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STATE OF CALIFORNIA
The Resources Agency

Department of Water Resources

BULLETIN No. 118-1

EVALUATION OF GROUND WATER RESOURCES
SOUTH BAY
Volume I: FREMONT STUDY AREA

AUGUST 1968

RONALD REAGAN
Governor
State of California

WILLIAM R. GIANELLI
Director
Department of Water Resources

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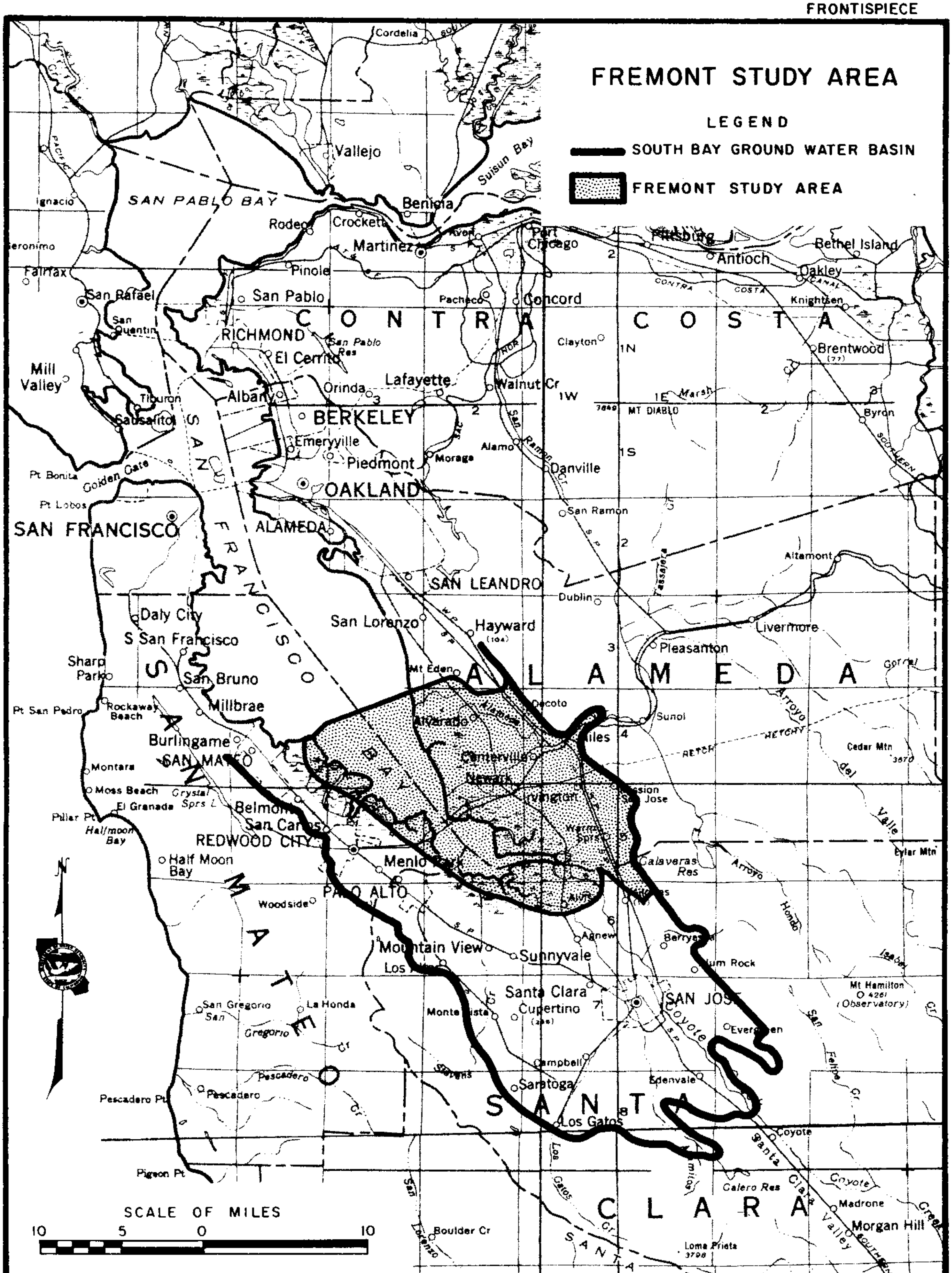
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BULLETIN NO. 118 SERIES

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, published in August 1967.

Bulletin No. 118-1, Evaluation of Ground Water Resources South Bay, Volume I: Fremont Study Area, published in May 1968.

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

Bulletin No. 118-2, Evaluation of Ground Water Resources Livermore and Sunol Valleys, Livermore Valley Study Area, to be published in 1969.

After completion of the evaluation studies, operations-economics studies of each ground water basin or study area will be scheduled and conducted on a cooperative basis with local agencies.

FOREWORD

The South Bay Ground Water Basin in Alameda, San Mateo, and Santa Clara counties underlies South San Francisco Bay and the gently sloping lands adjacent to the Bay. The ground water basin is divided into three main units: the Fremont study area, containing the Bay and southern Alameda County; the Santa Clara study area to the south; and the San Mateo study area to the west. This volume reports on the Fremont study area.

In the Fremont study area, extractions have exceeded recharge for many years. The result has been extensive salt water intrusion of the ground water aquifers.

In addition to ground water supplies, the Fremont study area receives imported water supplies from the South Bay Aqueduct of the State Water Project and from the City of San Francisco's Hetch Hetchy and Sunol aqueducts.

During the investigation, a mathematical model of the ground water basin was used to assist in the evaluation of the ground water resource. In addition, the role of the ground water resource in relation to the future water demands of the Fremont area was also explored. Recommendations are made on the actions and additional studies required to control saline water intrusion into the ground water basin.

The investigation of the South Bay Ground Water Basin was initially authorized under the authority provided by the California Legislature in the Porter-Dolwig Ground Water Basin Protection Law, Chapter 1620, Statutes of 1961, codified in Section 12920-12925, Chapter 7.5, Part 6, Division 6, of the California Water Code. It was the intent of the Legislature that the Department of Water Resources initiate investigations, plans, and studies and establish design criteria for construction of projects to correct and prevent irreparable damage to, or impaired use of, ground water basins of the State caused by critical conditions of overdraft, depletion, saline water intrusion, or degradation of water quality. This program is now being continued under the Planned Utilization of Ground Water Basins Program.

William R. Gianelli

William R. Gianelli, Director
Department of Water Resources
The Resources Agency
State of California
June 18, 1968

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State of California
The Resources Agency
DEPARTMENT OF WATER RESOURCES

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DEPARTMENT OF WATER RESOURCES

ENGINEERING CERTIFICATION

This report has been prepared under my direction as the professional engineer in direct responsible charge of the work, in accordance with the provisions of the Civil and Professional Engineers' Act of the State of California.

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Date May 13, 1968

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Alameda County Flood Control and Water Conservation District,

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ABSTRACT

The agricultural economy developed in the San Francisco area during the last century has been based on adequate supplies of ground water. Overuse of the ground water resource has brought about sea water intrusion and land subsidence. This bulletin reports findings of an evaluation of the ground water resource of an area which includes South San Francisco Bay and the agricultural areas now incorporated into the cities of Fremont and Union City.

The ground water reservoir studied was formed by deposition of materials carried by Alameda Creek. A detailed geology appendix to this bulletin was published in 1967. The hydrologic evaluation revealed that over 260,000 acre-feet of salt water has intruded the ground water reservoir. During the 1960-65 period, the rate of intrusion exceeded 10,000 acre-feet per year.

To assist in the evaluation, a mathematical model of the ground water reservoir was developed and programmed on analog and digital computers. Use of the high-speed computers allowed a more detailed analysis of flow between parts of the ground water reservoir.

Importation of water purchased from the State of California (South Bay Aqueduct of the State Water Project) and the City of San Francisco (Hetch Hetchy System) has brought water supply almost up to the level of water demand. Remaining demand may only be met by ground water if the ground water reservoir is protected from further salt water intrusion.

Included in the bulletin are recommendations for: planning and installation of a sea water barrier to protect the ground water resource, development of a new data collection network, analysis of the effect on the resource of the realignment of the Alameda Creek channel, and scheduling of studies of alternate operation plans for conjunctive use of surface and ground water.

CHAPTER I. INTRODUCTION

The lands of the Fremont study area in southern Alameda County were initially developed for agriculture, and ground water was used for irrigation. Water levels in the local aquifers were at a level which caused artesian discharge of fresh water to San Francisco Bay and adjacent tidelands.

By the 1920's, the use of irrigation supplies from the ground water basin had begun to cause saline water intrusion into the aquifers. Since the end of World War II, this part of California has experienced a tremendous urban expansion which has changed much of the land use. A growing urban complex, including incorporation of the City of Fremont, City of Newark, and City of Union City, has greatly increased the water use. This urban water demand, when added to the demands of agriculture, has resulted in serious overdraft of the ground water.

Overpumpage of ground water supplies has not only affected ground water levels; it has also resulted in a change of water quality in the area. As ground water levels have declined, degradation of ground water has followed due to downward movement of saline waters primarily through confining silt and clay layers. The upper aquifer has changed from an artesian aquifer to an unconfined aquifer. The hydraulic gradient has been reversed from bayward to landward and intrusion of the upper aquifer, which began during the 1920's, has resulted in saline water entering the aquifer under the bay and then moving landward.

Subsidence of the land surface, at a rate of 0.5 feet per year, has been documented in the area south of San Francisco Bay. The problem is associated mainly with aquifers to the south of the Bay; however, minor amounts of subsidence appear to affect the Fremont study area.

The continual overdraft of ground water in the Fremont area is now the basic water problem of southern Alameda County. The ultimate effect of continuing overdraft would be the complete intrusion of the forebay and all connecting aquifers.

The existence of a useful ground water basin in this area is the result of continuing work by the Alameda County Water District. This agency has constructed facilities to increase recharge of streamflow and has imported water for direct use and for planned recharge.

For this investigation, historical amounts of annual water supply to and disposal from the area for a selected study period were determined by classical methods where possible. To verify data relating to water supply and disposal, including amounts of saline water intrusion, a mathematical model of the ground water basin was developed. Analog and digital computers were used to operate the model through the study period.

The historical amounts of supply and disposal were modified to represent average present and projected cultural conditions and these modified figures were used to determine the role of ground water in meeting the water demand for the years 1970, 1990, and 2020.

Previous Investigations

The importance of ground water to the economy of southern Alameda County is evidenced by the several reports relating to the study area which have previously been published. There have been four major reports.

Ground Water Resources in the Niles Cone and Adjacent Areas, California. U. S. Geological Survey Water Supply Paper 345 is a published report of the first detailed study of the area, which was completed in 1915 by W. O. Clark. This report remained for many years the most complete and accurate description of ground water conditions in the portion of Alameda County bordered by San Francisco Bay.

Ground Water in Santa Clara Valley. U. S. Geological Survey Water Supply Paper 519 is another detailed accounting of ground water conditions in the area made by W. O. Clark in 1924. This time he expanded his investigation to include the entire area of the present study together with that portion of Santa Clara Valley south of the Coyote Narrows.

Alameda County Investigation. Bulletin No. 13, published by the Department of Water Resources in March 1963, is a report of an investigation conducted by the former Division of Water Resources for the Water Resources Board. (A preliminary report of this investigation was published by the Water Resources Board in 1955.) This water resource investigation of Alameda County, conducted between 1948 and 1955, covered the Livermore Valley and the area of the county adjacent to San Francisco Bay.

Intrusion of Salt Water into Ground Water Basins of Southern Alameda County. Bulletin No. 81, published by the Department of Water Resources in December 1960, is a report of an investigation conducted between July 1957 and June 1958.

The investigation included further detailed studies of the cause and extent of saline water intrusion into the ground water aquifers of southern Alameda County. Emphasis was placed upon the degree to which faulty and abandoned wells were contributing to the intrusion problem. Geologic conditions were investigated in detail in areas where sea water intrusion was known to have occurred.

Description of the Area

The location of the Fremont study area is shown in detail on the Frontispiece. The study area contains portions of Alameda, San Mateo and Santa Clara counties and includes: San Francisco Bay south of the San Mateo Bridge; the gently sloping lands to the east, between the bay and the base of the hills; the tidelands on the western shore of the bay; and the lands south of the bay, to the vicinity of Alviso.

The study area of 115,000 acres overlies the depositional cones of Alameda Creek and adjacent eastside streams. It also includes the zone of overlapping deposition of Coyote and Guadalupe creeks from the Santa Clara Valley, and the Alameda Creek deposition from the east.

The main topographic features of the study area are San Francisco Bay, the Coyote Hills, and Alameda Creek.

Large acreages are occupied by San Francisco Bay and by the salt evaporation ponds which have been developed on marsh and tidelands of the study area. The salt and other mineral extraction industries have operated in this area for more than a century.

The Problem: Saline Water Intrusion

Although salt water degradation of ground water in wells north of the Coyote Hills was first observed in 1920, intrusion of saline water into the ground water was not evident until 1924. Degradation continued and ground water in the shallow, or upper, Newark aquifer became progressively more unsuitable for irrigation use. The ranchers, in their search for suitable irrigation use. The ranchers, in their search for suitable irrigation supplies, drilled wells deeper into the second, or Centerville aquifer, which is separated from the Newark aquifer by a nearly impermeable clay layer. Fresh water from deeper aquifers relieved the immediate problem, and the extent of the intrusion of saline bay water was not fully realized until 1950 when degraded water first began to appear in the Centerville aquifer. The salinity was first noticed in the Alvarado-Newark-Centerville area and has since spread over a larger area.

The present extent of saline water intrusion is shown on Plates 1 and 2.

Degradation of ground water by intrusion of saline water is probably caused by a combination of a number of conditions. The Newark aquifer is not in direct contact with San Francisco Bay, but saline water may be entering the aquifer through openings in the bay mud and the clay cap, both of which overlie the aquifer. Tidal currents may have scoured the bay mud and exposed the aquifer, or the clay cap may have been breached by dredging, or by abandoned, unsealed wells.

Intrusion is caused by saline water from the bay and salt ponds flowing through the clay cap and into the Newark aquifer, under the pressure differential existing between the bay surface and the aquifer. Although the downward flow of salt water per square foot of area is very small, the annual amounts over the total area of bay and salt ponds are large.

The hydraulic conditions allowing saline water intrusion are shown on Figure 1. Pumping from the Centerville and deeper aquifers has created a depression, or trough, east of the Coyote Hills. The hydraulic gradient in the deeper aquifers is bayward from the forebay. The forebay is connected to all of the aquifers and receives recharge from the surface. The hydraulic gradient in the Newark aquifer is landward from the bay to the forebay.

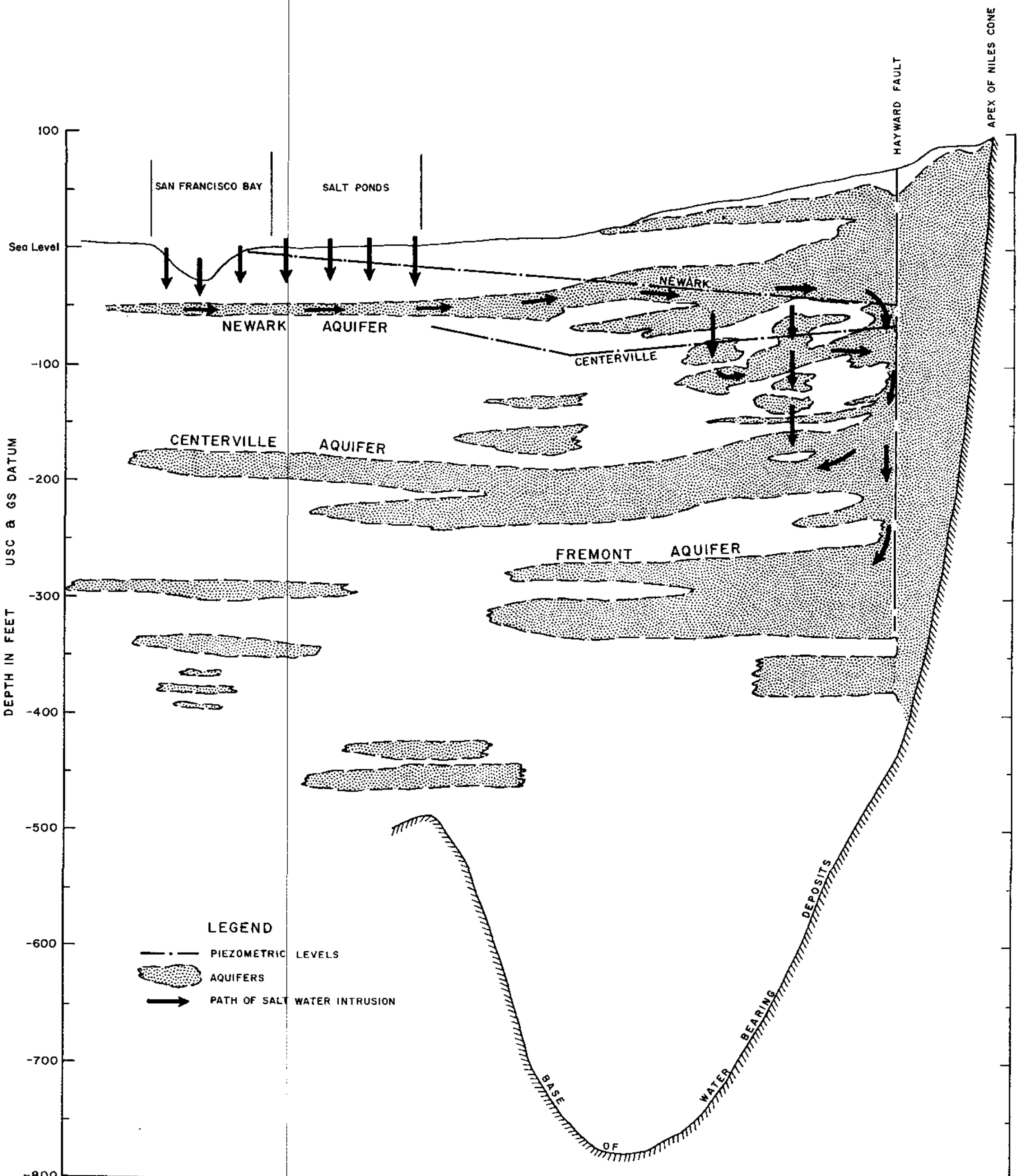
Under these hydraulic conditions, saline water enters the portion of the Newark aquifer under the bay and the salt ponds. It then moves landward toward the forebay, and enters the lower aquifers by way of the forebay or by passing through the thin clay layers near the forebay. After the saline water has entered a lower aquifer, it then moves bayward down the hydraulic gradient toward the pumping depression.

Water Agencies

Four organizations distribute water within the study area: the Alameda County Water District, the Citizens Utilities Company of California, and the water departments of the cities of Hayward and Milpitas. Service areas of the four organizations are shown on Plate 3.

Alameda County Water District

The Alameda County Water District (ACWD) is a publicly owned and operated agency, and is the major distributor of municipal water supplies within the cities of Fremont, Newark,



INTRUSION OF SALT WATER INTO THE FREMONT STUDY AREA and Union City. The District is also a water conservation agency, conserving surplus flows of Alameda Creek by diversion to percolation pits, and replenishing the underground water supplies for the benefit of all those who pump ground water within the District.

Since the late 1940's the area served by ACWD has been experiencing a rapid growth in population, and in residential, commercial, and industrial development.

In 1950 there were 2,080 service connections to the District's distribution system. By 1962, ACWD's service connections had increased to 18,151.

Wells presently provide the major source of supply for water distributed by the ACWD. Some water is currently being purchased from the City of San Francisco's water department to aid in meeting peak summer demands, to supply certain industries, and to supply the Warm Springs area of the City of Fremont. During 1961-62, about 13½ percent of the water distributed by the District was purchased from the City of San Francisco.

In 1961, the District contracted with the State of California to purchase water from the South Bay Aqueduct of the State Water Project in amounts increasing to a maximum of 42,000 acre-feet annually. The ACWD is one of three water agencies now contracting with the State for water supplies from the South Bay Aqueduct. The South Bay Aqueduct has been constructed with a capacity for an additional 10,000 acre-feet per year capacity which has not been contracted for at this time. The District presently uses South Bay Aqueduct water to supplement the natural recharge to the ground water basin.

Citizens Utilities Company of California

The residential and commercial areas in the Decoto District of Union City and the Niles District of Fremont, although within the ACWD service area, receive their municipal water supplies from the Citizens Utilities Company of California, a privately owned water utility which presently serves 3,100 customers.

Cities of Hayward and Milpitas Water Departments

The water departments of the cities of Hayward and Milpitas serve customers in portions of the study area. Both Hayward and Milpitas purchase water supplies from the City of San Francisco.

CHAPTER II. GEOLOGY

Bulletin No. 118-1, Evaluation of Ground Water Resources South Bay, Appendix A: Geology was published by the Department of Water Resources in August 1967 as a separate report. It contains a detailed description of the physiography, geologic formations and structure, and the characteristics of the ground water areas. This chapter is a summary of the information contained in that publication.

