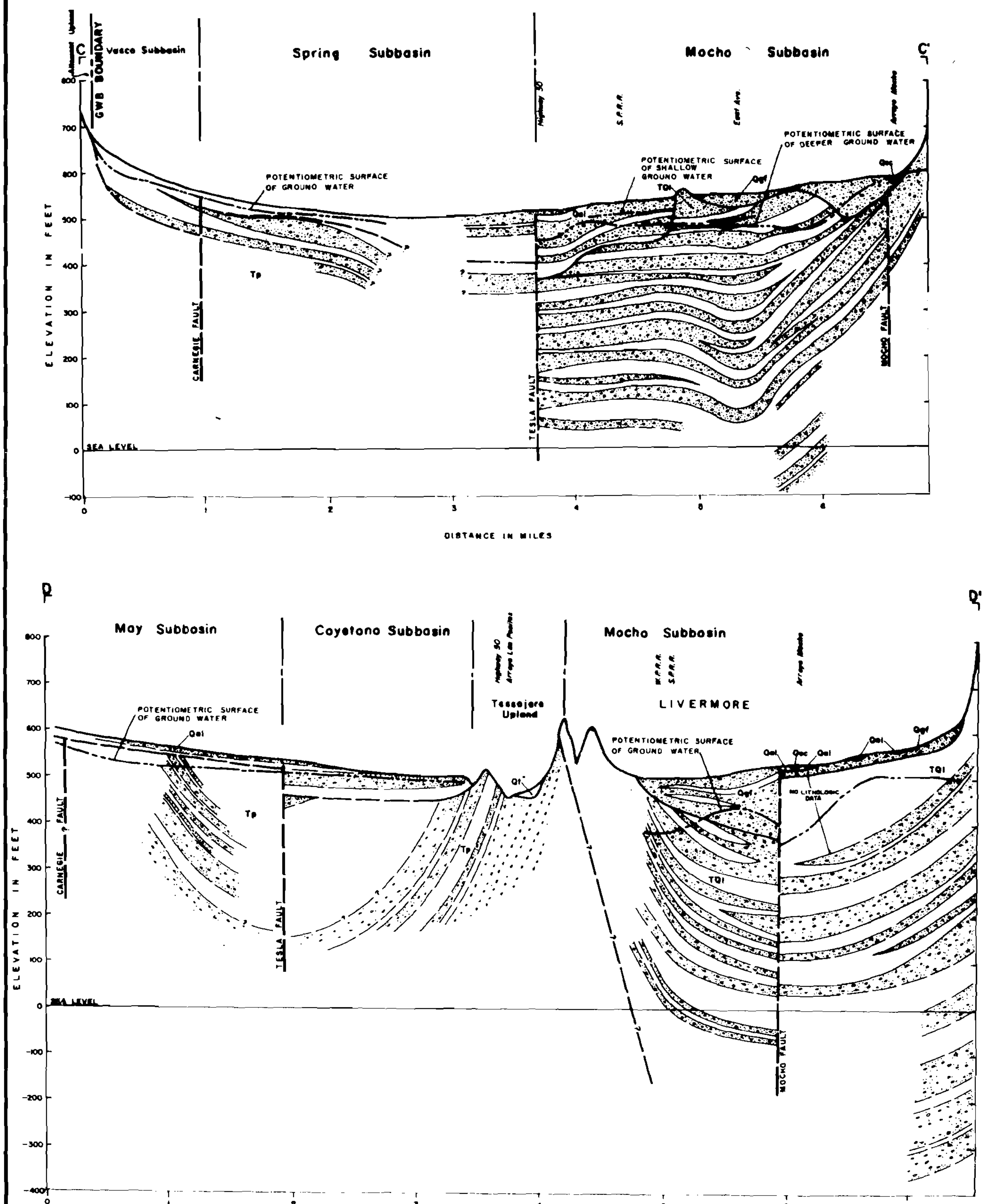

TQl
Qt
Qsc
JK
Tm
Qal
WILLIAMS
FAULT
D
U
SCALE OF MILES
1
0
1



For location of sections, see Fig. 4

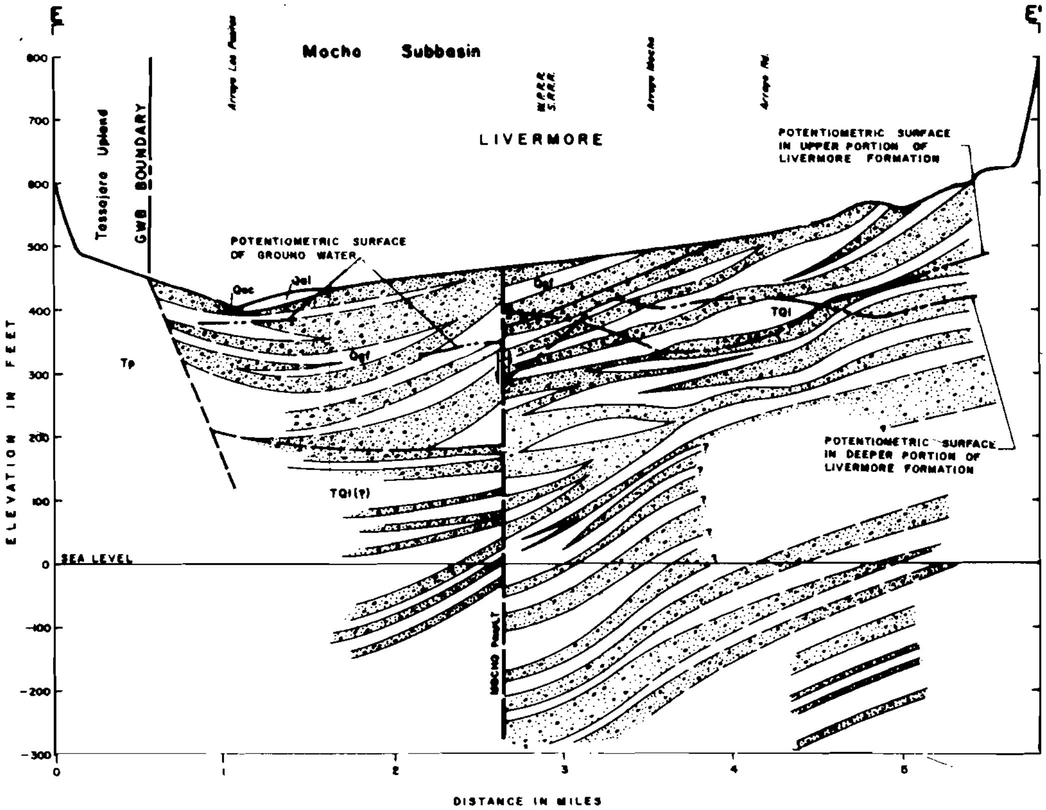
For legend, see Fig. 5, Sheet 6

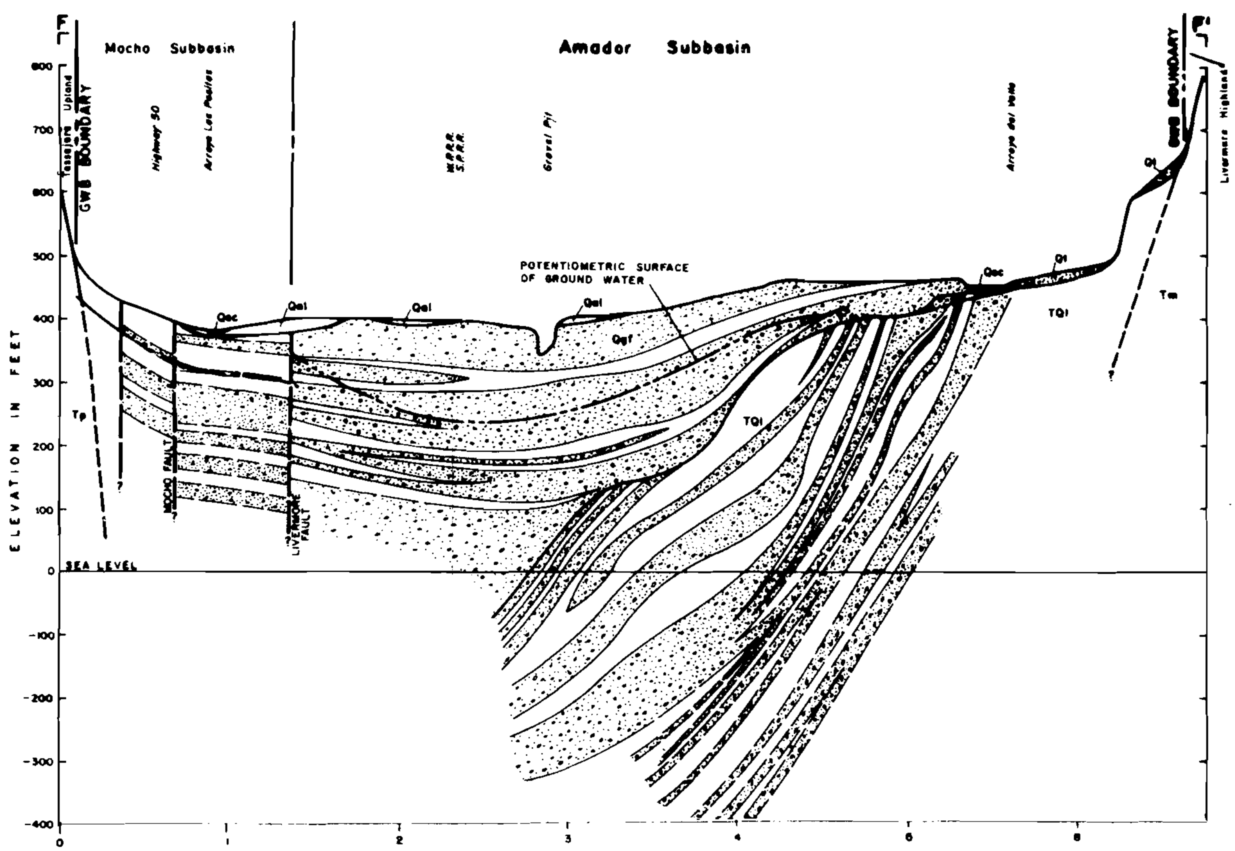
GEOLOGIC SECTIONS - LIVERMORE VALLEY



For location of sections, see Fig. 4, Shts. 2&3
For legend, see Fig. 5, Sheet 6

GEOLOGIC SECTIONS - LIVERMORE VALLEY

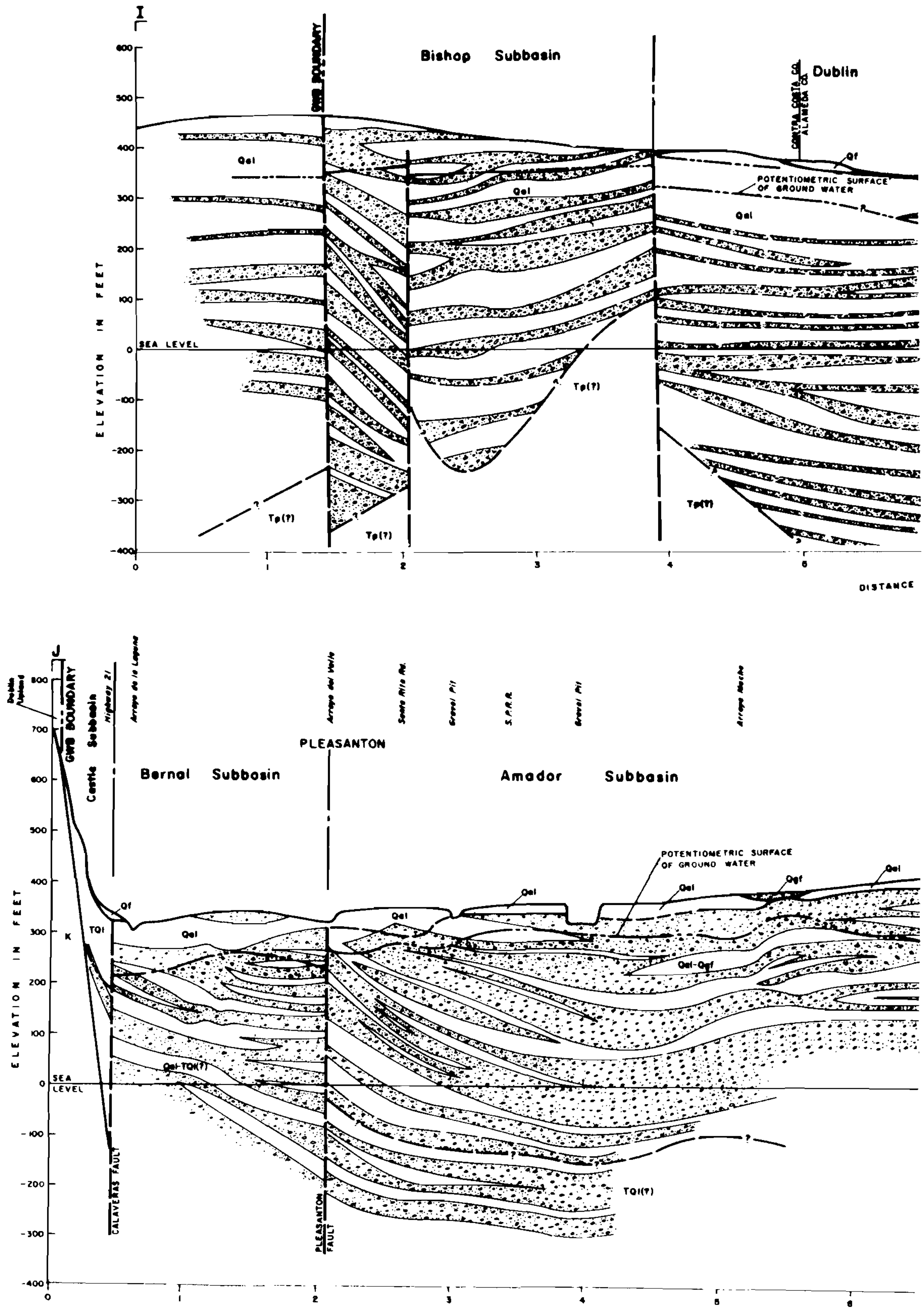




For location of sections, see Fig. 4, Sheet 2

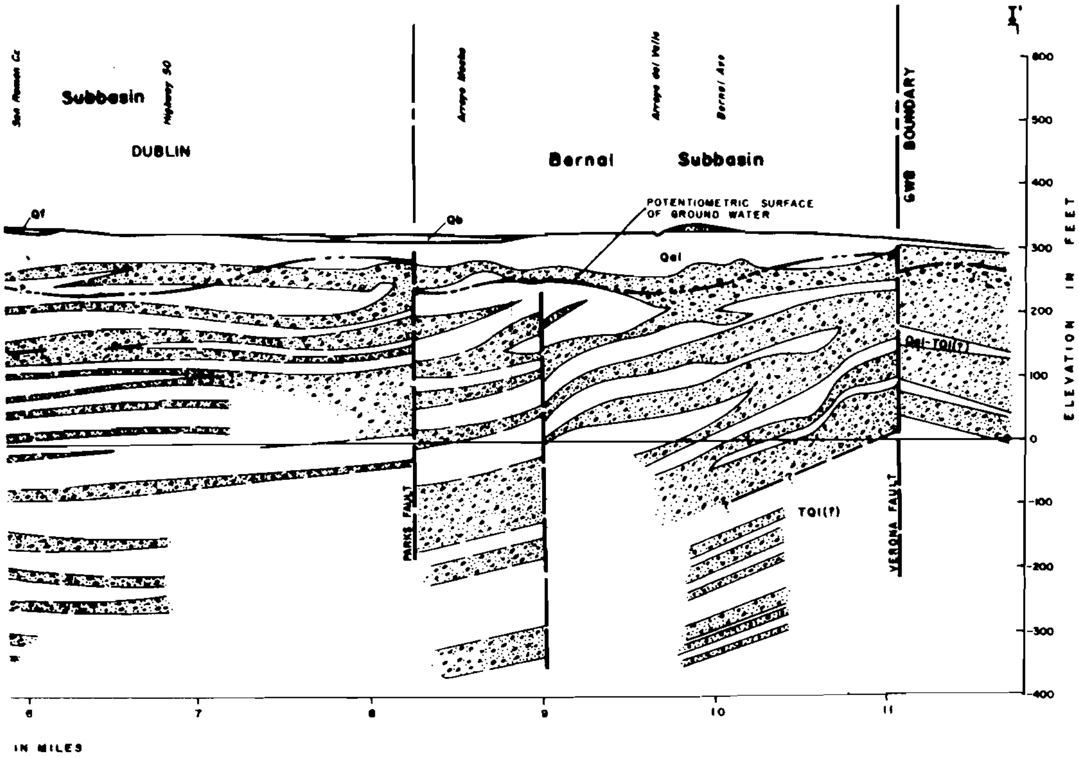
For legend, see Fig. 5, Sheet 6

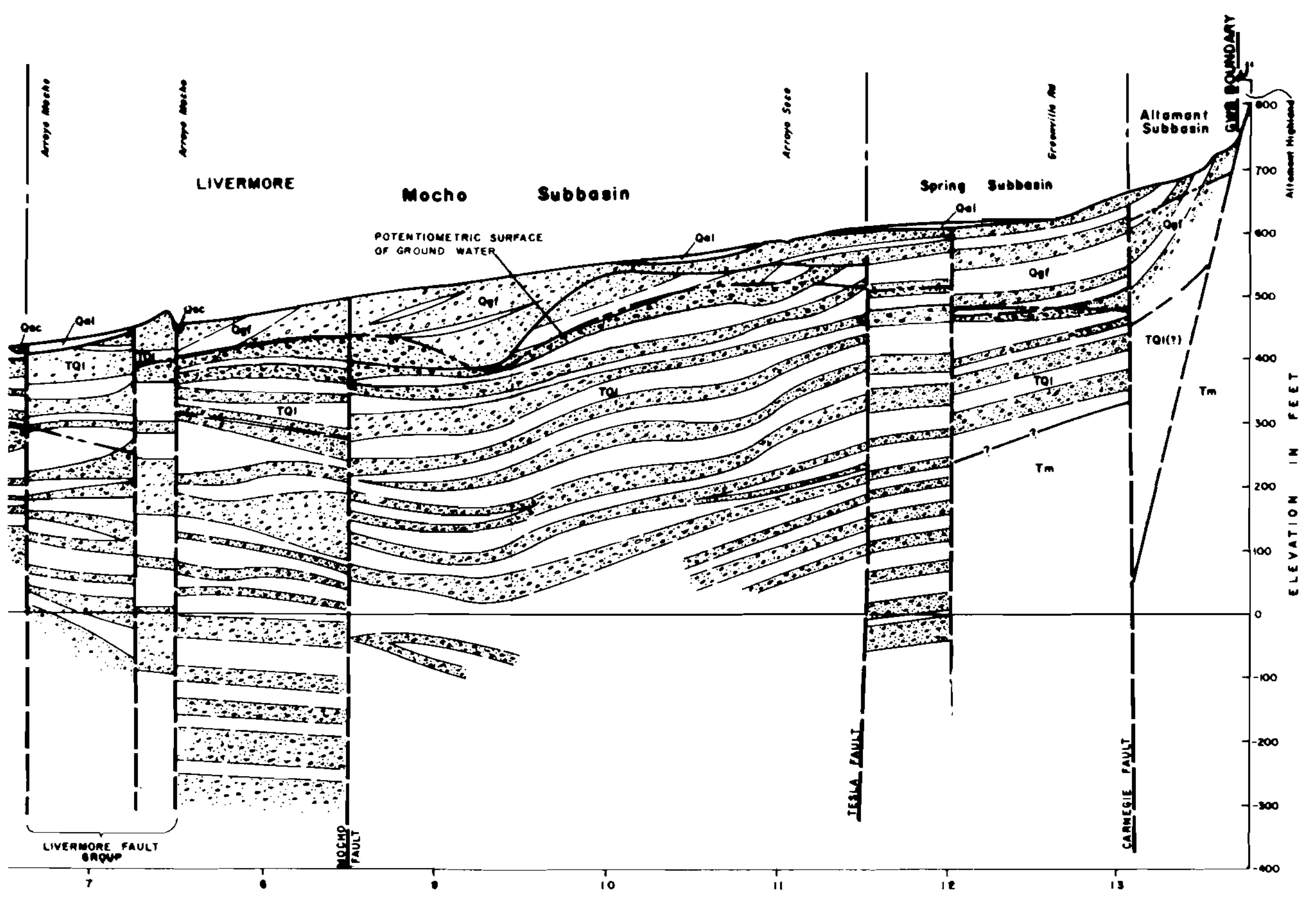
GEOLOGIC SECTIONS - LIVERMORE VALLEY



For location of sections, see Fig. 4, Shts. 1, 2 & 3
For legend, see Fig. 5, Sheet 6

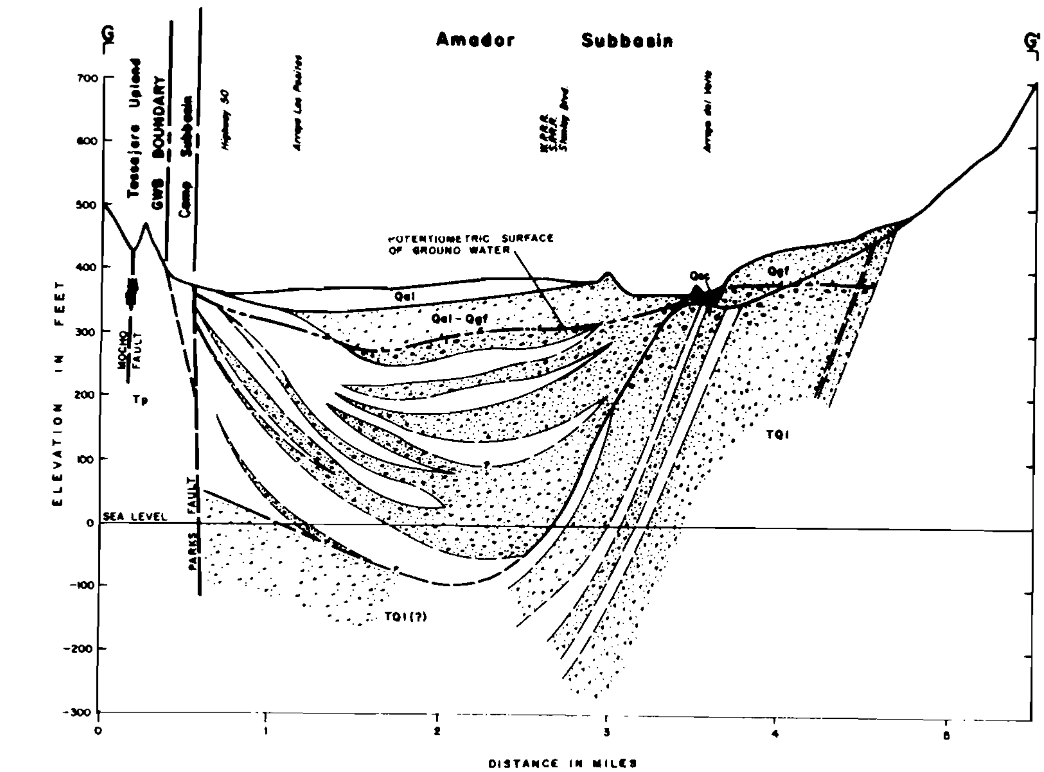
GEOLOGIC SECTIONS

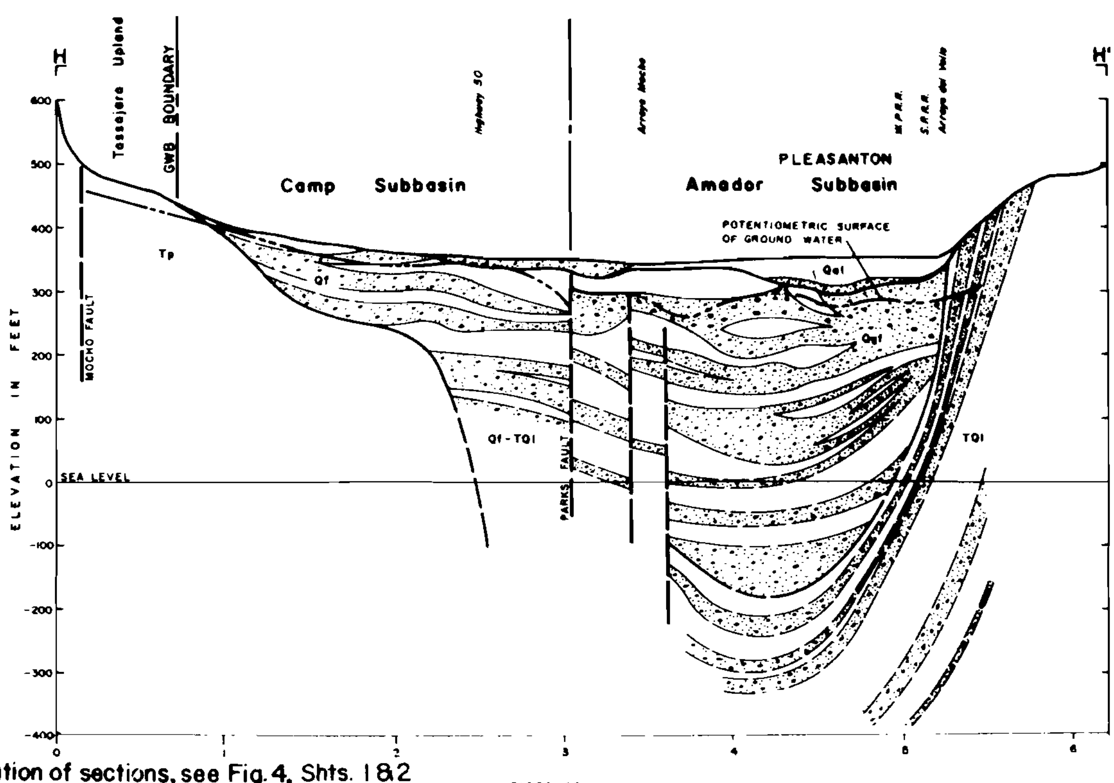




LIVERMORE VALLEY

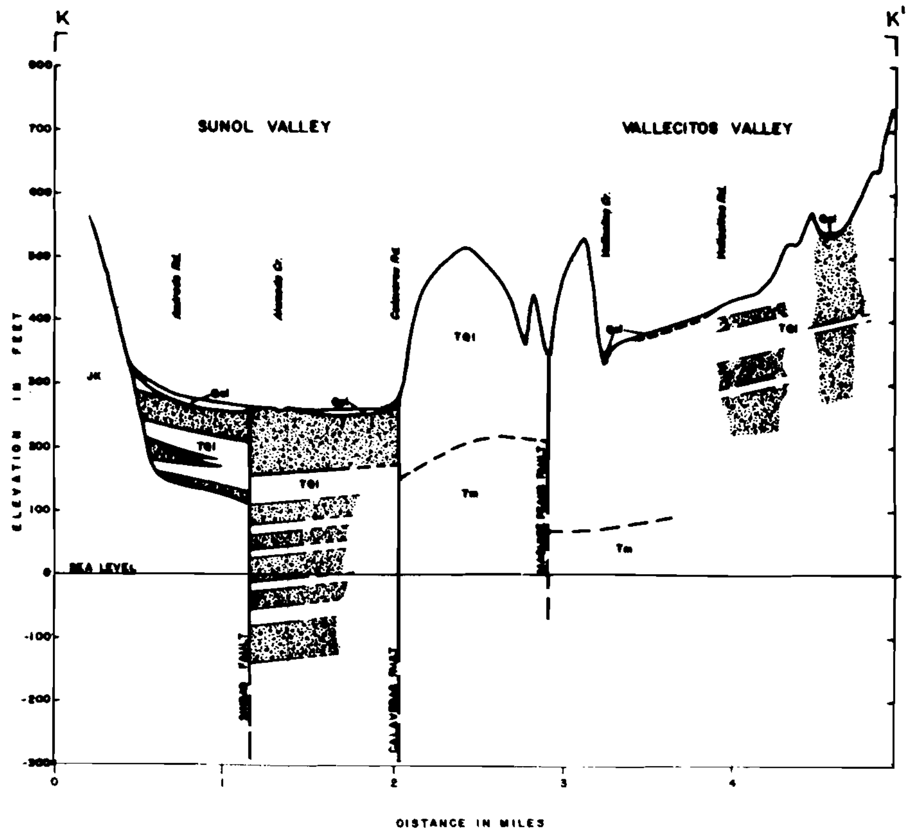
FIGURE 5





For location of sections, see Fig. 4, Shts. 1 & 2
For legend, see Fig. 5, Sheet 6