Physiography

The Fremont ground water area encompasses the eastern side of the South Bay Ground Water Basin north of the Alameda-Santa Clara county line. Within the boundaries of the Fremont ground water area are all or parts of nine physiographic features: the Niles Cone, Dry Creek Cone, San Lorenzo Cone, San Francisquito Cone, Bay Plain, San Jose Plain, Mission Upland, Mission Alluvial Apron, and the Warm Springs Alluvial Apron. These physiographic features are described in detail in the geology appendix, and are shown on Plate 4 of this report.

Geologic Formations

The geologic formations of the Fremont ground water area have been divided into two main groups: nonwater-bearing and water-bearing. The nonwater-bearing are practically devoid of water; however, in certain areas they may provide limited quantities of ground water to domestic or stock wells. In contrast, the water-bearing formations are capable of yielding ground water to wells in sufficient quantities for all types of uses.

Nonwater-Bearing Formations

The nonwater-bearing rocks are exposed in the highland area east of the Santa Clara Valley and in isolated hills rising above the alluvial plain. These rock types also occur below the valley floor at depths down to 1,500 feet. Nearly all of these rock types are consolidated and of low permeability; they do not have primary openings large enough to allow movement of ground water. In these rock types, ground water exists largely in secondary openings formed by fractures, joints, shear zones, and faults. These secondary openings provide minimal storage space and avenues for movement of ground water; thus, these rocks provide only small quantities of water to wells. Because secondary openings are not present uniformly in any given rock type or geographic area, their ability to yield ground water to wells is quite variable and is dependent on local structural conditions.

Domestic water supplies may be obtained from many types of nonwater-bearing rocks. The most common source of these supplies is from springs which occur chiefly along faults and fractures and at contacts between different rock types. Shallow wells may yield fair to moderate amounts of water in local areas where geologic structures and rock types are favorable.

The quality of ground water in the nonwater-bearing rocks is often poor. Most of these rocks are of marine origin; consequently, finer-grained zones still retain some of the original sea water. Some of the coarser-grained rocks have been flushed and contain fair to good quality ground water.

Water-Bearing Formations

The sediments making up the water-bearing formations are unconsolidated to semi-consolidated. In contrast to the older nonwater-bearing rocks, the water-bearing formations contain ground water in primary openings between the grains. These grains range in size from clay to silt, sand, and gravel and reach a maximum of boulder size in certain areas.

The water-bearing formations fall into two groups: the Santa Clara Formation of Plio-Pleistocene age; and Quaternary alluvium of Pleistocene to Recent age.

Santa Clara Formation. The Santa Clara Formation is exposed in the Mission Upland. Several other smaller exposures also occur at the base of the foothills to the east. The Santa Clara Formation underlies the Quaternary alluvium and rests unconformably on older formations of the nonwater-bearing group. It consists of obscurely bedded, poorly sorted, pebbly sandstone, siltstone, and clay. Exposures show the effects of chaotic bedding and curved slickensided surfaces due to multiple and continued sliding.

In the Mission Upland, exposures of the Santa Clara Formation in several sand and gravel quarries show well-sorted gravel lenses with practically no fines. These beds occur up to several feet thick and many feet long and appear to be very permeable. If they are common throughout the Mission Upland, they may account for the relatively high production of some wells in this area. Stream cross-bedding, scour and fill, and an extreme range in sorting all point to stream deposition. Exposures of this formation have an easterly dip ranging from 10 to 30 degrees.

Well data show that the permeability of the Santa Clara Formation tends to decrease from east to west toward the bay; hence, the highest production of wells is reported to be in the Mission Upland, on the eastern side of the basin. Well logs show that the sediments also tend to decrease in grain size and permeability with depth.

Quaternary Alluvium. Quaternary alluvium is the most important water-bearing formation in the Fremont ground water area. Permeability of the alluvium is generally high; consequently, all the water wells with large production draw their supply from it. The alluvium is composed of generally unconsolidated gravel, sand, silt, and clay. The sand and gravel deposits have the highest permeability and are thus the major aquifers; conversely, silt and clay layers have low permeability and, therefore, form aquicludes.

Alluvium along the eastern margin of the area was deposited by streams which drained the highlands and debouched onto a series of alluvial fans. Only the most recent of these fans are expressed physiographically today. The alluvium under San Francisco Bay is very fine-grained and is composed predominately of thick marine to brackish water clay layers, separated by thin, fine-grained sand and gravel stringers. The depth to the base of Quaternary alluvium could not be determined because of the marked similarity in lithology between it and the underlying Santa Clara Formation.

Geologic Structure

The Fremont ground water area occupies a portion of a major structural depression between the Diablo Range and the Santa Cruz Mountains. The two largest faults in the region lie on either side of this depression: the San Andreas rift zone, near the western side, and the Hayward fault along the eastern side. Movement along these faults and downwarping of the area between has created the bay depression.

Superimposed on this structural trough are many parallel northwest-trending features important to the occurrence and movement of ground water. Faulting has caused the bedrock under the bay depression to be broken into a series of parallel blocks, some of which have subsided and others of which have risen.

The Hayward fault (Plate 5) runs along the base of the foothills to the east and crosses the upper portion of the Niles Cone, where it forms an effective barrier to the lateral movement of ground water. The fault continues southeasterly between the Warm Springs and Mission subareas where it is marked by a well-formed, west-facing scarp, up to 200 feet in height and consisting of unconsolidated sediments of the Santa Clara Formation. Topographic evidence of the fault continues to a point just north of the Alameda-Santa Clara county line, where it appears to die out beneath the alluvium.

Where the fault crosses the Niles Cone, surface features include elongated depressions flanked by hills five to twenty feet high. The most recent fault movement in the Niles area has caused land on the northeastern side of the fault to be depressed 20 to 25 feet lower than on the opposite side. Historically, the direction of vertical movement has been in the opposite direction.

Ground Water Areas and Subareas

The South Bay Ground Water Basin contains three independent ground water areas: Fremont, Santa Clara, and San Mateo. The Fremont study area contains the portion of the Fremont ground water area south of the San Mateo Bridge (Plate 5). The Fremont study area has been divided into four ground water subareas, each having some degree of independence from the others. The areal extent of the Niles, Dry Creek, Warm Springs, and Mission ground water subareas is shown on Plate 5.

Niles Subarea

The Niles subarea is the largest ground water subarea in the Fremont ground water area. It includes the surficial extent of the Alameda Creek alluvial fan and extends southward and westward under San Francisco Bay and the Bay Plain.

The Niles subarea is the most important ground water region in Alameda County. The eastern portions of the subarea are extremely permeable and yield large quantities of ground water to wells. The stratified nature of the alluvium permits rapid transport of ground water from the recharge area, at the eastern edge of the subarea, to points of withdrawal to the west.

The Niles subarea is composed of a series of flat-lying aquifers separated by extensive clay aquicludes. In the vicinity of Niles, the alluvium is composed almost entirely of gravel. To the west, interbedded clay beds are thicker. The nature of the various aquifers and aquicludes in the Niles subarea has made it possible to delineate specific aquifers and to correlate them from one well to the next. The three uppermost aquifers in order downward are: the Newark, Centerville, and Fremont aquifers. Deeper, and unnamed, aquifers are referred to according to their average depth as the "400-foot" and "500-foot" aquifers.

Newark Aquiclude. Nearly all of the Niles subarea is covered by a thick veneer of silt and clay called the Newark aquiclude. It is present east of the Hayward fault in an area usually pictured as being completely devoid of a clay cover. In general, the thickness of the Newark aquiclude increases from the eastern edge of the Niles subarea westward toward San Francisco Bay. Because the aquiclude has a low permeability, it retards widespread infiltration of surface water into the underlying Newark aquifer. The thicker the aquiclude, the more effective it is in preventing salt water from moving into the underlying aquifer. Conversely, thinner portions of the aquiclude are less effective in preventing salt water intrusion.

Newark Aquifer. The Newark aquifer, lying directly below the Newark aquiclude, is an extensive gravel layer located between 60 and 140 feet below the ground surface. The aquifer is found east of Coyote Hills and underlies almost the entire Niles subarea. Nearly all logs of wells in the Niles subarea indicate the presence of the Newark aquifer. Wells at Ravenswood, on the western side of the bay, show that the aquifer continues underneath the bay both north and south of Dumbarton Bridge. The Newark aquifer is the main conductor of salt water eastward from San Francisco Bay. This eastward migration of salt water indicates that the Newark aquifer is fairly continuous throughout the Niles subarea.

The thickness of the Newark aquifer ranges from over 140 feet at the Hayward fault, to less than 20 feet at the western edge of the subarea. Those portions of the subarea in which the materials are particularly thick represent zones where coarse material has continuously been deposited by streams. The zones extend to the bay around the north and south ends of Coyote Hills.

Centerville Aquifer. Another important aquifer is the Centerville aquifer, which covers nearly as much of the Niles subarea as the overlying Newark aquifer. It is found nearly everywhere, except to the west of Coyote Hills. The Centerville aquifer lies at an average depth of between 180 and 200 feet below ground surface and is often referred to as the "180-foot aquifer".

An extensive thick clay aquiclude separates the Newark aquifer from the Centerville aquifer and largely protects this lower aquifer from receiving saline water from the Newark aquifer. The aquiclude is thickest under San Francisco Bay and thins to the east as the aquifers become thicker. Well log data suggest that the aquiclude has several thin zones which may allow some downward movement of saline water from the Newark aquifer into the Centerville aquifer.

The Centerville aquifer extends under San Francisco Bay as a flat-lying gravelly sand layer. The aquifer is the main source of ground water for wells located on the marsh along the western side of the bay, and for wells near Dumbarton Strait.

Fremont Aquifer. The Fremont aquifer is separated from the overlying Centerville aquifer by a thick clay aquiclude. The Fremont aquifer is not as well defined as the Newark and Centerville aquifers, but is generally thicker and more productive. From well log data, it can be inferred that the Fremont aquifer exists primarily in that portion of the Niles subarea east of Coyote Hills. The depth to the Fremont aquifer varies from 300 to 390 feet below ground surface. Near the Hayward fault, the Fremont aquifer merges with the overlying aquifers.

Deeper Aquifers. Wells in the Niles subarea, reaching depths greater than 400 feet, intercept highly productive deeper aquifers. Where wells are close together, these deeper aquifers can be correlated for short distances. The correlatable portions suggest that the aquifers are relatively flat lying. The aquifers below 400 feet may extend beyond the limits of the Niles subarea and serve as zones for migration of ground water. The configuration of water levels in wells tapping the deeper aquifers shows a gradient toward the northwestern boundary of the Niles subarea. This suggests that ground water in the Niles subarea moves toward the north to meet water moving outward from the adjacent San Leandro Cone. The deeper aquifers appear to be recharged by infiltration of water from both Alameda and San Lorenzo creeks.

The extensive nature of the deeper aquifers is important because, if the Niles subarea becomes degraded by salt water to considerable depths, the outward movement of ground water may also degrade the quality of water in adjacent areas. Some communities north of the Niles subarea use ground water from these deeper aquifers; thus, any sea water intruded into the Niles subarea could migrate toward pumping depressions and degrade ground water in these deeper aquifers.

Dry Creek Subarea

The Dry Creek subarea is located just south of the divide between the San Leandro Cone and Niles subarea. It is small and is superimposed on a portion of the Niles subarea.

The Dry Creek alluvial fan was formed as a rather late development in the depositional history of the area. Alluvium that is a part of the Dry Creek alluvial fan extends southwest from the hillfront about three miles; it attains a maximum thickness of about 350 feet.

Most of the subarea consists of clay, as sand and fine gravel aquifers are thin and discontinuous. The number and thickness of individual aquifers and their transmissibility decreases from the hillfront toward the bay.

Ground water in the Dry Creek subarea is largely confined by the thick clay layers which overlie and separate the individual aquifers. Water levels are usually high and recharge occurs at the eastern edge through infiltration from Dry Creek. Well logs show that aquifers in the Dry Creek subarea become thicker toward the southern portion, suggesting that well production should be higher there.

Mission Subarea

The Mission subarea includes all exposed portions of the Santa Clara Formation within the Mission Upland and also a small area of shallow alluvium overlying the Santa Clara Formation, just east of the Hayward fault. The thickness of the Santa Clara Formation in this subarea may exceed 500 feet; however, the deepest well in the subarea penetrates only 298 feet of the formation.

Most water wells in this subarea are in the northern portion. Yields here are between 200 and 400 gallons per minute. Well logs indicate that the upper 100 feet of materials contain over 50 percent gravel. Below 100 feet, even larger percentages of gravel are recorded.

The Santa Clara Formation dips easterly at less than 30 degrees. Consequently, while the overall permeability of the formation may be fairly high, the combination of stratification and eastward dip precludes any significant westward movement of ground water. The Hayward fault also acts as a barrier to the westward movement of ground water in this subarea. These features make it unlikely that any significant quantities of ground water could move from this subarea into the adjacent Warm Springs subarea.

Recharge of ground water to the Santa Clara Formation is derived primarily from infiltration of streamflow and precipitation. Ground water apparently moves northwesterly from the Mission subarea into the alluvium of the Niles subarea east of the Hayward fault.

Warm Springs Subarea

The Warm Springs subarea lies to the west of the Mission subarea and includes both the areal expanse of the Warm Springs Alluvial Apron and a portion of the alluvial sediments farther west.

The aquifers in the Warm Springs subarea are thin and fine-grained, and the opportunity for recharge is limited. Thus, the ground water in this subarea is relatively unimportant. A considerable number of shallow domestic wells and some irrigation wells are present. The largest known ground water production in the subarea is 90 gallons per minute, produced from a well over 200 feet deep. The rather low yield of wells in the Warm Springs subarea is explained by the low gravel content of the alluvium. Well logs show that the upper 100 feet of alluvium contains less than 17 percent gravel, except near the extreme southeastern boundary of the subarea where logs from two wells reported 24 percent gravel.

Recharge of ground water in the Warm Springs subarea occurs by the infiltration of water flowing across the area in small streams draining the Mission Upland. There is some movement of ground water toward the west into the Niles subarea, but because of the general low permeability, very little ground water actually is contributed to the adjacent subarea.

CHAPTER III. EVALUATION OF HISTORIC WATER SUPPLY AND DISPOSAL

The development and testing of a hydrologic inventory of the ground water system underlying the study area is necessary in the verification of the hydraulic characteristics of a ground water system.

An inventory of a system of ground water aquifers and aquitards is a determination of the balance between items of supply and disposal of ground water over a selected period. The difference between the total amounts of supply and disposal is one means of determining the change of the amount of water in storage. To verify the accuracy of the inventory, the change in storage is also determined by interpretation of the change in water levels in the water-bearing materials.

At the start of this study, there was a very limited amount of data about the large area under and adjacent to south San Francisco Bay; thus, the main body of data now available had to be developed for this study. (See Appendix A.)

Ground Water Basin Model

A mathematical model of the basin was developed based on work by the Southern District of the Department. (See Bulletin No. 104, Planned Utilization of Ground Water Basins of the Coastal Plain of Los Angeles County, Appendix C: Operation and Economics. December 1955.) This model was programmed on analog and digital computers. The high speed computers allowed a wide range of values to be tried in the basin model. As a result, amounts of supply and disposal which originated as a ranges of value, were refined to single values.

Study Period

In selection of a segment of time to use as a study period, it is desirable to specify certain criteria. The hydrologic condition during the study period should reasonably represent a long-time hydrologic condition. The time segment selected should begin at the end of a dry period and should end at the conclusion of a dry period in order to minimize the difference between the amount of water in transit between the end of the study period. The time segment should be within the period of available records, and if recent cultural conditions have been recorded, this information can aid in determination of the effect of urbanization on recharge to the ground water.

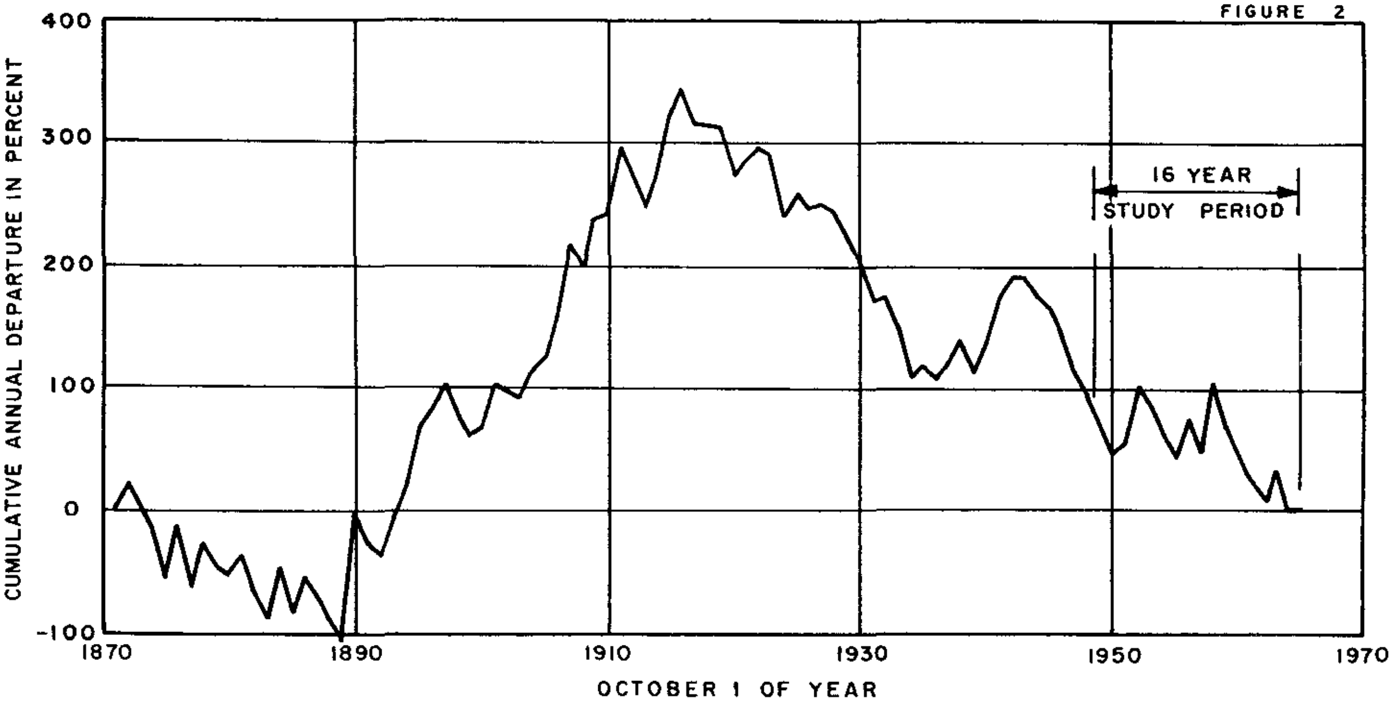
Review of possible study periods resulted in selection of the 16-year period, 1949-50 through 1964-65 as the best time segment available. Data limitations set the beginning of the study period. The earliest comprehensive land use survey of the area was made in 1949 by the State Division of Water Resources. The years preceding the beginning and end of the study period selected were dry, and available data for the late years includes current cultural conditions.

The relationship of precipitation during the long-term record and the study period is shown on Figure 2 as a graph of accumulative percent deviation from long-term mean.

The average precipitation for the 16-year period is 96 percent of the average of the 94 years of record. When applied to average conditions, the values determined for items of supply and disposal, based on the 16-year study period, will require minor adjustment.

A relationship between runoff in Alameda Creek at Niles for the 16-year and long-time average is not valid due to lowered ground water levels in the Livermore Valley, and construction of diversion and conservation facilities upstream of the Niles gage. Records from the Livermore Station show that precipitation averaged 14.42 inches for the 94-year period, 1871-1965, and 14.53 inches for the 16-year study period. The 16-year average is 100.7 percent of the 94-year period. Runoff at Niles during the 16-year period is considered to represent average conditions of runoff, since the precipitation in the Livermore Valley during the 16 years was normal and no projects affecting the streamflow were constructed during the period.

FIGURE 2



CUMULATIVE DEPARTURE OF ANNUAL PRECIPITATION
FROM 94 YEAR MEAN

Cultural Conditions

Changes in land and water use affect the amount of recharge obtained from precipitation, streamflow, and delivered water. Land use and the quantity of water required per acre for various types of land use (unit water use) may also be used to estimate amounts of water required to sustain a culture.

Land Use

The study area of 115,000 acres is in transition from an agricultural to an urban economy. With the continued rapid influx of population into southern Alameda County, the economy will become more aligned with that of the rest of the East Bay. If the present trend persists, nearly all productive agricultural areas will be urbanized by 1990.

Six types of land use were considered for this study: (1) irrigated agricultural land, (2) municipal developed land, (3) industrial developed land, (4) non-irrigated land (dry farm and native), (5) land occupied by San Francisco Bay, and (6) land occupied by salt evaporation ponds.

Land use surveys were made by the State Division of Water Resources in 1949 (Plate 6), and by the Alameda County Water District in 1958 and 1964 (Plate 7). Land use for the study period is based on interpolation of these surveys and is shown in Table 1.