GEOLOGIC SECTIONS - LIVERMORE VALLEY



LEGEND

WATER BEARING MATERIALS

POTENTIOMETRIC SURFACE

SUBBASIN BOUNDARY

GWB GROUND WATER BASIN BOUNDARY

FOR GEOLOGIC SYMBOLS SEE PLATE 5

For location of section, see Fig.4

GEOLOGIC SECTION - SUNOL VALLEY

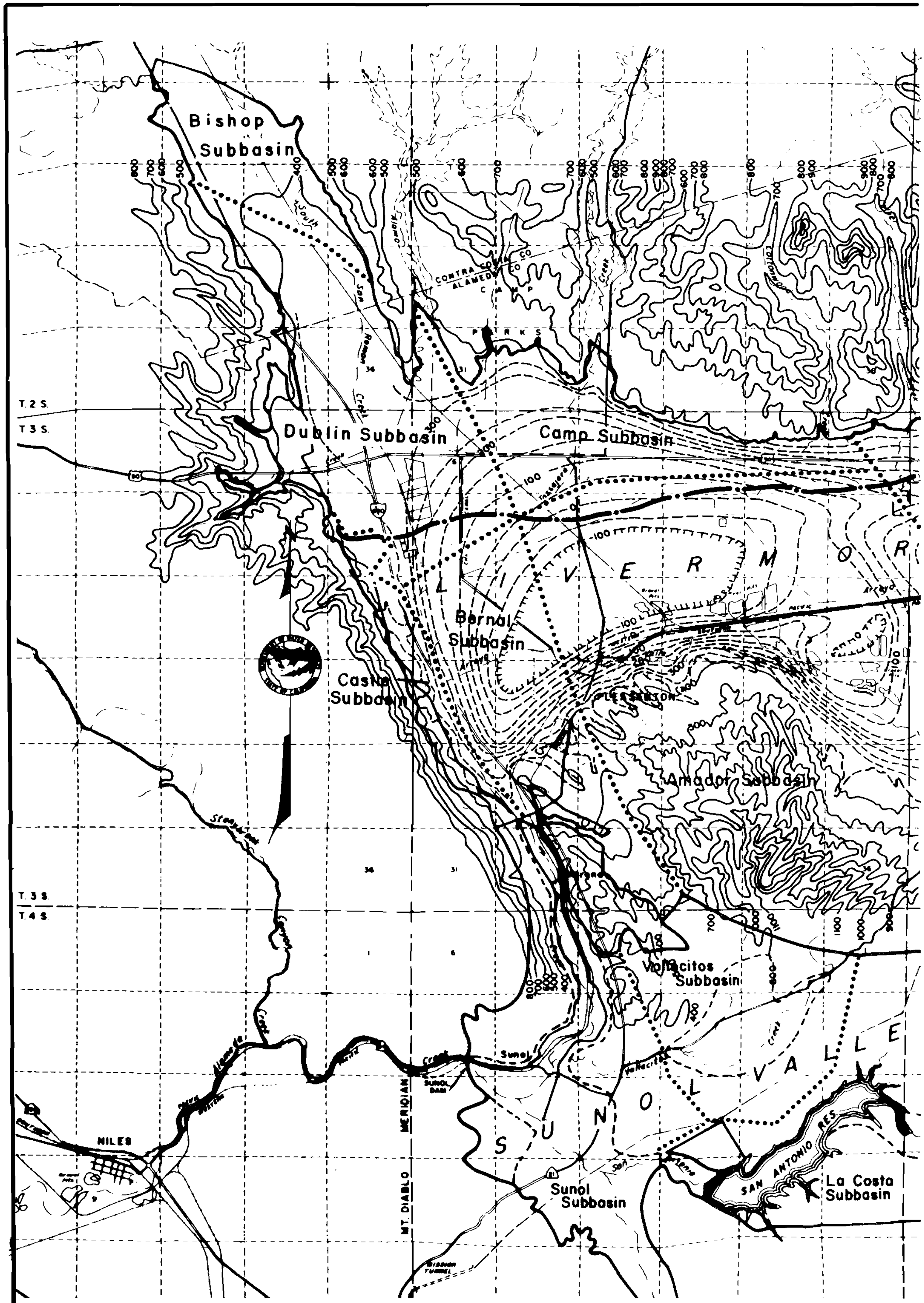
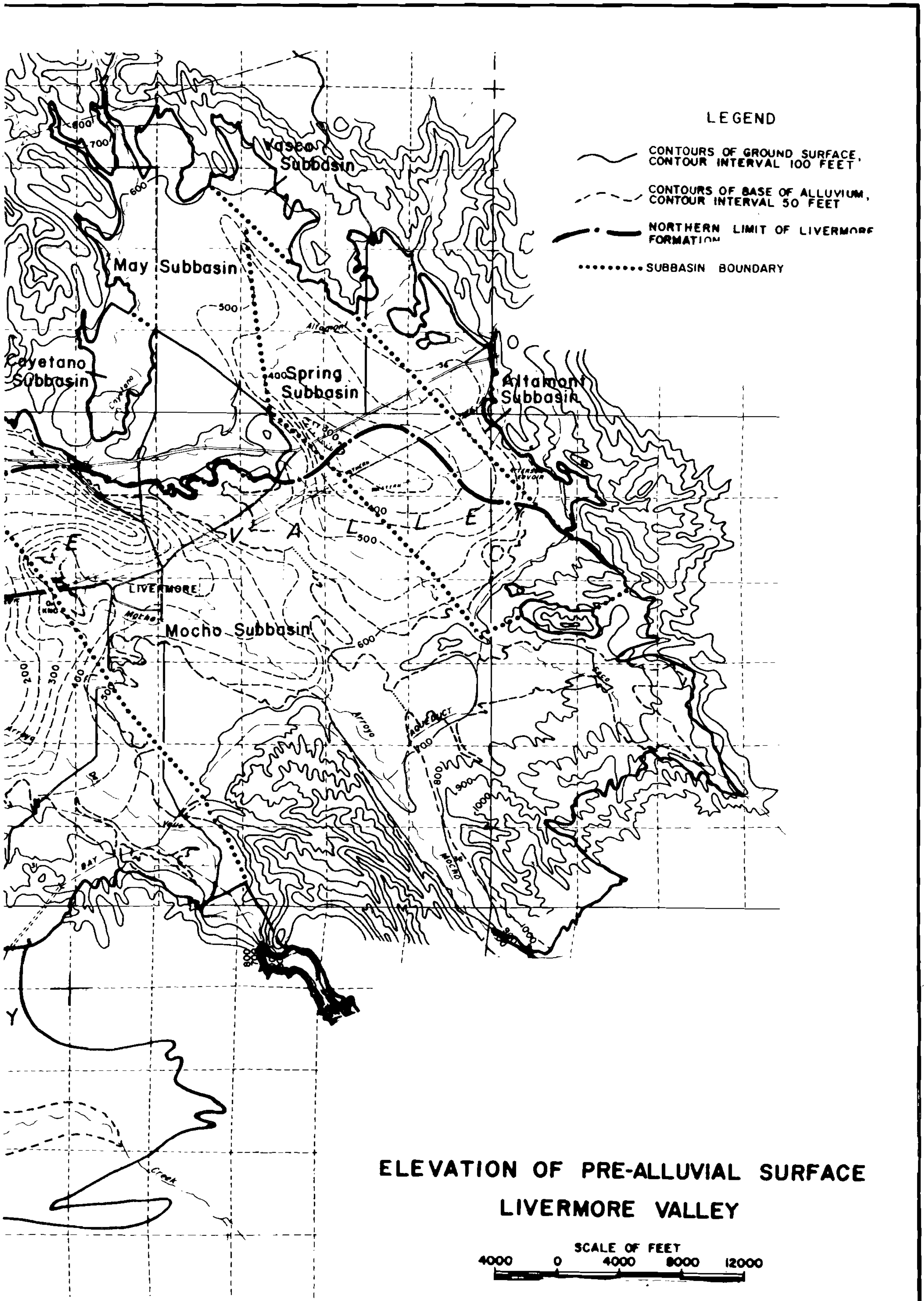

Bishop Subbasin
Dublin Subbasin
Camp Subbasin
Bernal Subbasin
Castle Subbasin
Amador Subbasin
Vallecitos Subbasin
Sunol Subbasin
La Costa Subbasin
L I V E R M O R
S U N O L V A L L E
CONTRA COSTA CO
ALAMEDA CO
CAMP PARKS
PLEASANTON
NILES
SAN ANTONIO RES.
MT. DIABLO MERIDIAN
SUNOL DAM
T. 2 S.
T. 3 S.
T. 4 S.

FIGURE 6



ELEVATION OF PRE-ALLUVIAL SURFACE
LIVERMORE VALLEY

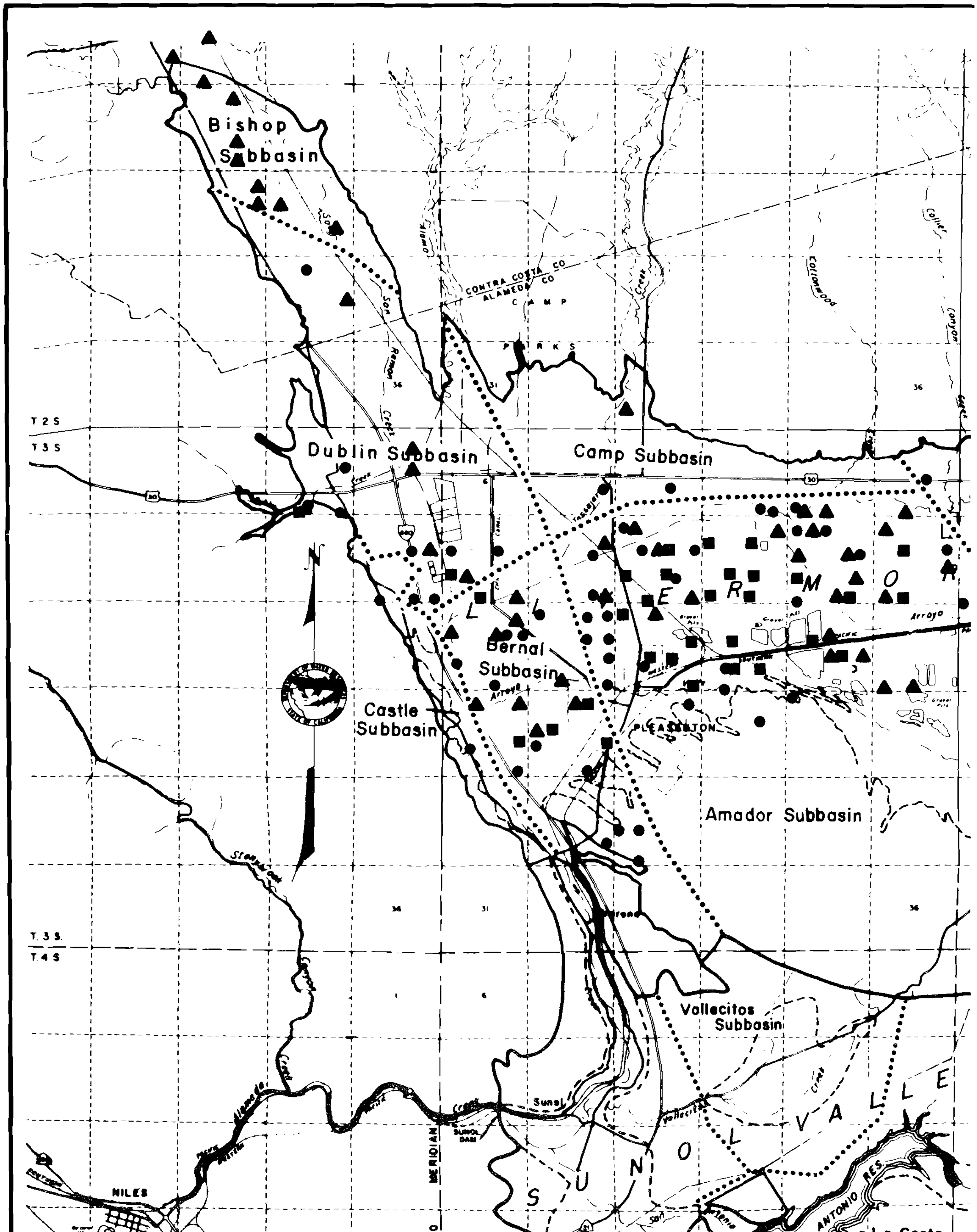
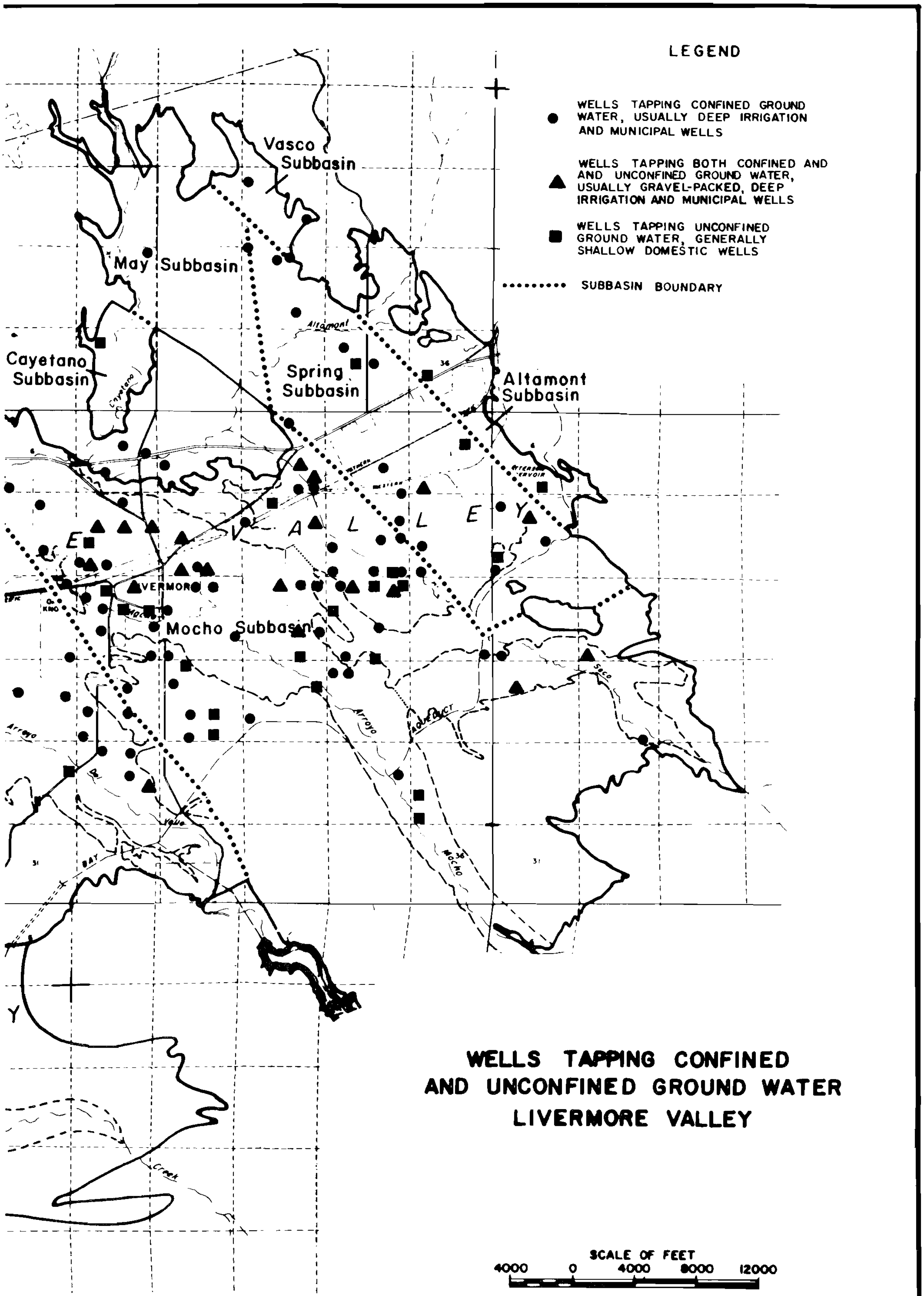
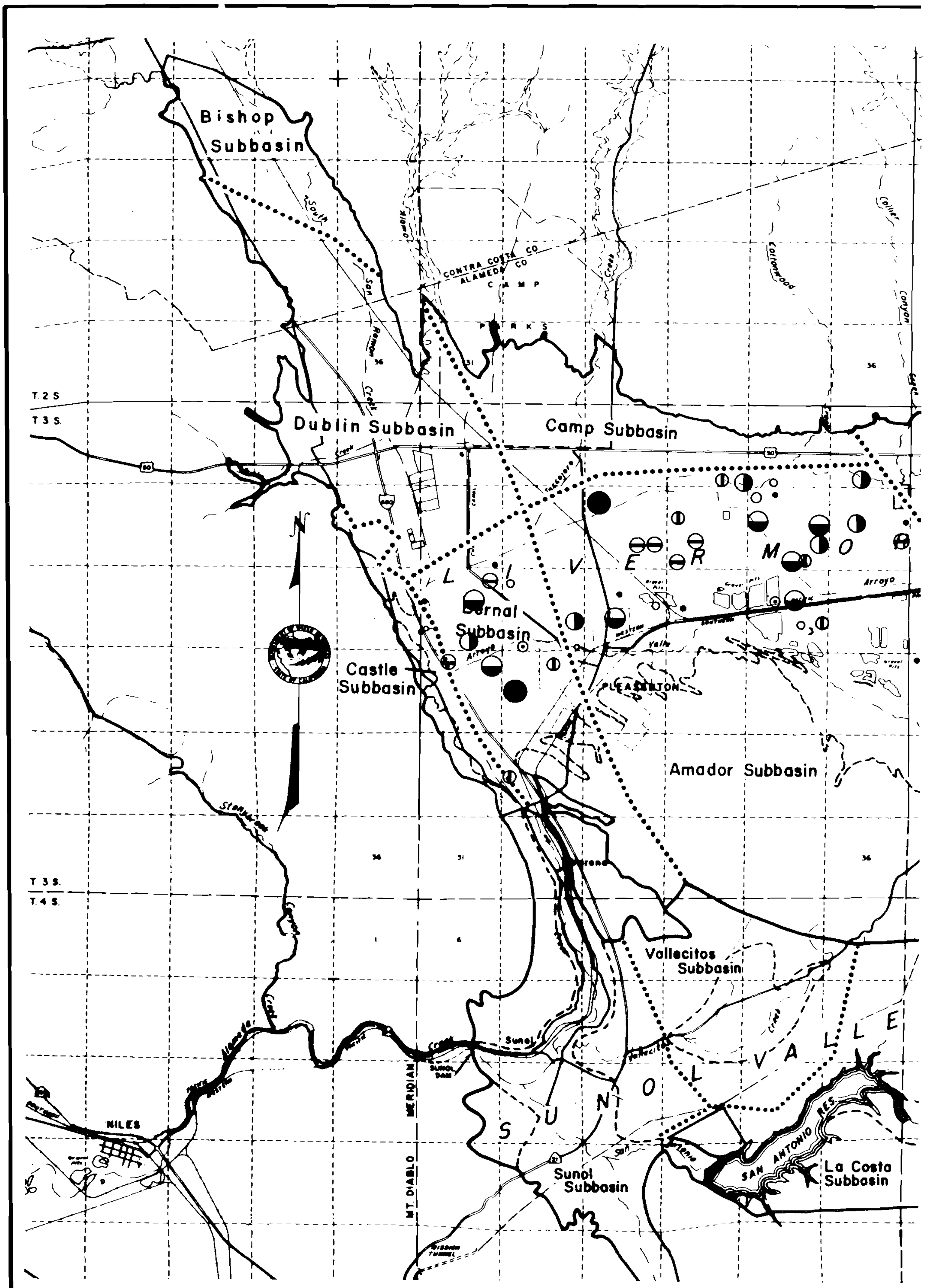
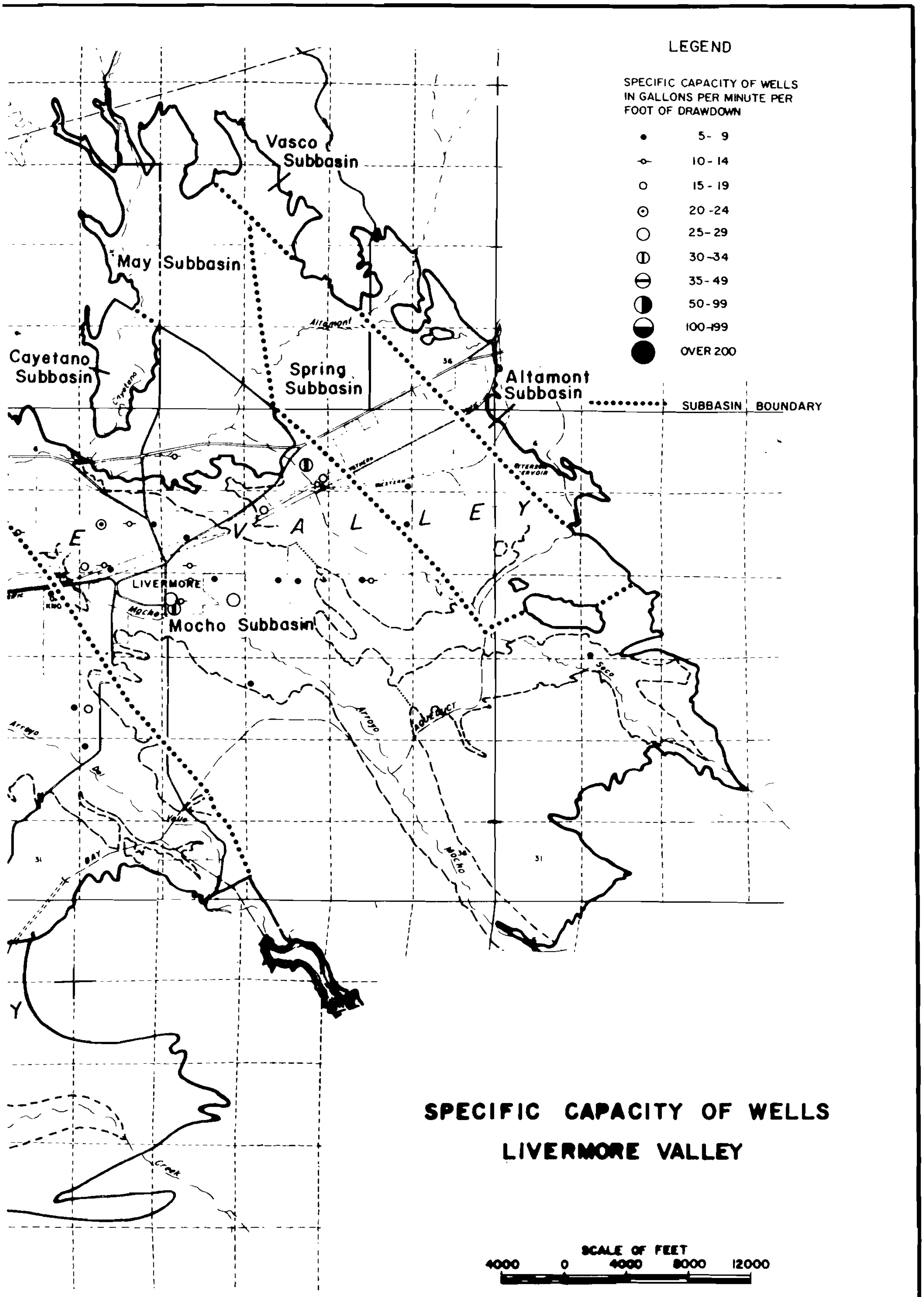

Bishop Subbasin
Dublin Subbasin
Camp Subbasin
Bernal Subbasin
Castle Subbasin
Amador Subbasin
Vallecitos Subbasin
Sunol Subbasin
La Costa Subbasin
CONTRA COSTA CO
ALAMEDA CO
CAMP PARKS
LIVERMORE
SUNOL VALLEY
PLEASANTON
SAN ANTONIO RES.
NILES
SUNOL DAM
MT. DIABLO MERIDIAN
T 2 S
T 3 S
T 4 S
Sunol
Arroyo
Cottonwood
Collier
Canyon
Creek

FIGURE 7

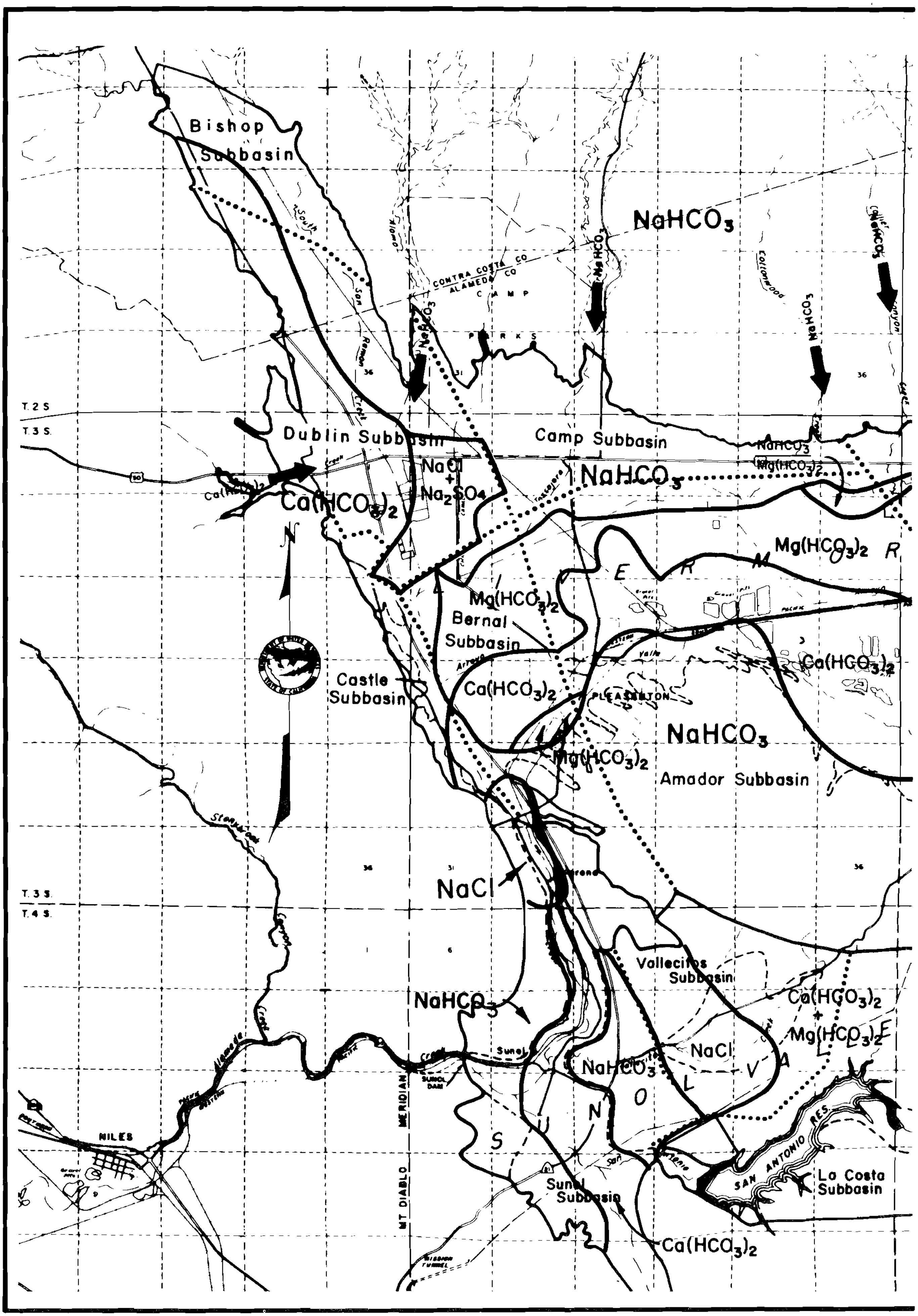


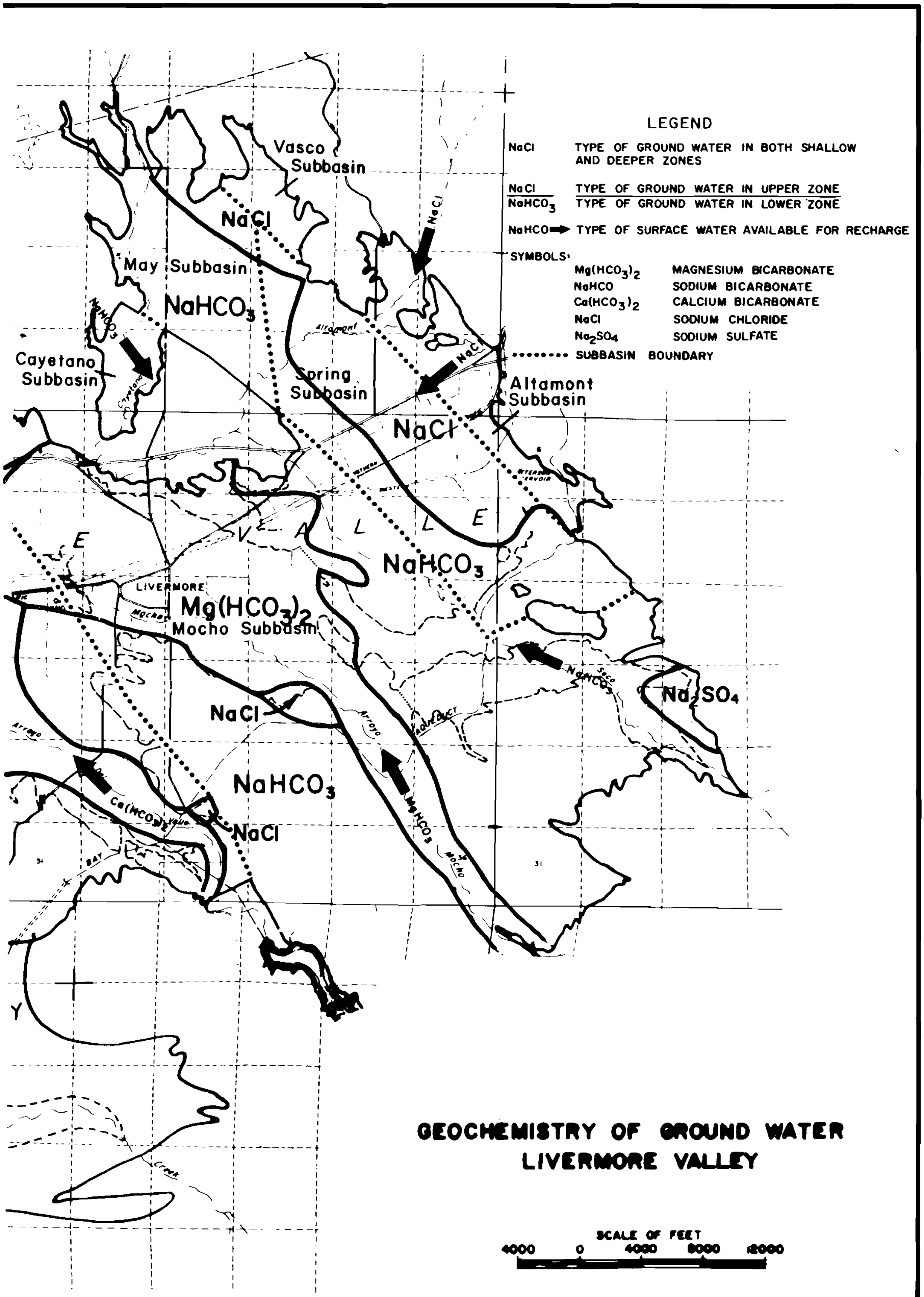
WELLS TAPPING CONFINED AND UNCONFINED GROUND WATER LIVERMORE VALLEY


Bishop Subbasin
Dublin Subbasin
Camp Subbasin
CONTRA COSTA CO
ALAMEDA CO
CAMP PARKS
T. 2 S.
T. 3 S.
T. 3 S.
T. 4 S.
LIVERMORE
Bernal Subbasin
Castle Subbasin
PLEASANTON
Amador Subbasin
Vallecitos Subbasin
SUNOL VALLEY
Sunol Subbasin
La Costa Subbasin
SAN ANTONIO RES.
NILES
MT. DIABLO MERIDIAN
SUNOL DAM
Arroyo
Valle
Sunol
Vallecitos