TABLE 1

Land Use
(In Acres)

Year	Irrigated Agriculture	Municipal	Industrial	Salt Ponds	Bay	Dry Farm and Native
1949-50	16,360	1,130	800	23,130	30,210	43,370
50-51	16,135	1,510	810	23,130	30,210	43,205
51-52	15,910	1,890	830	23,130	30,210	43,030
52-53	15,685	2,270	840	23,130	30,210	42,865
53-54	15,460	2,650	860	23,130	30,210	42,690
54-55	15,235	3,030	870	23,130	30,210	42,525
55-56	15,010	3,400	880	23,130	30,210	42,370
56-57	14,785	3,780	900	23,130	30,210	42,195
57-58	14,560	4,160	910	23,130	30,210	42,030
58-59	14,330	4,540	930	23,130	30,210	41,860
59-60	13,675	5,500	1,030	23,130	30,210	41,485
60-61	13,020	6,460	1,130	23,130	30,210	41,050
61-62	12,365	7,420	1,230	23,130	30,210	40,645
62-63	11,710	8,380	1,330	23,130	30,210	40,240
63-64	11,060	9,340	1,430	23,130	30,210	39,830
1964-65	10,700	9,900	1,480	23,130	30.210	39,580

Unit Water Requirements

The average amounts of water applied to crops grown in the area, listed in Table 2, are based on measurements of applied water in the study area or adjusted measurements made in other areas of the state. The values shown in Table 2 are higher than those shown in Bulletin No. 2[1] and reflect additional data obtained since publication of Bulletin No. 2.

TABLE 2

Unit Water Requirements
Irrigated Crops

Crop	Applied Water Requirement in Acre-Feet per Acre*
Lettuce	1.5
Tomatoes	2.0
Cucumbers	1.6
Corn	1.7
Sugar Beets	2.1
Cauliflower	1.5-2.6**
Irrigated Pasture	2.5
Beans (Pole)	1.4
Broccoli	1.5-2.6**
Cabbage	2.4
Chinese Vegetables	2.8
Pepper	2.7
Potatoes	1.5
Onions	2.7
Strawberries	3.8
Field Flowers	4.0
Apricots	2.0
Cherries	2.0
Pears	2.0
Walnuts	2.0
Study Area Average (1958 Land Use)	2.3

* At the farm headgate and for a single crop.
** Depends on date of planting.

[1] State of California, State Water Resources Board. Bulletin No. 2, Water Utilization and Requirements of California. June 1955.

Supply: Recharge to Ground Water

The reference, or free body, used in the ground water inventory is the ground water in storage. The inventory is made on an annual basis, and under the assumption that water which percolates below the root zone will reach the ground water mass during the same water year.

Items of supply, or recharge, to the ground water are derived mainly from precipitation, storm runoff, imported water, and pumped ground water. Specifically, the items of supply are:

1. Portion of precipitation percolating to ground water.

2. Portion of storm runoff, or streamflow, percolating to ground water.

3. Portion of imported water released into Alameda Creek and adjacent gravel pits which percolates to ground water.

4. Portion of applied (delivered) water percolating to ground water. (This item includes pumped ground water and imported water put directly into water distribution systems.)

5. Subsurface inflow.

6. Water released by compaction of clay beds.

When sufficient data are available, the amounts of precipitation and applied water recharged to ground water are computed for each type of land use. Starting at the beginning of a water year, and on a monthly-accounting basis, the monthly amounts of precipitation and applied water are used to satisfy soil moisture deficiency and consumptive use. Any excess of supply then becomes recharge to ground water.

As an alternative procedure, data can be transposed from an area in which a detailed analysis has been made, provided the rainfall and cultural conditions are similar.

Since records of applied water for individual crops are not available for the study period, even on an annual basis, for purposes of this study the data concerning annual amounts of precipitation and applied water becoming recharge developed for the San Fernando Valley[2] were used. Data are in the form of acre-feet of recharge, per acre, of a particular land use.

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[2] State Water Rights Board, Report of Referee, San Fernando Valley Reference. July 1962.

Precipitation

Department Bulletin No. 13, Alameda County Investigation, published in March 1963, was reviewed and information on precipitation developed during that investigation was found adequate for this study. The previous investigation concluded that the general precipitation pattern within southern Alameda County, which includes the Fremont study area, is quite uniform and that, for the purpose of hydrologic analysis of the ground water basin, the record at Niles was representative of the study area. Recorded and estimated annual precipitation near Niles since 1871-72 is shown in Table 3. The mean monthly distribution of precipitation is shown on Figure 3. The locations of precipitation stations and the areal distribution of mean precipitation (Isohyetal Map) are shown on Plate 8.

The amount of recharge from rainfall for each year is computed as the product of the average unit recharge value, the acreage, and the index of wetness. Average annual values of 0.20 acre-feet per acre for irrigated land, 0.12 for non-irrigated land, and 0.20 for municipal land are used in the computation and are based on values developed for the San Fernando Valley3/. The index of wetness is included to approximate the effect above and below normal precipitation. Effects of variations in thickness of the clay cap, separating the ground surface from the aquifer material, are not known. The unit values of recharge are the amounts of rain which fall on an area and percolate through the root zone and to the ground water body in that area. That part of the rainfall which is neither percolated nor consumed in the area becomes local runoff and may percolate while in transit to Alameda Creek or the San Francisco Bay. The disposition of this local runoff is discussed in the section on streamflow. Annual amounts of recharge from precipitation are shown in Table 4.

Streamflow

Alameda Creek is the main stream traversing the forebay of the area. Flow measurements since 1891-92 are available for the creek where it enters the area near Niles and for three years, 1916-1919, for the lower end of the recharge area near Decoto. Main flows now leave the area by a new channel, Patterson Creek, but the old Alameda Creek continues to receive excess flows. Both of the outflow channels have been gaged since 1958-59. Dry Creek, located near the upper end of the area and tributary to the Alameda Creek lower gage, is also measured.

Flows of other streams tributary to the study area were estimated by correlation with gaged streams. Recorded amounts of runoff for gages shown on Plate 8 are shown in Table 5. The mean monthly flows of Alameda Creek near Niles are shown graphically on Figure 4.

3/ Ibid.

TABLE 3

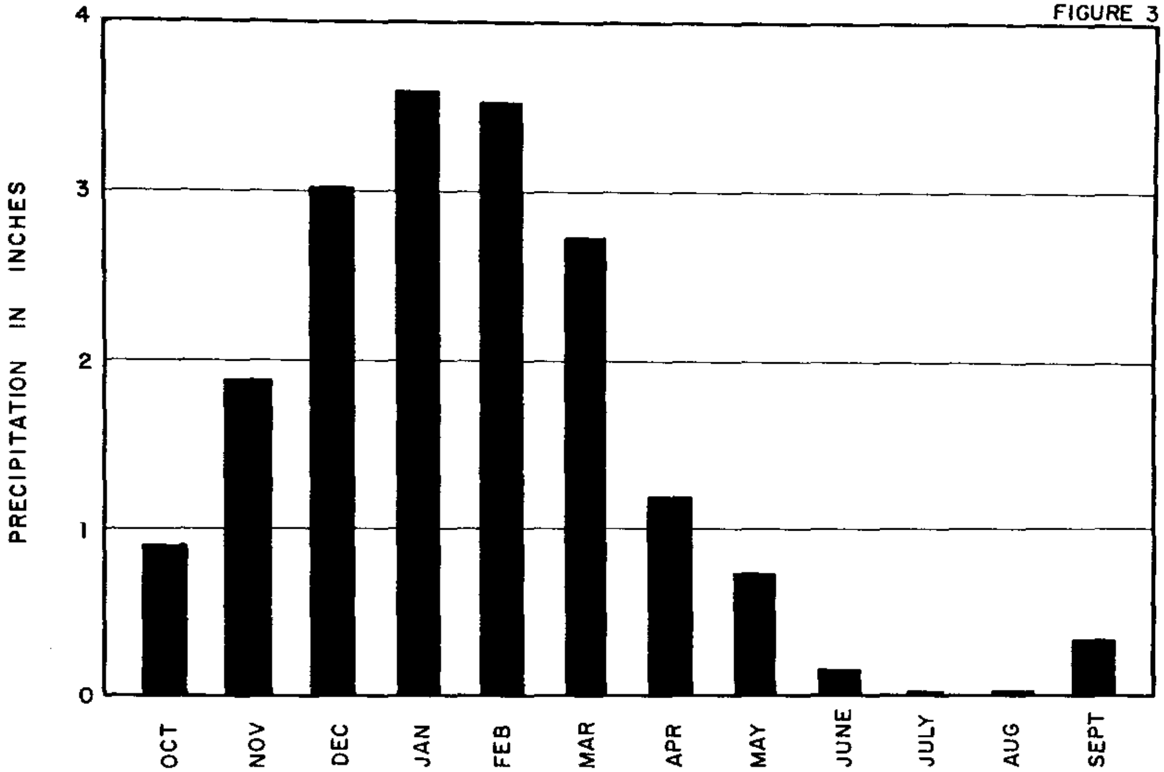
Annual Precipitation and
Index of Wetness
1871-1965

Year	Inches a/	Index of Wetness b/	Year	Inches	Index of Wetness	Year	Inches	Index of Wetness
1871-72	22.65	125	1905-06	24.20	133	1935-36	16.69	92
72-73	14.31	79	06-07	28.85	159	36-37	19.77	109
73-74	14.10	78	07-08	15.12	83	37-38	21.80	120
74-75	11.81	65	08-09	25.10	138	38-39	13.33	73
			09-10	18.65	103	39-40	22.20	122
1875-76	25.88	142	1910-11	27.59	152	1940-41	25.35	140
76-77	9.34	51	11-12	15.80	87	41-42	21.23	117
77-78	24.67	136	12-13	12.06	66	42-43	18.29	101
78-79	14.54	80	13-14	22.95	127	43-44	15.38	85
79-80	17.70	97	14-15	27.34	150	44-45	16.82	93
1880-81	20.06	110	1915-16	21.38	118	1945-46	14.39	79
81-82	13.55	75	16-17	13.50	74	46-47	12.60	69
82-83	13.80	76	17-18	18.15	100	47-48	14.72	81
83-84	26.25	144	18-19	17.49	96	48-49	12.72	70
84-85	10.70	59	19-20	11.06	61	49-50	14.00	77
1885-86	23.35	128	1920-21	20.62	113	1950-51	20.21	111
86-87	15.37	85	21-22	19.85	109	51-52	26.26	145
87-88	14.67	81	22-23	17.89	98	52-53	15.50	85
88-89	15.67	86	23-24	8.63	47	53-54	13.50	74
89-90	36.36	200	24-25	21.65	119	54-55	14.90	82
1890-91	14.04	77	1925-26	16.35	90	1955-56	23.85	131
91-92	16.18	89	26-27	18.79	103	56-57	12.99	71
92-93	23.72	131	27-28	16.55	91	57-58	28.30	156
93-94	23.19	128	28-29	14.48	80	58-59	12.30	68
94-95	26.63	147	29-30	14.78	81	59-60	13.83	76
1895-96	20.33	112	1930-31	12.22	67	1960-61	13.83	76
96-97	22.72	125	31-32	18.87	104	61-62	16.06	88
97-98	13.61	75	32-33	13.70	75	62-63	22.58	124
98-99	14.52	80	33-34	10.66	59	63-64	11.99	66
99-00	19.30	106	34-35	19.77	109	64-65	18.16	100
1900-01	25.22	139						
01-02	17.12	94						
02-03	17.20	95						
03-04	21.91	121						
04-05	20.19	111						

Averages
94 years, 1871-1965 -- 18.17 — 100
16 years, 1949-1965 -- 17.39 — 96

a/ Data on years prior to 1933-34 and after 1957-58 from gage at Niles, Latitude 37°34'07", Longitude 121°59'00".
Data on years 1933-34 through 1957-58 from gage at Niles, Latitude 37°43'42", Longitude 121°58'42".

b/ Index of wetness is the percent of 94-year average.

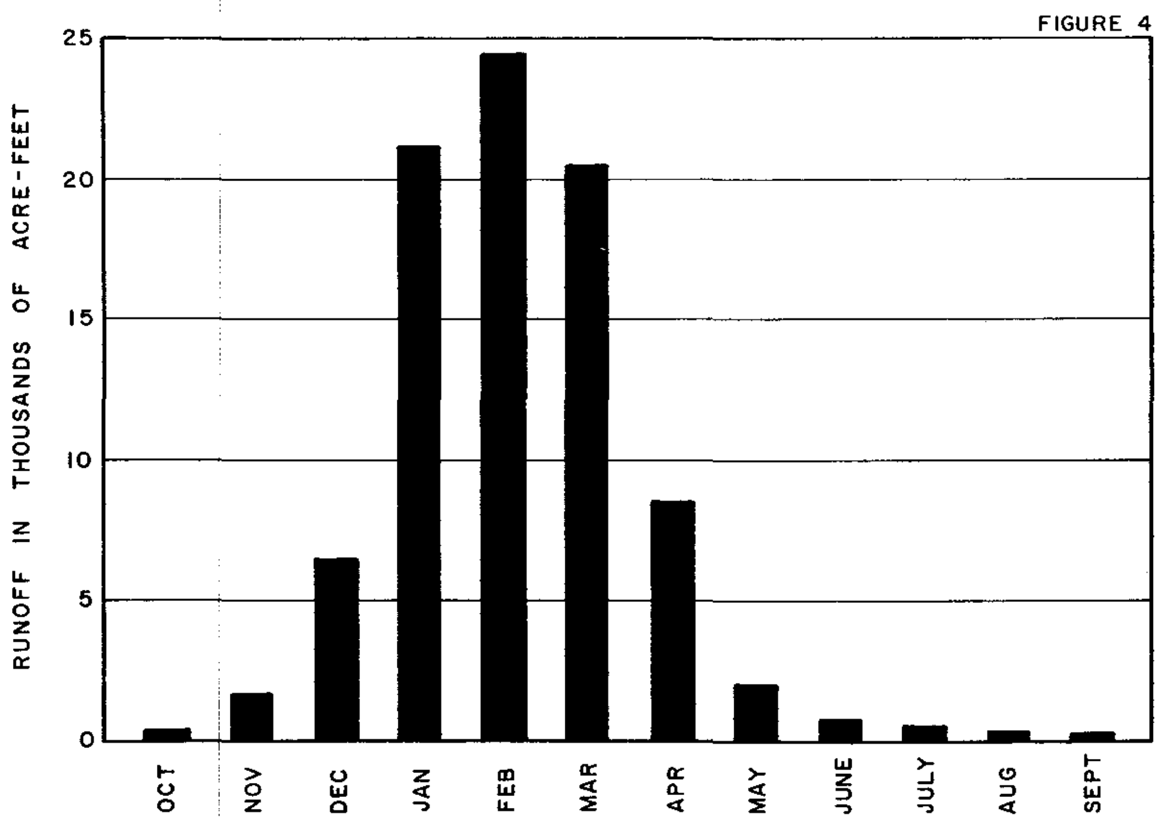


MEAN MONTHLY PRECIPITATION NEAR NILES
(BASED ON THE 94 YEAR PERIOD 1871-72 TO 1964-65)

TABLE 4

Recharge from Precipitation
(1,000 Acre-Feet)

Year	Land Use			
	Irrigated Agricultural Lands	Municipal Lands	Dry Farm, Native and Industrial Lands	Total
1949-50	2.5	0.2	4.1	6.8
1950-51	3.6	0.3	5.9	9.8
51-52	4.6	0.5	7.6	12.7
52-53	2.7	0.5	4.5	7.7
53-54	2.3	0.4	3.9	6.6
54-55	2.5	0.5	4.3	7.3
1955-56	3.9	0.9	6.8	11.6
56-57	2.1	0.5	3.7	6.3
57-58	4.5	1.3	8.0	13.8
58-59	2.5	0.6	3.5	6.6
59-60	2.1	0.8	3.9	6.8
1960-61	2.0	1.0	3.8	6.8
61-62	2.2	1.3	4.4	7.9
62-63	2.9	2.1	6.2	11.2
63-64	1.5	1.2	3.3	6.0
64-65	2.1	2.0	4.9	9.0



MEAN MONTHLY RUNOFF OF ALAMEDA CREEK NEAR NILES (BASED ON THE 74 YEAR PERIOD 1891-92 TO 1964-65)

Local runoff originating on the valley lands of the study area is that portion of precipitation not consumed or percolating to ground water. On its way to San Francisco Bay or a gaged channel, a portion of this local runoff may percolate. Due to the location of recharge facilities and gaging stations, the analysis of runoff has been divided into analysis of that portion of the study area bounded by Alameda Creek, Dry Creek, and the hills to the northeast, and analysis of runoff in the remaining study area, less the Bay and the salt ponds.

Runoff in the Alameda Creek-Dry Creek Area. In the area bounded by Alameda Creek, Dry Creek, and the hills to the northeast, surface flows available for percolation include those passing the upper gage on Alameda Creek and the Dry Creek gage, tributary ungaged runoff from the hills to the north, and local runoff developed within this area.

TABLE 5

Recorded Annual Runoff
(In Acre-Feet)

Alameda Creek Near Niles

Year	Acre-Feet	Year	Acre-Feet	Year	Acre-Feet
1891-92	56,000	1915-16	233,000	1940-41	200,000
92-93	360,000	16-17	86,000	41-42	128,100
93-94	147,000	17-18	12,600	42-43	79,490
94-95	263,000	18-19	107,000	43-44	35,010
		19-20	8,250	44-45	48,430
1895-96	118,000	1920-21	72,400	1945-46	15,740
96-97	204,000	21-22	131,000	46-47	2,080
97-98	7,020	22-23	58,000	47-48	899
98-99	64,100	23-24	2,060	48-49	5,610
99-00	51,700	24-25	18,700	49-50	8,680
1900-01	119,000	1925-26	31,000	1950-51	115,200
01-02	83,800	26-27	48,300	51-52	291,100
02-03	110,000	27-28	30,100	52-53	24,760
03-04	98,300	28-29	5,240	53-54	4,250
04-05	45,400	29-30	19,200	54-55	5,900
1905-06	203,000	1930-31	1,220	1955-56	214,100
06-07	324,000	31-32	57,400	56-57	7,880
07-08	46,500	32-33	6,980	57-58	245,700
08-09	239,000	33-34	7,920	58-59	14,660
09-10	84,200	34-35	30,490	59-60	11,940
1910-11	272,000	1935-36	77,150	1960-61	650
11-12	16,500	36-37	100,100	61-62	30,840*
12-13	6,550	37-38	286,000	62-63	57,558*
13-14	179,000	38-39	15,220	63-64	7,640*
14-15	182,000	39-40	92,580	64-65	71,920*

Averages
74 years, 1891-1965, 86,230
16 years, 1949-1965, 69,550

* Gaged amounts less South Bay Aqueduct water (Table 7).

Patterson Creek Near Union City

Year	Acre-Feet	Year	Acre-Feet	Year	Acre-Feet
1958-59	10,410	1960-61	7,290	1962-63	42,800
59-60	7,290	61-62	22,640	63-64	4,240
				64-65	60,960

Alameda Creek Near Decoto

Year	Acre-Feet	Year	Acre-Feet	Year	Acre-Feet
1916-17	74,000	1917-18	7,200	1918-19	91,400

Alameda Creek at Union City

Year	Acre-Feet	Year	Acre-Feet	Year	Acre-Feet
1958-59	142	1960-61	0	1962-63	3,860
59-60	614	61-62	1,300	63-64	99
				64-65	5,590

Dry Creek at Union City

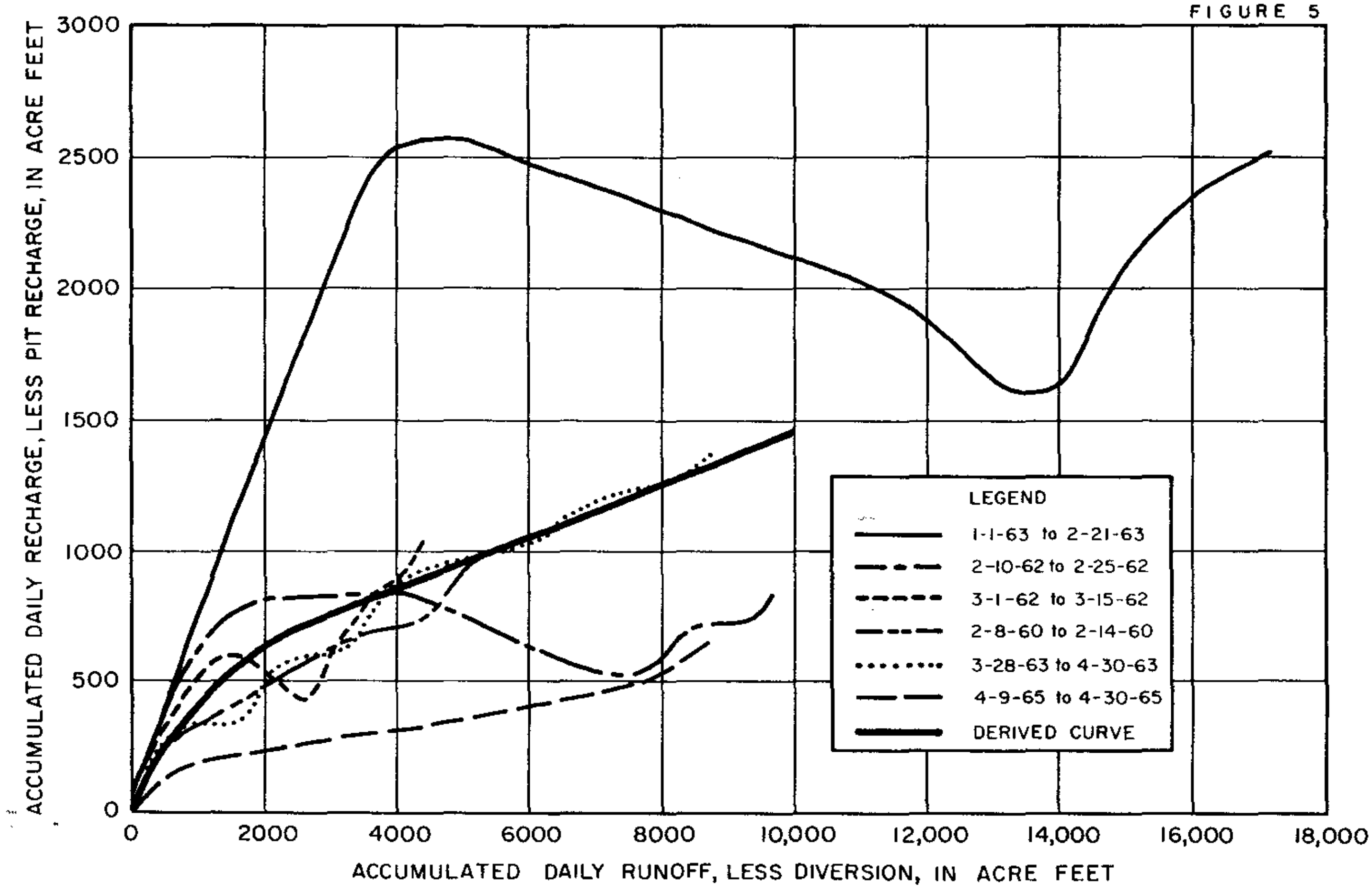
Year	Acre-Feet	Year	Acre-Feet	Year	Acre-Feet
1916-17	957	1959-60	463	1962-63	1,970
17-18	61	60-61	8	63-64	224
18-19	1,330	61-62	1,060		

A portion of the flow in Alameda Creek is diverted into percolation pits by the Alameda County Waters District (ACWD). The pits and diversion facilities are shown on Plate 9. The only known surface diversions during the study period are those made by ACWD. Since 1959, diversions into the pits have been determined by ACWD on the basis of percolation rates in the pits, and fluctuation of water levels in the pits. Prior to 1960, diversions from Alameda Creek into the pits were determined on the basis of partial records showing water levels in the pits. All of the water diverted into the pits during a water year was assumed to percolate to ground water during the same year.

Recharge in the Alameda Creek-Dry Creek area, exclusive of that occurring in the pits, is the total runoff available less diversions and outflow. The total runoff is the sum of flows in Dry Creek and Alameda Creek at the upstream boundary of the study area, plus local runoff produced within the area. The method of determining the amount of local runoff is described in the section on determining runoff in the remainder of the study area, (page 27). Recharge was calculated for the period of outflow record, 1958-59 through 1964-65. During the years 1961-62 through 1964-65, flows in Alameda Creek contained releases from the South Bay Aqueduct of the State Water Project. The amounts of recharge from runoff shown in Table 6 include recharge in the total area, including the pits, less amounts of South Bay Aqueduct water flowing past the Alameda Creek gage near Niles.

Using the data for the years after 1957-58, a correlation was found between daily accumulated recharge and daily accumulated runoff, each starting from a day of significant increase in flow in Alameda Creek and exclusive of diversions and pit recharge. The data and resulting generalized relationship are shown on Figure 5. Portions of some of the curves plotted on Figure 5 have a negative slope, caused by either an error in the streamflow record or by flow of water diverted into the pits which then flows back into the stream channel. Recharge during the years prior to 1958-59 was calculated by accounting for water in the system on a daily basis, using information shown on Figure 5 to determine percolation during periods of high flows. Amounts of recharge from streamflows in Alameda Creek and Dry Creek are shown in Table 6. These amounts do not include imported waters released into the creeks or pits.

FIGURE 5



RUNOFF-RECHARGE RELATIONSHIP
IN THE ALAMEDA CREEK-DRY CREEK AREA
(EXCLUSIVE OF DIVERSIONS AND PIT RECHARGE)

Runoff in the Remainder of Study Area. In the San Fernando Valley study unit values were developed for the portion of precipitation which became local runoff. The San Fernando Valley unit-runoff amounts were plotted against the index of wetness, and the resulting curve used to obtain unit runoff values for the study area. The local runoff obtained by this method was added to runoff originating in the hills south of Alameda Creek, and east of the study area. Of the total runoff flowing overland in the channels, it was estimated that 20 percent percolated before entering Alameda Creek or the San Francisco Bay. The annual amounts of recharge are shown in Table 6.

TABLE 6

Recharge from Runoff
(in 1,000 Acre-Feet)

Year	Area		
	Alameda-Dry Creek Area*	Local Channels on Valley Floor	Total
1949-50	6.3	1.1	7.4
1950-51	25.4	2.9	28.3
51-52	31.0	4.2	35.2
52-53	12.4	1.4	13.8
53-54	3.3	1.0	4.3
54-55	5.9	1.3	7.2
1956-56	20.9	3.5	24.4
56-57	6.2	0.9	7.1
57-58	22.9	5.3	28.2
58-59	5.0	0.8	5.8
59-60	5.1	1.5	6.6
1960-61	1.3	1.0	2.3
61-62	9.1	1.7	10.8
62-63	17.0	2.6	19.6
63-64	4.2	0.9	5.1
64-65	8.4	2.2	10.6
16-year average	11.5	2.0	13.5

* Amounts include recharge in pits but have been corrected to exclude water from State Water Project flowing in Alameda Creek.

Quality of Alameda Creek Flows. The drainage basin of Alameda Creek includes the Livermore and Sunol valleys and their surrounding hills. Since 1962, flows in Alameda Creek have contained South Bay Aqueduct water. Samples taken at the stream gaging station near Niles, between 1951 and 1962, (Plate 8) show the water to be bicarbonate in character with none of the major cations, calcium magnesium, or sodium being predominant. Due to fluctuations in electrical conductivity, concentrations of total dissolved solids, or boron, singly or in combination, this water ranged from Class I to Class II for irrigation use.

Springs in the northern and western portions of the watershed are the source of the boron. The hardness of the water ranges from moderate to very hard. The mineral constituents are within the criteria for domestic use. Since 1962, low flows in Alameda Creek reflect use of the channel to transport South Bay Aqueduct water.

Subsurface Flow

Subsurface flow is possible across most of the study area boundary except on the east at the contact with the Diablo Range.

There is indication that continuity and gradients in the lower aquifers permit subsurface flow to the north toward Hayward. There is also indication of continuity in the lower aquifers in a northwesterly direction under the Bay. No source area of subsurface flow to the northwest has been determined. A quantitative determination of subsurface flow was not made, since water level data were not conclusive and the results of the ground water inventory indicated the amount of subsurface flow was minor.

Imported Water

Agencies in the study area purchase some water from two suppliers of imported water: the City of San Francisco and the State of California.

City of San Francisco. Through its Hetch Hetchy Aqueduct the City of San Francisco delivers water to the cities of Hayward and Milpitas and to the Alameda County Water District. All of this supply is served to customers of the local water systems and is accounted for in the inventory as recharge of applied water. Alameda County Water District also receives small amounts of water from the City of San Francisco's Sunol Aqueduct. This water is delivered to the Bunting Pits (Plate 9) for recharge, and to other users along Alameda Creek.

The Hetch Hetchy Aqueduct transports imported water from the area adjacent to Yosemite National Park. A 1961 analysis of Hetch Hetchy Aqueduct water shows the mineral quality to be excellent and suitable for all normal uses. The water was calcium bicarbonate in character and had the following quality:

Constituent	Unit	1961 Sample
Total Dissolved Solids	ppm	28
Total Hardness	ppm	15
Chlorides	ppm	4
Sodium	%	30

State of California. The South Bay Aqueduct, first water delivery facility of the California State Water Project, has been a source of recharge water to the Fremont area since 1962, when the first section of this aqueduct to be completed was put into operation. Water was released from the aqueduct at the Altamont Turnout and flowed through the Livermore Valley to Niles until 1965, when the remainder of the aqueduct was completed. Since then, water has been released to Alameda Creek at the Vallecitos Turnout.

The water supply contract between the Department of Water Resources and the Alameda County Water District includes a water quality objective which reads in part:

Constituent	Unit	Monthly Average	Average for any 10-year period
Total Dissolved Solids	ppm	440	220
Total Hardness	ppm	180	110
Chlorides	ppm	110	55
Sulfates	ppm	110	20
Sodium	%	50	40

Tests showed the quality of water delivered through the South Bay Aqueduct during the period April 1962 to November 1965 to be as follows:

Constituent	Unit	Average for Period April 1962 to November 1965
Total Dissolved Solids	ppm	333
Chlorides	ppm	92
Sulfates	ppm	56
Sodium	%	50

Considerable variation in the mineral quality of South Bay Aqueduct water occurs between May-June and January-February. This seasonal variation will be eliminated and overall quality will improve when the proposed Peripheral Canal is constructed and placed in service to carry Sacramento River flows through the Delta to supply the South Bay Aqueduct as well as the other features of the State Water Project.

The ground water is recharged by water from the South Bay Aqueduct released to flow in Alameda Creek and then diverted into adjacent gravel pits near Niles. The annual amounts of South Bay Aqueduct water flowing past the Niles gage are based on computations performed by the Alameda County Water District which takes into account losses that occur between the turnout from the aqueduct and the Niles gage.

Amounts of water imported for spreading from the City of San Francisco's aqueducts and from the State of California's South Bay Aqueduct are listed in Table 7.

TABLE 7

Water Imported for Spreading
(In 1,000 Acre-Feet)

Year	Source		
	City of San Francisco*	State of California	Total
1949-50	3.1		3.1
1950-51	8.9		8.9
51-52	9.3		9.3
52-53	5.7		5.7
53-54	3.8		3.8
54-55	2.2		2.2
1955-56	5.8		5.8
56-57	4.9		4.9
57-58	3.5		3.5
58-59	3.7		3.7
59-60	2.2		2.2
1960-61	2.1		2.1
61-62	2.4	3.9	6.3
62-63	1.7	9.1	10.8
63-64	0.4	15.3	15.7
64-65	0.3	13.7	14.0

* Does not include amounts delivered to consumers.

Applied Water

Applied water includes imported water which is put directly into distribution systems, and pumped ground water. The pumped water includes that imported for recharge, percolation from streamflow and precipitation, and return of applied water.

Quality of Ground Water. The main body of ground water in the study area is contained in the Niles subarea (Plate 5). The quality of the ground water is related to four subdivisions within the subarea. The four subdivisions are (1) Newark aquifer, (2) the lower aquifers, (3) the forebay below the Hayward fault, and (4) that found in the area above the Hayward fault. Appendix D contains analyses of ground water samples taken from these four locations within the subarea.

In the aquifers of the study area, except where sea water intrusion is far advanced, the character of ground water is bicarbonate. In areas receiving direct recharge from Alameda Creek, such as the Niles subarea above the Hayward fault (Plate 5), and the Niles subarea forebay (Plate 5) below the Hayward fault, the calcium, magnesium, and sodium cations are evenly distributed. In areas further removed from the main recharge area, there exists a less even distribution of cations.

The quality of water in the Newark aquifer deteriorates rapidly from good, adjacent to the forebay, to unsatisfactory, towards the Bay. Adjacent to the Bay, the character of Newark aquifer water changes to a highly mineralized sodium chloride type with chloride concentrations in excess of 20,000 ppm.

Considerable difficulty was encountered in attempting to delineate the actual extent of intrusion and its history. When the land was subdivided, all wells were abandoned. Thus, there is no information for large areas. Some of the historical data were based on samples taken from wells which had been idle for long periods. Such samples were taken without pumping the wells and resulted in samples not representative of the ground water.

The isochlor map for the Newark aquifer, Plate 1, is based on an investigation of 78 shallow wells in the intruded area. It was possible to obtain samples from only 23 of the 78 wells. All 23 wells were sampled, using a mobile pump, until chloride concentrations became constant. Chloride analyses, water levels, temperature, and electrical conductivity readings were taken throughout the pumping operation.

In the Centerville-Fremont aquifer, quality in the intruded area is constantly varying, being alternately affected by winter recharge and summer pumping, although the overall trend is toward higher salinity. The extent of intrusion is shown on Plate 2.

Aquifers below the Fremont aquifer are called the "400-foot aquifer" and "500-foot aquifer". Individual wells have become unsuitable due to salt water degradation. The area of degradation appears limited to the northeast portion of the City of Newark and the vicinity of Alvarado in the City of Union City.

Excessive amounts of nitrates are found locally southwest of Union City and south of the Niles district of Fremont. In these areas, the nitrate concentration exceeds the 45 ppm limit for drinking water recommended by the United States Department of Health, Education, and Welfare.

Recharge from Applied Water. The annual amount of ground water recharge resulting from water applied to municipal land, 0.20 acre-feet per acre, was determined in the same manner as was the amount of recharge from precipitation4/, except that the degree of wetness was not used as a modifier. Based on local irrigation efficiencies, it was assumed that 30 percent of the water applied to agricultural land would become recharge to the ground water. The annual amounts of recharge from applied water are shown in Table 8. For industrial lands, it was assumed that no applied water became recharge.

TABLE 8

Recharge from Applied Water
(In 1,000 Acre-Feet)

Year	Land Use		
	Irrigated Agriculture	Municipal	Total
1949-50	11.3	0.2	11.5
1950-51	11.1	0.3	11.4
51-52	11.0	0.4	11.4
52-53	10.8	0.5	11.3
53-54	10.7	0.5	11.2
54-55	10.5	0.6	11.1
1955-56	10.4	0.7	11.1
56-57	10.2	0.8	11.0
57-58	10.0	0.8	10.8
58-59	9.9	0.9	10.8
59-60	9.4	1.1	10.5
1960-61	9.0	1.3	10.3
61-62	8.5	1.5	10.0
62-63	8.1	1.7	9.8
63-64	7.6	1.9	9.5
64-65	7.4	2.0	9.4

4/ Ibid.

Compaction of Clays

A study concerning land subsidence in the Santa Clara Valley, published by the U. S. Geological Survey 5/ reports that land subsidence in the Santa Clara Valley is caused by compaction of the fine-grained subsurface material, and that the rate of escape of water from the fine-grained beds determines the rate of compaction. A recent unpublished survey indicated that the rate of subsidence is up to 0.5 feet per year in the area south of San Francisco Bay. Rates within the Fremont study area are lower because sea water intrusion has prevented excessive declines in water levels.

Data published in the U. S. Geological Survey report were used to determine the depth of subsidence for the Fremont study area. The area of subsidence is limited to the area of confined water.

Compaction of the clay layers between the aquifers occurs when piezometric pressures in the aquifers are reduced and water flows from the clay layers into the aquifers. The volume of water released by this process is equal to the volume of the resulting subsidence. The greatest reduction of piezometric pressure has occurred in the Centerville and Fremont aquifers.

The water removed from the clay layers is assumed to have become part of the recharge to the lower aquifers, since these aquifers have the lowest pressures. The annual amount of recharge, due to subsidence occurring during the study period, was estimated to be a constant 4,260 acre-feet per year. The total amount was divided into inflow to the Fremont study area in the amount of 500 acre-feet per year, and inflow to the Santa Clara study area in the amount of 3,760 acre-feet per year.

Historic Recharge

The annual amounts of ground water recharge occuring during the study period are summarized in Table 9.

Disposal of Ground Water

In the hydrologic equation, items of disposal of ground water are considered to be those which reduce the amount of ground water in storage. These include: municipal, industrial, and agricultural extractions, and subsurface outflow.

5/ U. S. Geological Survey Water Supply Paper No. 1619-C

Extractions

Ground water extractions from the study area include municipal, industrial, and agricultural pumpage. The amounts of water pumped for individual domestic use are negligible.

Municipal. The major supplier of municipal water is the Alameda County Water District. The Citizens Utilities Company of California and the cities of Hayward and Milpitas serve small portions of the area. The two cities deliver only imported water. These four agencies provide for almost all municipal needs within the area. Their service areas, located within the study area, are shown on Plate 3.

The municipal extractions were determined from an examination of production and connection services which were provided by the Alameda County Water District (ACWD) and the Citizens Utilities Company of California.

Only records showing the number of service connections were available for the ACWD service area for the early part of the study period. Production for these early years was estimated by using the relationship between production and connections which was developed for the later years.

In the Citizens Utilities Company of California service area, production was recorded for only one year. Production for the remainder of the study period was estimated by using the relationship between service connections and production for that one year of record with the service connection records which were available for the entire study period.

Industrial. Ground water is the usual source of water for industrial use since most of the major industries in the area have their own wells to provide for their industrial water supplies. Records of industrial water use during the study period were requested from some 15 major industries pumping ground water. Discussions were held with executives of some of the industries. The survey and discussions provided data on historic water use, plant production, and company sales. Since the majority of industries did not measure their pumpage and the pumping plants did not have separate power records, pumpage was computed indirectly from knowledge of the amount of water required in the industrial process and the production of the industry. The resulting estimates of ground water extractions by industry are shown in Table 10.

Agricultural. Ground water is the source of supply for all irrigated agriculture in the study area. The amount of water applied to each acre is based on the average shown in Table 2 (2.3 acre-feet per acre). The annual amount of agricultural pumpage shown in Table 10 is the average amount applied to each acre, multiplied by the irrigated acreage for the year.

TABLE 9

Total Recharge
(In 1,000 Acre-Feet)

Year	Source					
	Precipitation (Table 4)	Applied Water (Table 8)	Runoff (Table 6)	Compaction	Artificial Recharge (Table 7)	Total
1949-50	6.8	11.5	7.4	0.5	3.1	29.3
1950-51	9.8	11.4	28.3	0.5	8.9	58.9
51-52	12.7	11.4	35.2	0.5	9.3	69.1
52-53	7.7	11.3	13.8	0.5	5.7	39.0
53-54	6.6	11.2	4.3	0.5	3.8	26.4
54-55	7.3	11.1	7.2	0.5	2.2	28.3
1955-56	11.6	11.1	24.4	0.5	5.8	53.4
56-57	6.3	11.0	7.1	0.5	4.9	29.8
57-58	13.8	10.8	28.2	0.5	3.5	56.8
58-59	6.6	10.8	5.8	0.5	3.7	27.4
59-60	6.8	10.5	6.6	0.5	2.2	26.6
1960-61	6.8	10.3	2.3	0.5	2.1	22.0
61-62	7.9	10.0	10.8	0.5	6.3	35.5
62-63	11.2	9.8	19.6	0.5	10.8	51.9
63-64	6.0	9.5	5.1	0.5	15.7	36.8
64-65	9.0	9.4	10.6	0.5	14.0	43.5

TABLE 10

Total Disposal
(In 1,000 Acre-Feet)

Year	Ground Water Pumpage			
	Water Agencies	Industry	Agriculture	Total
1949-50	2.2	5.3	37.6	45.1
1950-51	2.4	6.0	37.1	45.5
51-52	2.5	6.8	36.6	45.9
52-53	2.8	6.3	36.1	45.2
53-54	3.3	6.9	35.6	45.8
54-55	4.1	8.0	35.0	47.1
1955-56	4.8	7.4	34.5	46.7
56-57	5.2	7.7	34.0	46.9
57-58	5.4	8.3	33.5	47.2
58-59	6.3	7.8	33.0	47.1
59-60	7.2	7.8	31.5	46.5
1960-61	8.2	8.0	29.9	46.1
61-62	10.2	7.9	28.4	46.5
62-63	11.0	7.8	26.9	45.7
63-64	13.0	7.5	25.4	45.9
64-65	15.0	8.0	24.6	47.6

Subsurface Outflow

It was estimated that continuous subsurface outflow has occurred in the southern portion of the study area because of a consistent gradient toward the south in the vicinity of Alviso. This is an area of overlapping deposition, and the materials have very low permeability. The outflow quantity was calculated by application of Darcy's Law[6]. Estimates of permeability, thickness of aquifer, length of aquifer, and the gradient indicated an annual outflow of about 110 acre-feet per year. This amount was well within the expected error of the ground water inventory and, as previously noted, the net amount of subsurface flow was minor. In tabulations of ground water inventory, it is taken as zero.

Historic Disposal

The annual amounts of ground water disposal occurring during the study period are equal to the total annual pumpage shown in Table 10.

Change In Storage

Changes in the amount of ground water in storage can be determined both directly and indirectly. The direct method uses observations of water levels and quality, and estimates of specific yield. The indirect method uses the difference between the amounts of supply and disposal as shown in the ground water inventory.