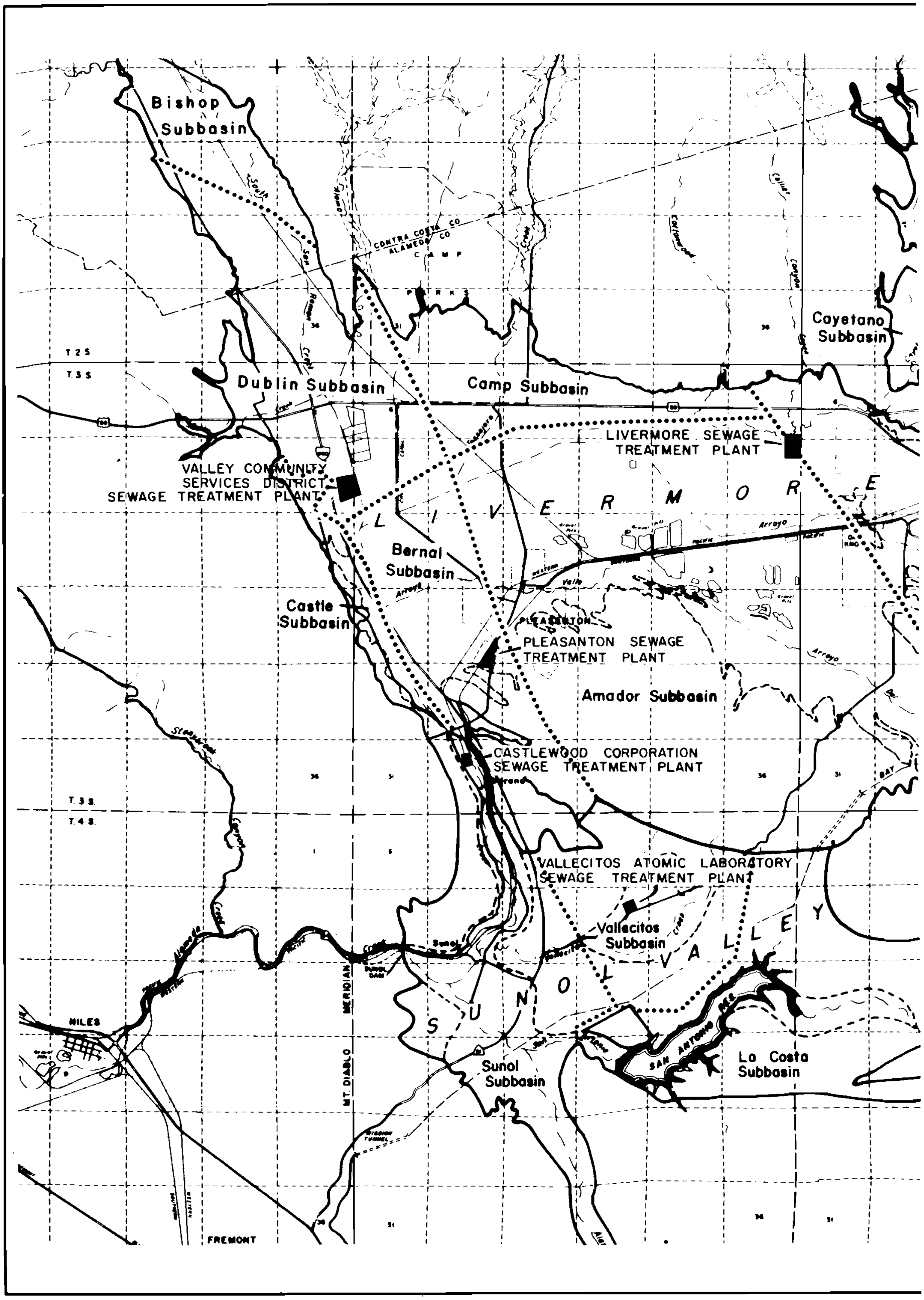


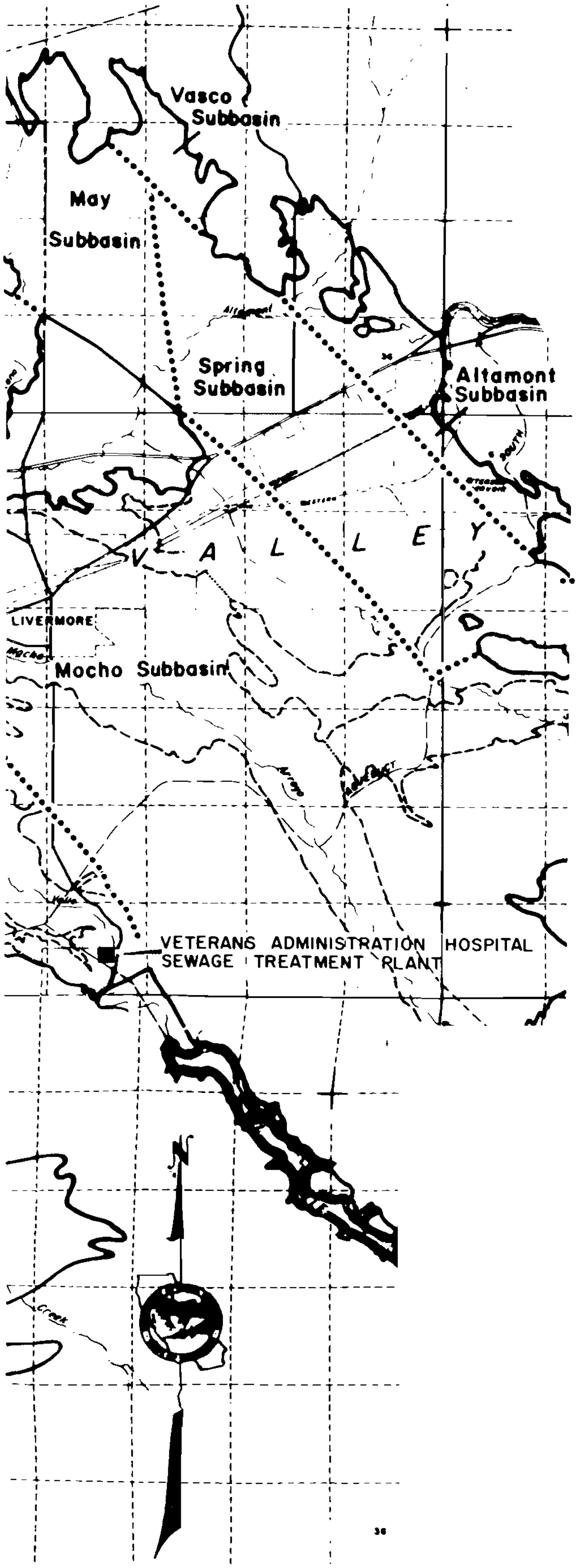
SPECIFIC CAPACITY OF WELLS
LIVERMORE VALLEY


Bishop Subbasin
NaHCO3
CONTRA COSTA CO
ALAMEDA CO
CAMP
PARKS
Dublin Subbasin
Camp Subbasin
NaCl + Na2SO4
NaHCO3
Ca(HCO3)2
Mg(HCO3)2
Bernal Subbasin
Castle Subbasin
Ca(HCO3)2
PLEASANTON
NaHCO3
Mg(HCO3)2
Amador Subbasin
LIVERMORE
T. 2 S.
T. 3 S.
T. 4 S.
NaCl
Vallecitos Subbasin
NaHCO3
Ca(HCO3)2 + Mg(HCO3)2
NaCl
NaHCO3
SUNOL VALLEY
NILES
MT DIABLO MERIDIAN
SAN ANTONIO RES.
La Costa Subbasin
Sunol Subbasin
Ca(HCO3)2



GEOCHEMISTRY OF GROUND WATER
LIVERMORE VALLEY


Bishop Subbasin
Dublin Subbasin
Camp Subbasin
Cayetano Subbasin
LIVERMORE SEWAGE TREATMENT PLANT
VALLEY COMMUNITY SERVICES DISTRICT SEWAGE TREATMENT PLANT
L I V E R M O R E
Bernal Subbasin
Castle Subbasin
PLEASANTON
PLEASANTON SEWAGE TREATMENT PLANT
Amador Subbasin
CASTLEWOOD CORPORATION SEWAGE TREATMENT PLANT
VALLECITOS ATOMIC LABORATORY SEWAGE TREATMENT PLANT
Vallecitos Subbasin
S U N O L V A L L E Y
Sunol Subbasin
La Costa Subbasin
SAN ANTONIO RES.
CONTRA COSTA CO
ALAMEDA CO
CAMP PARKS
T.2 S
T.3 S
T.3 S.
T.4 S.
MT. DIABLO MERIDIAN
NILES
FREMONT
SUNOL DAM



NOTES

1. CASTLEWOOD CORP. & V.A. HOSPITAL - EFFLUENT IS DISCHARGED TO PONDS FOR PERCOLATION AND EVAPORATION.
2. PLEASANTON - EFFLUENT IS USED FOR SPRINKLER IRRIGATION ON 90 ACRES OF PASTURE.
3. VALLECITOS ATOMIC LAB. - EFFLUENT IS DISCHARGED TO VALLECITOS CREEK.
4. VALLEY COMM. SERVICES DIST. - EFFLUENT IS DISCHARGED TO ALAMO CANAL, TRIBUTARY TO ARROYO DE LA LAGUNA.
5. LIVERMORE - MOST OF THE EFFLUENT IS DISCHARGED TO ARROYO LAS POSITAS, THE REMAINDER IS USED FOR IRRIGATION ON MUNICIPAL AIRPORT PROPERTIES, MUNICIPAL GOLF COURSE, AND NEARBY AGRICULTURAL LANDS.

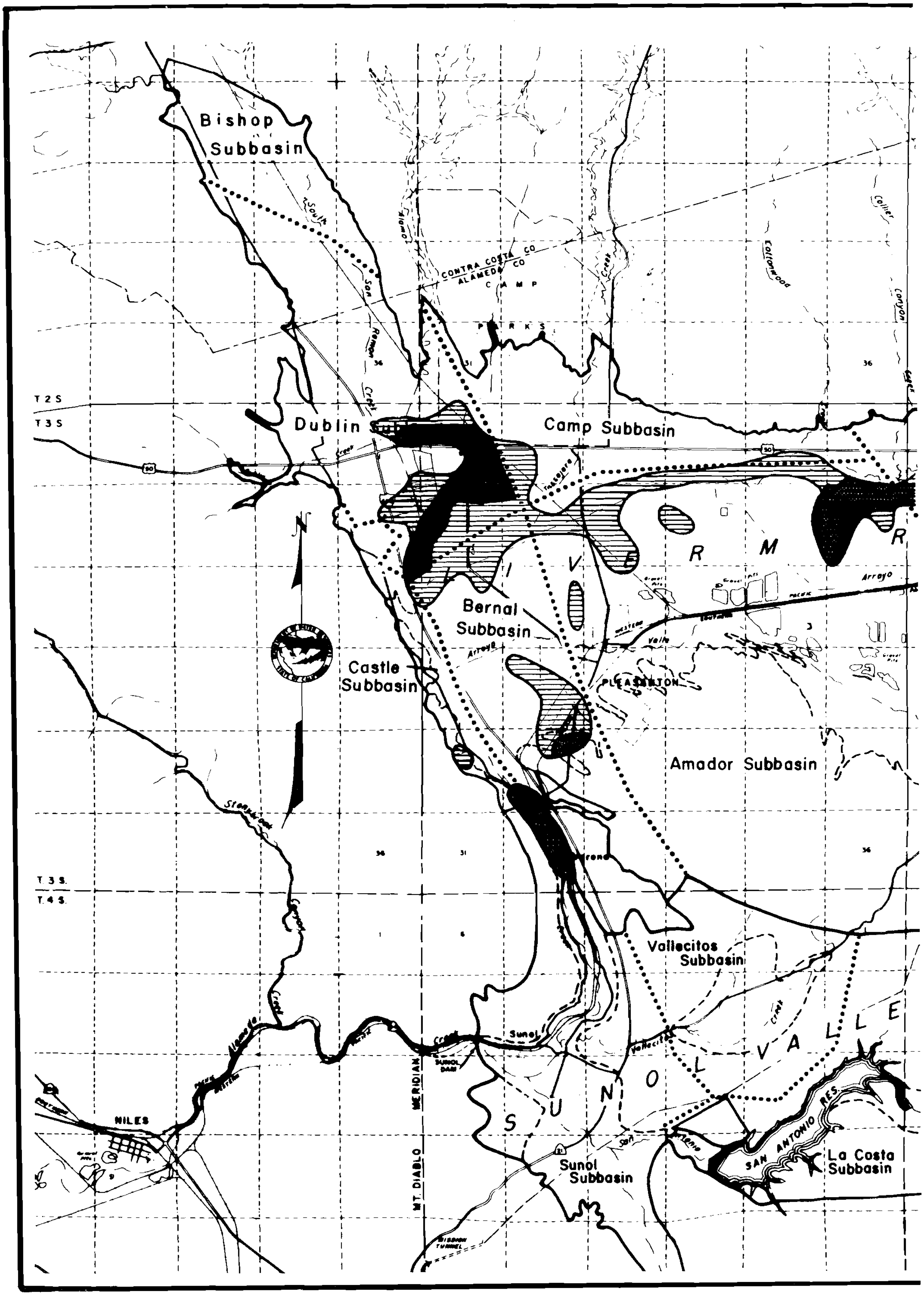
LEGEND

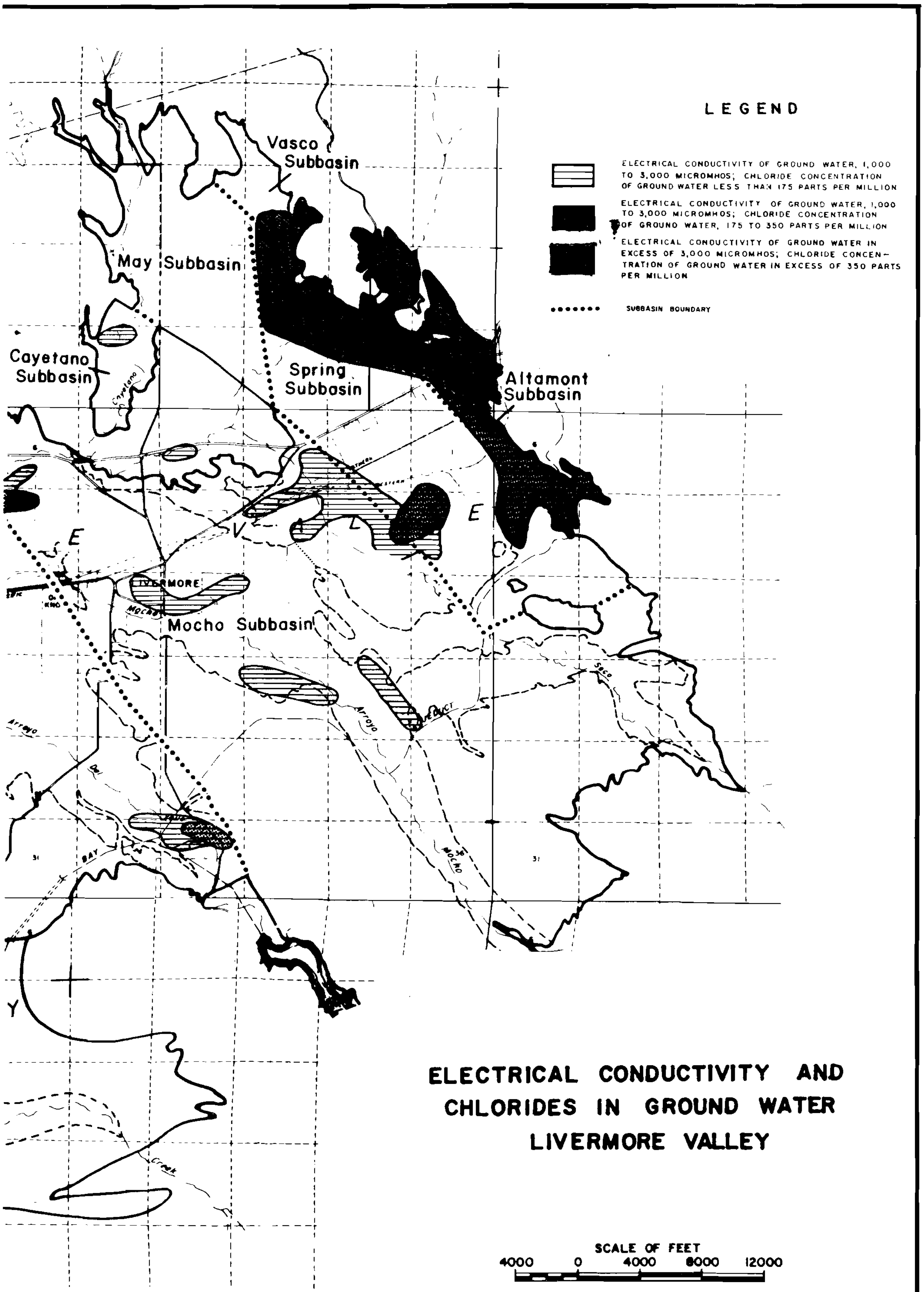
■ WASTE DISCHARGE LOCATION

••••••••• SUBBASIN BOUNDARY

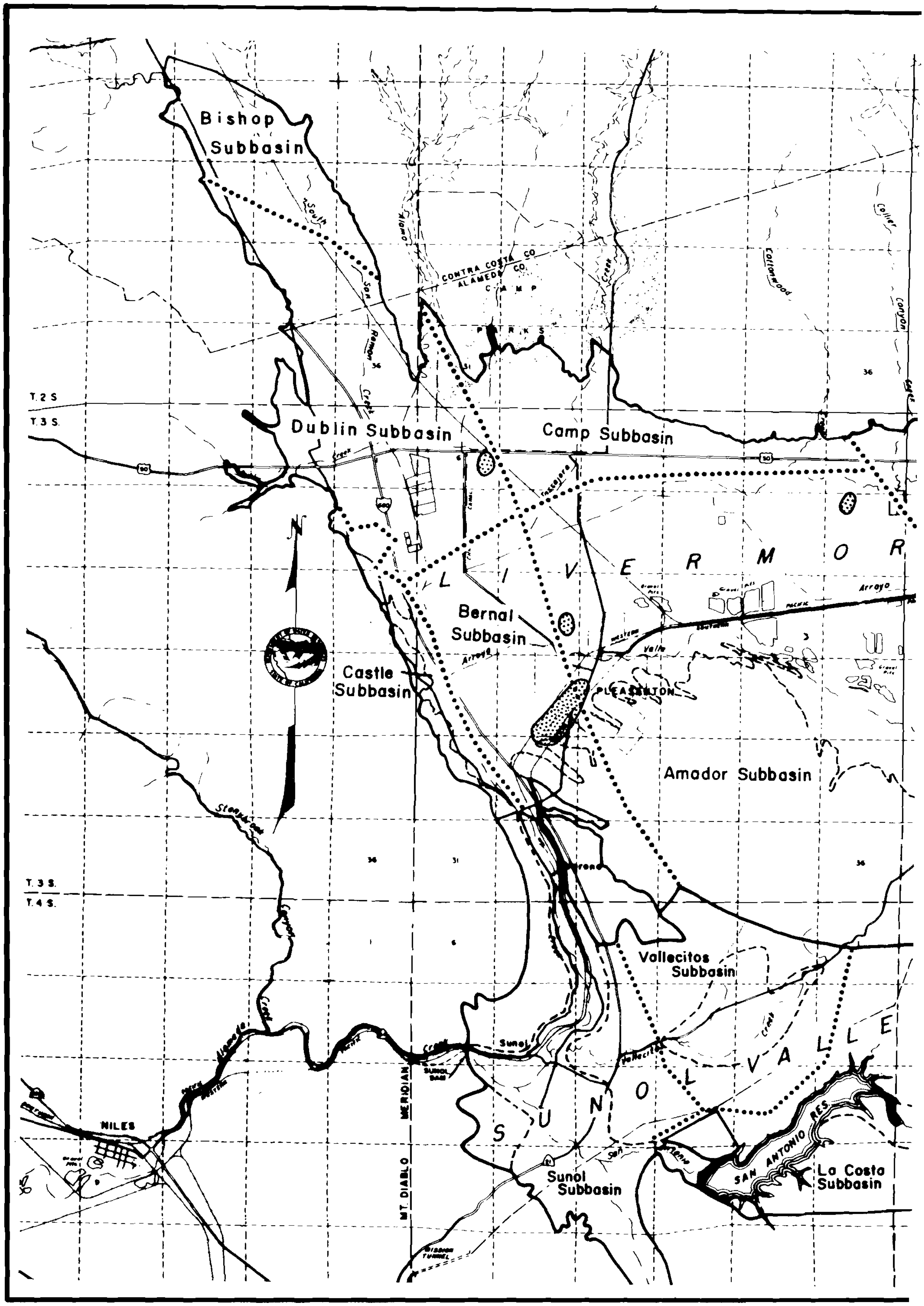
WASTE DISCHARGE LOCATIONS
LIVERMORE VALLEY

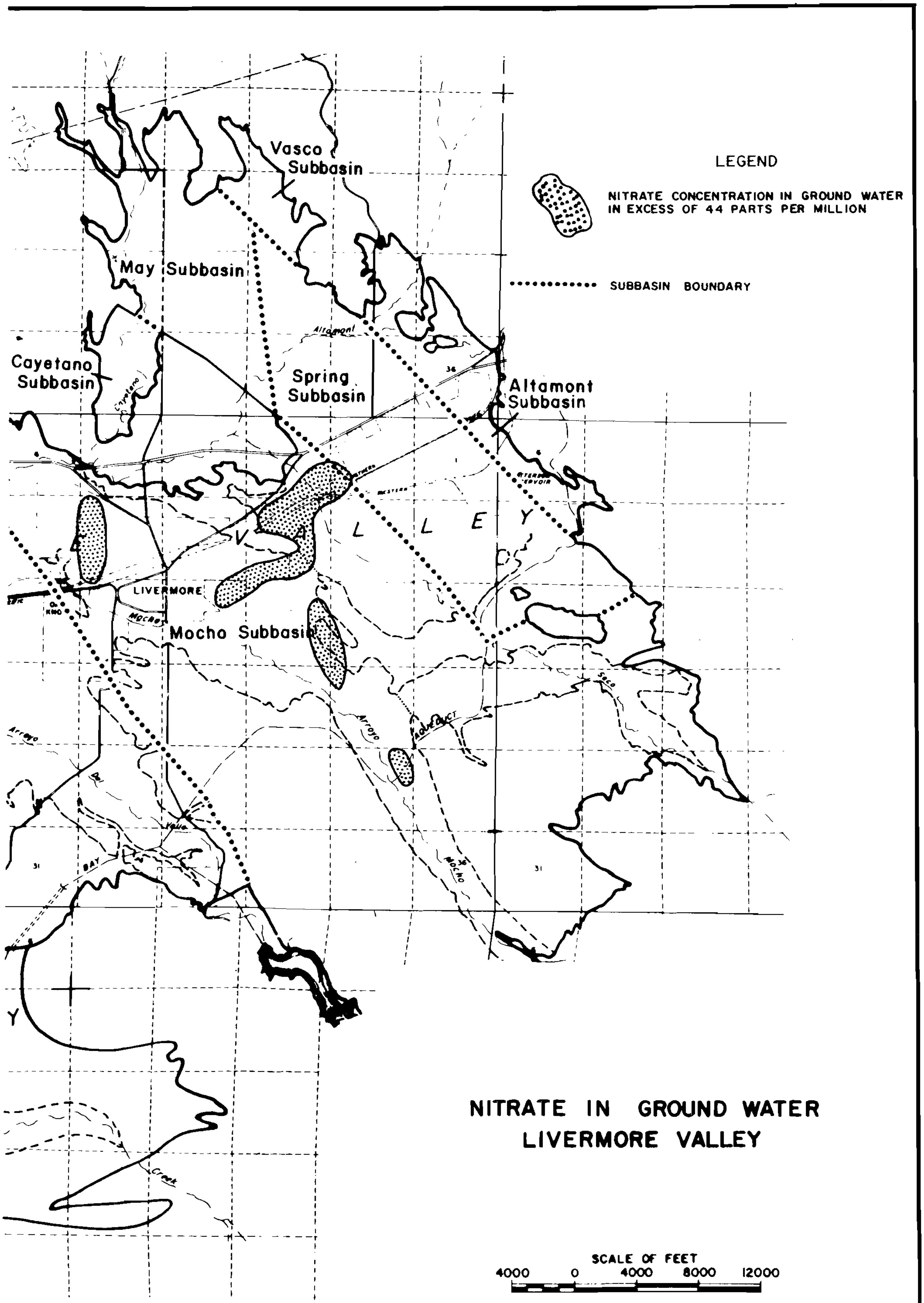
SCALE OF FEET
4000 0 4000 8000 12,000


Bishop
Subbasin
CONTRA COSTA CO
ALAMEDA CO
CAMP
PARKS
T 2 S
T 3 S
Dublin
Camp Subbasin
R
M
R
Bernal
Subbasin
Castle
Subbasin
PLEASANTON
Amador Subbasin
T 3 S
T 4 S
Vallecitos
Subbasin
Sunol
NILES
MERIDIAN
MT. DIABLO
S
U
N
O
L
V
A
L
L
E
SAN ANTONIO RES.
La Costa
Subbasin
Sunol
Subbasin

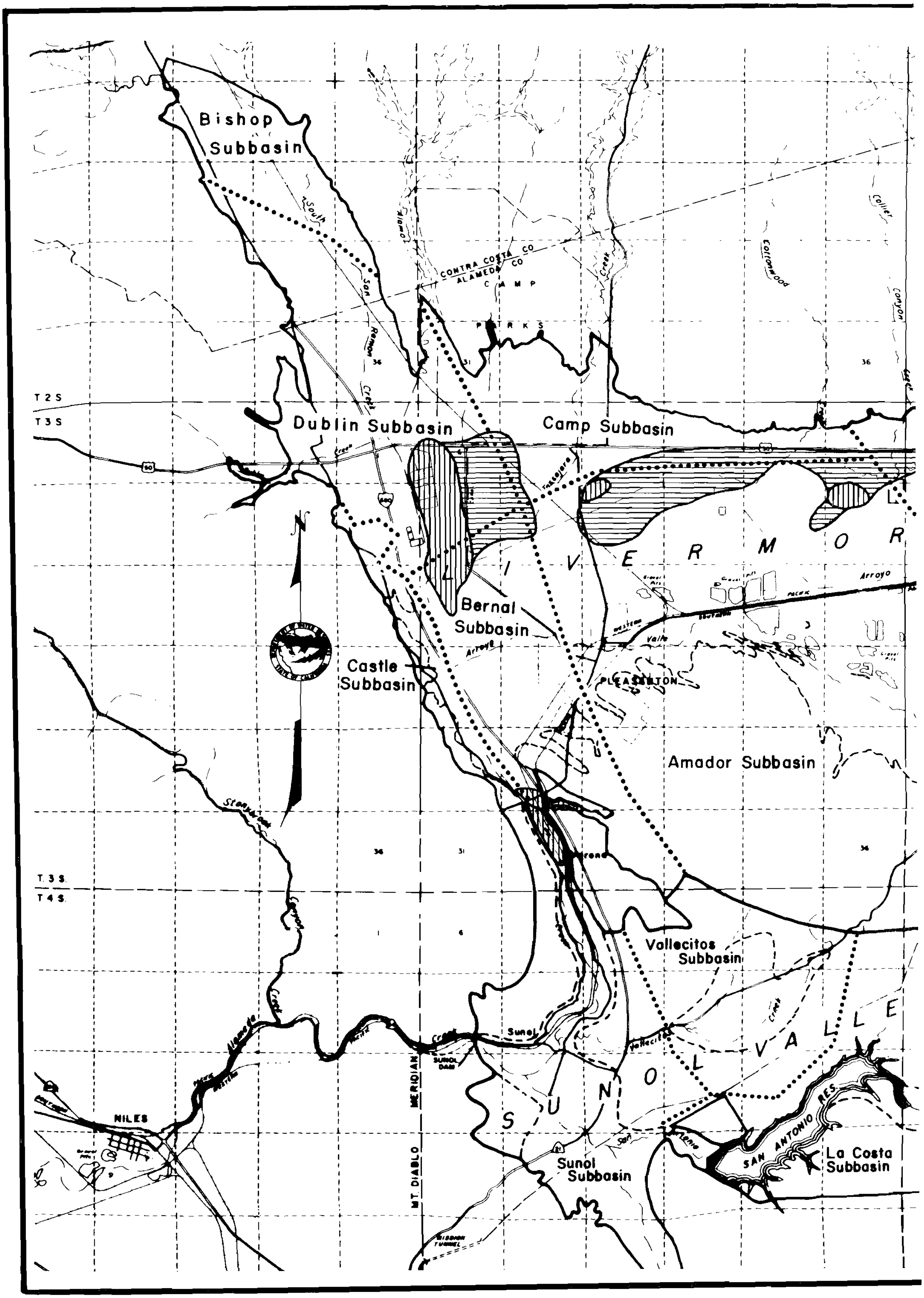


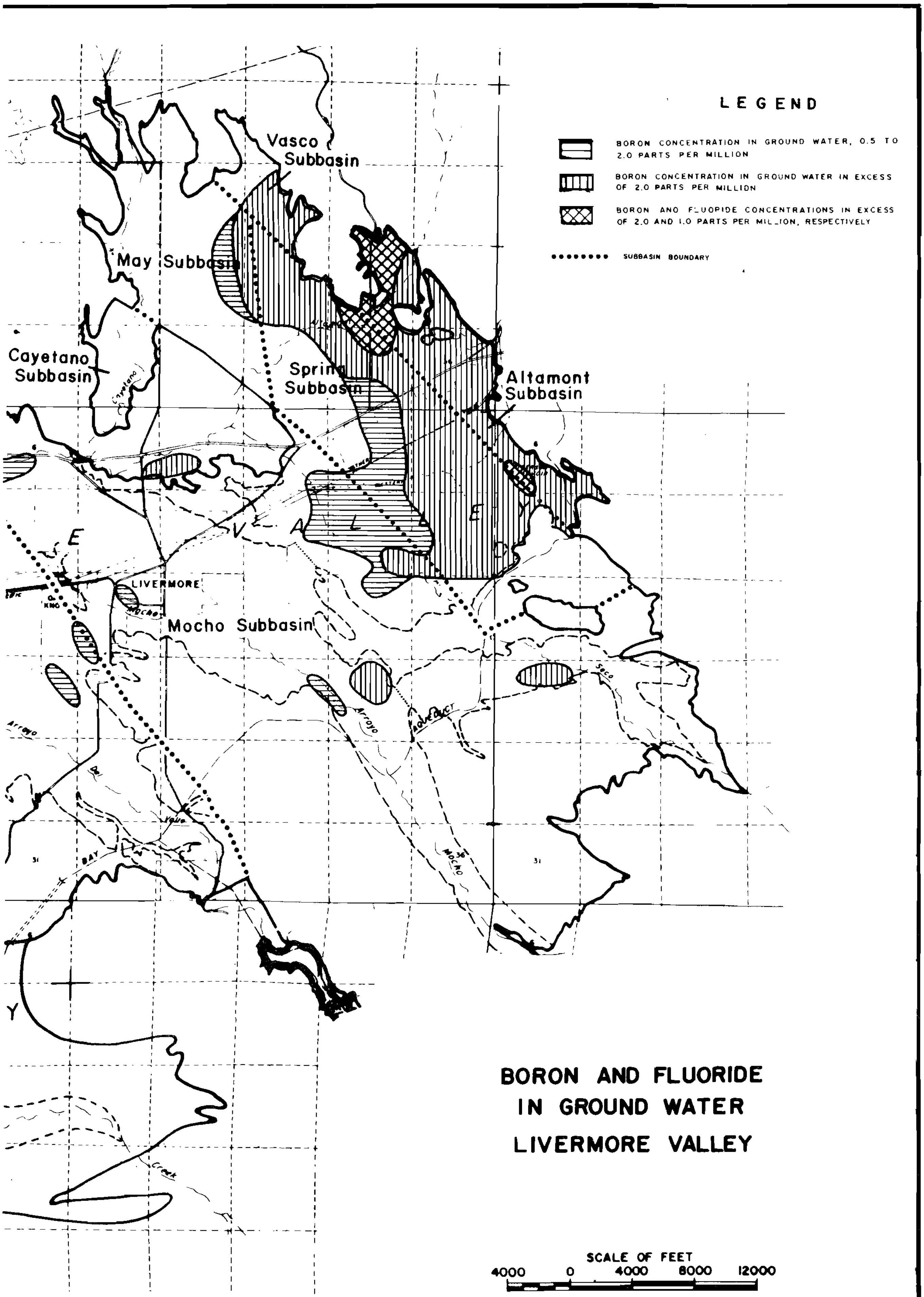
ELECTRICAL CONDUCTIVITY AND CHLORIDES IN GROUND WATER LIVERMORE VALLEY


Bishop Subbasin
Dublin Subbasin
Camp Subbasin
Bernal Subbasin
Castle Subbasin
Amador Subbasin
Vallecitos Subbasin
Sunol Subbasin
La Costa Subbasin
CONTRA COSTA CO
ALAMEDA CO
CAMP PARKS
L I V E R M O R
S U N O L V A L L E
PLEASANTON
NILES
SAN ANTONIO RES.
T. 2 S.
T. 3 S.
T. 4 S.
MT. DIABLO MERIDIAN
SUNOL DAM
N



NITRATE IN GROUND WATER
LIVERMORE VALLEY


Bishop Subbasin
Dublin Subbasin
Camp Subbasin
Bernal Subbasin
Castle Subbasin
Amador Subbasin
Vallecitos Subbasin
Sunol Subbasin
La Costa Subbasin
CONTRA COSTA CO
ALAMEDA CO
CAMP PARKS
LIVERMORE
PLEASANTON
SUNOL VALLEY
NILES
SAN ANTONIO RES.
MT. DIABLO MERIDIAN
SUNOL DAM
T 2 S
T 3 S
T 4 S
N



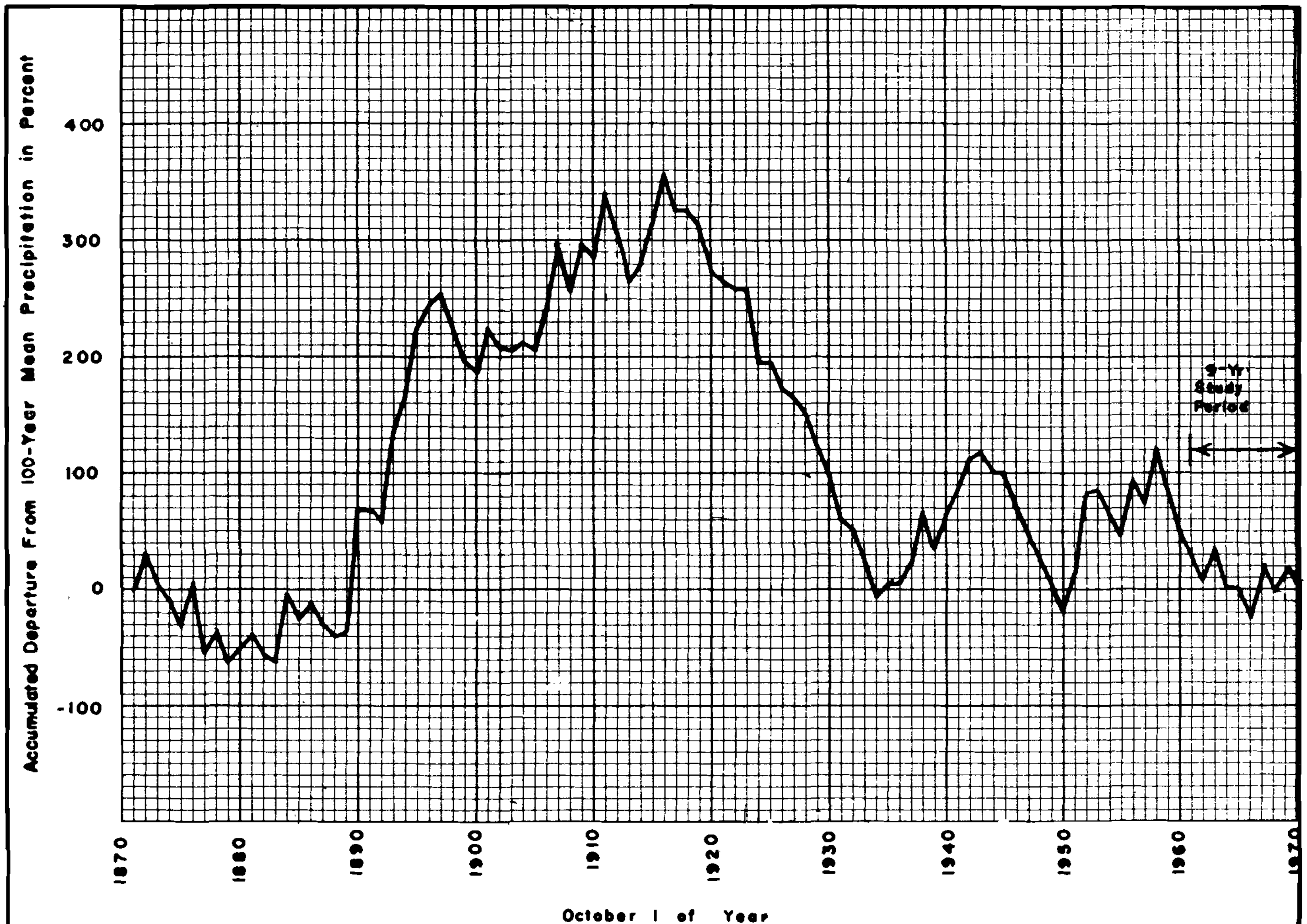
BORON AND FLUORIDE
IN GROUND WATER
LIVERMORE VALLEY

TABLE 3

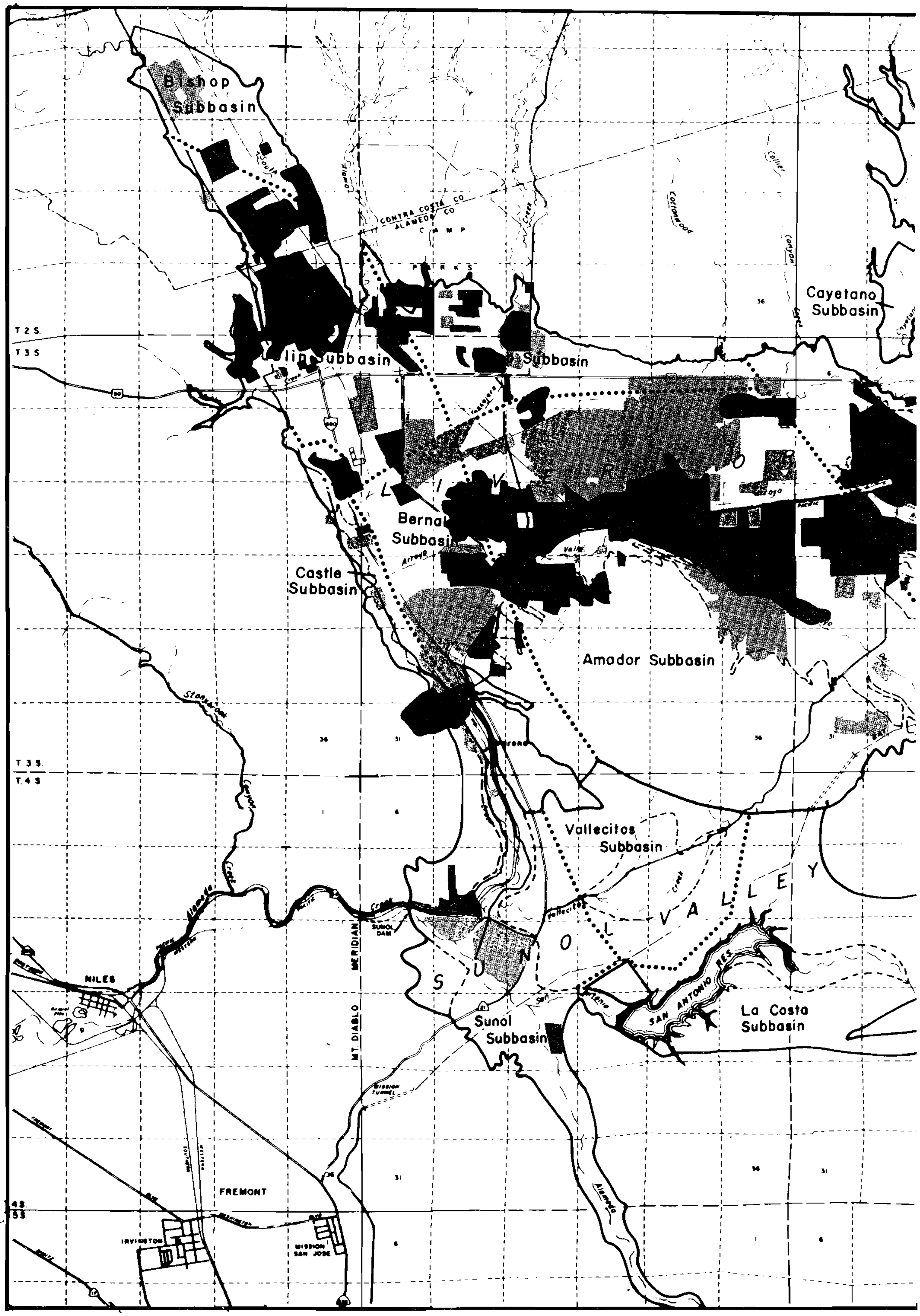
GROUND WATER IN THE VALLEY FILL MATERIALS
OF LIVERMORE VALLEY

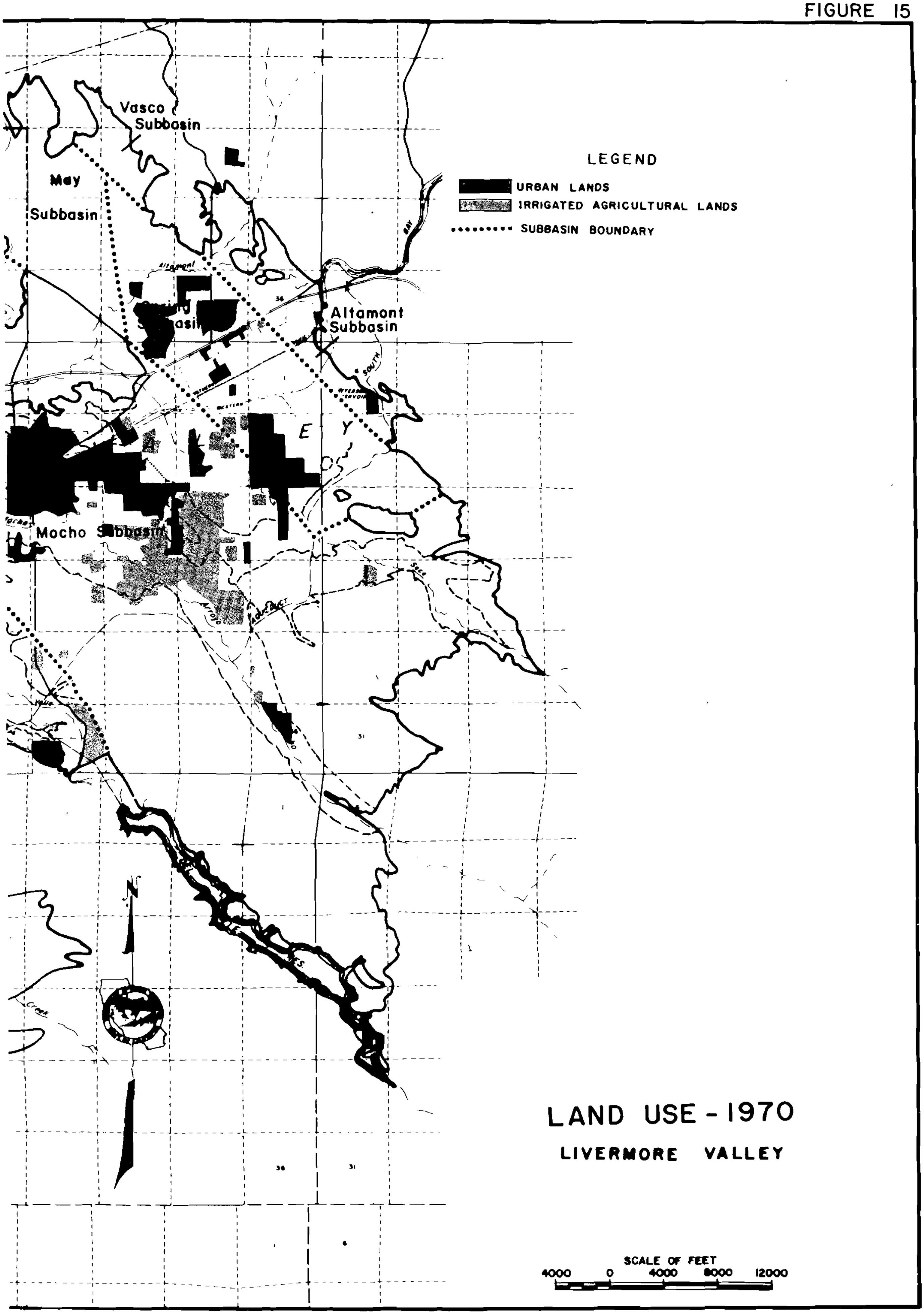
Subbasin	Depth of Valley Fill	Slope of Potentiometric Surface in the Valley-Fill Materials	Underlying Material
Bishop	300 to 600 feet	North; 15 feet per mile	Tassajara Formation
Dublin	500 feet	South; 20 to 30 feet per mile	Tassajara Formation
Castle	50 feet	Eastward, parallel to ground surface	Livermore Formation
Bernal	400 feet	Toward east half of T3S, R1E, Sec. 18 & 19; 40 feet per mile	Livermore Formation
Camp	100 to 300 feet	South; 70 feet per mile	Tassajara Formation
Amador	300 to 500 feet	Western portion: Level Eastern portion: North; 60 feet per mile Northern portion: South; 70 feet per mile	Livermore Formation
Mocho			
I (East)	50 feet	Westward	Livermore Formation
II (West)	150 feet	North and northwest; 20 feet per mile	
Cayetano	40 feet	South; 15 feet per mile	Tassajara Formation
May	40 feet	Southeast	Tassajara Formation
Spring	100 feet	North; 0 to 10 feet per mile	Livermore Formation
Vasco	100 feet	South; 70 feet per mile	Nonwater-bearing rock
Altamont	200 feet	South; 100 feet per mile	Nonwater-bearing rock

FIGURE 14



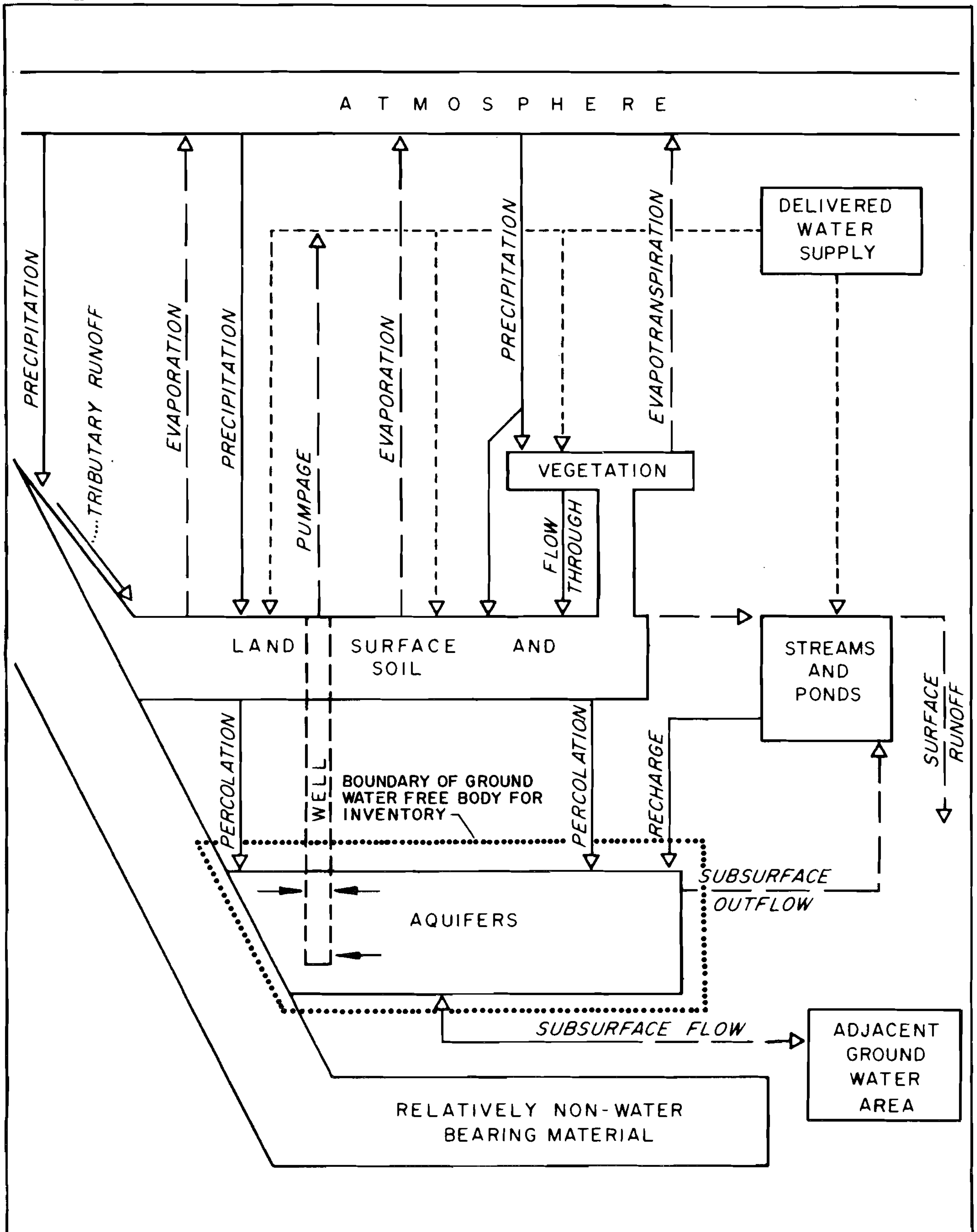
RELATIONSHIP OF ANNUAL PRECIPITATION TO MEAN PRECIPITATION


Bishop Subbasin
Cayetano Subbasin
T 2 S.
T 3 S
lin Subbasin
Subbasin
CONTRA COSTA CO
ALAMEDA CO
CAMP
PARKS
L I V E R M O R E
Bernal Subbasin
Castle Subbasin
Amador Subbasin
Vallecitos Subbasin
T 3 S.
T 4 S
S U N O L V A L L E Y
Sunol Subbasin
La Costa Subbasin
SAN ANTONIO RES.
NILES
FREMONT
IRVINGTON
MISSION SAN JOSE
MT DIABLO MERIDIAN
SUNOL DAM
MISSION TUNNEL



LAND USE - 1970
LIVERMORE VALLEY

FIGURE 16

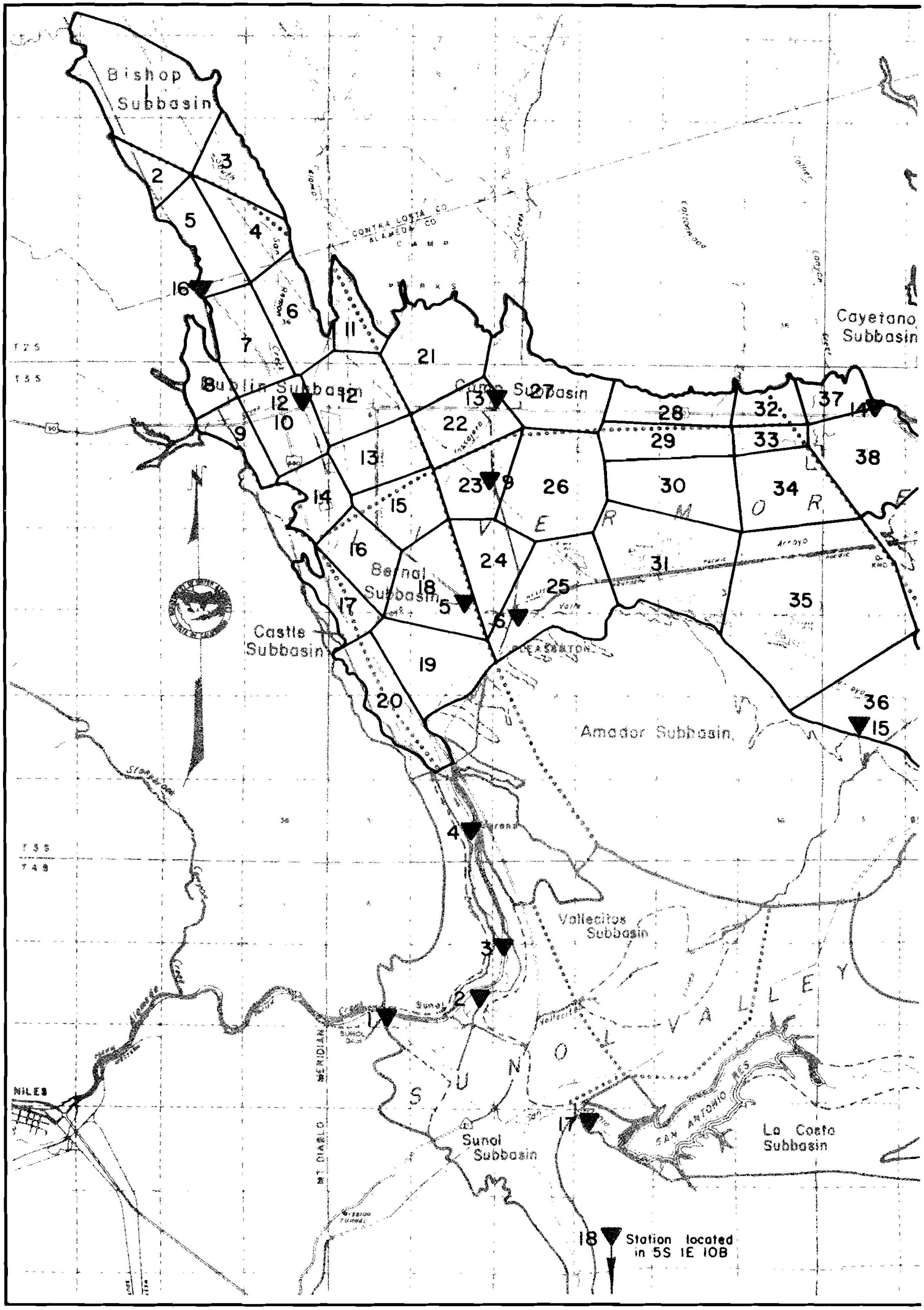


HYDROLOGIC SYSTEM (SCHEMATIC)

TABLE 4

SUBSURFACE FLOW BETWEEN SUBBASINS, LIVERMORE VALLEY

Subbasin Boundary	Subsurface Flow
Bishop-Dublin	Minor; potentiometric surface slopes away from fault boundary.
Dublin-Castle	Minor; potentiometric surface slopes eastward in materials of low permeability.
Dublin-Bernal	Minor; potentiometric surface slopes south from Dublin to Bernal, but there is drop in surface of 50 feet across fault.
Dublin-Camp	Minor; slope of potentiometric surface is parallel to boundary.
Castle-Bernal	Minor; potentiometric surface slopes eastward in materials of low permeability.
Camp-Amador	Minor east of Santa Rita Road; slope of potentiometric surface is parallel to boundary. Moderate west of Santa Rita Road; potentiometric surface slopes southerly at 40 feet per mile across boundary.
Amador-Bernal	Moderate; potentiometric surface slopes westerly at 30 feet per mile across boundary.
Mocho-Camp	Minor; slope of potentiometric surface is parallel to boundary.
Mocho-Amador	Nearly unrestricted along ancestral channel of Arroyo Mocho north of Oak Knoll. Negligible to north and south of ancestral channel as slope of potentiometric surface is parallel to boundary.
Vasco-May	Minor; potentiometric surface slopes southward in materials of low permeability.
Vasco-Spring	Minor; potentiometric surface slopes southward in materials of low permeability.
Cayetano-May	Minor; fault forms effective barrier.
May-Spring	Minor; water-bearing materials less than 50 feet thick across boundary.
Altamont-Spring	Minor; potentiometric surface drops 150 feet, east to west, across boundary.
Spring-Mocho	Minor to depth of 50 feet; materials are of low permeability. Negligible below 50 feet as fault forms effective barrier.


Bishop Subbasin
Dublin Subbasin
Camp Subbasin
Cayetano Subbasin
Bernal Subbasin
Castle Subbasin
Amador Subbasin
Vallecitos Subbasin
Sunol Subbasin
La Costa Subbasin
L I V E R M O R E
V A L L E Y
S U N O L
CONTRA COSTA CO
ALAMEDA CO
PLEASANTON
NILES
MT DIABLO MERIDIAN
SAN ANTONIO RES
T 2 S
T 3 S
T 4 S
18 Station located in 5S 1E 10B

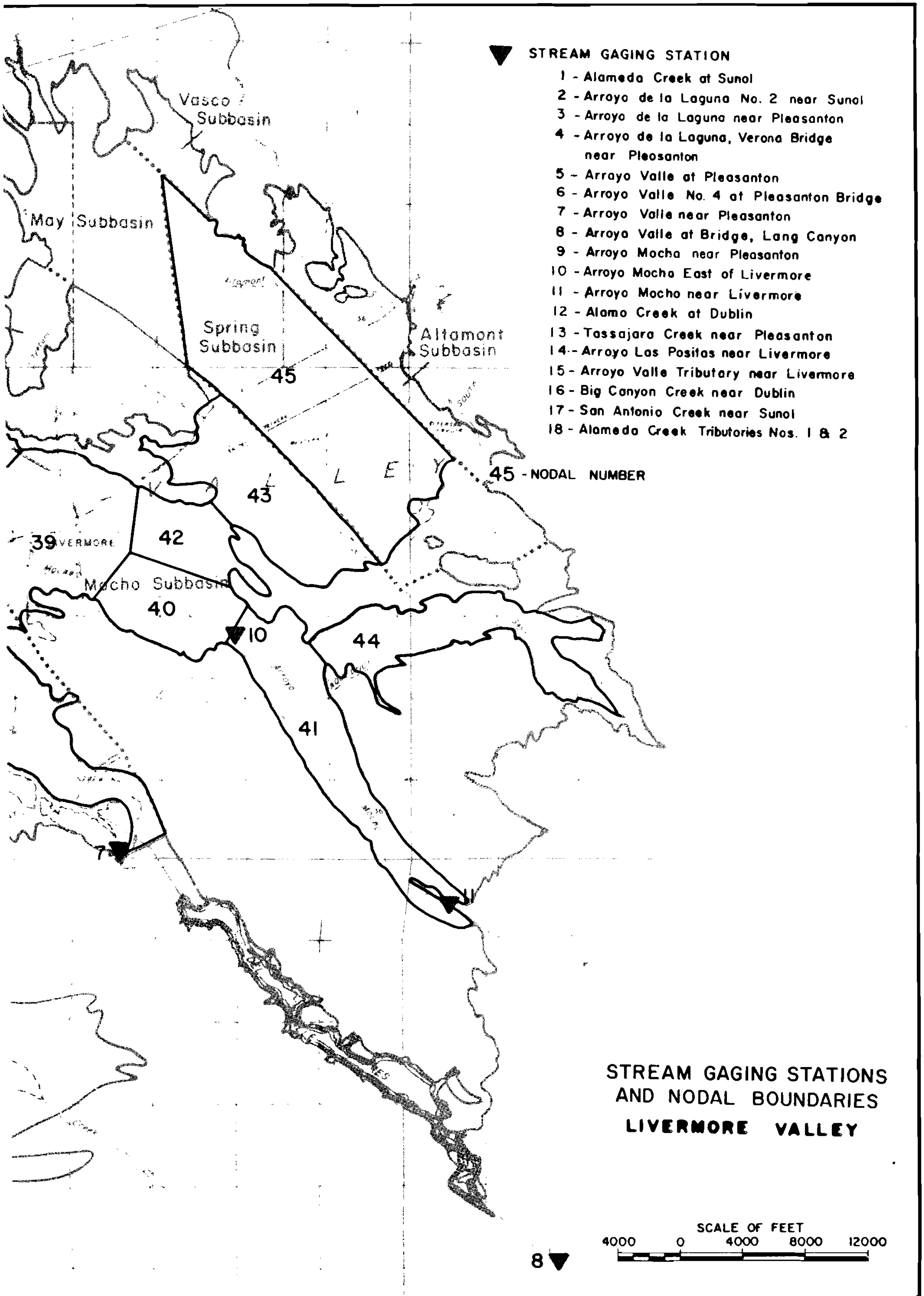
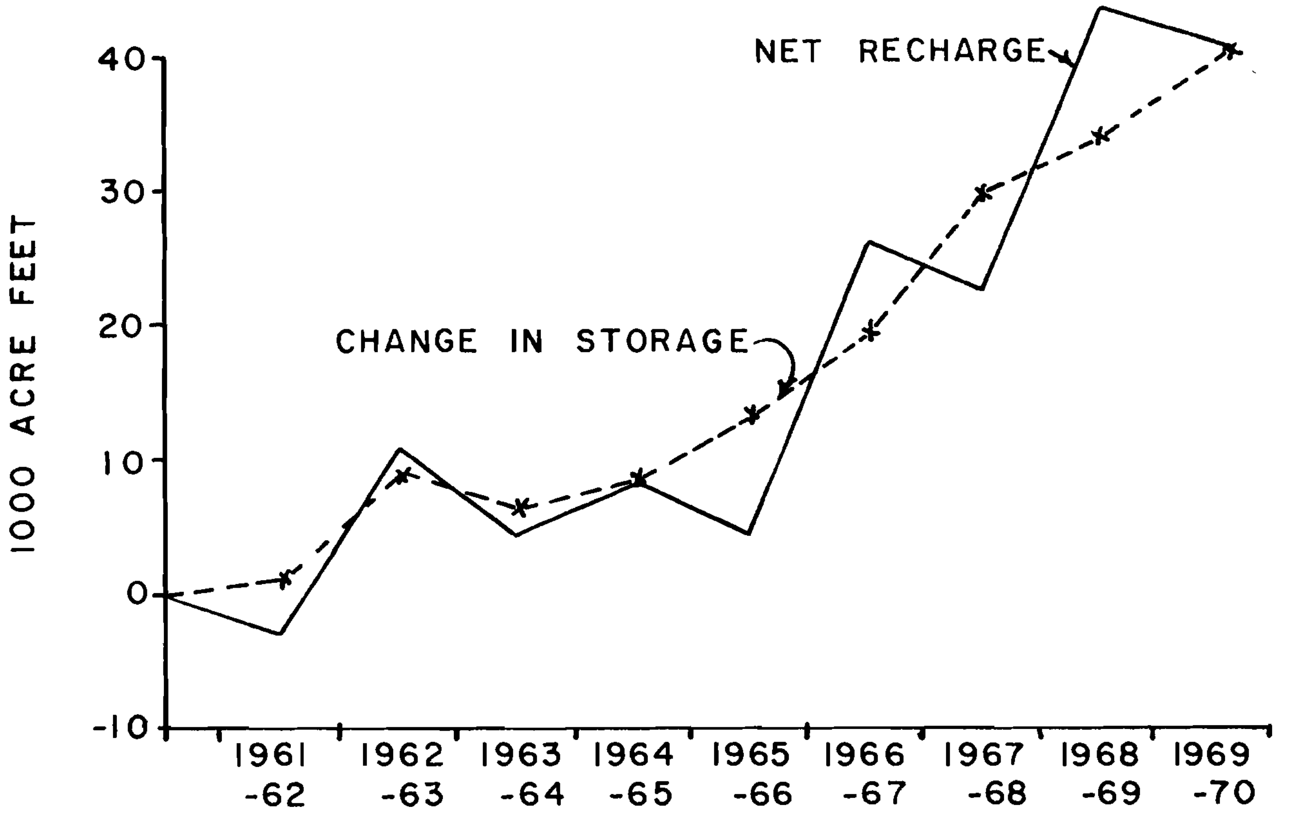
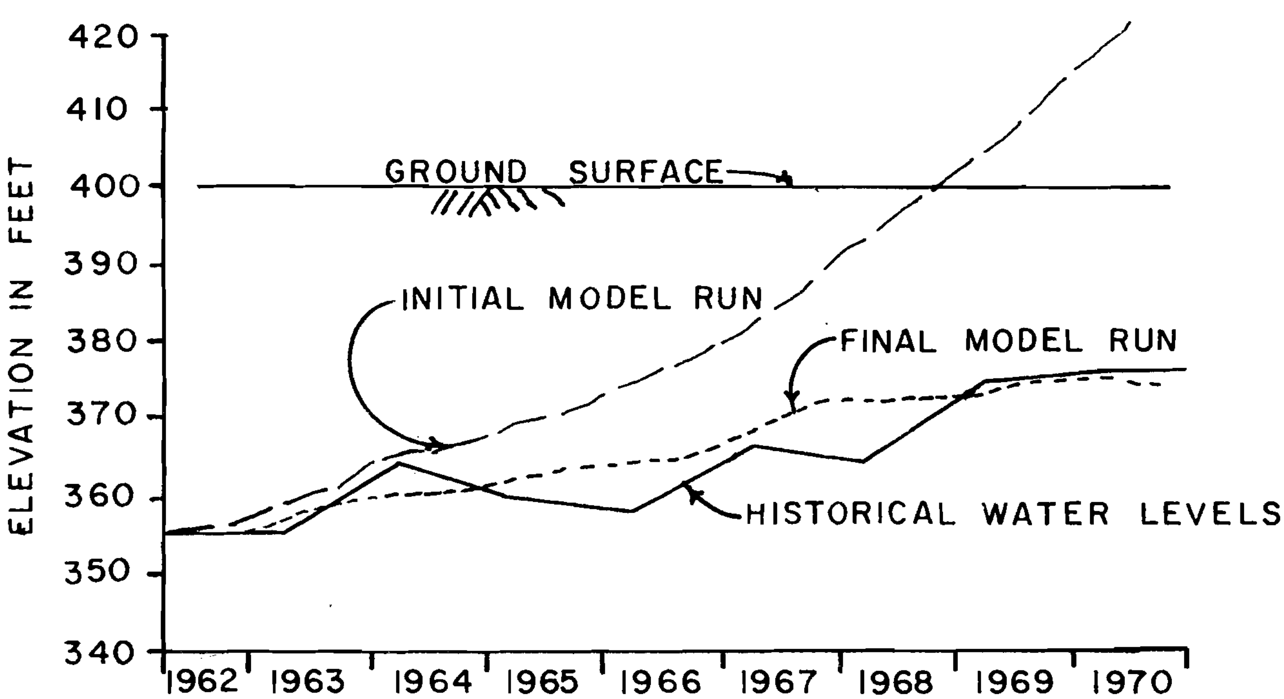

STREAM GAGING STATION
1 - Alameda Creek at Sunol
2 - Arroyo de la Laguna No. 2 near Sunol
3 - Arroyo de la Laguna near Pleasanton
4 - Arroyo de la Laguna, Verona Bridge near Pleasanton
5 - Arroyo Valle at Pleasanton
6 - Arroyo Valle No. 4 at Pleasanton Bridge
7 - Arroyo Valle near Pleasanton
8 - Arroyo Valle at Bridge, Lang Canyon
9 - Arroyo Mocho near Pleasanton
10 - Arroyo Mocho East of Livermore
11 - Arroyo Mocho near Livermore
12 - Alamo Creek at Dublin
13 - Tassajara Creek near Pleasanton
14 - Arroyo Las Positas near Livermore
15 - Arroyo Valle Tributary near Livermore
16 - Big Canyon Creek near Dublin
17 - San Antonio Creek near Sunol
18 - Alameda Creek Tributories Nos. 1 & 2
45 - NODAL NUMBER
Vasco Subbasin
May Subbasin
Spring Subbasin
Altamont Subbasin
Mocho Subbasin
39
40
41
42
43
44
45
10
11
7
8
STREAM GAGING STATIONS AND NODAL BOUNDARIES
LIVERMORE VALLEY
SCALE OF FEET
4000 0 4000 8000 12000

FIGURE 18



NET RECHARGE AND CHANGE IN STORAGE

FIGURE 19



NODE 38
TYPICAL MODEL VERIFICATION RUN

TABLE 5

GROUND WATER INVENTORY
LIVERMORE VALLEY GROUND WATER BASIN
(In Acre-Feet)

Water Year	Recharge From Rain and Applied Water	Stream Recharge	Artificial Recharge	Sub-surface Inflow	Pumpage From Valley Fill Materials	Net Recharge	Change in Storage[b]
1961-62	4,600	6,280	100	2,810	16,950	- 3,160	+ 1,380
1962-63	5,940	20,550	520	2,810	16,180	+ 13,640	+ 7,090
1963-64	3,860	6,370	180	2,810	19,440	- 6,220	- 2,520
1964-65	8,750	10,620	310	2,810	19,030	+ 3,460	+ 2,050
1965-66	7,240	7,130	920	2,810	21,230	- 3,130	+ 5,390
1966-67	15,830	21,460	1,010	2,810	19,510	+ 21,600	+ 5,520
1967-68	3,740	9,850	1,050	2,810	21,340	- 3,890	+ 10,840
1968-69	21,020	15,790	600	2,810	19,700	+ 20,520	+ 4,040
1969-70	8,160	7,660	650	2,810	21,590	- 2,310	+ 5,790
Total	79,140	105,710	5,340	25,290	174,970	+ 40,510	+ 39,580

a/ Net amount of inflow to and outflow from basin.
b/ Amount of ground water in storage gained or lost as determined from water levels.