The change in storage was first determined by use of the direct method and then compared to the change in storage data as determined by the indirect method.

There are two types of ground water areas: free and confined. In free ground water areas, the water levels fluctuate within the water-bearing materials. In confined ground water areas, the water-bearing material is capped by a material of low permeability and the piezometric surface is above the top of the water-bearing material.

Free Ground Water Areas

A 6,000 acre portion of the Niles Cone adjacent to the Hayward fault contains free ground water. Here, the depth of alluvium is sufficient to produce significant changes in ground water storage; confining clay layers are generally

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6/ Darcy's Law: The rate of flow is directly proportional to the hydraulic gradient.

missing. Of this area, 4,000 acres are west of the fault and are considered to be the forebay for aquifers extending to and under the Bay. The area to the west and south of the forebay was originally a pressure area. Partial dewatering of the Newark aquifer has brought the level down into the aquifer. The area of partial dewatering is about 9,000 acres. Water levels in the lower aquifers are still high enough for these aquifers to continue to act as a pressure area.

The change in storage in areas having free ground water levels is calculated as the product of the change in elevation of the water level and the specific yield of the materials involved.

Water Levels. Records of ground water level measurements in the study area are available from early in the 1890's. Ground water surfaces originally sloped toward San Francisco Bay; however, in some portions of the area, ground water levels have been below sea level since about 1913. In general, water levels have been progressively lowered by continued overdraft. Since the beginning of the study period (1949-50), the confined and free ground water levels west of the Hayward fault have been continuously below sea level in both the Newark and Centerville aquifers. Plates 10 and 11 indicate ground water contours of the Newark and Centerville aquifers for fall of 1964 and spring of 1965. Well hydrographs for the 1949-65 period of five wells, which are representative of water levels in the entire area, are shown on Plate 12.

Because of the barrier effect of the Hayward fault, water levels in the area east of the fault have always been higher than levels to the west. The differences in water levels varied between 50 and 70 feet during the study period. Ground water in this area is unconfined, but the permeability decreases rapidly in a southeasterly direction away from Alameda Creek.

Specific Yield. Values of specific yield in areas having a change in the amount of water in storage ranged from 12 to 21 percent. These values are based on the logs of wells in the area.

Confined Ground Water Areas

Any change in the amount of fresh ground water in storage in the aquifers is not reflected by changes in water levels, but rather by changes in water quality. The intrusion of saline water into the Newark aquifer from the overlying Bay and salt ponds has resulted in the displacement of fresh water from the aquifers and forebay.

Quality of San Francisco Bay Water. The chloride concentration of ocean water is approximately 19,000 ppm. Chloride concentrations in South San Francisco Bay probably exceeded 19,000 ppm during the summer months, prior to the construction of water conservation facilities and the buildup in the amount of wastes discharged to the Bay.

Chloride concentrations of South Bay water during the 1960's have been less than that of ocean water. Generally, the chloride concentrations in the Bay decrease with distance south of the Oakland Bay Bridge. This can be attributed to the large volume of relative-fresh waste water discharged to the Bay. During the 1964-65 fiscal year, the total of 18 major discharges to South San Francisco Bay was 174,000 acre-feet.

The San Francisco Bay water is a highly mineralized sodium chloride type. A December 1965 sample showed the following quality:

Constituent	Unit	December 1965 Sample
Total Dissolved Solids	ppm	28,200
Total Hardness	ppm	4,910
Chloride	ppm	14,400

During a University of California study, 17 stations in the South Bay were sampled during June through September 1, 1961. Samples from five of these stations, located south of the Dumbarton Bridge, had chloride concentrations ranging between 10,600 and 17,600 ppm. Samples from four stations located between the Dumbarton Bridge and San Mateo Bridge, had chloride concentrations between 15,600 and 18,700 ppm (maximum found during study period). During July 1963 and April and June 1964, samples from seven additional stations located between the San Mateo Bridge and Oakland, had chloride concentrations of 14,980 to 17,550 ppm.

Salt Evaporation Ponds. Ponds used to produce salt from Bay water are located on tidelands adjacent to the Bay in Alameda, Santa Clara, and San Mateo counties. Locations of these ponds are shown on Plate 7. The Leslie Salt Company owns all of the 40,000 acres of salt ponds in the three counties which comprise 23,000 acres of the land overlying the study area. In the production of salt, Bay water, at about 2.8 percent salt, is admitted to the first of a series of ten concentrating ponds. Over a four-to-five-year period, the brine is moved through the series of 400-to-500-acre ponds. In the final pond of the series, the brine concentration is about 21.5 percent salt.

After winter rains have ceased, continued evaporation causes a precipitation of salt from the brine in the ponds. The remaining fluid is drained off and the crystallized crude salt is harvested and stockpiled.

Volume of Intrusion. The volume of salt water present in the ground water basin is based on chloride concentrations of water samples taken principally in early 1966. The chloride concentrations for water in the Newark aquifer and in the Centerville-Fremont aquifer were plotted and lines of equal chloride concentrations (isochlors) drawn for each of the aquifers (Plates 1 and 2).

To determine the total volume of intrusion which has taken place, it is necessary to assign an average salinity to the intruding waters. The two sources of intrusion are: the Bay, with salinities varying between 10,600 and 18,900 ppm, and the salt evaporation ponds, with salinities varying from that of the Bay to 215,000 ppm. A composite salinity of 21,000 ppm was chosen to represent intruding water since this appears to be the average salinity of ground water in the upper aquifer around the perimeter of the Bay.

The volume of salt water present in each of the aquifers is based on the isochlors, the salinity of intruding water (21,000 ppm), the thickness of water bearing material 7/, the water levels in the aquifers, and the specific yield of the water bearing materials.

It is estimated that 248,000 acre-feet of saline water is present (at 21,000 ppm chlorides) in the Newark aquifer and 14,500 acre-feet in the Centerville aquifer.

Historic data concerning water levels and water quality in the Newark aquifer are insufficient for an exact quantitative determination of annual amounts of saline water intrusion. Assuming a direct relationship between intrusion and water surface elevations in the Newark aquifer, 50 percent of the intrusion took place prior to the study period. Annual amounts of intrusion during the study period were estimated by apportioning the 50 percent of total intrusion on the basis of water level data in the more easterly portions of the Newark aquifer. The results are shown in Table 11.

Annual Amounts of Change in Storage

The annual amounts of change in storage for free and confined ground water areas are shown in Table 11.

7/ California State Department of Water Resources. Bulletin No. 118-1, Evaluation of Ground Water Resources South Bay, Appendix A:Geology. August 1967. Plate 13, "Lines of Equal Thickness of Aquifers in 170 to 400 Foot Depth Interval, Niles Cone", and Plate 14, "Lines of Equal Thickness of the Newark Aquiclude in Niles Cone".

TABLE 11

Change in Storage
(In 1,000 Acre-Feet)

Year	Free Ground Water Area	Displaced by Saline Intrusion	Total
1949-50	- 5.0	-12.8	-17.8
1950-51	31.8	- 7.4	24.4
51-52	20.9	- 3.3	17.6
52-53	- 6.5	- 3.3	- 9.8
53-54	-14.8	- 5.4	-20.2
54-55	-11.7	- 8.0	-19.7
1955-56	15.1	- 6.9	8.2
56-57	-10.1	- 5.7	-15.8
57-58	18.4	- 4.5	13.9
58-59	-18.6	- 5.7	-24.3
59-60	-11.2	- 9.5	-20.7
1960-61	-12.2	-12.8	-25.0
61-62	3.6	-13.7	-10.1
62-63	15.2	-11.3	3.9
63-64	- 2.3	-11.3	-13.6
64-65	16.3	- 9.5	6.8

Total Available Storage

The total amount of storage available above elevation -400 feet in the forebay and aquifers associated with the Niles Cone is 1.3 million acre-feet. The distribution of this storage capacity is:

Location	Acre-Feet of Storage
Unconfined area above the Hayward fault	82,000
Unconfined area below the Hayward fault	40,000
Newark, Centerville, and Fremont aquifers	
West of Coyote Hills	692,000
East of Coyote Hills	547,000
Total	1,361,000

Adjustment of Ground Water Inventory

At the beginning of the study, a determination of the range of values and the most probable value were determined for each of the items in the inventory. To obtain a good understanding of the sensitivity of the supply and disposal items and to reduce the unaccounted-for amount of water, a mathematical model of the main ground water area was prepared and processed by analog and digital computers. (See Appendix E.)

During analysis of the data and while modeling the main ground water area, many changes were made in the internal values such as transmissability and specific yield and in external values such as recharge and pumpage. However, after modification of these values, in keeping with the knowledge of the area, there remained a residual difference in change in storage, as computed by inventory and by specific yield methods. The accumulated change in storage determined by the two methods and the resulting difference are shown in Table 12 and Figure 6.

Annual differences between amounts of change in storage, as computed by the two methods, are to be expected because major items, such as stream recharge, intrusion, agricultural pumpage and return, are based on indirect methods. To obtain a reasonable balance it was necessary to use values at the extremes of their range. For example, the values of specific yield were reduced to 60 percent of their original value, and amount of recharge from streams was increased significantly during wet years.

The accuracy obtained in this study is sufficient for a reconnaissance level investigation. Feasibility studies of operation plans will require greater accuracy. The program necessary to develop data of desirable accuracy is discussed in Chapter V.

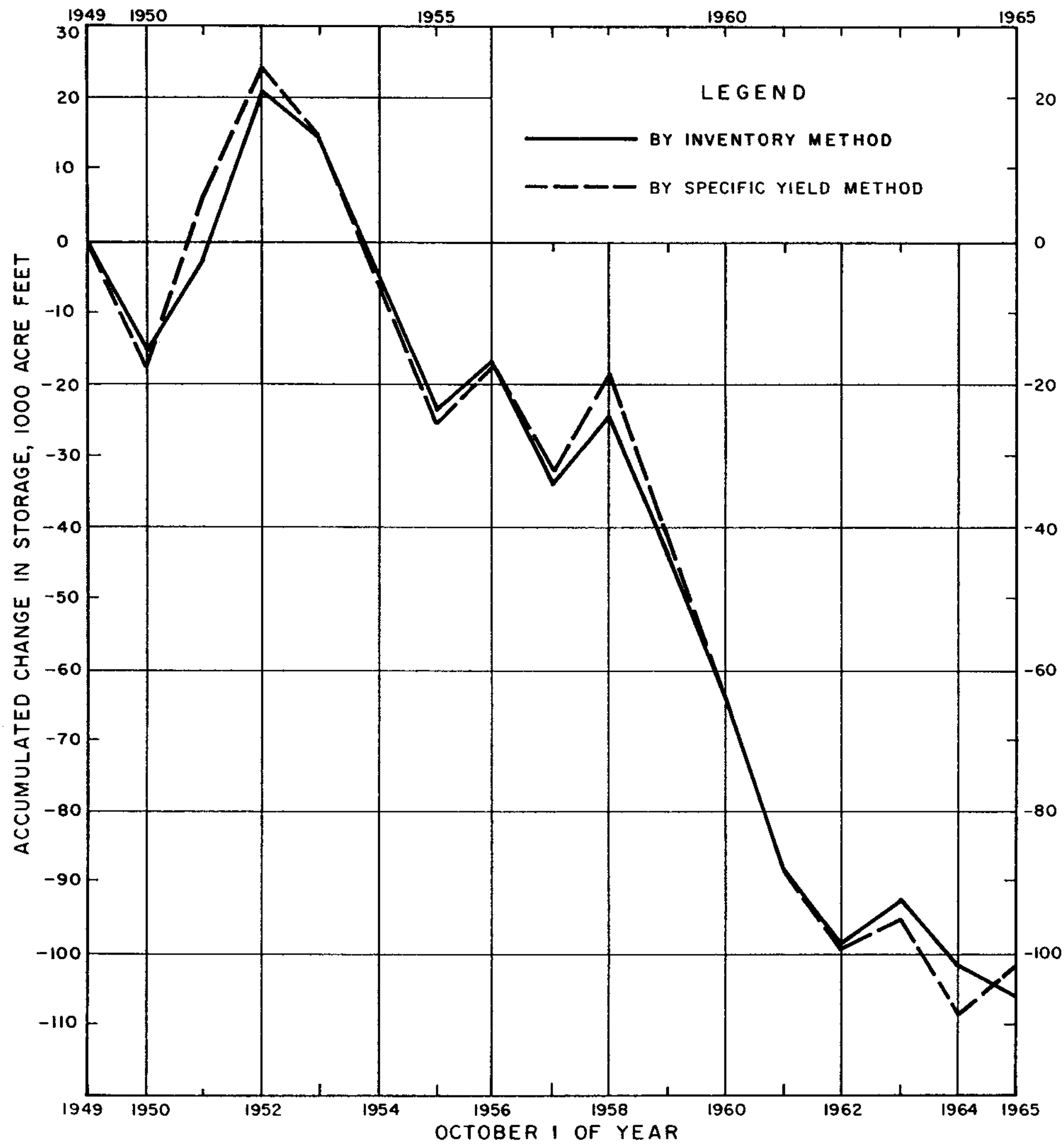
TABLE 12

Ground Water Inventory
1949-50 Through 1964-65
(In 1,000 Acre-Feet)

Year	Re-charge[a] (1)	Dis-posal[b] (2)	Change in Storage: By Inventory (1)-(2) =3	Change in Storage: By Specific Yield[c] (4)	Accumulated Change in Storage: By Inventory (5)=Σ(3)	Accumulated Change in Storage: By Specific Yield (6)=Σ(4)	Accumulated Difference (7)=(5)-(6)
1949-50	29.3	45.1	-15.8	-17.8	-15.8	-17.8	2.0
1950-51	58.9	45.5	13.4	24.4	- 2.4	6.6	-9.0
51-52	69.1	45.9	23.2	17.6	20.8	24.2	-3.4
52-53	39.0	45.2	- 6.2	- 9.8	14.6	14.4	0.2
53-54	26.4	45.8	-19.4	-20.2	- 4.8	- 5.8	1.0
54-55	28.3	47.1	-18.8	-19.7	-23.6	-25.5	1.9
1955-56	53.4	46.7	6.7	8.2	-16.9	-17.3	-0.4
56-57	29.8	46.9	-17.1	-15.8	-34.0	-33.1	-0.9
57-58	56.8	47.2	9.6	13.9	-24.4	-19.2	-5.2
58-59	27.4	47.1	-19.7	-24.3	-44.1	-43.5	-0.6
59-60	26.6	46.5	-19.9	-20.7	-64.0	-64.2	0.2
1960-61	22.0	46.1	-24.1	-25.0	-88.1	-89.2	1.1
61-62	35.5	46.5	-11.0	-10.1	-99.1	-99.3	0.2
62-63	51.9	45.7	6.2	3.9	-92.9	-95.4	2.5
63-64	36.8	45.9	- 9.1	-13.6	-102.0	-109.0	7.0
64-65	43.5	47.6	- 4.1	6.8	-106.1	-102.2	-3.9

a. From Table 9
b. From Table 10
c. From Table 11

FIGURE 6



ACCUMULATED CHANGE IN STORAGE

CHAPTER IV. THE ROLE OF GROUND WATER IN FUTURE WATER SUPPLY

Intensive urban and industrial development has already pushed south along both sides of San Francisco Bay until the study area, at the southern tip of the Bay, is one of the few remaining pockets of relatively underdeveloped land in the Bay Area. Many industries have recently located in the part of Alameda County bordered by the southern end of the Bay, and are now occupying increasingly larger portions of the amount of land still available for development.

Urban and industrial development in the study area is expected to accelerate between now and 1990, and to extend after the next 50 years to lands now occupied by salt evaporation ponds. Residential development should be spurred by operation of the Bay Area Rapid Transit District's system.

Part of the Fremont study area will be served by the Alameda County Water District (ACWD) and the Citizens Utilities Company of California, and part of the area will be served by the cities of Hayward and Milpitas. ACWD and the Citizens Utilities Company will use the ground water basin in serving areas within the boundaries of Union City, Fremont, and Newark, and the adjacent hill areas which may become parts of these cities. The portions of Hayward and Milpitas which lie within the study area will be served directly with imported water supplies. The use of ground water by individuals and industries will continue in the study area.

Projected service areas, and the extent of hill areas, valley lands, and salt ponds are shown on Plate 13.

Projected Population and Land Use

About 40 percent of the future population increase in Alameda County is expected to occur in the Washington Planning Unit, one of several units into which the Alameda County Planning Department has divided the County. This Unit, which includes most of the Fremont study area, contains hill lands, valley lands, salt marshes, and evaporation ponds. It is shown on Plate 13.

For analysis of supply and demand, it was assumed that development prior to 2020 will occur first on the valley lands. Economic pressures will then bring about intensive hillside development and some development of areas now devoted to salt ponds. Sufficient valley land is available for development until 2020, and conservation groups are continuing pressure to maintain the salt marshes as part of the present Bay environment.

For this study, population was not projected on the basis of overall density, due to the surrounding salt ponds and hills. The year 2020 density for a combination of industry, single residential units and apartments was taken as equivalent to 20 persons per acre on the valley lands only. It was also assumed that 20 percent of the urban land will be in industrial use. Agriculture is expected to be phased out by 1985. Legislation to preserve the agricultural areas could affect the rate of change in land use, but this consideration is beyond the scope of this investigation.

Present and projected population, and acres devoted to municipal, industrial, and irrigated agriculture are shown in Table 13 for the Washington Planning Unit.

TABLE 13

Projected Population and Land Use
Washington Planning Unit

Year	Population	Land Use in Acres		
		Municipal	Industrial	Irrigated Agriculture
1960	61,000			
1965	112,000	8,970	1,400	10,000
1970	170,000	11,800	2,000	7,500
1980	285,000	16,800	3,200	2,500
1990	400,000	21,000	4,600	0
2000	500,000	24,800	5,600	0
2010	600,000	26,800	6,400	0
2020	700,000	28,000	7,000	0

Projected Water Demand

The projected water demand represents the demands to be made on the Alameda County Water District and the Citizens Utilities Company of California for service and future amounts of ground water to be pumped from the basin by individual domestic and industrial corporation wells to meet increased demand. The future service area is shown on Plate 13.

The major difference between lands in the Washington Planning Unit and lands to be served by agencies using local ground water, occurs along the eastern shore of the Bay where lands are primarily devoted to salt evaporation ponds. Therefore, the future urban demand in the service areas of the Alameda County Water District and the Citizens Utilities Company of California can be estimated based on the population projections for the Washington Planning Unit for the years prior to 2020. Historic unit-use values for residential lands in the Washington Planning Unit plus unit-use values for new industry are estimated to be 0.152 acre-feet per person in the year 1990 and 0.168 in the year 2020. The projected water demands shown in Table 14 are based on the assumption that the current annual pumpage by industry of 8,000 acre-feet will continue.

In Table 14, the water demand for agriculture is based on a unit application of 2.3 acre-feet per acre of land, and on agricultural land use figures developed for the Fremont study area.

TABLE 14

Projected Water Demand in Service Areas of Alameda County Water District (ACWD) and Citizens Utilities Company of California (In Acre-Feet)

	Water Demand		
Year	Agriculture	Urban	Total
1965	24,610	23,000	47,610
1970	18,510	33,490	52,000
1990	5,750	68,800	74,550
2020	0	125,600	125,600

Water Supply

Future water supplies for the service areas of the ACWD and the Citizens Utilities Company of California will be obtained from four sources:

1. State of California's South Bay Aqueduct of the State Water Project.
2. City of San Francisco's Hetch Hetchy Aqueduct.
3. City of San Francisco's Sunol Aqueduct.
4. South Bay Ground Water Basin.

In Table 15, the amounts obtainable from the first three sources are based on either already executed contracts or water rights.

TABLE 15

Estimated Future Imported Water Deliveries to ACWD (In Acre-Feet)

Year	State of California	City of San Francisco	
		Hetch Hetchy	Sunol
1964-65	13,700	1,500	430
1969-70	16,200	4,000	430
1979-80	24,800	9,000	430
1989-90	36,900	10,000	430
2019-20	42,000*	10,000	430

* 42,000 acre-feet from 1995.

Local Ground Water

The average amount of ground water which may be extracted annually without adversely affecting the ground water resource may be termed the average operational pumpage. The amount of this pumpage may be equal to the total average recharge to the ground water basin, including that derived from the pumped water itself, only if the ground water basin is protected against salt water intrusion. The amounts of annual pumpage permitted under an operational plan will vary with demand for water, regimen of precipitation and runoff, and amounts of imports available. The amount of average recharge to the ground water basin is a function of culture and imports.

Land use projections made for the purpose of projecting ground water recharge and use differ in the study area due to the presence of salt water in the upper aquifer. For the purpose of determining ground water recharge, it is assumed that the portion of the Newark aquiclude west of the Coyote Hills will be isolated from the main ground water basin. It is also assumed that salinity control facilities would be installed at the easterly boundary of the salt evaporation ponds. The effective recharge area would contain 42,000 acres and is shown on Plate 14. Projections of municipal and industrial land use in the recharge area for the year 2020 were made by assuming the Milpitas and Hayward portions of the study area will have the same percentage of available land developed as the Washington Planning Unit. Amounts for years between 1965 and 2020 were determined by using the trends determined for the Washington Planning Unit. Projections of land use for the recharge area are shown in Table 16.