CHAPTER II. GROUND WATER IN LIVERMORE VALLEY

Livermore Valley Ground Water Basin has been divided into a number of subbasins on the basis of the fault traces shown on Figures 3 and 4 and on hydrologic discontinuities. The twelve subbasins in the Livermore Valley are listed on Table 1 and their location and areal extent are shown on Figure 2. The depth of alluvial deposits and the water-bearing formation underlying the alluvium in Livermore Valley are listed for each subbasin on Table 3.

This chapter discusses the ground water characteristics in each subbasin. It should be noted that the subbasins in the central and western portions of Livermore Valley contain the major volume of ground water in storage. The slope of the potentiometric surface within each subbasin is described on Table 3 and the subsurface flow between subbasins is described on Table 4. Typical ground water quality analyses from each subbasin are shown on Table 6.

Bishop Subbasin

The Bishop subbasin comprises 1,666 acres of valley lands in the far northwestern portion of Livermore Valley Ground Water Basin. It lies entirely within Contra Costa County, is drained by South San Ramon Creek, and is a portion of that area locally designated as San Ramon Valley (see Figure 3).

The subbasin is bounded on the east and west by rolling hills composed of sediments of the Tassajara Formation. The northern boundary is along a diagonal fault which runs through Sections 9, 10, and 15, T2S, R1W. The southern boundary is along a nearly parallel fault which passes through Sections 22, 23, and 25, T2S, R1W.

Ground Water Occurrence, Movement and Quality

Ground water in the Bishop subbasin occurs throughout the valley-fill materials. The depth to water in deeper wells ranges from 50 feet near the southern boundary to 130 feet near the northern boundary. This difference in depth, when converted to water-surface elevation, indicates that the potentiometric surface of ground water slopes northward at about 15 feet per mile.

From water level data, it is inferred that ground water moves in a northerly direction as far as a parallel cross-fault located 1,500 feet south of the northern boundary fault. At this location, water levels are about 15 feet higher on the north side, indicating that there is little, if any, northward flow of ground water across this fault. From this interior fault northward, the potentiometric surface slopes northward at a gradient of about 30 feet per mile.

Ground water within the Bishop subbasin ranges from unconfined in the shallow zones to confined in zones deeper than 100 feet.

TABLE 6

GROUND WATER QUALITY IN SUBBASINS
LIVERMORE AND SUNOL VALLEYS

Subbasin	Well No.	Well Depth (feet)	Month Sampled	Water Type	Specific Conductance (micromhos)	Dissolved Solids (mg/l)	Total Hardness (mg/l)	Noncarbonate Hardness (mg/l)	Percent Sodium	Sodium Adsorption Ratio	Chloride (mg/l)	Boron (mg/l)	Nitrate (mg/l)	Fluoride (mg/l)	pH	Irrigation Class
Bishop	2S/1W-22A1	450	8/53	$Ca(HCO_3)_2$	665	390	244	0	31	1.44	63	0.07	2.2	0.1	7.7	I
			6/65	$NaHCO_3$	1010	540	260	12	47	2.92	158	0.2	0.8	---	8.2	II
Dublin	3S/1W-1B1	560	3/61	$NaHCO_3$	794	471	194	0	55	3.42	62	0.3	0.1	0.2	8.0	I
	3S/1W-1L1	---	5/60	$Ca(HCO_3)_2$	898	570	364	80	26	0.74	50	0.2	0.2	0.5	7.3	I
	3S/1E-6R1	99	5/60	Na_2SO_4	2760	1780	722	323	53	5.95	342	1.2	2.9	0.6	7.8	II
	3S/1E-7G1	150	10/60	NaCl	1630	926	256	53	68	7.00	329	0.8	0.4	0.3	8.6	II
Castle	3S/1E-30G1	258	7/52	$NaHCO_3$	1180	679	404	0	36	2.29	103	0.72	0.3	0.2	7.5	II
Bernal	3S/1E-7R2	205	8/57	$Mg(HCO_3)_2$	1120	666	431	---	28	1.62	112	0.05	15.0	0.1	7.7	II
	3S/1E-18B1	260	8/57	$NaHCO_3$	1190	693	34	---	94	20.2	70	0.83	0.5	1.3	8.5	III
	3S/1E-20M3	220	8/57	$Ca(HCO_3)_2$	988	599	458	102	16	0.83	60	0.4	20.0	0.1	8.0	I
	3S/1E-29M1	207	12/59	$CaCl_2$	1950	1120	660	234	34	2.68	375	7.1	2.5	0.0	7.0	III
	3S/1E-29M2	100+	12/59	NaCl	2630	1530	660	239	50	5.36	620	5.4	1.4	0.0	7.2	III
Camp	2S/1E-33M1	120	7/57	$NaHCO_3$	1560	943	342	---	59	5.4	140	1.0	8.4	1.0	7.8	II
Amador	3S/1E-3Q1	350	6/66	$NaHCO_3$	1080	616	298	0	48	3.2	119	1.8	20.	---	8.4	II
	3S/1E-11H1	303	6/57	$Mg(HCO_3)_2$	630	357	283	---	15	0.6	31	0.26	15.	0	7.2	I
			8/69	$Mg(HCO_3)_2$	861	572	365	92	41	1.2	100	0.4	18.	---	8.5	I
	3S/1E-13P2	400	7/52	$Ca(HCO_3)_2$	554	325	226	32	25	1.0	34	0.49	1.2	0	7.6	I
			6/66	$Ca(HCO_3)_2$	730	412	252	8	33	1.6	62	1.0	1.5	---	7.8	II
	3S/2E-28P1	---	10/58	NaCl	1420	743	160	0	76	8.2	268	0.84	1.5	0.3	8.0	II
Mocho	3S/1E-1G1	208	7/57	$NaHCO_3$	613	365	210	---	37	1.7	19	0.3	3.5	0.2	7.8	I
	3S/2E-8H1	625	7/52	$NaHCO_3$	710	427	220	0	41	2.1	66	0.57	14	0.1	8.6	II
			8/69	$Mg(HCO_3)_2$	721	445	287	77	25	1.2	62	0.5	61	---	7.7	II
	3S/2E-12M1	702	9/58	$NaHCO_3$	1436	---	226	---	71	7.9	201	9.1	0	0.1	7.8	III
	3S/2E-22E1	445	7/54	$Mg(HCO_3)_2$	853	527	332	38	30	1.6	87	0.12	24	0.3	8.5	I
	3S/2E-22E2	105	2/57	NaCl	1240	671	393	---	34	2.0	246	0.11	27	0.2	6.5	II
	3S/2E-22M1	965	8/57	$NaHCO_3$	902	512	264	---	41	2.3	141	0.29	14	0.2	7.7	I
	3S/3E-21E1	---	10/57	Na_2SO_4	1510	1009	224	0	71	7.5	135 1/	2.7	13	1.6	8.5	III
Cayetano	2S/2E-32D1	80	11/57	$NaHCO_3$	1270	784	164	0	74	7.7	175	0.74	29	0.6	8.6	II
May	2S/2E-16N1	112	7/52	NaCl	1550	880	340	81	53	4.2	263	0.08	101	0.7	8.1	II
Vasco	(See May Subbasin)															
Spring	3S/2E-2B1	200	1951	NaCl	---	1101	408	---	51	4.3	357	3.	3.	---	7.7	III
	3S/2E-2F1	---	---	$Na,Ca(HCO_3)_2$	---	722	298	---	38	2.1	101	1.	5.	---	7.5	II
Altamont	2S/2E-25N1	---	---	NaCl	---	1244	240	---	72	8.0	251	5.8	3.	---	---	III
Sunol	4S/1E-20B1	200	10/57	$NaHCO_3$	844	464	177	0	58	3.8	92	0.1	1.4	0.1	8.1	I
	4S/1E-20K1	90	7/54	$Ca(HCO_3)_2$	829	554	283	3	40	2.2	47	0.35	2.6	0.3	7.5	I
Vallecitos	4S/1E-2K1	335	12/57	$Ca(HCO_3)_2$	958	581	340	108	29	1.5	58	0.03	149	0.3	7.5	I
	4S/1E-2L1	283	12/57	NaCl	459	232	101	3	52	2.2	88	0.03	0.1	0.1	8.4	I
	4S/1E-2N1	177	2/58	$Mg(HCO_3)_2$	1320	732	456	0	35	2.3	157	0.06	8.1	0.2	7.4	II
	4S/1E-10J1	80	3/56	NaCl	883	491	240	53	44	2.5	153	0.23	17	0.3	7.9	I
			10/59	NaCl	1120	621	284	68	47	3.0	223	0.5	14	0.3	8.4	II
La Costa	(See Vallecitos Subbasin)															

1/ SO_4 = 281 mg/l

Water quality data are available from only one well in the Bishop subbasin. The analyses from Well 2S/1W-22A1, on Table 6, indicate that water from this well, when sampled in August 1953, was an excellent quality calcium bicarbonate water. The analysis from this well in June 1965 indicates that water in this well had changed to a sodium bicarbonate character. The water had deteriorated to a Class II irrigation water on the basis of the electrical conductivity being 1,010 micromhos. (See Appendix B for water quality criteria.)

Description of Aquifer System

The Bishop subbasin contains one of the deepest developed prisms of water-bearing materials in Livermore Valley Ground Water Basin (see Section I-I', Figure 5). Here sediments are up to 800 feet in depth. The depth of contact between the valley-fill materials and the underlying Tassajara Formation is uncertain due to the similarity of the materials. It is possible that the greater portion of the sediments below a depth of 100 feet are a part of the Tassajara Formation.

The prism of sediments identified as valley-fill materials contains from eight to ten separate zones of sand and gravel separated by zones of silt and clay. The sand and gravel zones are connected, giving the entire prism some degree of hydraulic continuity.

From the southern boundary north to the intermediary fault, the various sand and gravel beds dip to the north very gently at from one to three degrees. North of the intermediary fault, the sediments dip to the south at about three to eight degrees.

Yield of Wells

There are two wells in the Bishop subbasin for which yield data are available. Both are irrigation wells and yield about 850 gallons per minute. Their specific capacities cannot be determined because drawdown data are unavailable.

Subsurface Inflow and Outflow

Subsurface inflow to the Bishop subbasin is considered to be moderate because there is a fair degree of hydraulic continuity between the water-bearing sediments of the Tassajara Formation located in the adjacent uplands and the water-bearing materials beneath the valley floor. Some subsurface outflow from the Bishop subbasin may occur to the north into San Ramon Valley Ground Water Basin. This is inferred from the small water level differential, about 10 feet, across the north boundary fault and the northward sloping potentiometric surface. There is believed to be no subsurface outflow to the south into the Dublin subbasin because of the large 40-foot differential in water levels across the fault and because both of the potentiometric surfaces slope away from the fault.

Dublin Subbasin

The Dublin subbasin covers 4,957 acres of land in the northwest portion of Livermore Valley Ground Water Basin. Most of the subbasin is within Alameda County, but the northern portion extends into Contra Costa County. The communities of San Ramon Village and Dublin occupy most of the northern part of the subbasin (see Figure 3).

The subbasin is drained by South San Ramon Creek, which flows southward out of the Bishop subbasin. Alamo Creek enters the subbasin from the northeast and Dublin Creek enters from the west. Both of these two creeks merge with South San Ramon Creek and flow southward out of the subbasin as Arroyo de la Laguna.

The Dublin subbasin is bounded on the west by nonwater-bearing marine sediments and on the northwest and northeast by continental water-bearing sediments of the Tassajara Formation. A portion of the southern boundary is along the contact between valley-fill materials and the sediments of the Livermore Formation which are in the adjacent Castle subbasin. The remaining boundaries are fault controlled.

To the north is the diagonal fault separating the Dublin subbasin from the Bishop subbasin; to the east is the Pleasanton fault which separates this subbasin from the Camp subbasin; and to the south is the Parks fault which separates the subbasin from the Bernal subbasin.

Ground Water Occurrence, Movement, and Quality

Ground water in the Dublin subbasin is both unconfined and confined. In the shallower, unconfined aquifers, it is generally about 20 feet below the ground surface and has a potentiometric surface which slopes southward at about 20 feet per mile.

The potentiometric surface of the deeper, confined aquifers is reflective of a multiple aquifer system. In the northern part of the subbasin it is about 80 feet below ground and slopes southward at about 30 feet per mile. However, in the southern part of the subbasin it is only about 50 feet below ground and slopes southward at about 20 feet per mile.

Ground water in the Dublin subbasin is of three basic types. Along the western part of the subbasin, west of South San Ramon Creek, ground water is of calcium bicarbonate character of excellent quality. A typical analysis of this type of water is shown for Well 3S/1W-1L1 on Table 6. The character of the ground water in this area is reflective of the character of surface water draining the hills to the west, as represented by the analysis of surface water from Dublin Creek shown on Table 6. East of South San Ramon Creek and north of Highway 580, ground water is of a sodium bicarbonate nature of excellent quality. A typical analysis of this type of water is shown for Well 3S/1W-1B1 on Table 6. This type of ground water is reflective of that contained in the Tassajara Formation and of surface water available for recharge from Alamo Creek. An analysis of surface water from Alamo Creek is shown on Table 20 in Appendix B. That portion of the Dublin subbasin east of South San Ramon Creek and south of Highway 580 contains a

Class II irrigation water that ranges from sodium chloride to sodium sulfate in composition. A few deeper wells in this area produce sodium bicarbonate water, but the concentration of chloride and sulfate ions is higher in these wells than in water from wells in other parts of the subbasin. Analyses from Well 3S/1E-6R1 is typical of the sodium sulfate water in the subbasin; that from Well 3S/1E-7G1 is typical of the sodium chloride water in the subbasin. This portion of Livermore Valley has long been a sink area, and chloride and other salts have been precipitated in the valley-fill materials. These salts cause the poor quality water found in this area when they are again dissolved.

Description of Aquifer System

Aquifers of the Dublin subbasin are essentially flatlying. However, there are local variations which cause dips of up to eight degrees and result in slightly undulating aquifer horizons. The direction of dip in the aquifers is generally to the south in the northern part of the subbasin and to the north in the southern part.

The maximum depth of sediments in the Dublin subbasin is about 800 feet. As shown on Geologic Section I-I' on Figure 5, the valley-fill materials lap northward onto older sediments of the Tassajara Formation. Positive identification of the sediments below a depth of 500 feet as belonging to the Tassajara Formation, Livermore Formation, or valley-fill materials could not be determined on the basis of available data.

Yield of Wells

Well yield data are available from three wells in the Dublin subbasin. These wells yield about 350 gallons per minute and have specific capacities which range from 3.3 to 14.0 gallons per minute per foot of drawdown (see Figure 8).

Subsurface Inflow and Outflow

Subsurface inflow to the Dublin subbasin from the Bishop subbasin to the north is considered to be negligible. No subsurface inflow is derived from the nonwater-bearing rocks to the west and a small amount comes from the adjacent areas of Tassajara sediments to the northwest and northeast. Similarly, only minor quantities of ground water are derived from the Livermore Formation in the Castle subbasin to the southwest. A small amount of ground water apparently moves through the sediments of the channel of Alamo Creek and into the Dublin subbasin at its northeastern corner.

The water-bearing sediments of the Dublin subbasin appear to be essentially isolated from those in the Camp subbasin to the east. This is because the Pleasanton Fault, which forms the common boundary between these two subbasins, acts as a permeability barrier and ground water movement is apparently southward, parallel to the fault.

Some subsurface outflow from the Dublin subbasin occurs across the fault boundary separating it from the Bernal subbasin to the south. Ground water flow is restricted to the surficial deposits that have not been offset by movement along the Parks fault. Potentiometric surfaces on both sides of this boundary slope southerly. Water levels north of the boundary are some 50 feet higher than those to the south, indicating a significant constraint to large outflows.

Castle Subbasin

The Castle subbasin extends along the southern half of the west side of Livermore Valley Ground Water Basin; it encompasses 905 acres. The subbasin comprises 544 acres of uplands underlain by the Livermore Formation and 361 acres of adjacent valley-fill material (see Figure 3).

The subbasin is bounded on the west by nonwater-bearing marine sediments, on the east by the Calaveras fault, on the north by the contact between the Livermore Formation and the valley-fill materials of the Dublin subbasin, and on the south by the drainage divide separating the Livermore Valley and Sunol Valley Ground Water Basins.

Surface drainage is by minor streams tributary to the Arroyo de la Laguna. The principal development is the Castlewood Country Club residential area which occupies the southern portion of the subbasin.

Ground Water Occurrence, Movement, and Quality

Ground water in the Castle subbasin occurs in both the valley-fill materials and in the sediments of the Livermore Formation. It is usually confined to some degree and has a potentiometric surface which generally follows the topography. Depths to ground water range from 25 feet to 110 feet, depending on location and elevation above the valley floor.

There is only one analysis of ground water from the Castle subbasin. This analysis is from Well 3S/1E-30G1 and is shown on Table 6. The water from this well is a Class II sodium bicarbonate irrigation water; it is derived principally from the Livermore Formation.

Description of Aquifer System

Very few well logs are available and hence little is known of the aquifer system in the Castle subbasin. Most of the wells draw from the Livermore Formation, which is present as a sequence of gravel, sand, and silt interlayered by clay. All of these materials apparently slope toward the valley at dips ranging up to ten degrees (see Section J-J', Figure 5).

Yield of Wells

Data are not available concerning yield of wells in the Castle subbasin. It appears that the sediments of the subbasin are sufficiently permeable to provide reliable yields of ground water to domestic or stock wells but not for high capacity wells required for municipal and agricultural use.

Subsurface Inflow and Outflow

There is no subsurface inflow of ground water into the Castle subbasin. Subsurface outflow to the north into the Dublin subbasin is negligible. There is no outflow across the southern boundary of the subbasin because the direction of ground water movement is parallel to the boundary. Ground water outflow is from the Castle subbasin eastward into the Bernal subbasin through permeable materials which overlie but are not affected by the Calaveras Fault. This is inferred from the lack of a significant differential of water levels and the eastward slope of the potentiometric surface across the fault zone.

Bernal Subbasin

The Bernal subbasin is located in the southwestern corner of Livermore Valley Ground Water Basin. All ground water in the valley moves toward this subbasin which covers 2,711 acres of valley lands devoted to agricultural and urban development. The City of Pleasanton is located in the east-central part of the subbasin. Also included in the subbasin, in addition to the valley lands, are 895 acres of uplands devoted primarily to rangeland (see Figure 2).

The subbasin is bounded on the east by the Pleasanton Fault, on the north by the Parks Fault, and on the west by the Calaveras Fault. Much of the southern boundary is along the contact between the water-bearing sediments of the Livermore Formation and nonwater-bearing rocks. A small portion of this southern boundary is formed by the Verona Fault.

All the streams draining Livermore Valley merge in the Bernal subbasin and then leave the subbasin and the valley as Arroyo de la Laguna.

Ground Water Occurrence, Movement, and Quality

Ground water occurs throughout the valley floor portion of the Bernal subbasin under conditions ranging from unconfined to confined. As in the other subbasins, each water-bearing zone has its own potentiometric surface. All potentiometric surfaces at any particular location generally have nearly the same elevation. In general, this combined potentiometric surface slopes toward a pumping depression located in the eastern half of Sections 18 and 19, T3S, R1E, at an average gradient of 40 feet per mile. The depth to the potentiometric surface in this depression is about 100 feet.

Ground water in the Bernal subbasin is generally of fair to excellent quality. Much of it is of Class II irrigation quality due to electrical conductivities exceeding 1,000 micromhos. The central part of the subbasin contains water of magnesium bicarbonate character. A representative analysis of this type of water is shown on Table 6 for Well 3S/1E-7R2. The northern and southern parts of the subbasin contain a sodium bicarbonate water; Well 3S/1E-18B1 on Table 6 is representative of this water type. The water from this well is of Class III irrigation quality due to excessively high sodium ion content with respect to calcium and magnesium ion content. The west and south-central parts of the subbasin contain a calcium bicarbonate water typified by the analysis from

Well 3S/1E-20M3. The Bernal subbasin is the ultimate destination for ground water moving through the Livermore Valley Ground Water Basin. Because of this, there is a high variability and mixing of the dominant cations, calcium, magnesium, and sodium, in ground water found in the subbasin. In the south part of the subbasin, in the vicinity of the Verona Fault, Class III irrigation quality ground water is encountered in wells. This water ranges from sodium chloride to calcium chloride in composition and is represented on Table 6 by the analyses from Wells 3S/1E-29M1 and 3S/1E-29M2. This poor quality water is the result of connate waters from the adjacent marine sediments commingling with sodium and calcium bicarbonate waters from areas to the north.

Description of Aquifer System

Most of the water-bearing materials in the valley portion of the Bernal subbasin are part of the valley-fill materials. These materials are present as a sequence of sandy gravel and sandy clayey gravel aquifers up to 100 feet in thickness. The aquifers are separated by silty clay confining beds up to 30 feet in thickness. The total thickness of the valley-fill materials is estimated to be at least 400 feet. The materials all dip uniformly to the northeast at about two degrees.

Conformably underlying the valley-fill materials are sediments of the Livermore Formation. These sediments are composed of fairly thick beds of sandy gravel and cemented gravel, are up to 150 feet in thickness, and are separated by relatively thin beds of silty clay and hard clay. The beds of the Livermore Formation, which are of unknown total thickness, dip northeasterly at from one to five degrees (see Section J-J', Figure 5).

Yield of Wells

Production data are available from 17 wells in the Bernal subbasin. The yields of these wells range from 113 gallons per minute to 1,100 gallons per minute. The specific capacities of wells in this subbasin range from 3.6 gallons per minute per foot of drawdown for a well drilled in the northern part of the subbasin, to 261 gallons per minute per foot of drawdown for a well drilled southwest of Pleasanton (see Figure 8).

Subsurface Inflow and Outflow

There is no subsurface inflow of ground water into the Bernal subbasin across that portion of the southern boundary formed by the contact between the Livermore Formation and the nonwater-bearing rocks. Similarly there is no inflow of ground water across the Pleasanton Fault south of the City of Pleasanton. This is because any movement of ground water here is essentially parallel to the fault.

There is some inflow of ground water into the Bernal subbasin from the Amador, Dublin, and Castle subbasins. This occurs through permeable zones overlying the traces of the Pleasanton Fault, Parks Fault, and the Calaveras Fault.

A small portion of the south boundary of the Bernal subbasin is formed by the Verona Fault. Across this fault there is a water level differential of about 20 feet, with levels on the south side being lower. However, the potentiometric surface to the south of the fault slopes southward toward Sunol Valley and that to the north slopes northward toward the ground water depression in the central part of the subbasin. Because the two surfaces slope away from the fault, it can be reasonably assumed that there is little if any flow of ground water across this fault. If in the future a southward gradient should be established north of the fault, then there may be some subsurface outflow of ground water from the Bernal subbasin into Sunol Valley Ground Water Basin.

Camp Subbasin

The Camp subbasin is located along the north side of Livermore Valley Ground Water Basin. It covers 2,858 acres and is the site of Camp Parks. The subbasin is drained by Tassajara Creek and Cottonwood Creek, which enter from the hills to the north, cross the subbasin along a southerly course, and flow into the Amador subbasin (see Figure 3).

The subbasin is bounded on the west by the Pleasanton Fault. The Parks Fault forms the southern boundary west of Santa Rita Road. East of this road the southern boundary is formed by a permeability barrier caused by the interfingering of alluvial fan sediments from the north and from the south. To the east, the subbasin boundary is formed by the Mocho Fault. The north boundary of the subbasin is formed by the contact between the valley-fill materials and the underlying Tassajara Formation.

Ground Water Occurrence, Movement, and Quality

Unconfined to semiconfined ground water occurs in varying amounts throughout the subbasin. The combined potentiometric surface of the various water-producing zones lies at about 10 to 25 feet below ground. This surface generally reflects the topography and slopes to the south at a gradient of about 70 feet per mile. Ground water apparently moves southward as far as Highway 580. South of the highway, it apparently moves westward, parallel to the permeability barrier, as far as Santa Rita Road. West of this point it moves southward through permeable zones overlying the trace of the Parks Fault and into the Amador subbasin.

Ground water in the Camp subbasin is a sodium bicarbonate water as represented by the analysis from Well 2S/1E-33M1 on Table 6. This ground water is of irrigation Class II and is a reflection of the sodium bicarbonate water occurring in the Tassajara Formation to the north and also that flowing southward in Tassajara Creek and Cottonwood Creek. Table 21 in Appendix B presents mineral analyses of surface waters from these two creeks which provide recharge to the Camp subbasin.

Description of Aquifer System

Ground water in the Camp subbasin occurs in beds of sandy clay and sandy gravel which overlie the Tassajara Formation. The thickness of these overlying materials ranges from 100 feet at Camp Parks to at least 300 feet immediately north of the Parks Fault. All of the water-bearing zones in the Camp subbasin have a southerly dip of from one to three degrees (see Section H-H', Figure 5).

Yield of Wells

There are no data available concerning ground water production in the Camp subbasin. It is estimated that domestic or stock supplies of ground water may be obtained from shallow wells nearly everywhere in the subbasin. Possible areas where supplies would be limited are adjacent to the hill front along the northern edge of the subbasin. South of Highway 580 it is estimated that there is a sufficient thickness of sediments to yield irrigation supplies of ground water from the valley-fill materials.

Because of the low permeability of the underlying Tassajara sediments, it is doubtful if yields from wells penetrating these deeper sediments would be increased significantly.

Subsurface Inflow and Outflow

There is no flow of ground water across the northern boundary of the subbasin due to a lack of hydraulic continuity between the valley-fill materials and the Tassajara Formation. No subsurface flow occurs across either the Pleasanton Fault on the west or across the Mocho Fault to the east because ground water flow is in a southerly direction, parallel to the faults.

That portion of the southern boundary of the subbasin east of Santa Rita Road is considered to be nearly a total barrier to ground water movement because ground water north of the barrier apparently moves in a westerly direction parallel to the barrier. West of Santa Rita Road, where the Parks Fault forms the subbasin boundary, there is a ground water gradient of about 40 feet per mile across the fault, and there appears to be some ground water outflow from the subbasin at this location.

Amador Subbasin

The Amador subbasin is located in the central portion of Livermore Valley Ground Water Basin. It contains a greater number of high production wells than any other subbasin in the valley. Most of the subbasin, which comprises 10,790 acres of valley lands, is used for agriculture and gravel extraction. Also included are 7,571 acres of contiguous uplands which are used principally for rangeland (see Figure 3).

Amador subbasin is drained by Arroyo Valle and Arroyo Mocho, the two principal streams of Livermore Valley. Minor streams such as Tassajara Creek, Cottonwood Creek, and Arroyo las Positas also cross the subbasin. All streams drain in a generally westward direction toward the adjacent Bernal subbasin.

The Amador subbasin is bounded on the east by the middle zone of the Livermore Fault and on the west by the Pleasanton Fault. The north boundary, east of

Santa Rita Road, is formed by a permeability barrier which has been formed by the interfingering of alluvial deposits. West of Santa Rita Road, the northern boundary is formed by the Parks Fault. The south boundary of the subbasin is formed partly by the contact of the water-bearing Livermore Formation with nonwater-bearing rocks and partly by the drainage divide between Livermore Valley and Sunol Valley.

Ground Water Occurrence, Movement, and Quality

Ground water occurs in the Amador subbasin in conditions ranging from unconfined to confined. Unconfined ground water occurs in near-surface zones, principally near the channel of Arroyo Valle and in the uppermost aquifer in the central part of the subbasin. Ground water in other parts of the subbasin is under some degree of confinement.

Although each water-bearing zone in the Amador subbasin has its own potentiometric surface, these surfaces all tend to have similar elevations at any one particular location. This potentiometric surface is fairly level in the western part of the subbasin where it is about 90 feet below the ground surface. In the eastern part of the subbasin, the surface slopes northwesterly at an average gradient of about 60 feet per mile just north of the Veterans' Hospital. Here the slope of the potentiometric surface approximates that of Arroyo Valle, and the depth to water is about 10 feet. North of Vallecitos Road the gradient steepens to about 120 feet per mile until it reaches a trough located just north of the gravel pits. In the trough the potentiometric surface lies about 100 to 150 feet below ground. North of the trough the potentiometric surface slopes upward toward the Parks Fault at a gradient of about 70 feet per mile. At this latter location the depth to water ranges from 20 to 50 feet.

Ground water in the Amador subbasin occurs as a good to excellent quality sodium bicarbonate, magnesium bicarbonate, and calcium bicarbonate water. On Table 6 the analysis from Well 3S/1E-3Q1 is typical for the sodium bicarbonate water. The water from this well is of irrigation Class II due to the presence of 1.8 mg/l of boron. The analysis from Well 3S/1E-11H1 is typical of the magnesium bicarbonate waters; this water is of excellent quality. The analysis from Well 3S/1E-13P2 is typical of the calcium bicarbonate waters. The sample taken from this well in July 1952 indicated that the water was of excellent quality. That taken in June 1966 showed that the quality had deteriorated to irrigation Class II on the basis of an increase in boron. The analysis from Well 3S/2E-28P1 is an irrigation Class II quality sodium chloride water. This water probably is derived from marine sediments which underlie the southern part of the subbasin at depths which may be as little as 200 feet.

Description of Aquifer System

Much of the ground water produced in the Amador subbasin is derived from thick water-bearing zones in the valley-fill material. These aquifers are composed of sandy gravel and sandy clayey gravel that are up to 150 feet in thickness. Separating the aquifers are confining beds of silty clay that are up to 50 feet in thickness. Many of the aquifers merge near the course of Arroyo Valle, where the combined aquifers are present as a deposit of sandy gravel up to 300 feet in thickness. To the north, the aquifers thin, become more clayey, and tend to pinch out near the northern edge of the subbasin.

Postdepositional folding has warped the valley-fill materials into a gentle syncline. On the south side of the Amador subbasin the sediments dip northward at about one to two degrees; those on the north dip southerly at three to four degrees. The total thickness of the valley-fill materials reaches a maximum of at least 500 feet along the axis of the syncline, which runs roughly east-west through the center of the subbasin.

Underlying the valley-fill materials at a slight unconformity is the Livermore Formation. This formation is composed of massive sandy gravel and cemented gravel that occurs in beds up to 200 feet in thickness separated by thin, discontinuous beds of clay. Sediments of the Livermore Formation make up the entire upland area south of Livermore Valley. Here they dip to the north at about five degrees. The sediments pass beneath the valley floor and attain a maximum depth of 500 feet near the axis of the syncline. North of the synclinal axis, the Livermore Formation beds rise in a northward direction as far as the Parks Fault, where fault movement has brought them into juxtaposition with the Tassajara Formation. At the fault, the depth to the top of the Livermore Formation sediments is about 300 feet.

Yield of Wells

Production data are available from 56 wells in the Amador subbasin. The yield of these wells ranges from 42 to 2,820 gallons per minute. The specific capacity ranges from 1.1 gallons per minute per foot of drawdown for a well drilled in the Livermore Formation to 217 gallons per minute per foot of drawdown for a well drilled in the valley-fill materials (see Figure 8).

Subsurface Inflow and Outflow

There is no ground water movement across the south boundary of the Amador subbasin because the boundary coincides with that of the ground water basin. The eastern boundary of the subbasin is formed by the middle zone of the Livermore Fault, which is an effective barrier to ground water inflow from the Mocho subbasin except in the vicinity of the ancestrial channel of Arroyo Mocho north of Oak Knoll, where ground water moves across this fault essentially unimpeded. This is shown on Figure 9 by the area of influence of magnesium bicarbonate water which originated in Arroyo Mocho. The northern boundary of the subbasin is formed in part by a permeability barrier and it is estimated that there is no flow of ground water across this barrier. The remainder of the boundary is formed by the Parks Fault, which allows some subsurface inflow.

The western boundary of the subbasin is formed by the Pleasanton Fault. Based on an average westward water level drop of 30 feet across this fault and the continuance of ground water quality characteristics across the fault, it is assumed that there is some subsurface flow westward to the Bernal subbasin.

Mocho Subbasin

The Mocho subbasin is one of the three most important subbasins in Livermore Valley Ground Water Basin. It is the largest subbasin, occupying 9,181 acres of valley lands and 13,946 acres of contiguous uplands. The subbasin is the location of the City of Livermore, the principal community in the valley. Outside of the city, the valley area is devoted to agriculture and industry, while the contiguous uplands are principally rangeland (see Figure 3).

Arroyo Seco and Arroyo Mocho are the principal streams draining the Mocho subbasin. However, Cayetano and Altamont Creeks join near the subbasin boundary and flow across the subbasin as Arroyo de las Positas.

The Mocho subbasin is bounded on the east by the Tesla Fault and on the west by the central zone of the Livermore Fault. To the north is a contiguous ground water terrain made up of the Tassajara Formation. This terrain has no hydrologic continuity with the subbasin. To the south the valley floor blends into the Livermore Uplands, which in turn lap onto a mountainous area composed of nonwater-bearing marine rocks.

The Mocho subbasin has been divided into Mocho I (eastern) and Mocho II (western) provinces. The Mocho I province is drained by Arroyo Seco, while Mocho II province is drained by Arroyo Mocho.

Some degree of hydraulic continuity exists laterally between most members of the two provinces except there is an apparent lack of hydraulic continuity between near-surface materials in the Mocho I province and related materials in the Mocho II province.

Ground Water Occurrence, Movement, and Quality

Ground water in the Mocho subbasin ranges from unconfined in near-surface zones to confined in the deeper zones. Each water-bearing zone has its own potentiometric surface. Shallow, unconfined ground water generally is within 25 feet of the ground surface. This body of ground water has a water level surface which slopes generally northward or northwestward at about 20 feet per mile.

Deeper confined ground water generally has a potentiometric surface which lies from 75 to 150 feet below ground. A number of wells in the subbasin tap zones of confined ground water having a potentiometric surface that is much shallower, and several wells tap zones having potentiometric surfaces that are above ground. Of the latter, Well 3S/2E-14Q1 is a flowing well which has a potentiometric surface two feet above ground. The uppermost perforated zone in this well is at a depth of 419 feet and the total head of this perforated zone is 421 feet.

Ground water in the Mocho subbasin generally is a fair to excellent quality sodium bicarbonate and magnesium bicarbonate water. The analysis from Well 3S/1E-1G1, on Table 6, is typical of the excellent quality sodium bicarbonate waters. The sample taken in July 1952 from Well 3S/2E-8H1 indicated that the water was an irrigation Class II sodium bicarbonate water. The well was sampled in August 1969 and indicated an irrigation Class II magnesium bicarbonate water. In both cases the water contained boron equal to or in excess of 0.5 mg/l. The analysis from Well 3S/2E-12M1 is typical for the Class III sodium bicarbonate waters. This poor quality water contains 9.1 mg/l of elemental boron and an excessive amount of sodium ion. A mixture of three water types occurs in a small area in the south-central part of the subbasin. Table 6 presents analyses of these three water types. That from Well 3S/2E-22E1 is of an excellent quality magnesium bicarbonate water that has been derived principally from alluvial materials receiving recharge from Arroyo Mocho. The analysis from adjacent Well 3S/2E-22E2 is of a Class II sodium chloride water of indeterminate origin. A short distance south, Well 3S/2E-22M1 yields a Class III sodium sulfate water. This water is similar in many respects to sodium and calcium sulfate ground water occurring in the marine sediments to the east.

Description of Aquifer System

The water-bearing materials in the portion of the Mocho I province adjacent to East Avenue (T3S, R2E, Sections 11 and 14) consist of a thin veneer of valley-fill materials not over 50 feet in thickness. These overlie a sequence of sediments of the Livermore Formation that are at least 600 feet thick. The valley-fill materials are composed of sand, gravel, and cemented gravels which are essentially flat-lying. They extend westward from the Spring subbasin and lap onto the nearly buried ridge of Livermore Formation sediments, which separates the two Mocho provinces.

Ground water contained in the valley-fill materials of the Mocho I province is recharged from near-surface materials in the Spring subbasin. This shallow ground water is almost completely isolated from shallow ground water in the Mocho II province by the buried ridge separating the two provinces.

The valley-fill portion of the Mocho I province, near Tesla Road (T3S, R2E, Section 24) consists of a heterogenous mixture of gravelly fan detritus overlying truncated beds of the Livermore Formation. This fan detritus is estimated to be not more than 25 feet in thickness. It contains shallow, unconfined ground water which apparently moves westward from Arroyo Seco toward Arroyo Mocho.

The valley-fill materials in the Mocho II province consist of deposits along the course of Arroyo Mocho, which merge with gravelly fan detritus near Tesla Road. The deposits along Arroyo Mocho are estimated to be not over 30 feet in thickness. North of Tesla Road the valley-fill materials become separated into identifiable strata consisting of beds of sandy gravel and cemented gravel separated by beds of silt and clay. Here the valley-fill materials are thickest along the course of the antecedent Arroyo Mocho. This buried stream channel leaves the present course of Arroyo Mocho near Tesla Road, runs roughly parallel to the Mocho Fault as far as Oak Knoll, and then turns westward toward the Amador subbasin, passing to the north of Oak Knoll. The valley-fill materials in this buried channel consist mainly of permeable sand, gravel, and boulders. Adjacent to the channel are less permeable ancient floodplain deposits consisting of stratified beds of silt and clay separated by beds of sand and gravel which represent periods of overwash.

Underlying the valley-fill materials throughout the Mocho subbasin are sediments of the Livermore Formation. These sediments also constitute the uplands north and south of the valley floor. There apparently is little discontinuity in the Livermore Formation sediments across the Mocho Fault or between Mocho I and Mocho II provinces.

The Livermore Formation consists of a thick sequence of aquifers comprised of sandy gravel and cemented gravel. These are separated by thinner aquitards of silty clay and clayey gravel. Postdepositional warping has folded the Livermore Formation into a syncline whose axis runs east-west through the City of Livermore. Beds on the south limb of the syncline dip to the north at from five to ten degrees, those beneath the valley floor are nearly horizontal, and those on the north limb of the syncline dip to the south at from ten to twenty degrees.

Beneath the valley floor some of the upper beds of the Livermore Formation have been truncated by erosion. These are now covered by valley-fill materials which provide a source for some recharge. Similarly some beds of the Livermore Formation have been exposed during downcutting of the antecedent Arroyo Mocho. These exposed beds are now buried by channel fill and may provide some degree of recharge to the valley-fill materials (see Sections B-B' through E-E', Figure 5).

Yield of Wells

Production data are available from 32 wells in the Mocho subbasin. The yield of these wells ranges from 99 gallons per minute to 950 gallons per minute. The specific capacities of wells in this subbasin range from 2.1 gallons per minute per foot of drawdown for a well drilled into the Livermore Formation, to 49 for a well drilled into coarse material near Arroyo Mocho (see Figure 8).

Subsurface Inflow and Outflow

To the north, the Mocho subbasin is in contact with the contiguous ground water upland formed by the Tassajara Formation. There is no subsurface flow across the boundary because of a lack of hydraulic continuity. There is also no flow of ground water across the southern boundary of the subbasin which is at the contact between the Livermore Formation and the nonwater-bearing marine rocks.

The eastern boundary of the subbasin is formed by the Tesla Fault, which separates the subbasin from the Spring subbasin. Above a depth of 50 feet, the Tesla Fault does not transect the aquifers and does not restrict subsurface flow into the subbasin. Below a depth of 50 feet, the elevation and configuration of the potentiometric surfaces are different on opposite sides of the fault zone, and it is concluded that the Tesla Fault transects the aquifers below this depth.

The western boundary of the Mocho subbasin is formed by the middle zone of the Livermore Fault group. This middle zone has a marked effect on adjacent water levels. For example, near Oak Knoll there are two wells that are of similar depth and construction and are located on opposite sides of the fault. Difference in water levels between the two wells is on the order of 150 feet, and indicates that subsurface flow from Mocho subbasin to Amador subbasin is greatly restricted by the Livermore Fault. Farther north, in the vicinity of the ancestral Arroyo Mocho channel, ground water moves essentially unimpeded across the fault zone. The breaching of the Livermore Fault by the ancestral Arroyo Mocho is confirmed by the continuity of ground water quality from the surface flow of Arroyo Mocho in the hills to ground water in the Mocho II province and in the northern portion of the Amador subbasin.

Cayetano Subbasin

The Cayetano subbasin is located in the northern part of Livermore Valley Ground Water Basin. It covers 562 acres of valley lands and is drained by Cayetano Creek, which flows southward across the subbasin. To the west, south, and east, are sediments of the Tassajara Formation, which constitute a separate ground water terrain. To the north is the Tesla Fault, which separates this subbasin from the adjacent May subbasin (see Figure 3).

Ground Water Occurrence, Movement, and Quality

Ground water occurs in limited amounts in the valley-fill materials which overlie the Tassajara Formation. Most ground water produced in this subbasin is derived from these underlying continental sediments. The combined potentiometric surface of ground water in the valley-fill materials and in the Tassajara Formation is about 10 to 20 feet below ground. This combined surface slopes southward at a gradient of about 15 feet per mile.

There is only one analysis of ground water available from the Cayetano subbasin. This analysis, from Well 2S/2E-32D1, shown on Table 6, is of an irrigation Class II sodium bicarbonate water. The water from the well contains 0.74 mg/l of elemental boron and an excessive amount of sodium ion.

Description of Aquifer System

The principal aquifer in the valley-fill materials is a flat-lying bed of sand and gravel which occurs between a depth of 25 and 40 feet. Ground water contained in this bed is partially confined by overlying silty clays.

The aquifers of the Tassajara Formation consist of beds of sandstone and tuffaceous sandstone, which dip northward at up to 30 degrees along the south flank of a syncline. Ground water contained in these lower aquifers is confined (see Section D-D', Figure 5).

Yield of Wells

There are no data available concerning the yield of ground water to wells in the Cayetano subbasin. Small yields of ground water may be derived from shallow wells tapping only the valley-fill materials. However, more reliable yields may be obtained from wells which also tap the deeper aquifers of the Tassajara

Formation. Even then, however, wells may be expected to yield only quantities of ground water sufficient for domestic or stock purposes.

Subsurface Inflow and Outflow

The Cayetano subbasin is nearly surrounded and is underlain by sediments of the water-bearing Tassajara Formation. There is little hydrologic continuity between the Tassajara Formation and the overlying valley-fill materials.

It is assumed that there is no appreciable ground water movement across the Tesla Fault because there is no water level differential and there is a lack of appreciable thickness of valley-fill materials north of the fault.

The Cayetano subbasin, although an integral part of Livermore Valley Ground Water Basin, is nearly isolated from the remainder of the valley as far as ground water is concerned.

Because the potentiometric surface slopes to the south, ground water moves in this direction, probably surfaces along Cayetano Creek, and moves out of the subbasin as surface outflow.

May Subbasin

The May subbasin, located in the northern part of Livermore Valley Ground Water Basin, occupies 2,433 acres of valley lands devoted entirely to agriculture. The subbasin is drained by Cayetano and Altamont Creeks, which cross the subbasin in southerly and southwesterly directions, respectively (see Figure 3).

The subbasin is bounded on the west and north by rolling hills composed of sediments of the Tassajara Formation. It is bounded on the south by the Tesla Fault, on the east by an unnamed fault, and on the northeast by the Carnegie Fault.

Ground Water Occurrence, Movement, and Quality

Ground water occurs only in limited amounts in a relatively thin veneer of valley-fill materials which overlie a thick section of sediments belonging to the Tassajara Formation. Some ground water is produced from the valley-fill materials, but most is produced from the underlying sediments.

There are no data available relative to the depth to water in the valley-fill materials. But, as the total thickness of valley-fill materials does not exceed 40 feet, the depth to water in these materials is probably considerably less than 40 feet. The potentiometric surface of ground water in the underlying Tassajara Formation ranges from 30 to 50 feet below ground. This latter surface slopes southward at an average gradient of about 80 feet per mile in the northern part of the subbasin and about 10 feet per mile in the southern part. Ground water in the Tassajara Formation is generally confined, while that in the overlying valley-fill materials is unconfined.

There is only one analysis of ground water from the May subbasin. The analysis from this well, Number 2S/2E-16N1 shown on Table 6, indicates that ground water in the northern part of the subbasin is an irrigation Class II sodium chloride water. Although analyses are not available, it may be assumed that ground water throughout most of the remainder of the subbasin is similar to that described for the Cayetano subbasin.

Description of Aquifer System

Based on the few logs of wells available from the May subbasin, the valley-fill materials consist of thin beds of sandy gravel and sandy clay separated by equally thin beds of silt and clay. All of these materials dip southeastward at from one to three degrees.

Below the valley-fill materials are beds of sand and gravel, clay and gravel, clay, and silty clay belonging to the Tassajara Formation. These beds, which range up to 50 feet in thickness, dip southward at an average gradient of ten degrees, as they are on the north limb of a syncline (see Sections A-A' and D-D', Figure 5).

Yield of Wells

There are no production data available from wells tapping the valley-fill materials in the May subbasin. It is estimated that due to the relative thinness of materials, only a meager supply of ground water could be obtained from domestic wells tapping only the valley-fill materials.

Similarly, there are no production data available from wells tapping the deeper Tassajara aquifers. Although deeper wells may be capable of producing sufficient quantities of ground water for stock or domestic uses, it is unlikely that adequate irrigation supplies could be obtained.

Subsurface Inflow and Outflow

The May subbasin is bounded on the northerly and westerly sides and underlain at shallow depth by sediments of the Tassajara Formation. There is little hydraulic continuity between the Tassajara Formation and the valley-fill materials, and consequently no appreciable subsurface flow between them.

The south boundary of the May subbasin is formed by the Tesla Fault. Movement along this fault has brought Tassajara Formation sediments to the south into juxtaposition with valley-fill materials to the north; it is assumed that there is no flow of ground water across this fault.

The northeastern boundary of the May subbasin is formed by the Carnegie Fault. Because water levels slope southward from the Vasco subbasin toward the May subbasin, it is assumed that there is a flow of ground water across the fault zone and into the May subbasin.

The east boundary is an unnamed fault which does not transect the near surface aquifers in the valley-fill materials. This leads to the assumption that there is a small amount of subsurface outflow across the boundary fault and into the adjacent Spring subbasin.

Spring Subbasin

The Spring subbasin, located in the eastern portion of Livermore Valley Ground Water Basin, occupies 4,097 acres of valley lands and 682 acres of contiguous uplands. Development of the subbasin is agriculture, urban, and industry. The major drainage is Altamont Creek, which crosses the northern part of the subbasin along a southwesterly course (see Figure 3).

The subbasin is bounded on three sides by faults: the Tesla, Carnegie, and an unnamed fault. The fourth, or southeast side is formed by the drainage divide in the water-bearing uplands and also in part by the water-bearing materials lapping onto nonwater-bearing rock.

Ground Water Occurrence, Movement, and Quality

Ground water occurs in variable amounts in both the valley-fill materials and in the underlying sediments of the Livermore Formation. Ground water occurring in shallow zones of the valley-fill materials is essentially unconfined. In the deeper zones of the Livermore Formation, ground water is under some degree of confinement.

Each water-bearing zone within the subbasin has its own potentiometric level. The near-surface zone, within 100 feet of the ground surface, has a potentiometric surface ranging from 15 feet to 80 feet below ground. This potentiometric surface is essentially flat-lying, but in certain local areas it has a slight northward slope of about 10 feet per mile. Due to a local pumping depression, a southward gradient of about 100 feet per mile was noted immediately north of the unnamed fault in Section 2, T3S, R2E.

The potentiometric surface in the deeper Livermore Formation is at a depth of about 175 feet below the ground surface. The potentiometric surface slopes northward at about 50 feet per mile, or roughly parallel to the ground surface.

Much of the ground water in the Spring subbasin is of sodium chloride character and is assigned to irrigation Class II and III. The analysis from Well 3S/2E-2B1, shown on Table 6, is typical of this poor quality water, which may be related to similar poor quality water in the marine sediments to the east. In the northwestern part of the subbasin is found a Class II sodium bicarbonate water typified by the analysis from Well 3S/2E-2F1 on Table 6. The water from this well has a conductivity in excess of 1,000 micromhos and contains 1.0 mg/l of elemental boron.

Description of Aquifer System

The Spring subbasin is composed of a wedge-shaped sequence of water-bearing strata. These strata lap onto an underlying surface of nonwater-bearing rocks which rise in the northward direction from a depth of about 300 feet near East Avenue to less than 50 feet near Altamont Creek.

The water-bearing sequence is divisible into two parts, the Livermore Formation and the valley-fill materials. The Livermore Formation is composed of beds of cemented gravel, sandy gravel, and sandy clay separated by beds of less permeable clay and silty clay. Aquifers in this formation are up to 70 feet in thickness and dip northward at from 5 degrees to 20 degrees. They lap onto the underlying nonwater-bearing rocks at a depth of 400 feet near East Avenue and at a depth of 250 feet farther north.

The valley-fill materials are of similar composition to the sediments of the Livermore Formation, as they are composed principally of reworked Livermore Formation detritus. The water-bearing zones of the valley-fill materials dip northward at from one to five degrees and lap onto the nonwater-bearing rocks as far north as Highway 580. North of the highway the surface of the nonwater-bearing rocks becomes level and the valley-fill materials lie conformably thereon.

The valley-fill materials within 50 feet of the ground surface are not disrupted by the Tesla Fault. These near-surface aquifers continue uninterrupted from the Spring subbasin into the Mocho subbasin; and ground water in these aquifers is consequently free to move down gradient from the Spring subbasin into the Mocho subbasin (see Sections A-A' and B-B', Figure 5).

Yield of Wells

There are production data available from only two wells in the Spring subbasin. They yield 205 gallons per minute and 525 gallons per minute, and their specific capacities are 4.0 and 4.6 gallons per minute per foot of drawdown, respectively (see Figure 8).

Subsurface Inflow and Outflow

There are very small amounts of subsurface inflow from the Altamont subbasin and from the May subbasin. The Tesla Fault, to the west, acts as a partial barrier to the movement of ground water below a depth of 50 feet. This is illustrated by noting that water levels near East Avenue, in zones below a depth of 50 feet, are about 10 to 20 feet lower to the east than on the west side of the fault. In contrast, about a mile to the northwest, near South Vasco Avenue, water levels in similar zones are lower on the west side of the fault by about 20 feet. This difference in water levels can be explained in part by ground water recharge from Arroyo Seco, near East Avenue, and by the pumping patterns west of the fault, near South Vasco Avenue.

Because the potentiometric surface of zones below a depth of 50 feet have a general westward slope across the Tesla fault, it is estimated that there is a subsurface outflow of ground water from the Spring subbasin into the Mocho subbasin.

Vasco Subbasin

Vasco subbasin is the smallest unit in Livermore Valley Ground Water Basin. It occupies 568 acres in the northeastern portion of the valley. The subbasin is surrounded on three sides by marine nonwater-bearing rocks. It is bounded on the fourth side by the Carnegie Fault, which separates this subbasin from the May subbasin and Spring subbasin to the south (see Figure 3).

Ground Water Occurrence, Movement, and Quality

Ground water in the Vasco subbasin occurs in valley-fill materials which are estimated to be not over 100 feet in thickness. Ground water is partially confined and the potentiometric surface is at a depth which ranges from 40 feet in the northern part of the subbasin to 10 feet near the Carnegie Fault. The potentiometric surface slopes from the hillfront southward toward the Carnegie Fault at an average gradient of about 70 feet per mile.

There are no quality data available from the Vasco subbasin. It may be assumed that most ground water in this subbasin is similar to the sodium chloride water shown for Well 2S/2E-16N1 in the May subbasin.

Description of Aquifer System

Based on the few well logs available from the Vasco subbasin, ground water occurs mainly in a sand which occurs between depths of from 85 to 100 feet. This aquifer apparently rests directly on nonwater-bearing rocks. It is overlain by beds of sandy clay which yield little ground water. The sand apparently has been truncated on the south by movement along the Carnegie Fault.

Yield of Wells

There are no production data from wells in the Vasco subbasin. However, it is estimated that wells here could adequately serve domestic or stock needs, but it is doubtful that irrigation supplies could be obtained.

Subsurface Inflow and Outflow

The Vasco subbasin is underlain and nearly surrounded by nonwater-bearing rock; therefore, subsurface inflow into the subbasin is considered to be nonexistent. There does not appear to be any water level differential across the Carnegie Fault and it can be assumed that the fault has little, if any, effect on the movement of ground water. Since ground water levels slope southward across the fault, it is presumed that there is an outflow of ground water from the Vasco subbasin to the May and Spring subbasins to the south.

Altamont Subbasin

The Altamont subbasin is located in the northeastern part of Livermore Valley Ground Water Basin. It occupies 1,476 acres of valley lands and is drained by Altamont Creek and other tributaries, which debouch from the hills to the east and flow across the subbasin on a westward course. The subbasin is bounded on three sides by nonwater-bearing rocks and on the fourth side by the Carnegie Fault, which separates this subbasin from the Spring subbasin to the west (see Figure 3).

Ground Water Occurrence, Movement, and Quality

Ground water in the Altamont subbasin occurs in valley-fill materials which are estimated to be up to 200 feet in thickness. The potentiometric surface of ground water contained within the valley-fill materials is about 30 feet below ground, and slopes toward the southwest at a gradient of about 100 feet per mile.

Ground water in the Altamont subbasin is a poor quality sodium chloride water reflective of much of the surface water draining the marine sediments to the east. The analysis from Well 2S/2E-25N1, on Table 6, is typical of this sodium chloride water, which is of irrigation Class III.

Description of Aquifer System

Ground water occurs in a number of beds of sandy gravel and sandy clay which are separated by less permeable beds of silt and clay. These sediments, which are primarily valley-fill materials, have been truncated to the west by movement along the Carnegie Fault. The beds dip uniformly southwestward at from three to six degrees (see Section J-J', Figure 5).

Yield of Wells

There are no data available concerning the yield of wells in the Altamont subbasin. It is estimated that sufficient water can be derived from wells for domestic or stock purposes. However, it is doubtful that reliable supplies of irrigation quantities of ground water can be derived from wells in the Altamont subbasin.

Subsurface Inflow and Outflow

Because the Altamont subbasin is nearly surrounded by nonwater-bearing rocks, as well as being underlain by the same, there is no subsurface inflow into the subbasin.

There is a water level difference of about 150 feet across the Carnegie Fault, with levels west of the fault being lower. This indicates that there is very little subsurface outflow to the Spring subbasin.

CHAPTER III. GROUND WATER IN SUNOL VALLEY

Sunol Valley Ground Water Basin is divisible into three subbasins on the basis of faults, topography, and hydrology. The three subbasins and their respective areal extent are listed on Table 1; the areal extent of the three basins is shown on Figure 2. Typical ground water quality analyses from each subbasin are shown on Table 6.

Sunol Subbasin

The Sunol subbasin occupies the entire western side of Sunol Ground Water Basin and contains 3,395 acres of valley-fill materials and 1,895 acres of contiguous uplands. The entire western side and the north and south portions of the eastern side of the subbasin are bounded by nonwater-bearing rocks. The central portion of the eastern side is bounded by the Maguire Peaks Fault, which separates the subbasin from the Vallecitos and La Costa subbasins. The extreme northern boundary of the subbasin is formed by the Verona Fault, which separates Sunol and Livermore Valley Ground Water Basins (see Figure 2).

Surface drainage within the subbasin is provided by Alameda, Vallecitos, and San Antonio Creeks, and also Arroyo de la Laguna. Surface drainage out of the subbasin is by way of Alameda Creek.

Ground Water Occurrence, Movement, and Quality

Ground water in Sunol subbasin is both confined and unconfined. The combined potentiometric surface of both ground water bodies slopes to the northwest and is near the ground surface.

Ground water in the Sunol subbasin generally is an excellent quality sodium bicarbonate to calcium bicarbonate water, as represented by the analyses from Wells 4S/1E-20B1 and 4S/1E-20K1 on Table 6. Several wells less than 25 feet deep are reported to have amounts of nitrate and chloride ion in excess of U. S. Public Health standards.

Description of Aquifer System

The aquifer system in the Sunol subbasin consists of valley-fill materials which overlie sediments of the Livermore Formation. The total thickness of the two units is not great except in the area between the Calaveras and Sinbad Faults, where the total thickness may exceed 500 feet. The total thickness of water-bearing materials west of the Sinbad Fault is less than 200 feet; in the remaining valley floor areas it is less than 100 feet.

Eight well logs are available for the subbasin. These indicate that sediments beneath the valley floor are composed largely of sand and gravel with discontinuous layers of clay. The only significant thickness of clay near the ground surface is reported on one log of a well in the northern portion of the valley floor area. The 16-foot thick clay layer reported on the log suggests the presence of a bed that may confine ground water and restrict infiltration of surface water.

The permeable nature of the alluvium in the south-central portion of the valley floor is shown on three well logs by extensive gravel beds in the stream channel of Alameda Creek, and by the presence of off-stream gravel beds.

Recharge in the Sunol subbasin occurs by infiltration of surface water along Alameda Creek, Arroyo de la Laguna, San Antonio Creek, and Vallecitos Creek. Some ground water flows into the alluvium from the Livermore Formation in the uplands, but this contribution is minor.

At depth, the Sinbad and Calaveras Faults separate the Livermore Formation from nonwater-bearing rocks and no ground water movement across these two faults is expected. At shallow depths the faults may act as a partial barrier between the Livermore Formation and the valley-fill materials.

In the south portion of the subbasin, permeable alluvium is underlain at shallow depth by nonwater-bearing rocks which are exposed in the bordering highlands (see Section K-K', Figure 5).

Yield of Wells

There are no pump test data from wells in the Sunol subbasin. Limited bailer test data from two domestic wells indicate that wells from 100 to 300 feet in depth should yield up to 20 gallons per minute.

The largest ground water extractions in the subbasin have occurred at the Sunol filter galleries, which consist of a system of underground concrete pipes buried at depths of about 15 feet below ground surface and perforated to accept ground water. The galleries are a unit of the San Francisco Water System.

Subsurface Inflow and Outflow

Subsurface inflow from Vallecitos and La Costa subbasins to the east is minimal due to the Maguire Peaks and Calaveras Faults and to the thin depths of alluvium in the channels of Vallecitos and San Antonio Creeks. Subsurface outflow is nonexistent due to the presence of Sunol Dam, which is located at the outlet of the subbasin and which is founded on nonwater-bearing rock.

Vallecitos Subbasin

The Vallecitos subbasin occupies a rolling terrain immediately to the northeast of Sunol subbasin. The subbasin comprises 3,278 acres of upland and 912 acres of valley floor lands. The latter constitutes Vallecitos Valley. The west side of the subbasin is delineated by the Maguire Peaks Fault, which separates this subbasin from the Sunol subbasin. To the south and east, the drainage divide between Vallecitos Valley and La Costa Valley forms the subbasin boundary. The north boundary of the subbasin is formed by the drainage divide separating Sunol Valley Ground Water Basin and Livermore Valley Ground Water Basin (see Figure 2).

Surface drainage within the subbasin is provided by Vallecitos Creek, which flows from the subbasin at its west side and subsequently enters Alameda Creek.

Ground Water Occurrence, Movement, and Quality

Ground water in Vallecitos subbasin is present under both confined and unconfined conditions. The combined potentiometric slope of the ground water roughly follows the ground surface as it slopes toward the center of Vallecitos Valley and thence slopes westward toward the low end of the subbasin.

Ground water in the Vallecitos subbasin ranges from a calcium bicarbonate and magnesium bicarbonate to a sodium chloride water as shown on Table 6 by the analyses from Wells 4S/1E-2K1, 4S/1E-2L1, 4S/1E-2N1, and 4S/1E-10J1. It is interesting to note that the analysis from Well 4S/1E-2N1 is an irrigation Class II water, while that from adjacent Well 4S/1E-2L1 is a sodium chloride water of excellent quality. The high nitrate concentration of 149 mg/l at Well 4S/1E-2K1, may be due to percolation from surface sources.

Description of Aquifer System

Four well logs are available from the Vallecitos subbasin. These logs indicate that ground water is contained in zones of sandy clay and cemented gravels of the Livermore Formation. Depths to water at three of the wells range from 48 to 71 feet. A well located near the central part of the subbasin reportedly flowed at 7 gallons per minute when drilled in 1964. Recharge to the subbasin occurs by infiltration of surface water draining the rolling terrain along Vallecitos Creek and its tributaries.

Yield of Wells

Yield data are available from two wells in the Vallecitos subbasin. Both wells produce from the Livermore Formation, and yield 4 gallons per minute with a 10-foot drawdown; their specific capacities are both 0.4 gallons per minute per foot of drawdown.

Subsurface Inflow and Outflow

Subsurface inflow of ground water into the Vallecitos subbasin is considered to be negligible due to the nature of the subbasin boundaries. There is little outflow from the subbasin due to the impermeability of the Maguire Peaks Fault zone.

La Costa Subbasin

The La Costa subbasin is situated in rolling terrain in the southeastern portion of the Sunol Ground Water Basin. The subbasin comprises 4,230 acres of uplands and 710 acres of valley lands. A major feature of La Costa subbasin is James H. Turner Dam and San Antonio Reservoir, a part of the San Francisco Water Department Hetch Hetchy facilities. The reservoir, which has a maximum storage capacity of 50,500 acre-feet, covers a maximum of 825 acres of valley floor and bordering uplands. Surface drainage within the subbasin is by way of San Antonio Creek and its tributaries. All internal drainage enters San Antonio Reservoir. Surface outflow from the subbasin is controlled by Turner Dam (see Figure 2).