TABLE 16

Projected Land Use
Fremont Study Area
East of Coyote Hills

Year	Land Use in Acres				
	Municipal	Industrial	Salt Ponds	Irrigated Agriculture	Dry Farm, Native
1965	9,900	1,480	940	10,700	18,980
1970	12,900	2,100	940	8,050	18,010
1990	22,800	4,900	940	0	13,360
2020	30,815	7,900	940	0	1,560

To develop the role of ground water in meeting the water demands for the period 1964-2020, average recharge was determined for the years 1970, 1990, and 2020. The year 1990 was used because imports will be close to their maximum in that year and also because agriculture will be phased out. The years 1990 and 2020 are commonly used in other water supply and demand studies of the Department.

The following assumptions were made:

1. Land use is as shown in Table 16.

2. Unit values of recharge of precipitation and applied water are constant.

3. All water imported from the City of San Francisco's Hetch Hetchy Aqueduct is put directly into the distribution systems.

4. All water imported from the South Bay Aqueduct of the State Water Project and the City of San Francisco's Sunol Aqueduct will be used for ground water recharge.

5. All water demands will be met.

6. A protection system will be installed to prevent loss of the ground water resource.

Recharge from Precipitation. The average annual amounts of recharge from precipitation are based on normal rainfall and on 0.20 acre-feet of water recharged per acre from irrigated lands, 0.12 per acre from non-irrigated lands, and 0.20 per acre for urban lands.

Recharge from Runoff. The amounts of runoff produced in the future will increase because of urbanization, but the opportunities for percolation will be decreased because some local channels will be paved; however, opportunities for percolation will be increased in those channels remaining unpaved because they will carry greater flows. In addition, the continued urbanization of the Livermore Valley and the operation of Del Valle Dam and its reservoir, to be completed in 1969-1970, will affect the recharge of runoff in the study area.

For this analysis, the historic diversions to percolation pits have been adjusted to having the percolation [illegible] used by Alameda County Water District and known as Pits A, [illegible] D, and G available throughout the study period. Their combined storage capacity is approximately 1,800 acre-feet. It is assumed that the pits would be filled at least once during the runoff period, if runoff was available.

The percolation pits are located adjacent to Alameda Creek (Plate 9) and began operation in 1958. With inclusion of operation of the percolation pits during the 1949-1959 period, the additional diversion and percolation in the Alameda Creek-Dry Creek system is as follows:

Year	Acre-Feet
1949-50	1,800
50-51	2,400
51-52	2,400
52-53	1,800
53-54	0
54-55	0
55-56	2,400
56-57	0
57-58	2,400
58-59	600
Average 1949-1965	862

Until definite plans for control of local channels and the operation of the Del Valle facility are available, it is assumed that direct channel recharge will be equal to the study period average.

Recharge from Applied Water. The amounts of recharge to be derived from water applied to urban lands in the Fremont study area are 0.20 acre-feet per acre of land. For irrigated lands, 30 percent of the applied water requirement of 2.3 acre-feet of water per acre of land was taken as recharge.

Subsurface Flow. Both subsurface inflow and outflow were assumed to average zero for long-time conditions.

Compaction of Fine Clays. With the stabilization of the ground water basin, this amount is assumed to be zero.

Average Annual Recharge. Table 17 is a summary of the average annual amounts of recharge to ground water from all sources. Average annual recharge implies a long-time average.

The variation in the amounts of average annual recharge shown in Table 17 is a function of two factors: the development of the area, and the amount of water spread for recharge to ground water.

TABLE 17

Average Annual Recharge
Under Present and Projected Conditions*
(In 1,000 Acre-Feet)

Source of Recharge	Level of Development 1960	1965	1970	1990	2020
Rain					
- Irrigated Agriculture	2.7	2.1	1.6	0.0	0.0
- Non-Irrigated Lands	2.6	2.5	2.4	2.2	1.1
- Urban Lands	1.1	2.0	2.6	4.6	6.3
Applied Water					
- Irrigated Agriculture	9.4	7.3	5.6	0.0	0.0
- Urban Lands	1.1	2.0	2.6	4.6	6.3
Runoff	14.6	14.6	14.6	14.6	14.6
Imported Water for Planned Recharge					
- South Bay Aqueduct	0.0	13.7	17.0	36.9	42.0
- Sunol Aqueduct	.4	.4	.4	.4	.4
Total Average Annual Recharge	31.9	44.6	46.8	63.3	70.7

*Assumes intrusion barrier and no channel lining.

The volume of ground water storage available in the study area is not large; therefore, it is not unreasonable to assume that over a long period of time the ground water basin will be operated so that long-time changes in the amount of ground water in storage will be kept at a minimum. The ground water basin will be operated so that over a long-time period the average ground water pumpage will equal average annual recharge.

Relationship of Supply and Demand

The relationship of supply and demand for selected years from 1960 through 2020 are shown in Table 18. The average water demand is compared with the average available supply and both supply and demand are expressed as delivered water, not as the amounts of water used.

The information shown in Table 18 indicates that the importation of water from the South Bay Aqueduct of the State Water Project ended the large deficiency of supply, and that until about 1990 the scheduled increases in amounts of water to be imported from the State Water Project and from the City of San Francisco's aqueduct will almost keep pace with the increasing demands for water supply in the study area. After 1990, additional sources of imported water will be required in order to meet the water demands in the area.

TABLE 18

Average Water Supply and Demand
Under Present and Projected Conditions[a]
(In 1,000 Acre-Feet)

	1960	1965	1970	1990	2020
Average Annual Demand	46.5[b]	47.6[b]	52.0	74.6	125.6
Average Annual Pumpage[c]	31.9	44.6	46.8	63.3	70.7
Average Delivered Import		1.5	4.0	10.0	10.0
Average Annual Supply		46.1	50.8	73.3	80.7
Additional Pumpage = Water from Storage	14.6	1.5	1.2	1.3	34.9

a. Assumes intrusion barrier and no channel lining.
b. From Table 10.
c. Average annual recharge from Table 17.

In Table 18, the overpumpage required to satisfy demands will not bring about additional intrusion if a barrier is in operation but will, over a period of years, seriously deplete the amount of ground water remaining in storage. The maximum annual variation in amounts of recharge (Table 12) during the study period was 40,000 acre feet. A series of dry years would require withdrawal of a large percentage of ground water in storage. Excessive withdrawals will drastically lower water levels in the forebay and may cause significant rates of land subsidence to occur.

CHAPTER V. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

The recommendations set forth in this report are intended to form the basis for: (1) a program to develop reliable data on the entire study area, and (2) an operations-economics study to develop a range of operational plans for consideration by water agencies.

Summary

For many years, the withdrawal of ground water from storage in the Fremont study area has been in excess of recharge. The initial response to this overdraft was a decline in water levels in the ground water basin to below sea level. The second and continuing response has been the inflow of saline water to bring about equilibrium.

Salt water intrusion has been progressive in the following manner: (1) into the Newark aquifer adjacent to San Francisco Bay; (2) horizontally through the Newark aquifer eastward towards the forebay; (3) vertically from the Newark aquifer through the forebay into the Centerville and Fremont aquifers; (4) through thin portions of the aquiclude separating these aquifers, and through wells perforating into more than one aquifer; and finally, (5) westerly in the Centerville and Fremont aquifers toward pumping wells.

The main mechanism of saline water intrusion into the Newark aquifer has been the flow of salt water from San Francisco Bay and possibly the salt ponds on the tidelands, at a low rate through the Newark aquitard. This flow is made possible because a hydraulic gradient exists from the surface of the Bay to the piezometric level of the Newark aquifer.

The salinity of the source of intruding waters is in the 10,600 to 18,900 parts per million range for south San Francisco Bay water, and up to 215,000 parts per million for water from the salt evaporation ponds. The amount of salt water intruded into the system of aquifers is 262,000 acre-feet of water, with an assumed average salinity of 21,000 parts per million. The salinities of ground water in the area east of the Coyote Hills range from 100 to 10,000 parts per million and the volume of the aquifers which have been intruded is many times the 262,000 acre-feet of salt water.

The Hayward fault is a significant impediment to the flow of ground water, but it does not prohibit all flow.

There is no evidence of hydraulic connection between the Fremont study area and the Santa Clara area to the south. In the Santa Clara area, the land surface has subsided twelve feet during the period of record; subsidence has occurred at a rate of six inches a year. In the Fremont study area, subsidence is also taking place, but at a very low rate.

Hydraulic connections between the Fremont study area and the area to the west of the study area are minimal. Hydraulic connections to upper aquifers north of the Fremont study area are also minimal, with hydraulic continuity appearing to exist only at depths greater than 400 feet.

In developing an inventory of recharge to, and withdrawals from the ground water basin, the accuracy of the existing data permitted only a probable range of values to be determined instead of one number. To obtain a balanced inventory, it was necessary to use amounts of recharge that were on the high side of the range of values. This procedure and the possibility of a limit to the amount of imported water which can be artificially recharged may restrict the role which ground water can play in meeting the water demands of the area. In addition, the ground water basin cannot be maintained with a continuing deficiency of supply, since the amount of fresh water remaining in storage is not large.

Conclusions

From 1967 to about 1990, the water supply available to the Fremont study area will be approximately equal to the demand for water. After 1990 however, the need for additional water supplies to meet increasing demands in the area will intensify rapidly.

The combination of small amounts of fresh water in storage and the probability of the occurrence of dry years, points up the precarious position of the ground water resource and the need for prompt action by the local agencies.

The findings of this study are important to the economy of the area. Lack of exact data may impair the accuracy of the computed amounts of saline water intrusion and the average annual amounts of pumping which can be permitted while maintaining the ground water basin, but the order of magnitude of the findings and the trends indicated do form a reliable basis for recommending future actions.

Recommendations

It is recommended that immediate attention be given to protecting the fresh ground water remaining in storage, and to development of reliable data for the entire study area. To accomplish these ends, the recommended program should include:

1. Development of plans for alternative sea water intrusion barriers and study of the costs associated with such barriers. Alternative sea water intrusion barriers would include: a pumping trough to intercept incoming saline water, an injection mound to block incoming saline water, or combinations of a pumping trough and an injection mound. The sea water intrusion barrier would be located along the edge of the salt evaporation ponds in order to make use of the natural barrier created by the Coyote Hills. The use of effluent from treatment plants for an injection mound would be considered.

2. Revision of the ground water quality and water level monitoring program to provide greater areal coverage and increased reliability of data. Addition of measuring points to include use of existing wells and installation of new piezometers.

3. Installation of additional meters and gages to measure diversions from Alameda Creek into the percolation pits, and refinement of inflow-percolation relationships for the Alameda Creek and percolation pit areas.

4. Continuation of the effort to further define the hydrologic parameters of the ground water basin.

5. Scheduling of additional studies to preserve the ground water basin and to assist in development of a basis for formulating alternate operation plans. These additional studies should include:

   a. Development of criteria for use in operation of artificial recharge facilities, and in estimating the maximum annual amounts of water which could be recharged by use of the facilities.

   b. Investigation of the effects of the proposed realignment of the Alameda Creek channel on natural and artificial recharge.

   c. Development of alternative pumping patterns and their costs.

   d. Development of alternative surface distribution systems and their costs.

   e. Comparison of alternate operation plans for conjunctive operation of the ground water basin.

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Appendix A

GEOLOGY

Published in August 1967 as a separate volume. See page ii of this report for more information.

Appendix B

WELL LOCATIONS

WELL LOCATIONS

Six United States Geological Survey - 7.5 minute guadrangle sheets have been reproduced in this appendix as Figures 8 through 13, pages 65 through 70. These figures show the location of wells in the Fremont Study Area and in adjacent lands. The wells are identified with the state well numbers. The well location map index is shown on Figure 7.

Well Numbering System

The well numbering system used in this appendix is the numbering system used by the United States Geological Survey. It is based on township, range, and section subdivisions of the Federal Land Survey, and conforms to that used in all ground water investigations of the U. S. Geological Survey in California and the State Department of Water Resources.

Under this system, each section is divided into sixteen 40-acre plots, which are lettered as follows:

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

Wells are numbered within each of these 40-acre plots according to the order in which they are located. For example, a well having the number 2S/1W-26B8 would be in Township 2 South, Range 1 West, Section 26, and would be further identified as the 8th well located in the 40-acre "B" plot.

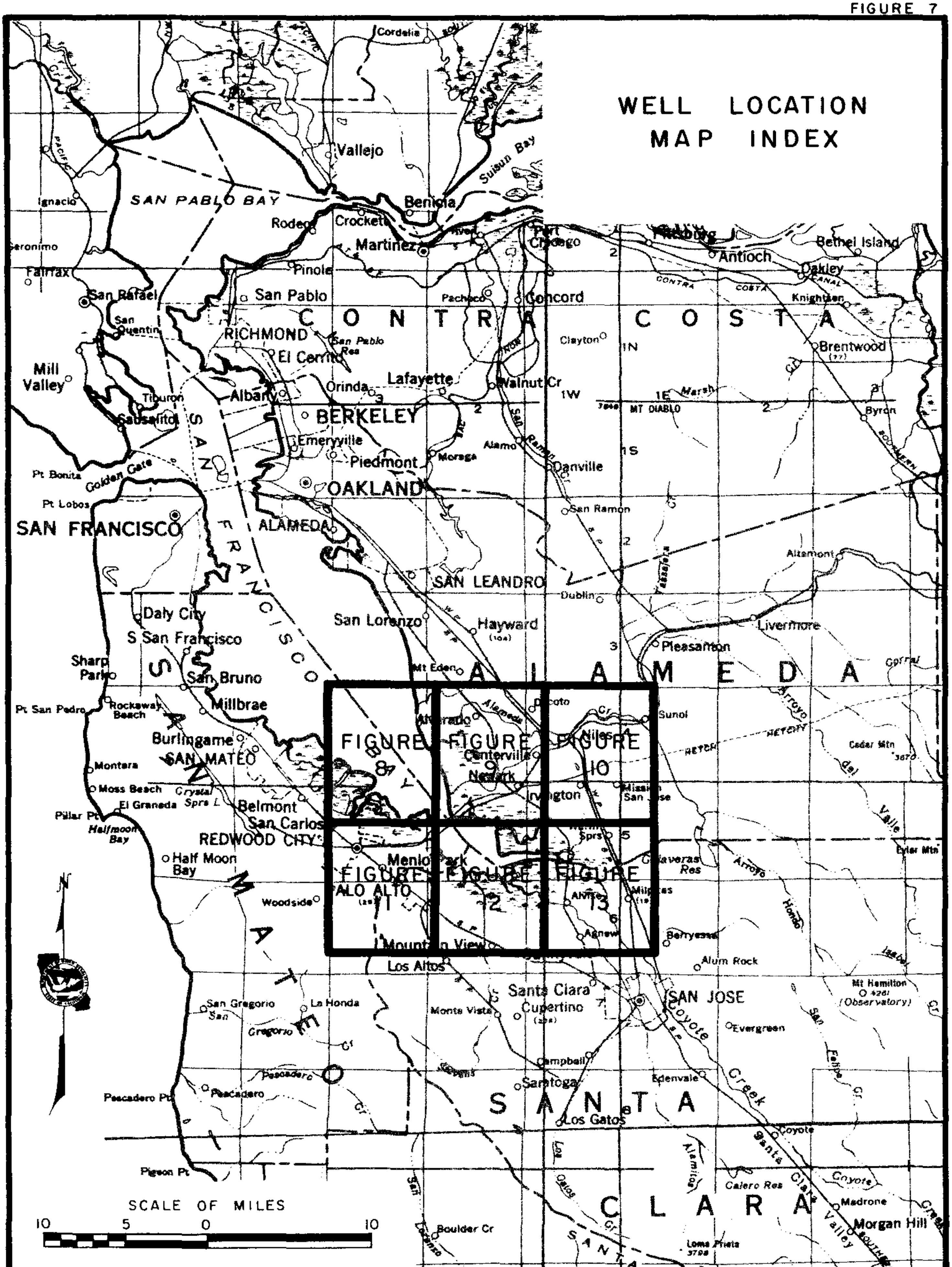
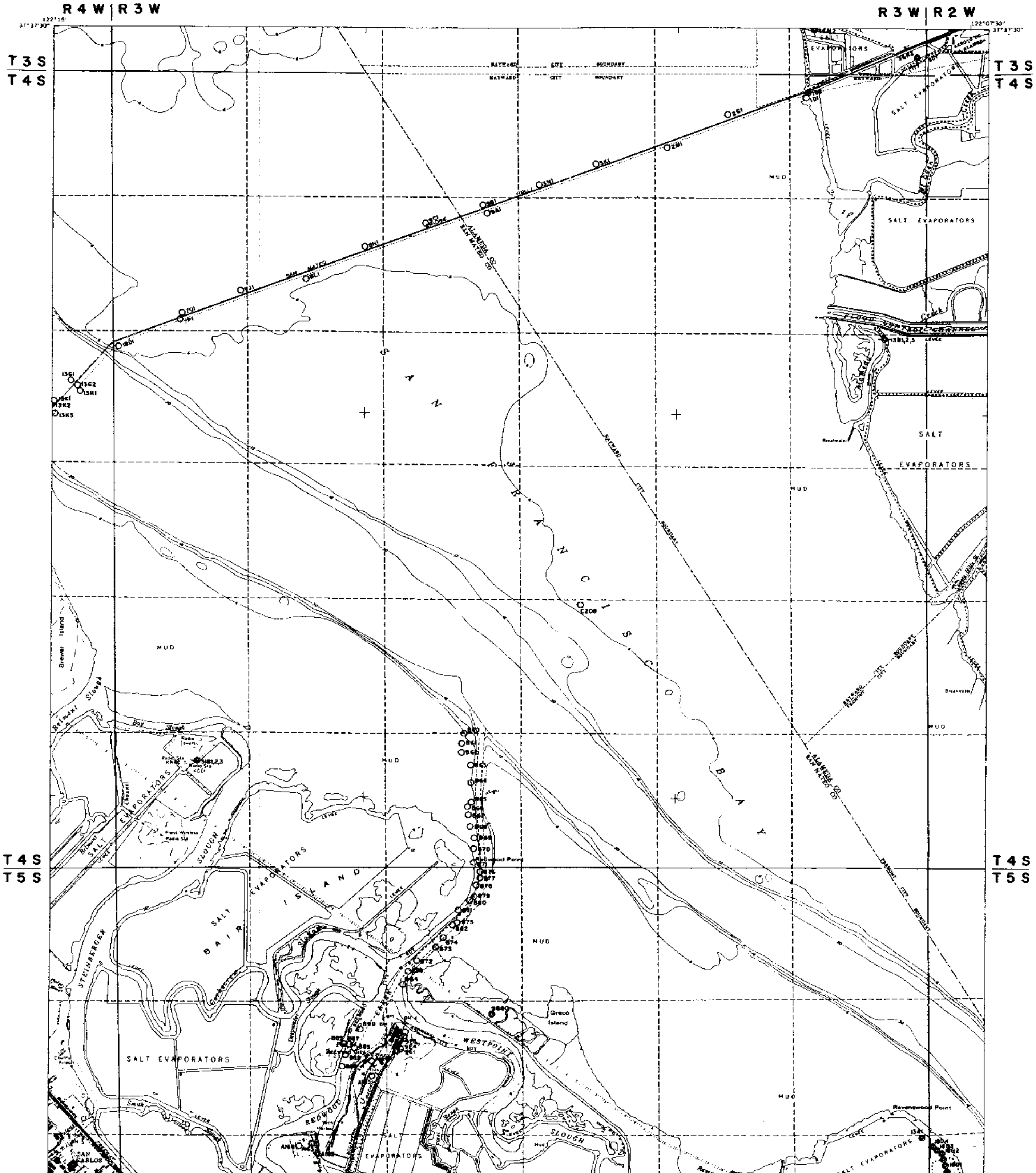

WELL LOCATION
MAP INDEX
FIGURE 8
FIGURE 9
FIGURE 10
FIGURE 11
FIGURE 12
FIGURE 13
SAN PABLO BAY
CONTRA COSTA
ALAMEDA
SANTA CLARA
SAN MATEO
SAN FRANCISCO
SAN FRANCISCO
OAKLAND
BERKELEY
SAN JOSE
Vallejo
Benicia
Martinez
Richmond
Concord
Antioch
Livermore
Pleasanton
Hayward
San Leandro
Palo Alto
Mountain View
Santa Clara
Los Gatos
Morgan Hill
SCALE OF MILES
10
5
0
10