Ground Water Occurrence, Movement, and Quality

There are no data available concerning ground water conditions or quality in the La Costa subbasin. It may be reasonably assumed that ground water moves down slope toward San Antonio Reservoir. The quality of ground water in the subbasin is probably very similar to that found in the Vallecitos subbasin immediately to the north.

Description of Aquifer System

There are no well log data available for the La Costa subbasin. It may be assumed that ground water occurs in zones of sandy clay and cemented gravel very similar to that in the Vallecitos subbasin.

Yield of Wells

Because there are no well yield data available from this subbasin, it may be assumed that wells completed in this subbasin should have a specific capacity of about 0.4 gallons per minute per foot of drawdown.

Subsurface Inflow and Outflow

Subsurface inflow of ground water into the La Costa subbasin is considered negligible because of the nature of the subbasin boundaries. Subsurface outflow from the subbasin is nonexistent due to the presence of Turner Dam, which is founded on impermeable, nonwater-bearing rock.

CHAPTER IV. HISTORIC SUPPLY, USE, AND DISPOSAL OF WATER IN LIVERMORE VALLEY

To evaluate how a ground water basin stores and transmits water requires knowledge of water use in addition to geology, hydrology, and water quality. In terms of a hydrologic system, the amount of water supplied to the basin must all be accounted for by change in the amount of water in storage, consumption of water, and outflow from the basin. This relationship is stated by a quantitative statement called the hydrologic equation:

INFLOW - OUTFLOW = CHANGE IN STORAGE

For the portion of the hydrologic system relating directly to ground water, the terms are defined as follows:

INFLOW = recharge from rain + recharge from applied water + recharge from streams + artificial recharge + subsurface inflow.

OUTFLOW = pumpage + evapotranspiration by phreatophytes + rising water + subsurface outflow.

CHANGE IN STORAGE = change in amount of ground water in storage.

The interrelation between elements in such a system is shown on Figure 16. Each of the inflow and outflow items in the hydrologic equation is determined annually over a period of recent years and tested for accuracy by comparing the net amount (inflow - outflow) to the change in ground water storage.

Study Period

Precipitation in the study area serves as the best index to water supply for a ground water basin because it is the original source of most of the water supply to the basin. Hydrologic conditions during the study period should reasonably represent the long-time hydrologic conditions. A wide range of conditions, wet, dry, and normal years, should be represented during a study period. The period should both begin and end after a period of subnormal precipitation to minimize the amount of infiltrating water in transit to the ground water body.

The 9-year study period from the 1961-62 to 1969-70 water years was selected as a period when conditions in Livermore Valley most nearly met the above criteria. The relationship between precipitation during the 9-year study period and that during the 100-year period of record at the National Weather Service Livermore Station is shown graphically on Figure 14. The mean annual precipitation during the 9-year study period is 14.27 inches, and compares favorably with the mean for the 100-year period of record, 1872-1971, of 14.58 inches.

Land use surveys were conducted in Livermore Valley during 1949-50, 1965-66, and 1969-70. Records of land use, water levels, and ground water pumpage are almost nonexistent prior to 1950.

Ground Water Model

A mathematical model was developed to represent the Livermore ground water basin. The model uses a series of complex mathematical equations to simulate the reactions of the ground water basin to changing conditions. Solution of these equations, which is accomplished through the use of a digital computer, enables the prediction of water levels under certain given conditions dependent on factors in the hydrologic equation. After verification, the model is a valuable tool which can be used by local agencies to evaluate alternate plans for meeting future water needs of the valley.

The first step in developing the model was to subdivide the valley into small areas called nodes. The number of nodes and their configuration was based on geologic and hydrologic knowledge. The perimeter and base of the model was taken as the surficial contact between the alluvium and the underlying Tassajara and Livermore Formations.

Although the Livermore Formation is included in the ground water basin, it was excluded from the ground water model because it was not considered feasible to develop a two-layer model of the ground water system. The 45 nodes of the Livermore model are shown on Figure 17. Many of the boundaries of the nodes were determined by the numerous faults which cross the valley.

For use by the model, the items of inflow and outflow are combined into an item called net recharge. Computer input consists of annual values for each node of net recharge and water levels plus constant amounts of transmissivity, specific yield, storage coefficient, and the numbers describing the physical limits of the model. Output from the model is the theoretical water levels based on net recharge and the historic water levels. The net recharge, transmissivity, and water levels for each node were adjusted until the best agreement between computed and historic water levels was obtained. All adjustments were based on the accuracy of the data items and within the probable values. Changes in hydrology were applied uniformly to the entire model. The physical constants of the model are listed in Table 7. In determining values for items in the hydrologic equation, a surface balance was made for the entire valley and subbalances were made for major parts of the valley using stream gaging stations as outflow points.

Precipitation

Annual mean precipitation is shown by contour lines on Figure 20, which also shows the locations of precipitation stations. Annual amounts of precipitation for the Livermore station are shown on Table 8. Relative wetness is also listed on Table 8, and is shown graphically on Figure 14.

Streamflow

The five major streams entering Livermore Valley are Arroyo las Positas, Arroyo Mocho, Arroyo Valle, Alamo Creek, and Tassajara Creek. The only streams with records of flows during all of the study period are Arroyo Mocho and Arroyo Valle. The other streams have flow records for the period 1912 to 1930. To correct the deficiencies in the streamflow data, the stream gaging station on Arroyo de la Laguna was reactivated in 1969 and a new gaging station was established on a tributary to Arroyo Mocho. Records of stream gaging stations are presented on Table 9.

TABLE 7

PHYSICAL CONSTANTS OF LIVERMORE VALLEY MODEL

Node No.	Area (acres)	Ground Elevation (feet)	Depth of Alluvium (feet)
1	1,258	420	100
2	215	430	100
3	372	390	100
4	428	380	100
5	424	400	100
6	501	350	100
7	532	350	100
8	270	390	40
9	244	370	50
10	498	340	35
11	295	380	90
12	628	335	60
13	457	322	87
14	352	325	75
15	413	322	272
16	466	318	168
17	301	360	20
18	679	334	434
19	703	320	270
20	534	320	130
21	802	360	100
22	544	338	238
23	414	337	387
24	503	340	465
25	883	340	290
26	953	345	445
27	823	358	108
28	388	375	125
29	388	362	362
30	718	360	410
31	1,213	330	380
32	235	410	110
33	165	390	240
34	683	398	248
35	2,357	402	302
36	1,753	480	80
37	259	325	93
38	867	400	200
39	1,839	493	143
40	913	550	75
41	1,624	750	100
42	686	545	70
43	1,658	552	52
44	1,366	750	50
45	3,958	557	157
Total Nodal Area	35,562		

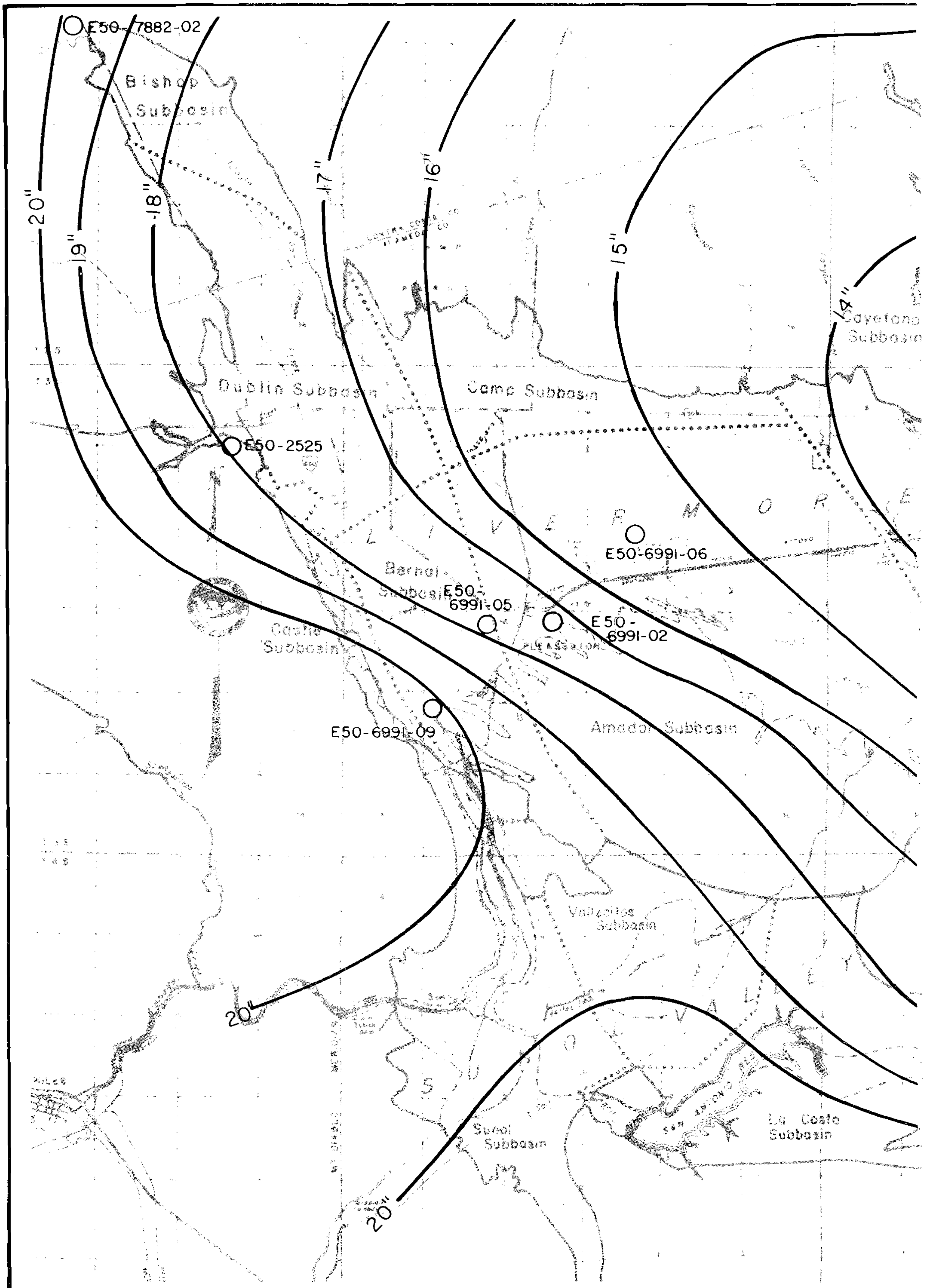

E50-7882-02
Bishop Subbasin
20"
19"
18"
17"
16"
15"
14"
Cayetano Subbasin
Dublin Subbasin
Camp Subbasin
E50-2525
L I V E R M O R E
E50-6991-06
Bernal Subbasin
E50-6991-05
E50-6991-02
Castle Subbasin
E50-6991-09
Amador Subbasin
Vallecitos Subbasin
Sunol Subbasin
La Costa Subbasin
20"
20"

FIGURE 20

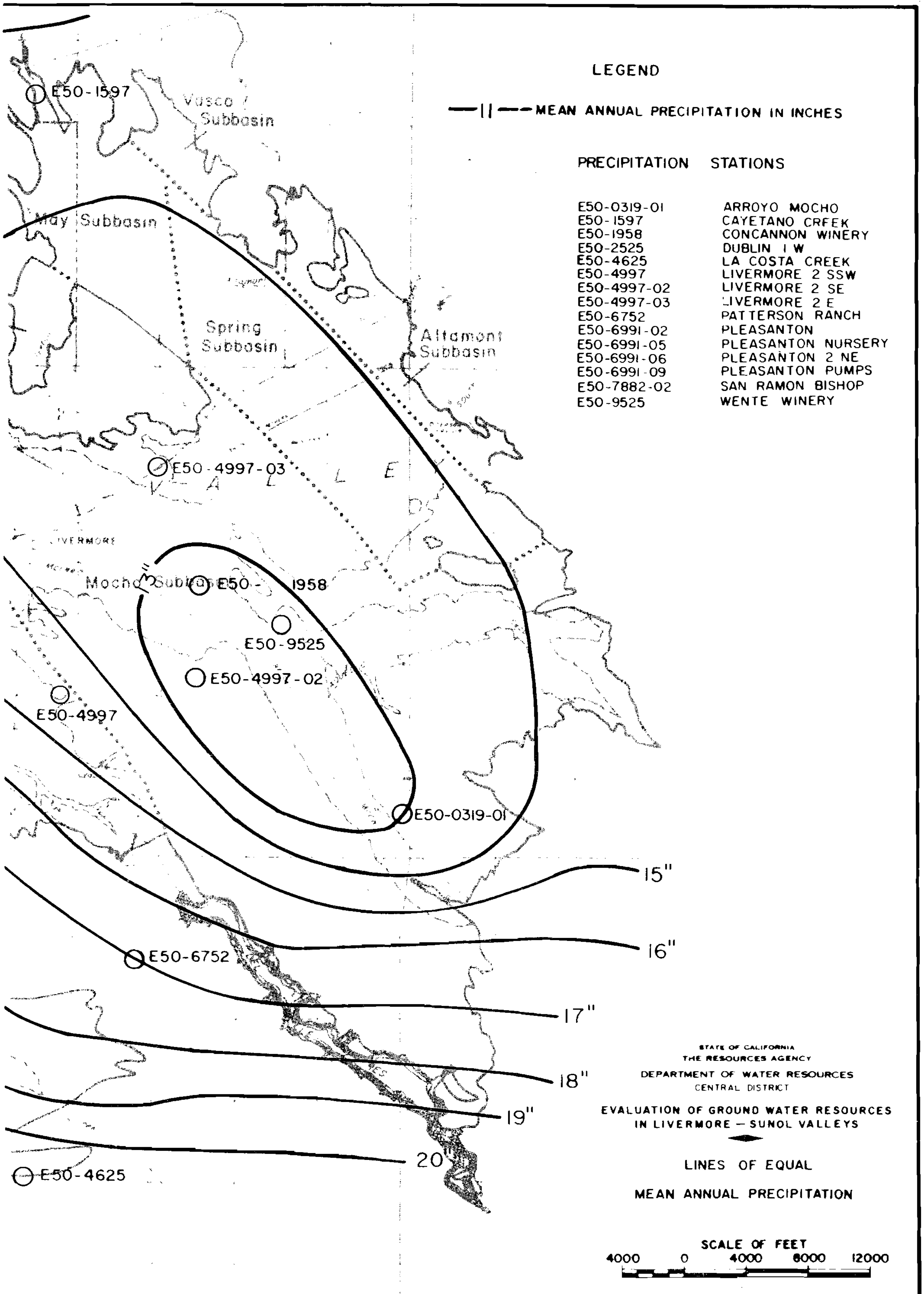

LEGEND
11 MEAN ANNUAL PRECIPITATION IN INCHES
PRECIPITATION STATIONS
E50-0319-01 ARROYO MOCHO
E50-1597 CAYETANO CREEK
E50-1958 CONCANNON WINERY
E50-2525 DUBLIN I W
E50-4625 LA COSTA CREEK
E50-4997 LIVERMORE 2 SSW
E50-4997-02 LIVERMORE 2 SE
E50-4997-03 LIVERMORE 2 E
E50-6752 PATTERSON RANCH
E50-6991-02 PLEASANTON
E50-6991-05 PLEASANTON NURSERY
E50-6991-06 PLEASANTON 2 NE
E50-6991-09 PLEASANTON PUMPS
E50-7882-02 SAN RAMON BISHOP
E50-9525 WENTE WINERY
Vasco Subbasin
May Subbasin
Spring Subbasin
Altamont Subbasin
Mocho Subbasin
E50-1597
E50-4997-03
E50-1958
E50-9525
E50-4997-02
E50-4997
E50-0319-01
E50-6752
E50-4625
13"
15"
16"
17"
18"
19"
20"
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
CENTRAL DISTRICT
EVALUATION OF GROUND WATER RESOURCES
IN LIVERMORE — SUNOL VALLEYS
LINES OF EQUAL
MEAN ANNUAL PRECIPITATION
SCALE OF FEET
4000 0 4000 8000 12000

TABLE 8

ANNUAL PRECIPITATION AND
INDEX OF WETNESS
1871-1971

Year	Annual Precip. (inches)[a]/	Index of Wetness[b]/
1871-72	19.06	131
72-73	10.69	73
73-74	12.56	86
74-75	11.37	78
1875-76	19.99	137
76-77	6.01	41
77-78	17.66	121
78-79	10.11	69
79-80	15.98	110
1880-81	16.45	113
81-82	12.04	83
82-83	13.87	95
83-84	22.80	156
84-85	11.66	80
1885-86	16.52	113
86-87	11.57	79
87-88	13.09	90
88-89	15.05	103
89-90	29.86	205
1890-91	14.28	98
91-92	13.38	92
92-93	25.84	177
93-94	18.61	128
94-95	23.14	159
1895-96	17.41	120
96-97	16.06	110
97-98	10.00	69
98-99	10.81	74
99-00	13.11	90
1900-01	20.32	139
01-02	11.93	83
02-03	14.12	97
03-04	15.27	105
04-05	13.87	95
1905-06	19.52	134
06-07	22.94	157
07-08	9.94	68
08-09	19.17	131
09-10	13.98	96
1910-11	21.18	145
11-12	10.08	69
12-13	8.04	55
13-14	16.91	116
14-15	19.51	134
1915-16	20.86	143
16-17	10.18	70
17-18	14.41	99
18-19	12.75	87
19-20	8.34	57
1920-21	13.33	92
21-22	14.00	96
22-23	14.42	99
23-24	5.21	36
24-25	14.56	100
1925-26	11.51	79
26-27	13.35	92
27-28	12.80	88
28-29	10.09	69
29-30	11.02	76
1930-31	9.08	62
31-32	13.20	91
32-33	10.45	72
33-34	10.12	70
34-35	16.18	111
1935-36	14.47	99
36-37	17.31	119
37-38	21.13	145
38-39	9.62	66
39-40	18.77	129
1940-41	18.08	124
41-42	18.13	125
42-43	15.61	107
43-44	11.99	82
44-45	14.34	99
1945-46	10.69	73
46-47	10.56	72
47-48	11.02	76
48-49	11.35	78
49-50	11.65	80
1950-51	19.62	135
51-52	24.29	167
52-53	14.96	103
53-54	11.22	77
54-55	12.42	85
1955-56	21.43	147
56-57	11.45	79
57-58	21.49	147
58-59	9.73	67
59-60	8.88	61
1960-61	11.46	79
61-62	11.59	80
62-63	18.47	127
63-64	9.49	65
64-65	14.37	99
1965-66	10.70	73
66-67	21.70	149
67-68	10.55	72
68-69	18.78	129
69-70	12.70	87
1970-71	16.10	110

a/ Data for water year, at Station E5-4997, Livermore.
b/ Index of wetness is the percent of 100-year average.

TABLE 9

STREAM GAGING RECORDS
(in acre-feet)

San Antonio Creek near Sunol
Latitude 37° 34' 39" Longitude 121° 51' 24"
Drainage Area = 37.0 Square Miles

Year	Amount	:	Year	Amount	:	Year	Amount
1911-12	1,338		1920-21	9,000		1949-50	4,349
1912-13	1,780		1921-22	13,300		1950-51	27,247
1913-14	17,300		1922-23	6,100			
1914-15	19,700		1923-24	0		1959-60	180
1915-16	26,200		1924-25	3,560		1960-61	478
1916-17	6,830		1925-26	4,840		1961-62	4,250
1917-18	2,330		1926-27	7,540		1962-63	7,190
1918-19	11,900		1927-28	6,610		1963-64	1,840
1919-20	2,990		1928-29	1,150		1964-65	165
			1929-30	4,270			

Alamo Creek at Dublin
Latitude 37° 42' 00" Longitude 121° 52' 40"
Drainage Area = 26.6 Square Miles

Year	Amount	:	Year	Amount	:	Year	Amount
1914-15	8,480		1917-18	90		1948-49	175
1915-16	13,800		1918-19	6,640		1949-50	286
1916-17	4,170		1919-20	13			

Tassajara Creek near Pleasanton
Latitude 37° 42' 00" Longitude 121° 52' 40"
Drainage Area = 26.6 Square Miles

Year	Amount	:	Year	Amount	:	Year	Amount
1914-15	3,770		1920-21	--		1926-27	1,850
1915-16	9,120		1921-22	1,900		1927-28	869
1916-17	1,040		1922-23	1,200			
1917-18	184		1923-24	0		1929-30	23
1918-19	2,068		1924-25	890			
1919-20	--		1925-26	182		1948-49	65
						1949-50	39

Arroyo de la Laguna near Pleasanton at Verona
Latitude 37° 37.6' Longitude 121° 52.9'
Drainage Area = 410 Square Miles

Year	Amount	:	Year	Amount	:	Year	Amount
1948-49	3,182		1949-50	4,417		1951-52	98,030

Arroyo de la Laguna near Pleasanton*
Latitude 37° 36' 25"   Longitude 121° 52' 30"
Drainage Area = 406 Square Miles

Year	Amount	: Year	Amount	: Year	Amount
1911-12	2,618	1919-20	61	1927-28	11,900
1912-13	492	1920-21	14,700	1928-29	1,140
1913-14	130,000	1921-22	43,300	1929-30	7,750
1914-15	59,400	1922-23	19,600		
1915-16	115,000	1923-24	666	1969-70	35,390
1916-17	33,700	1924-25	5,560	1970-71	31,390
1917-18	1,640	1925-26	18,000	1971-72	11,080
1918-19	37,600	1926-27	23,400		

Arroyo las Positas near Livermore
Latitude 37° 42' 00"   Longitude 121° 47' 45"
Drainage Area = 64.6 Square Miles

Year	Amount	: Year	Amount	: Year	Amount
1911-12	4,717	1918-19	1,240	1925-26	330
1912-13	105	1919-20	--	1926-27	730
1913-14	1,680	1920-21	--	1927-28	261
1914-15	3,700	1921-22	1,400	1928-29	128
1915-16	9,300	1922-23	--	1929-30	148
1916-17	686	1923-24	0		
1917-18	213	1924-25	385	1949-50	35

Arroyo Valle near Livermore*
Latitude 37° 37' 15"   Longitude 121° 45' 30"
Drainage Area = 149 Square Miles

Year	Amount	: Year	Amount	: Year	Amount
1911-12	2,523	1921-22	34,900	1941-42	19,418
1912-13	1,700	1922-23	15,000	1942-43	793
1913-14	85,400	1923-24	5	1943-44	13,200
1914-15	47,000	1924-25	4,100	1944-45	28,300
1915-16	63,300	1925-26	19,700	1945-46	9,000
1916-17	23,400	1926-27	26,500	1946-47	4,300
1917-18	3,170	1927-28	11,600	1947-48	3,063
1918-19	23,100	1928-29	1,880	1948-49	8,000
1919-20	3,880	1929-30	10,400	1949-50	7,180
1920-21	12,200	1930-31	1,000	1950-51	40,770

Latitude 37° 37' 15"   Longitude 121° 45' 28"

Year	Amount	: Year	Amount	: Year	Amount
1957-58	80,780	1962-63	25,410	1967-68	2,980
1958-59	15,630	1963-64	3,420	1968-69	26,920
1959-60	7,480	1964-65	26,650	1969-70	18,530
1960-61	807	1965-66	5,220	1970-71	13,780
1961-62	21,630	1966-67	45,130	1971-72	8,910

*Flows regulated by Del Valle Reservoir after August 1968.

Arroyo Valle at Pleasanton*
Latitude 37° 40' 02" Longitude 121° 53' 02"
Drainage Area = 171 Square Miles

Year	Amount	:	Year	Amount	:	Year	Amount
1957-58	80,010		1962-63	22,640		1967-68	2,430
1958-59	11,960		1963-64	1,530		1968-69	24,940
1959-60	5,640		1964-65	25,380		1969-70	15,650
1960-61	0		1965-66	3,700		1970-71	10,310
1961-62	17,920		1966-67	49,280		1971-72	3,880

Arroyo Valle above Lang Canyon
Latitude 37° 33' 00" Longitude 121° 39' 57"
Drainage Area = 126 Square Miles

Year	Amount	:	Year	Amount	:	Year	Amount
1963-64	3,190		1966-67	42,610		1969-70	18,840
1964-65	27,180		1967-68	2,840		1970-71	13,780
1965-66	5,440		1968-69	55,020		1971-72	1,580

Arroyo Mocho near Livermore
Latitude 37° 36' 50" Longitude 121° 41' 10"
Drainage Area = 36.7 Square Miles

Year	Amount	:	Year	Amount	:	Year	Amount
1911-12	408		1917-18	514		1923-24	26
1912-13	257		1918-19	3,120		1924-25	494
1913-14	10,700		1919-20	978		1925-26	2,430
1914-15	8,350		1920-21	1,670		1926-27	3,190
1915-16	11,800		1921-22	4,780		1927-28	1,270
1916-17	2,920		1922-23	1,420		1928-29	362

Latitude 37° 37' 24" Longitude 121° 42' 13"
Drainage Area = 38.2 Square Miles

Year	Amount	:	Year	Amount	:	Year	Amount
1963-64	400		1966-67	5,900		1969-70	2,060
1964-65	2,690		1967-68	721		1970-71	2,420
1965-66	576		1968-69	7,800		1971-72	283

Arroyo Mocho near Pleasanton*
Latitude 37° 41' 19" Longitude 121° 52' 41"
Drainage Area = 143 Square Miles

Year	Amount	:	Year	Amount	:	Year	Amount
1962-63	14,640		1966-67	7,990		1970-71	8,600
1963-64	17,010		1967-68	2,410		1971-72	2,250
1964-65	20,330		1968-69	11,960			
1965-66	4,780		1969-70	6,700			

*Flows affected by releases from South Bay Aqueduct.

The drainage areas tributary to Livermore Valley are shown on Figure 21. Flows from ungaged tributary areas were estimated by using the rainfall-runoff relationship of the gaged areas. Interpolation between the various runoff curves was done by the mean annual rainfall and the morpholic character of the ungaged area. The rainfall-runoff curves used were Tassajara Creek, Arroyo las Positas, Arroyo Valle, Arroyo Mocho, and Dry Creek at Union City, shown on Figures 22 through 26. Annual amounts of surface inflow during the study period are shown on Table 10.

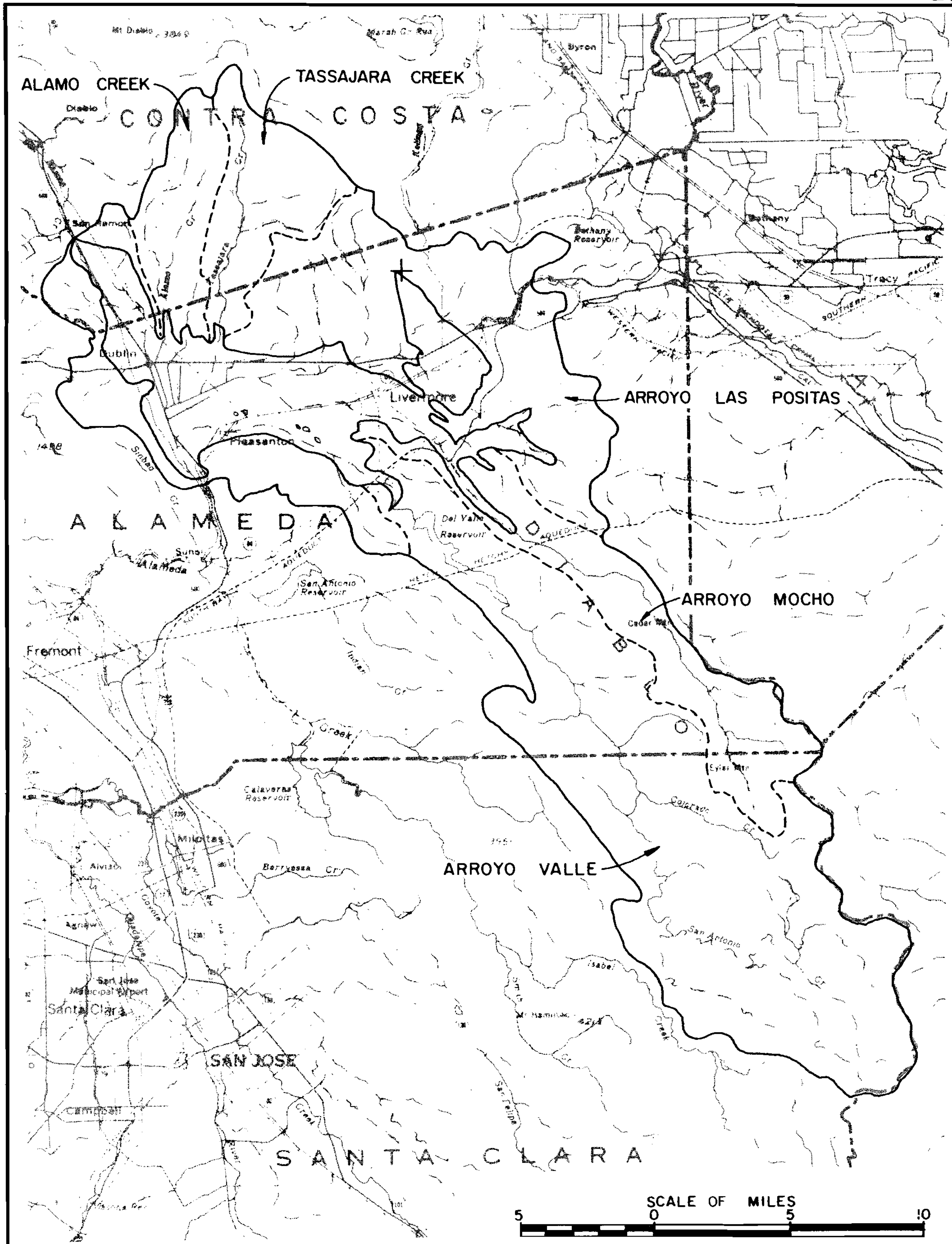
Arroyo de la Laguna is the only stream flowing out of Livermore Valley. Flow records are available for the period 1912 through 1930, and for 1949, 1950, 1952, and 1970 to 1972. To compute the flow for the stream for the study period, the correlation shown on Figure 27 was developed between runoff in the Arroyo Valle and the Arroyo de la Laguna. To obtain the full natural flows used in this correlation, gage flows at Arroyo Valle beginning in September 1968 were adjusted due to the operation of Del Valle Reservoir. The flow records for Arroyo de la Laguna for 1969 to 1972 were adjusted for return flow of sewage and the operation of Del Valle Reservoir. Most of the data for the correlation were for the years 1920 through 1930, when there was very little urban development and drainage channels had not yet been built.

Imported Water

In addition to the surface flow into the valley, import waters also were considered in estimating streamflows. The two sources of import water to Livermore Valley are City of San Francisco's Hetch Hetchy Aqueduct and the State Water Project's South Bay Aqueduct. The Lawrence Livermore Laboratory is the only user receiving Hetch Hetchy water, which started in 1961. The South Bay Aqueduct started delivering water in 1962. At the present time there are seven delivery points from the South Bay Aqueduct to Livermore Valley. All of the water from the South Bay Aqueduct is used in the Valley except the deliveries to Alameda County Water District. The District's water is released to Arroyo Valle and flows through the stream channels of Arroyo Valle, Arroyo de la Laguna, and Alameda Creek to Fremont. Between 1962 and 1965 the District's water was released from Altamont Turnout. Table 11 lists the imports to Livermore Valley. The only releases from South Bay Aqueduct that affect the streamflows are the ones from Altamont Turnout, releases to Arroyo Mocho, and releases to Alameda County Water District from Del Valle Reservoir.

Sewerage Discharges

There are two discharges of treated sewage to stream channels. One is the City of Livermore's discharge to Arroyo las Positas and the other is Valley Community Services District's discharge to Alamo Canal. The City of Livermore's discharge varies from 0 to 3,000 acre-feet per year for the study period. Valley Community Services District's discharge varied from 200 to 2,500 acre-feet per year for the study period. The characteristics of waste water discharges from the three main plants in Livermore Valley during 1971 are listed in Table 12.



AREA OF RUNOFF TRIBUTARY TO LIVERMORE VALLEY

FIGURE 22

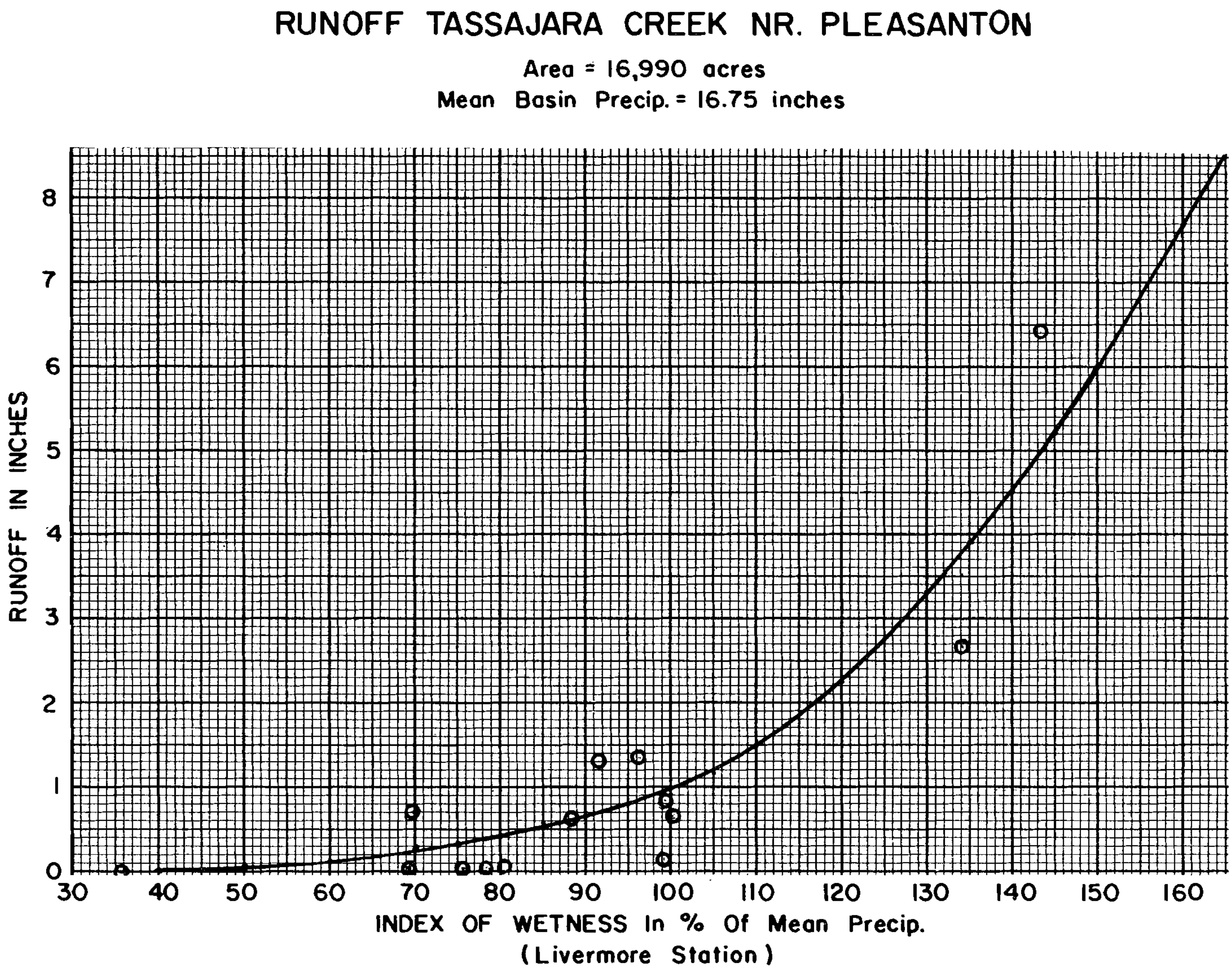

RUNOFF TASSAJARA CREEK NR. PLEASANTON
Area = 16,990 acres
Mean Basin Precip. = 16.75 inches
RUNOFF IN INCHES
0
1
2
3
4
5
6
7
8
30
40
50
60
70
80
90
100
110
120
130
140
150
160
INDEX OF WETNESS In % Of Mean Precip.
(Livermore Station)

FIGURE 23

RUNOFF ARROYO LAS POSITAS NR. LIVERMORE

Area = 41,140 acres
Mean Basin Precip. = 14.56 inches

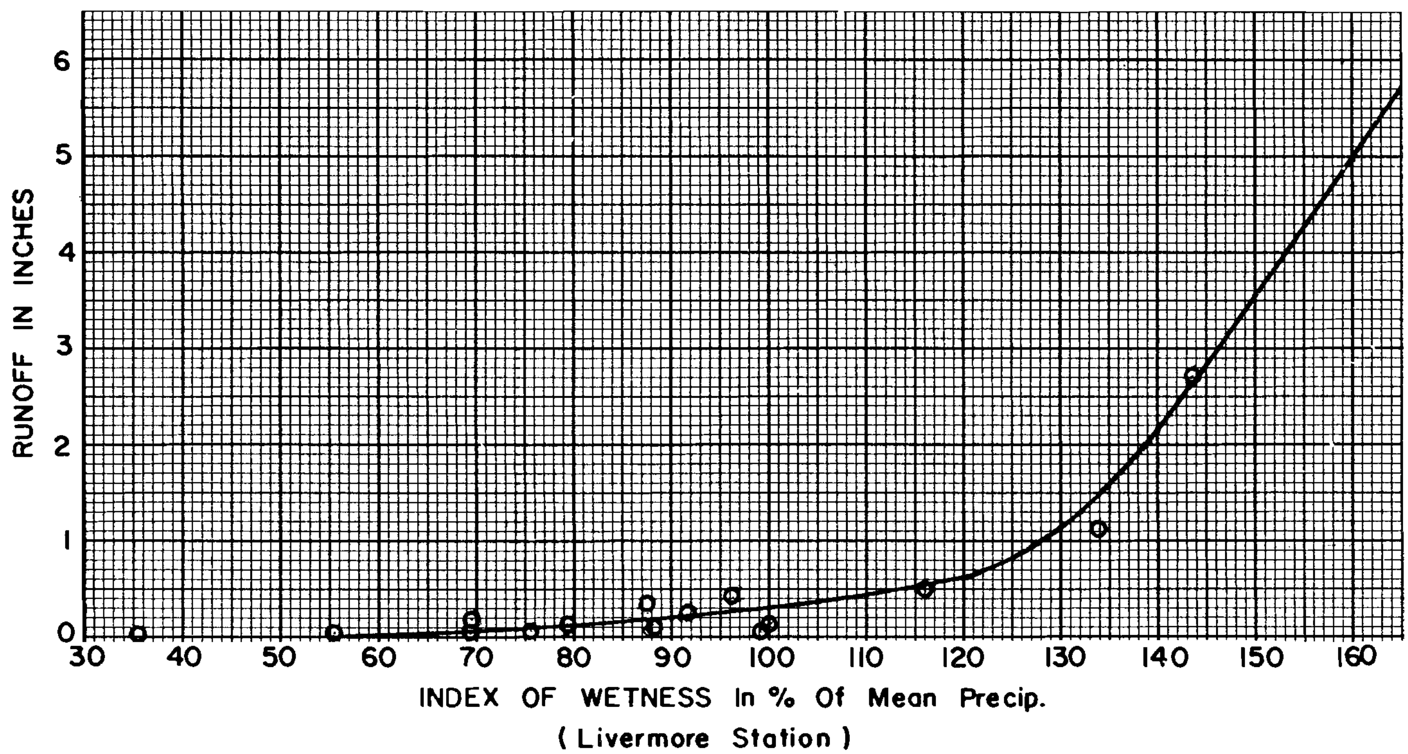


FIGURE 24

RUNOFF ARROYO VALLE NR. LIVERMORE

Area = 95,360 acres

Mean Basin Precip. = 19.70 inches

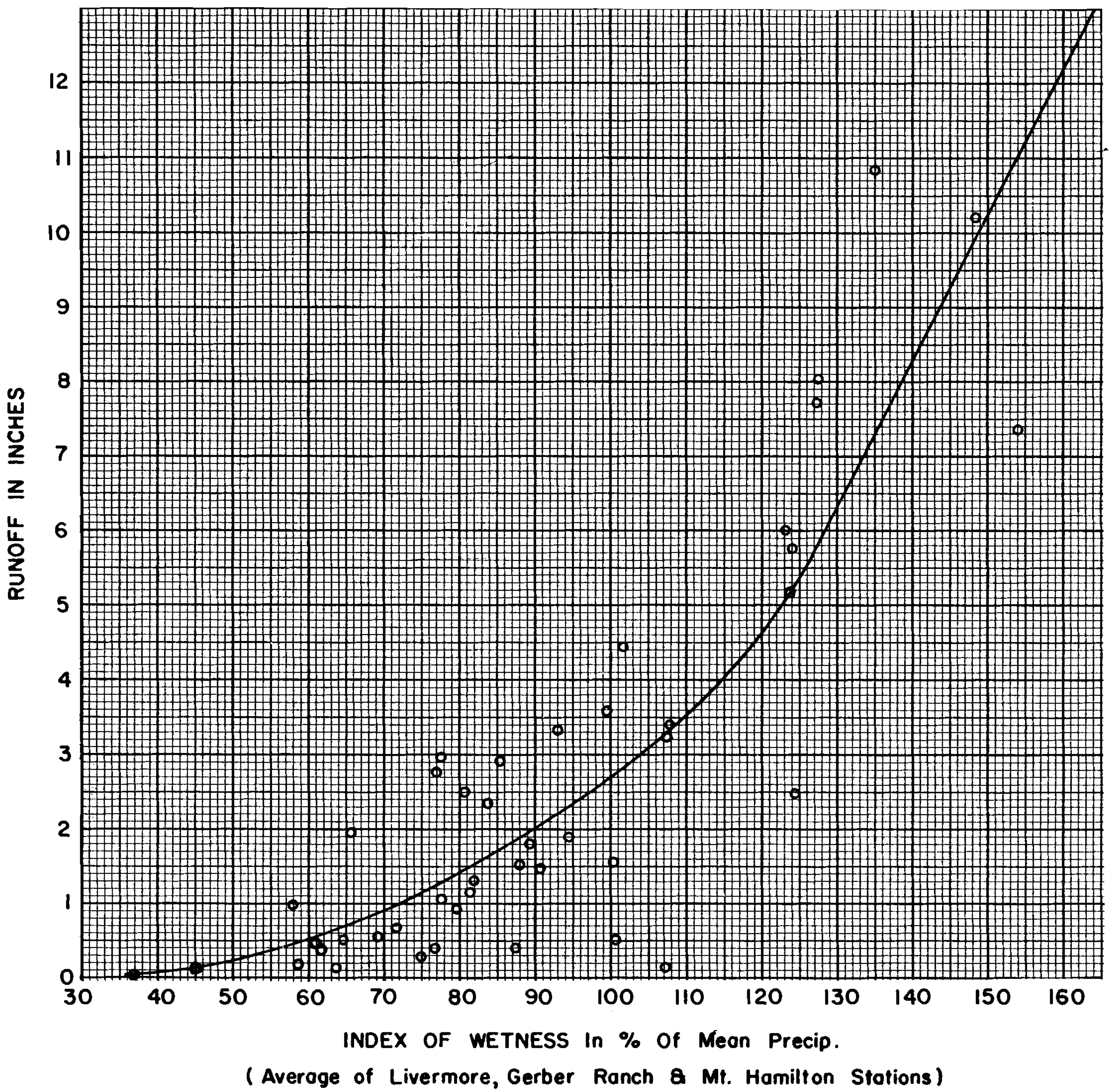
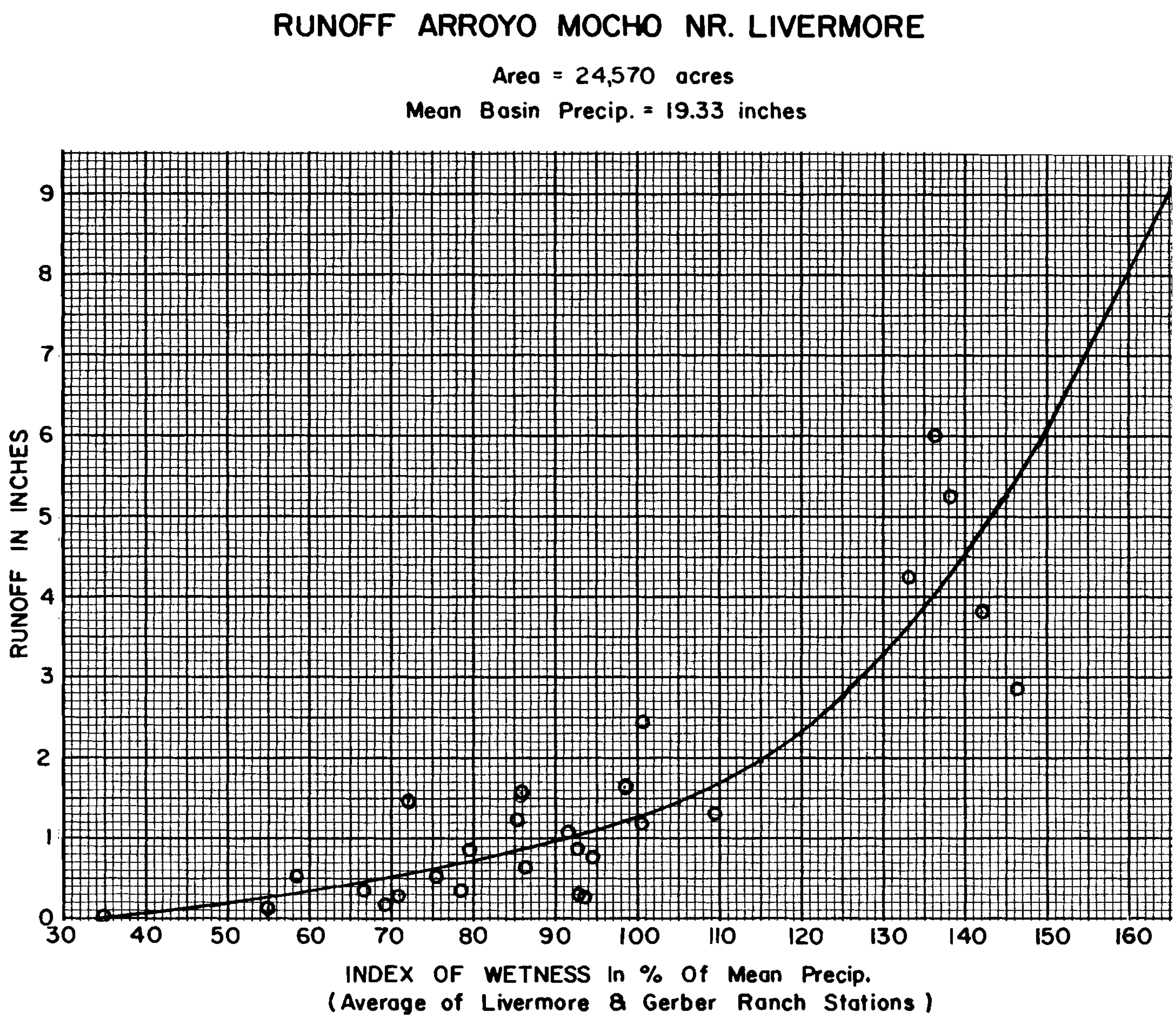
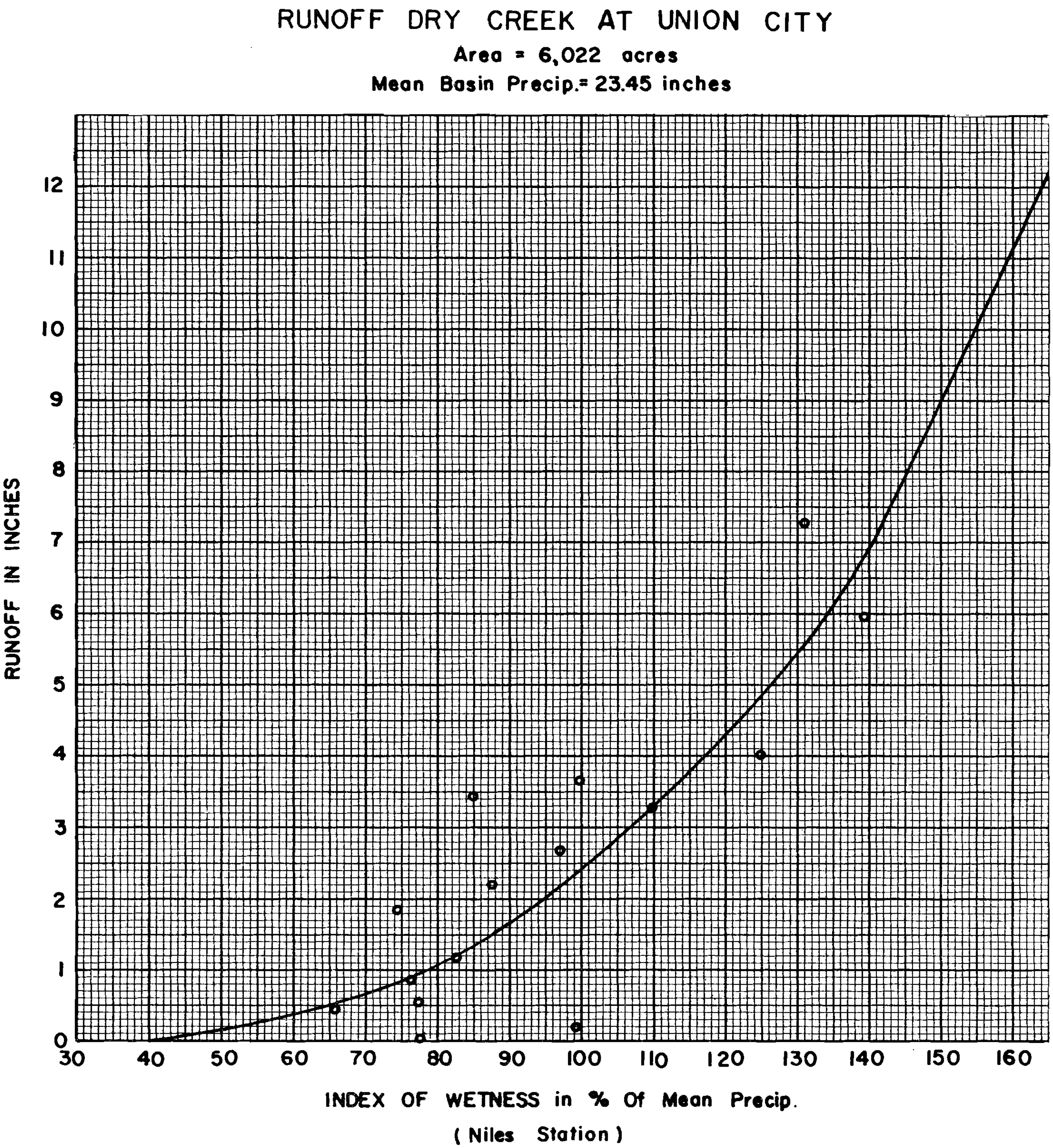


FIGURE 25



RUNOFF ARROYO MOCHO NR. LIVERMORE
Area = 24,570 acres
Mean Basin Precip. = 19.33 inches
RUNOFF IN INCHES
0
1
2
3
4
5
6
7
8
9
30
40
50
60
70
80
90
100
110
120
130
140
150
160
INDEX OF WETNESS In % Of Mean Precip.
(Average of Livermore & Gerber Ranch Stations)

FIGURE 26



RUNOFF DRY CREEK AT UNION CITY
Area = 6,022 acres
Mean Basin Precip.= 23.45 inches
RUNOFF IN INCHES
0
1
2
3
4
5
6
7
8
9
10
11
12
30
40
50
60
70
80
90
100
110
120
130
140
150
160
INDEX OF WETNESS in % Of Mean Precip.
(Niles Station)

TABLE 10

ESTIMATED TRIBUTARY RUNOFF TO MODEL AREA
(Acre-Feet)

Node No.	1961-2	1962-3	1963-4	1964-5	1965-6	1966-7	1967-8	1968-9	1969-70
1	80	460	40	170	60	850	60	500	100
2	30	180	16	70	20	330	20	200	50
3	18	110	8	40	13	200	13	120	20
4	2	13	1	4	2	20	1	14	3
5	100	550	50	210	80	1,000	70	600	140
6	3	20	2	6	2	40	2	20	4
7	15	80	7	30	10	160	11	90	20
8	60	350	30	130	50	640	50	380	90
9	160	840	80	330	120	1,500	110	890	240
10	-	-	-	-	-	-	-	-	-
11	490	2,990	280	1,010	390	5,750	360	330	650
12	-	-	-	-	-	-	-	-	-
13	-	-	-	-	-	-	-	-	-
14	90	490	50	180	70	900	70	530	120
15	-	-	-	-	-	-	-	-	-
16	-	-	-	-	-	-	-	-	-
17	40	200	20	80	30	370	30	220	60
18	-	-	-	-	-	-	-	-	-
19	80	200	50	200	70	330	50	380	100
20	80	390	40	160	50	690	50	420	100
21	60	390	30	120	40	780	40	430	80
22	-	-	-	-	-	-	-	-	-
23	-	-	-	-	-	-	-	-	-
24	-	-	-	-	-	-	-	-	-
25	50	150	30	150	40	230	30	260	50
26	-	-	-	-	-	-	-	-	-
27	430	430	30	130	50	870	50	380	90
28	360	360	30	120	80	1,050	40	510	70
29	-	-	-	-	-	-	-	-	-
30	-	-	-	-	-	-	-	-	-
31	70	70	12	70	20	120	13	110	30
32	10	10	1	3	3	30	1	14	2
33	-	-	-	-	-	-	-	-	-
34	-	-	-	-	-	-	-	-	-
35	60	170	40	160	50	290	40	330	80
36	21,820	25,900	3,500	27,140	5,340	46,000	3,090	27,900	16,720
37	80	540	20	130	40	1,040	30	440	80
38	18	130	10	40	15	410	15	170	30
39	4	40	2	12	3	130	3	40	6
40	12	30	1	14	2	160	2	80	12
41	2,010	6,740	400	2,750	580	6,340	730	8,070	2,110
42	0	14	0	3	1	60	1	14	0
43	1	18	0	5	1	70	1	20	3
44	90	760	17	240	70	2,830	60	920	130
45	130	1,110	20	350	100	4,100	80	1,340	190
Total	26,453	43,735	4,817	34,057	7,402	77,290	5,123	45,722	21,380

FIGURE 27

LIVERMORE VALLEY ANNUAL SURFACE OUTFLOW

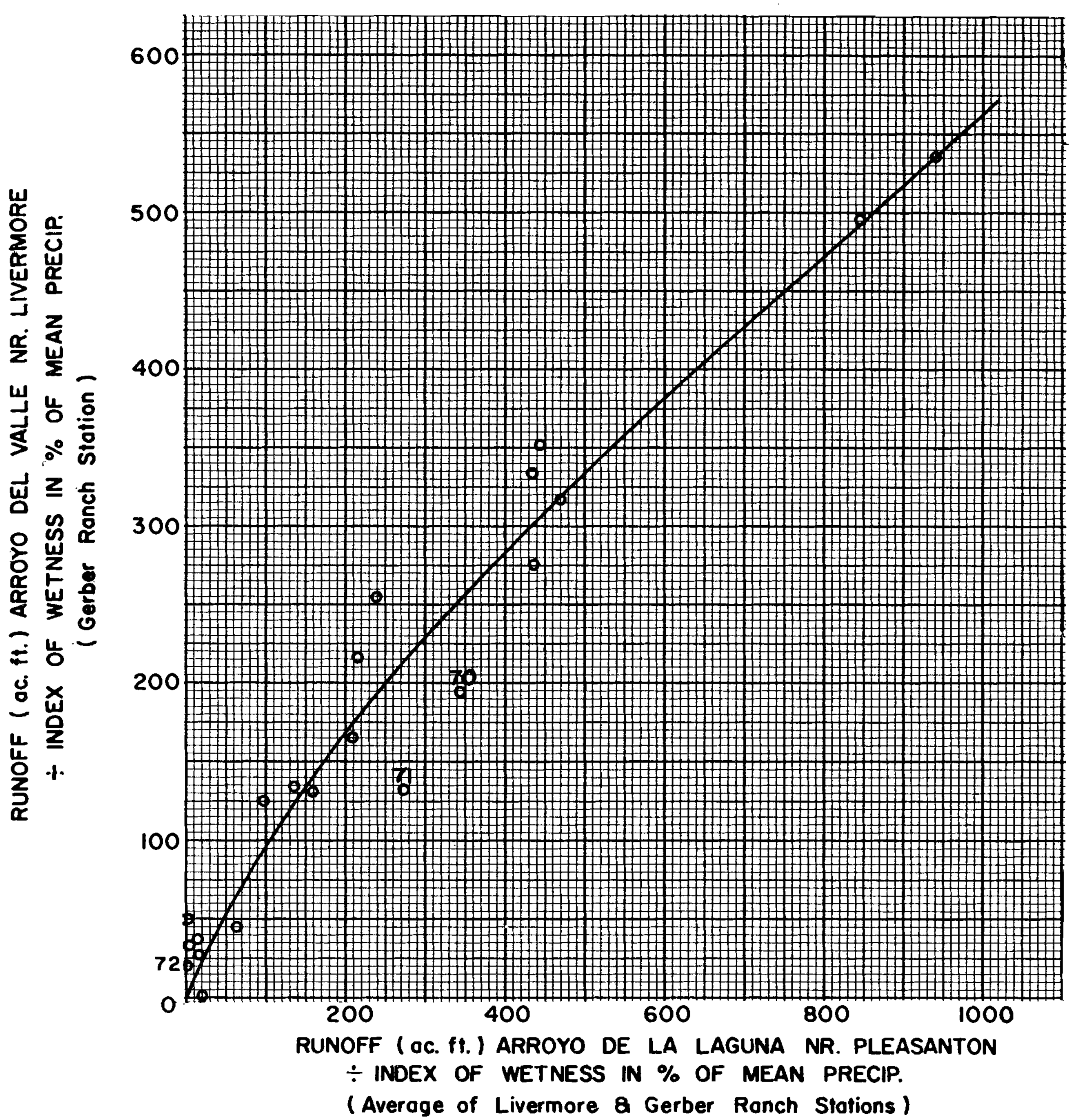


TABLE 11

LIVERMORE VALLEY IMPORTED WATER

(Quantities in Acre-Feet)

		South Bay Aqueduct								
	Aqueduct	Altamont Turnout Zone 7	Altamont Turnout ACWD	Patterson Turnout	Wente #2 Turnout	Mocho Turnout	Wente #1 Turnout	Cresta[6/] Blanca	Arroyo del Valle ACWD	Misc.
1961-62	411	103	5,574	218	---	---	---	---	---	50[1/]
1962-63	393	638	11,195	836	---	---	---	---	---	11[1/]
1963-64	478	424	18,196	1,385	---	---	---	---	---	247[1/]
1964-65	481	557	16,253	1,732	138	---	---	---	---	103[1/]
1965-66	577	1,937	2,688	2,402	362	---	---	---	---	13[1/]
1966-67	589	1,718	---	2,434	146	---	---	---	---	628[2/]
1967-68	586	1,727	---	3,375	265	---	140	---	---	250[2/]
1968-69	764	1,273	---	3,392	441	270	220	160[4/]	703	134[3/]
1969-70	696	1,211	---	4,538	735	2,268	339	93	11,900	83[3/]
1970-71	684	1,278	---	4,230	826	2,479	317	160	7,100[5/]	---

1/ Construction water.
2/ Industrial Pipe and Green & Winston Construction Company.
3/ Industrial Pipe.
4/ 140 acre-feet release from Del Valle Reservoir.
5/ 7,194 acre-feet from storage in Del Valle Reservoir.
6/ May include natural flow of Arroyo Valle.

TABLE 12

MUNICIPAL EFFLUENT CHARACTERISTICS, 1971[1/]

Parameter[2/]	Livermore	VCSD	Pleasanton
Total Annual Flow, acre-feet	4,100	3,200	1,180
Average Flow, mgd	3.67	2.85	1.06
Biochemical Oxygen Demand, BOD	8	2.5	55
Percent Removal	97	99	82
Suspended Solids, SS, Final	11.6	14	75
Percent Removal	95	94	68
Total Dissolved Solids, TDS	720	1,000	730
Hardness as $CaCO_3$	200	360	240
Alkalinity as $CaCO_3$	75	225	410
Specific Conductance (μm)	1,000	1,450	1,180
Hydrogen Ion Conc (pH)	7.0	7.3	7.6
Number of Samples	48	56	36
Chloride, Cl	180	200	100
Sulfate, SO_4	85	205	75
Bicarbonate, HCO_3	70	260	475
Sodium, Na	140	180	130
Potassium, K	10	8	10
Calcium, Ca	40	70	50
Magnesium, Mg	25	50	30
Silica, SiO_2	20	20	30
Nitrate, NO_3 as (N)	22	13	.05[3/]
Total Nitrogen, N	23	14	43[4/]
Fluoride, F	.2	.1	.3
Boron, B	1.3	.7	1.0
Phosphate, PO_4 as (P)	17	15	15
Number of Samples	24	4	2

1/ From "Water Quality Management Plan for the Alameda Creek Watershed Above Niles", by Brown and Caldwell.
2/ Expressed as mg/l, unless otherwise noted.
3/ No nitrification at Pleasanton plant.
4/ Primarily in the form of ammonia and organic nitrogen.

Land Use

Cultural conditions affect many of the items in the hydrologic equation. The land use was determined for each year of the study period by using the three land use surveys and a general understanding of the economy of Livermore Valley. The economy of the Livermore Valley historically has centered around agriculture, with the valley lands being devoted to viticulture and the uplands being used for grazing. The present industrial development in the valley consists of wineries, sand and gravel extraction plants, nuclear research laboratories, and some minor industries. The major change in land use during the study period has been the continuing urbanization of agricultural land.

Annual changes in land use were estimated by using information from the planning departments of Alameda County and the Cities of Livermore and Pleasanton as to the date, size, and location each subdivision started, and information on the general change of agricultural land use during the 1960's provided by the farm advisor. Table 13 lists the land use by node from the 1966 and 1970 surveys. Figure 15 shows the 1970 land use.

Water Use

All the agriculture in the valley, except vineyards, is irrigated from ground water. Prior to the study period vineyards were irrigated only by surface water for the first part of the growing season, until the stream went dry. The vineyards are now irrigated by a combination of surface and imported water purchased from Zone 7.

The average amount of water applied to agricultural and urban lands was estimated by using measured values from other areas of the State and adjusting them. The values used do not in all cases conform to values expected for commercial farming, since a portion of the area is in transition to urban. Annual amounts were varied in relation to relative wetness and the occurrence of significant rainfall in the period preceding the growing season. Annual amounts of the depth of water applied to gross acreage of irrigated lands are shown in Table 14.

Ground Water Pumpage

The ground water pumpage was determined in two parts: the first for municipal and industry, and the second for agricultural purposes.

Pumpage for municipal use was based on records of individual wells furnished by California Water Service, Pleasanton Township and Water District, Valley Community Service District, Veterans Hospital, and the old Parks Army Base. An estimate of the pumpage from the underlying Livermore and Tassajara Formations by some of the wells was based on geology and was not considered as part of the pumpage for the model. Pumpage by gravel companies was estimated from the knowledge of the gravel operation and the estimated amounts of gravel extracted, since records of pumpage were not available.

Agricultural pumpage was estimated by multiplying the estimated depth of applied water times the area of each crop in each node. The total pumpage and the portion of the pumpage from the Tassajara and Livermore Formations are listed by use in Table 15.