FIGURE 8



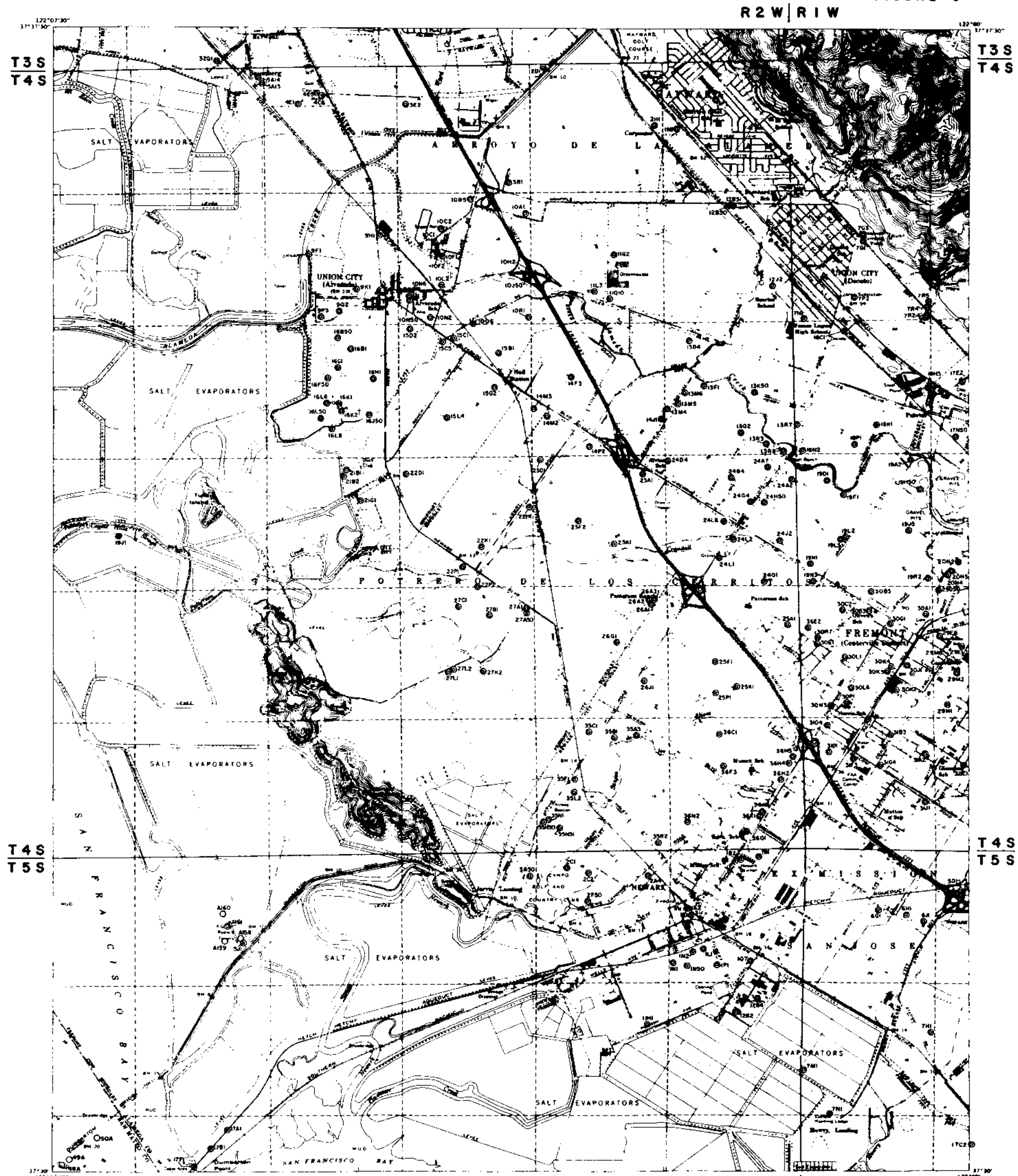
SCALE OF FEET
2000 0 2000 4000 6000

LEGEND
- O TEST HOLE
- WELL
- MULTIPLE TEST HOLE

REDWOOD POINT, CALIF.
3619

WELL LOCATION MAP

FIGURE 9



LEGEND

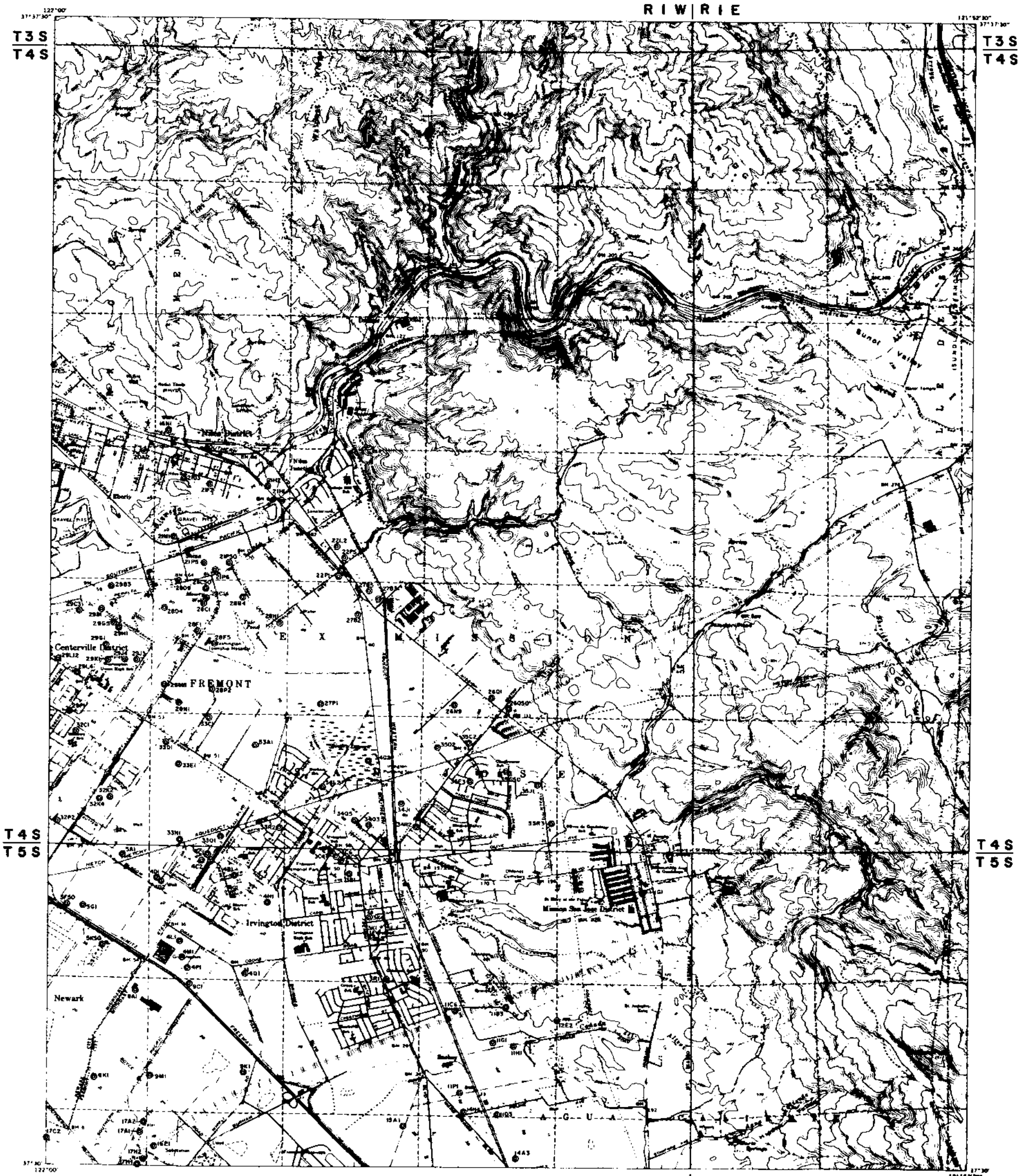
- ○ TEST HOLE
- ● WELL
- -◎- MULTIPLE TEST HOLE

SCALE OF FEET

2000 0 2000 4000 6000

NEWARK, CALIF.
3620

WELL LOCATION MAP



LEGEND

- O TEST HOLE
- ◎ WELL
- -◎- MULTIPLE TEST HOLE

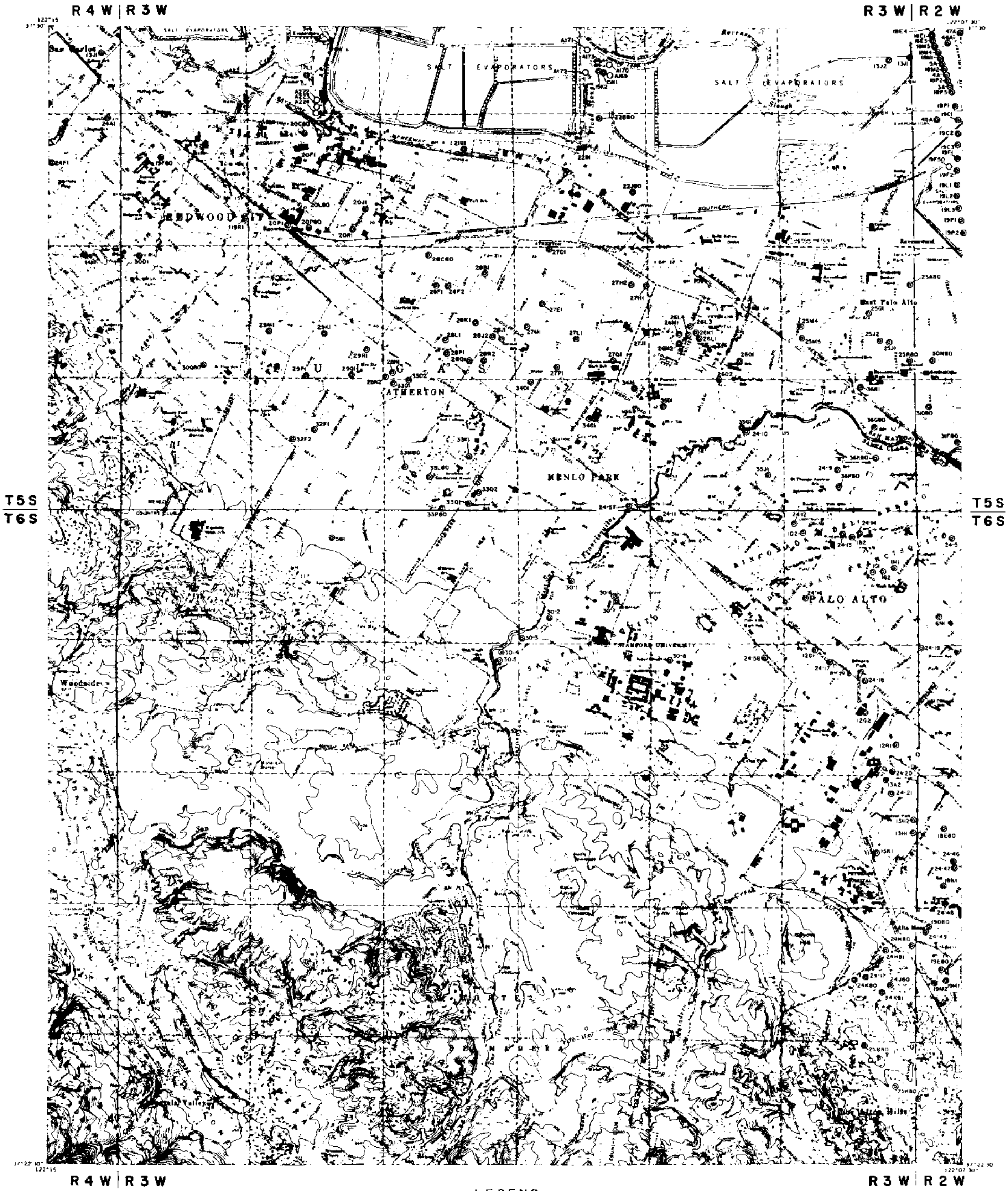
SCALE OF FEET

2000 0 2000 4000 6000

NILES, CALIF.
3621

WELL LOCATION MAP

FIGURE II



LEGEND

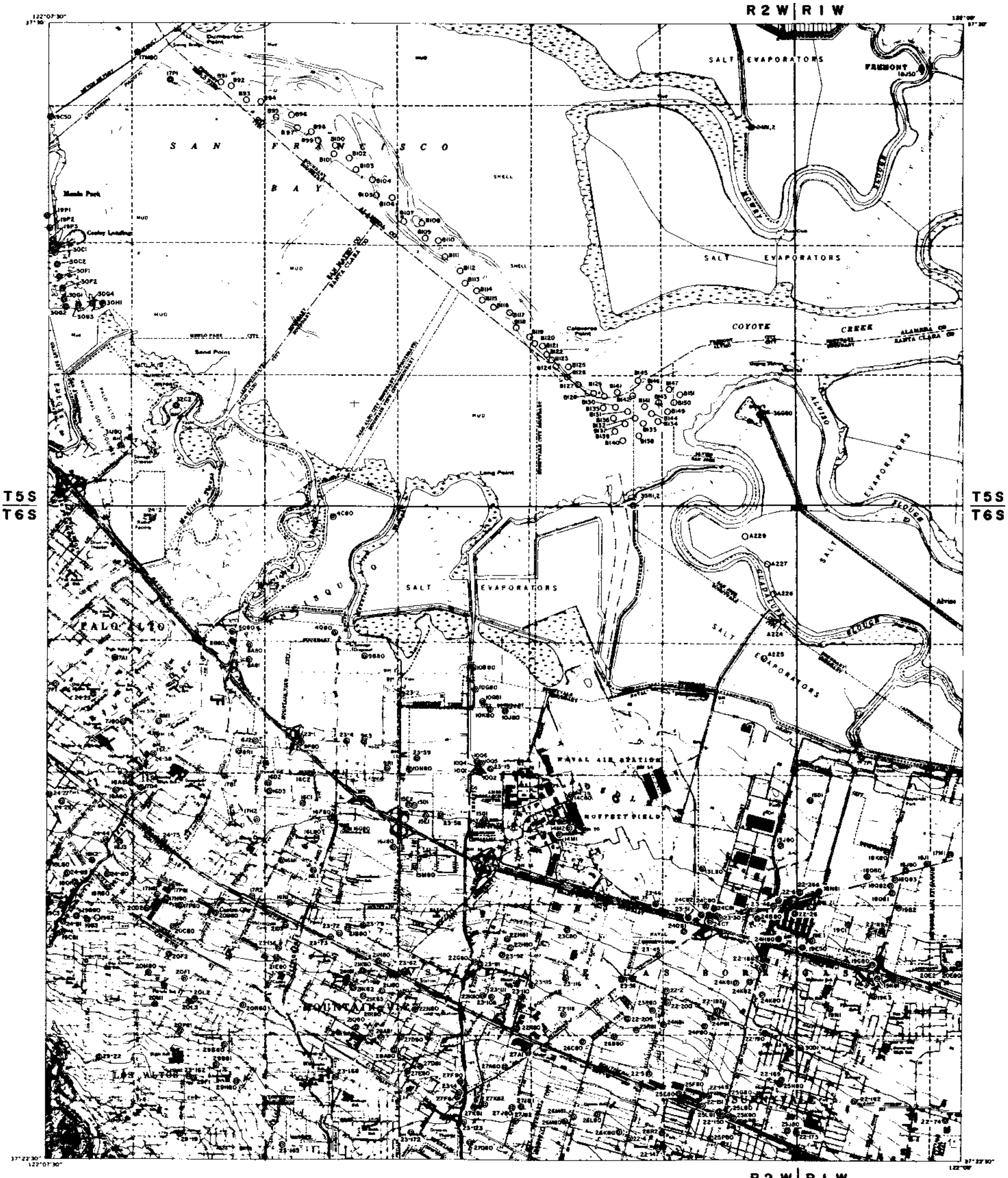
- ○ TEST HOLE
- ◉ WELL
- -◉- MULTIPLE TEST HOLE

SCALE OF FEET

2000 0 2000 4000 6000

PALO ALTO, CALIF.
3719

WELL LOCATION MAP



LEGEND

○ TEST HOLE

◉ WELL

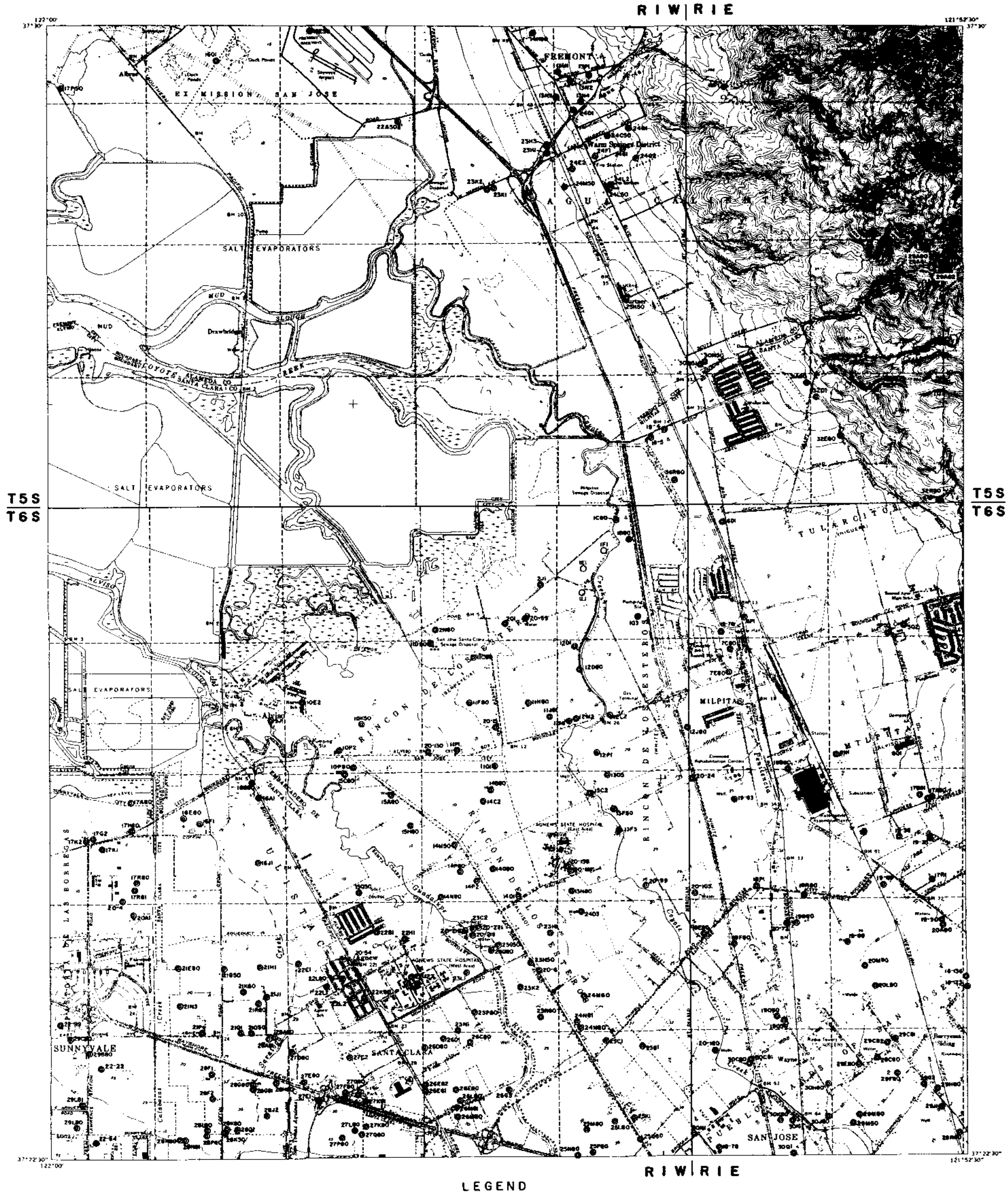
-◉- MULTIPLE TEST HOLE

SCALE OF FEET

2000 0 2000 4000 6000

MOUNTAIN VIEW, CALIF.
3720

WELL LOCATION MAP



WELL LOCATION MAP

Appendix C

DETERMINATION OF TRANSMISSIBILITY AND STORAGE COEFFICIENT

DETERMINATION OF TRANSMISSIBILITY AND STORAGE COEFFICIENTS

The transmissibility and storage coefficients of aquifers in the Fremont study area are based on data derived from drawdown and recovery tests made during this investigation and on specific capacity data provided by the Pacific Gas and Electric Company. These estimates of transmissibilities, storage capacities, and specific yields developed from the data were then used in the mathematical model (Appendix E), and were modified during the verification of the model.

Definitions

Following are definitions pertinent to information presented in this Appendix:

Permeability, Coefficient of (Field) - The rate of flow of water, in gallons a day, under prevailing conditions, through each foot of thickness of a given aquifer, in a width of one mile, for each foot per mile of hydraulic gradient.

Porosity - The sum of specific yield and specific retention which is equivalent to the total void space in the material, expressed as a percentage of the total volume of the material.

Specific Capacity - The discharge in gallons per minute per foot of drawdown in a pumped well.

Specific Yield - The volume of water drained by the force of gravity from saturated material, over a reasonably long period of time, expressed as a percentage of the total volume of the saturated material.

Storage Capacity - The quantity of usable ground water contained within a ground water basin, expressed in acre-feet, and computed as the product of specific yield and volume of usable storage in a ground water basin.

Storage Coefficient - The volume of water released from storage, in each vertical column of aquifer having a base one foot square, when the water level declines one foot. In an unconfined aquifer the storage coefficient approximates specific yield; in a confined aquifer the storage coefficient is related to elasticity of the aquifer and is usually very small.

Transmissibility - The ability of the saturated portion of an aquifer to transmit water; a function of the permeability and cross-sectional area of a given aquifer or group of aquifers.

Transmissibility, Coefficient of - The rate of flow of water, in gallons per day, at the prevailing water temperature, through each one foot wide vertical strip, having a height equal to the thickness of the aquifer, and under a unit hydraulic gradient.

Yield Factor - The specific capacity of a well, in gallons per minute per foot of drawdown times 100, all divided by the thickness of the aquifer expressed in feet.

Drawdown and Recovery Tests

Drawdown and recovery tests were made at nine locations in the Niles Cone area. In a drawdown test, the ground water level is measured at frequent intervals from the time the pump is turned on until either the water level stabilizes, or the rate of change of the water level becomes negligible. Water levels are also measured in nearby observation wells which are perforated in the same interval as the pumping well. The discharge of the pumping well is continuously measured. A recovery test is essentially the reverse of a drawdown test, that is, the pump is shut off and water levels are measured until the static water level is attained. Water levels are also measured in nearby observation wells when making recovery tests.

Transmissibility and Storage Coefficients

Transmissibility and storage coefficients of an aquifer can be computed when data from a pumping well and one or more observation wells are available. Where there are no data from an observation well, only the transmissibility can be determined. Both transmissibilities and storage coefficients were computed for this study. They were computed by using several methods. The most reliable values thus derived were then averaged to arrive at a reasonable estimate. Table 19 presents the data for the nine test locations.

(1) Theis Method

$$T = \frac{114.6\ Q\ W(u)}{h_o - h}$$

$$S = \frac{T\ t\ u}{1.87\ r^2}$$

where T = transmissibility in gal/day/ft of width
Q = well discharge in gal/min
$W(u)$ = the exponential integral termed the well function of u
$h_o - h$ = drawdown in feet
S = storage coefficient (dimensionless)
t = time in days since pumping started
r = distance in feet from discharging well to pumping well
u = the argument u is given by

$$u = \frac{1.87\ r^2\ S}{T\ t}$$

(2) Jacob Method

$$T = \frac{264\ Q}{h_o - h}$$

$$S = \frac{0.3\ T\ t_o}{r^2}$$

where t_o is the time intercept on the zero drawdown axis, and the other symbols the same as in the Theis method.

(3) Recovery Method

$$T = \frac{264\ Q}{h_o' - h'}$$

where $h_o - h'$ = recovery.

TABLE 19

Aquifer Tests Conducted in Niles Cone Area

Pumping Well	Observation Well	Type of Test[1]	Transmissibility Coefficient[2] T_t	T_j	T_r	T	Storage Coefficient[3] S_t	S_j	S	Specific Capacity[4]
4S/1W- 7G3	--	R	--	39,200	59,600	49,400	--	--	--	35.9
4S/1W- 7G3	4S/1W- 7G1	D	39,200	45,200	57,300	47,230	9.34×10^{-4}	13.8×10^{-4}	11.6×10^{-4}	--
4S/1W-30K1	4S/1W-19JT1	D	236,000	333,000	--	284,500	1.51×10^{-4}	1.13×10^{-4}	1.32×10^{-4}	--
4S/1W-30K1	-19LT1	D	290,000	775,000	--	290,000	2.02×10^{-4}	3.57×10^{-4}	2.79×10^{-4}	--
4S/1W-30K1	-30AT1	D	865,000	1,160,000	--	1,012,500	3.03×10^{-4}	2.32×10^{-4}	2.67×10^{-4}	--
4S/1W-30K1	-30BT1	D	865,000	1,260,000	--	1,062,500	3.86×10^{-4}	2.69×10^{-4}	3.27×10^{-4}	--
4S/1W-30K1	-30E4	D	965,000	1,333,000	--	1,149,000	2.51×10^{-4}	1.60×10^{-4}	2.06×10^{-4}	--
4S/1W-30K1	-30L1	D	1,066,000	1,250,000	--	1,158,000	2.03×10^{-4}	1.97×10^{-4}	2.00×10^{-4}	--
4S/1W-21P6	--	R	--	--	3,770,000	3,770,000	n.a.	n.a.	n.a.	352.0
4S/1W-21P6	4S/1W-21P7	D	3,880,000	--	3,090,000	3,485,000	n.a.	n.a.	n.a.	--
4S/1W-21P6	-21P9	D	4,110,000	--	3,750,000	3,930,000	n.a.	n.a.	n.a.	--
4S/1W-28D9	--	R	--	1,008,000	--	1,008,000	--	--	--	160.0
4S/1W-28D9	4S/1W-28C1	D	1,103,000	--	--	1,103,000	9.17×10^{-4}	--	9.17×10^{-4}	--
4S/1W-28D9	-28C10	D	725,000	814,000	--	768,500	2.58×10^{-4}	3.2×10^{-4}	2.89×10^{-4}	--
4S/1W-28D9	-28D2	D	1,162,000	832,000	--	997,000	17.0×10^{-4}	78.4×10^{-4}	47.7×10^{-4}	--
4S/2W-21G1	--	R	--	130,000	132,500	131,250	--	--	--	30.0
4S/2W-21G1	4S/2W-21G2	D	121,000	121,000	111,000	118,000	8.73×10^{-5}	7.33×10^{-5}	8.03×10^{-5}	--
5S/1W- 6H1	--	R	--	--	173,800	173,800	--	--	--	160.0
5S/1W- 6H1	5S/1W- 6J1	D	71,000	174,000	558,000	174,000	5.53×10^{-6}	5.3×10^{-4}	5.4×10^{-5}	--
5S/1W- 7N1	--	R	--	84,500	85,100	84,800	--	--	--	66.4
5S/1W- 7N1	5S/1W- 7M1	D	114,600	103,000	137,000	118,000	4.48×10^{-5}	4.3×10^{-5}	4.39×10^{-5}	--
5S/2W-12B2	--	R	--	124,700	193,000	158,800	--	--	--	66.4
5S/2W-12B2	5S/2W-12B4	D	125,600	150,000	225,000	166,900	8.11×10^{-5}	6.3×10^{-5}	7.2×10^{-5}	--
5S/2W-18E3	--	R	--	14,240	--	14,240	--	--	--	7.0
5S/2W-18E3	5S/2W-18E2	D	--	15,090	14,700	14,895	--	5.0×10^{-4}	5.0×10^{-4}	--

1/ D - Drawdown test; R - Recovery test
2/ T_t - Theis method; T_j - Jacob method; T_r - Recovery method; T - Most reasonable average value; In gallons per day per foot of width
3/ S_t - Theis method; S_j - Jacob method; S - Most reasonable average value
4/ In gallons per minute per foot of drawdown
n.a. - Storage coefficient not applicable due to well being in area of unconfined ground water.

Specific Capacity and Aquifer Thickness Maps

In addition to the determination of transmissibilities and storage coefficients, the pump tests were used to determine specific capacities at various locations. Data derived were augmented with specific capacity data from other sources to delineate a contour map showing lines of equal specific capacity which is presented on Figure 14.

Maps showing the wetted thickness of the Newark aquifer west of the Hayward fault also were prepared. The map was developed from interpretation of the geologic peg model and geologic cross sections. An aquifer thickness map of the interval below the Newark aquifer also was prepared from the peg model and cross sections. The contours on this latter map represent thickness of aquifers in the depth interval from 170 feet to 400 feet. These maps are presented on Figures 15 and 16.

Permeability

The thickness of the aquifers vary throughout the study area and the saturated thickness varies in the area of unconfined ground water. To eliminate this variation, the values of transmissibility are changed to values of permeability by the relation:

$$T = K_p Y$$

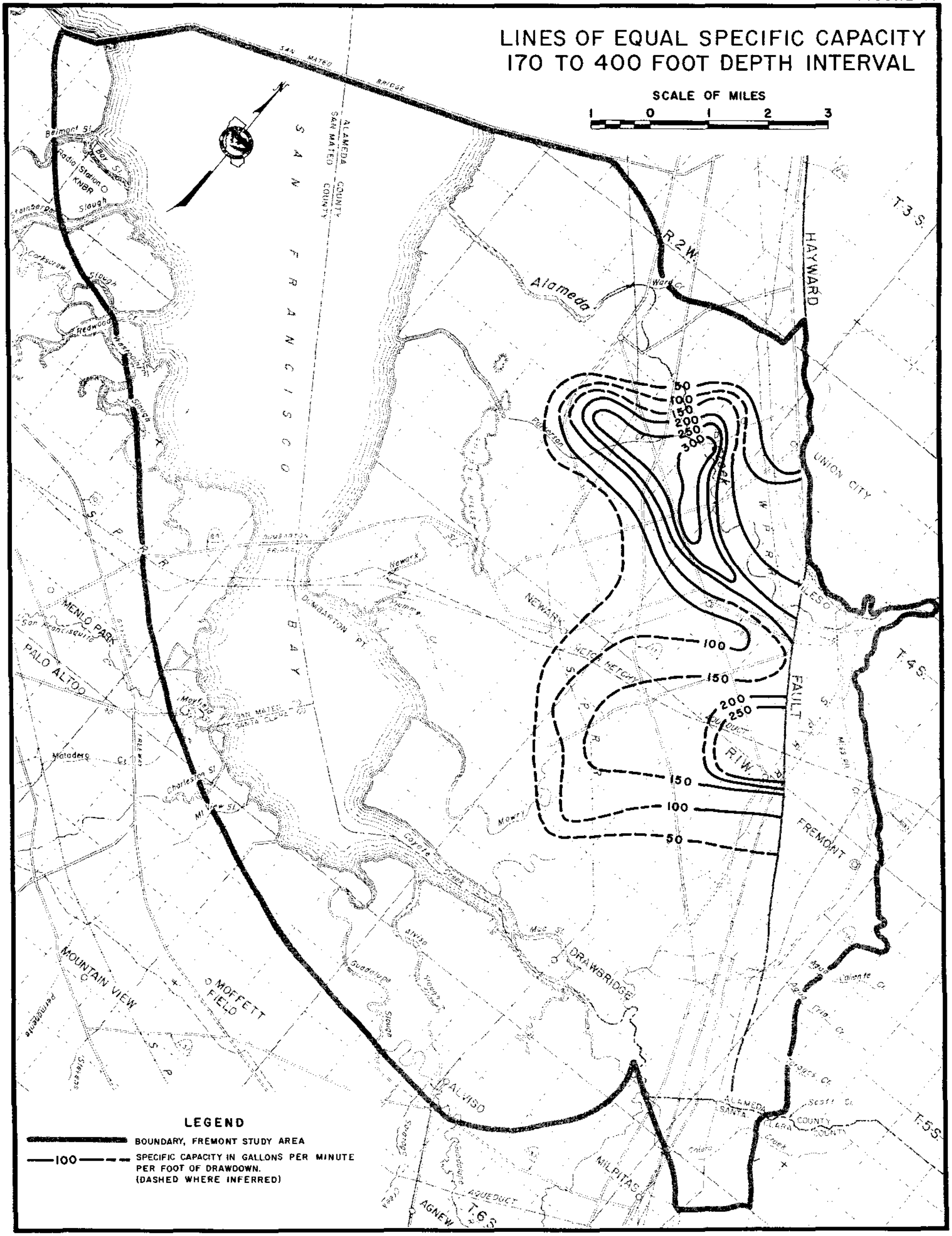
where K_p = coefficient of permeability in Meinzer units

Y = saturated thickness of aquifer

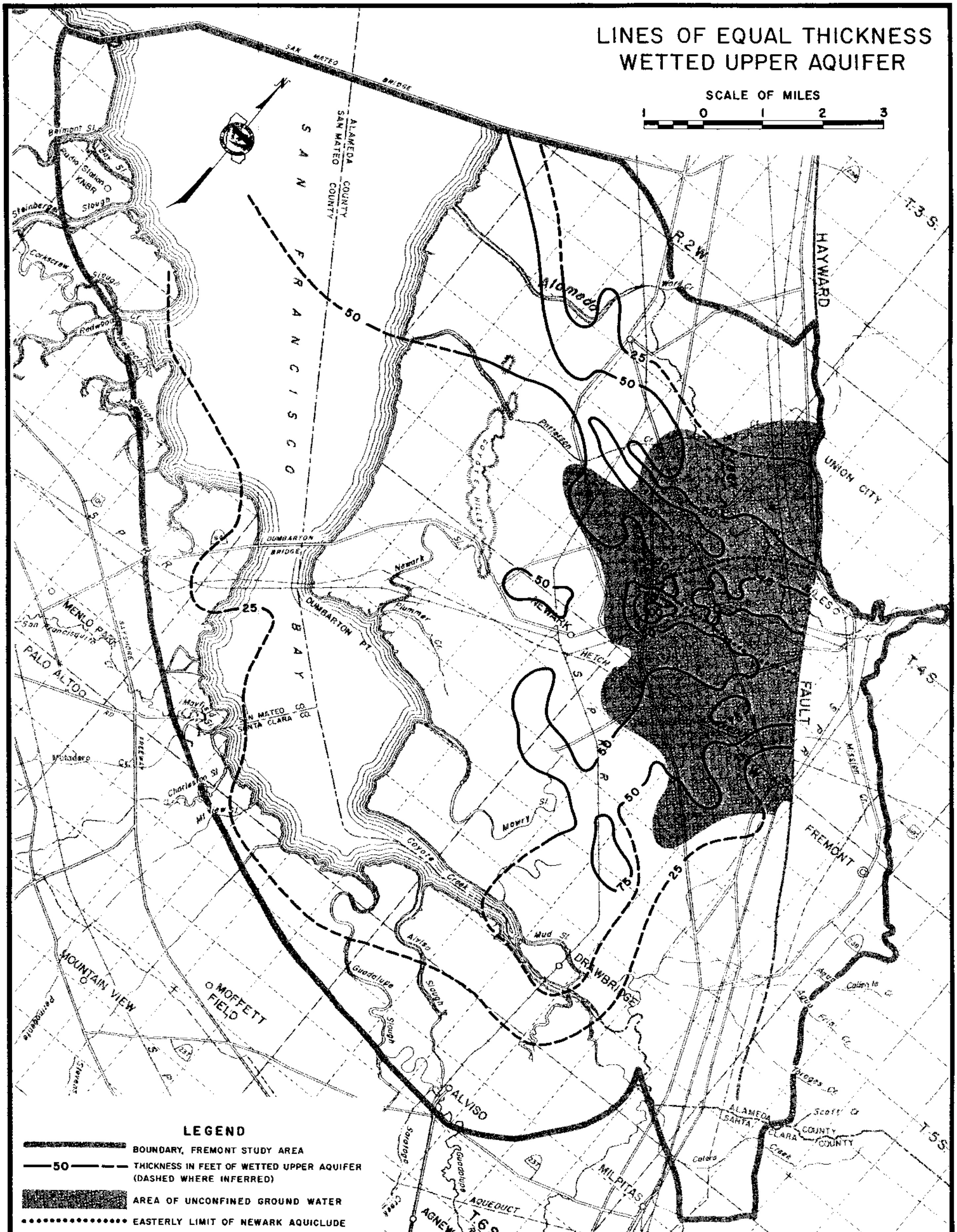
Transmissibility Maps

Transmissibility maps were prepared for the Newark and Centerville-Fremont aquifers by combining permeability data with aquifer thickness data derived from the contour maps. Using this method, the transmissibility at a given point is the estimated thickness of the aquifer multiplied by the estimated permeability . The transmissibility values thus derived can then be contoured. The contours developed by this method are shown on Figures 17 and 18. The transmissibility across each nodal boundary was subsequently determined by interpolation from the resulting contour map. This interpolated value was then used in the relationship TJ/L, which is the transmissive factor of a particular nodal boundary. Transmissive factors for all boundaries were included in the input data for the computer study.

FIGURE 14



LINES OF EQUAL SPECIFIC CAPACITY
170 TO 400 FOOT DEPTH INTERVAL


LINES OF EQUAL THICKNESS
WETTED UPPER AQUIFER
SCALE OF MILES
1 0 1 2 3
LEGEND
BOUNDARY, FREMONT STUDY AREA
50 THICKNESS IN FEET OF WETTED UPPER AQUIFER (DASHED WHERE INFERRED)
AREA OF UNCONFINED GROUND WATER
EASTERLY LIMIT OF NEWARK AQUICLUDE
SAN MATEO BRIDGE
ALAMEDA COUNTY
SAN MATEO COUNTY
SAN FRANCISCO BAY
DUMBARTON BRIDGE
DUMBARTON PT.
HAYWARD FAULT
UNION CITY
NEWARK
FREMONT
MENLO PARK
PALO ALTO
MOUNTAIN VIEW
MOFFETT FIELD
ALVISO
MILPITAS
AGNEW
DRAWBRIDGE
R.2W.
T.3S.
T.4S.
T.5S.
T.6S.
Coyote Creek
Alviso Slough
Guadalupe Slough
Mowry Sl.
Alameda
COYOTE HILLS
Newark
Plummer
Mud Sl.
Belmont Sl.
Steinberger Slough
Corkscrew Slough
Redwood Cr.
Charleston Sl.
ALAMEDA COUNTY
SANTA CLARA COUNTY
SAN MATEO CO.
SANTA CLARA CO.
AQUEDUCT
25
50
75

LINES OF EQUAL THICKNESS OF AQUIFERS 170 TO 400 FOOT DEPTH INTERVAL

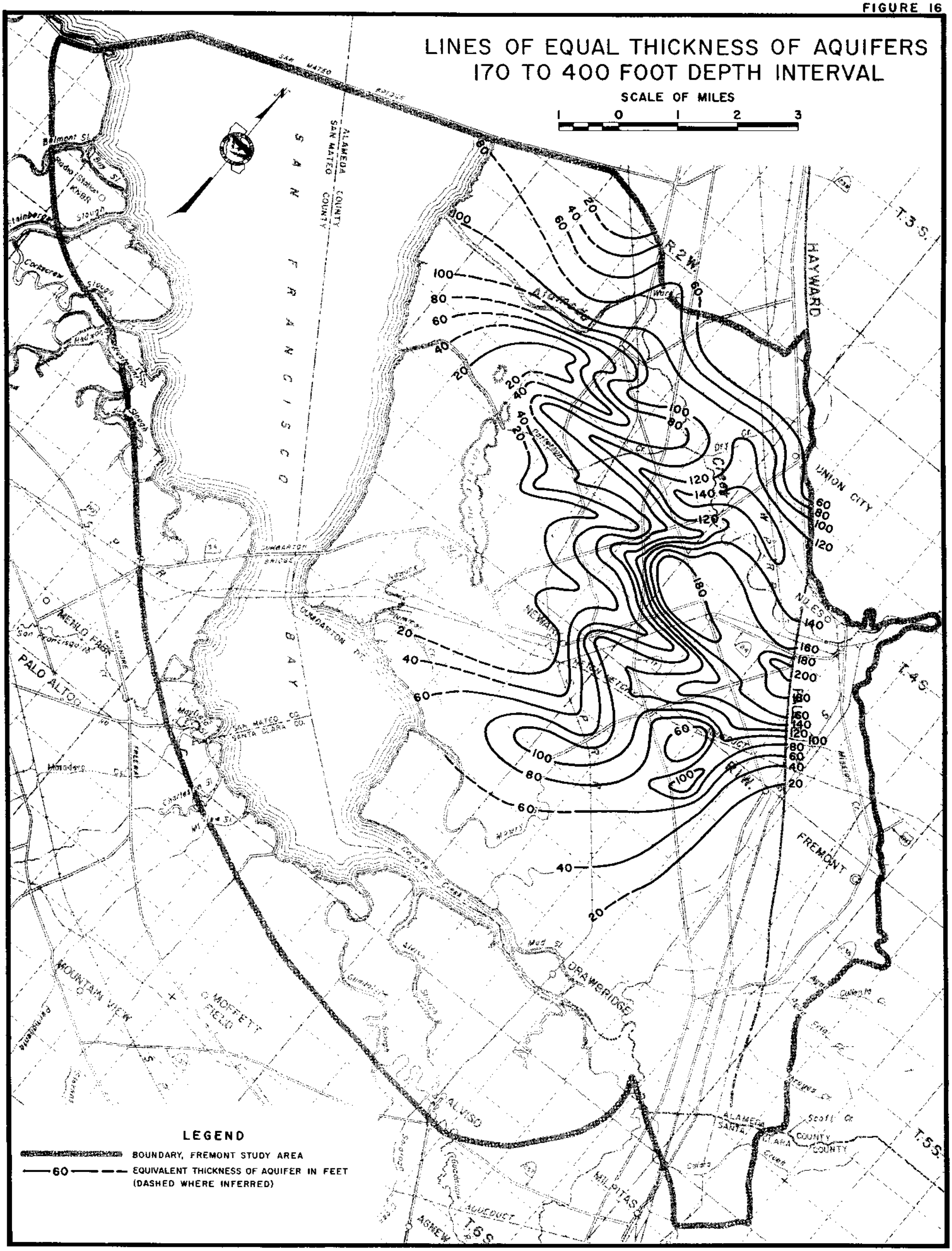
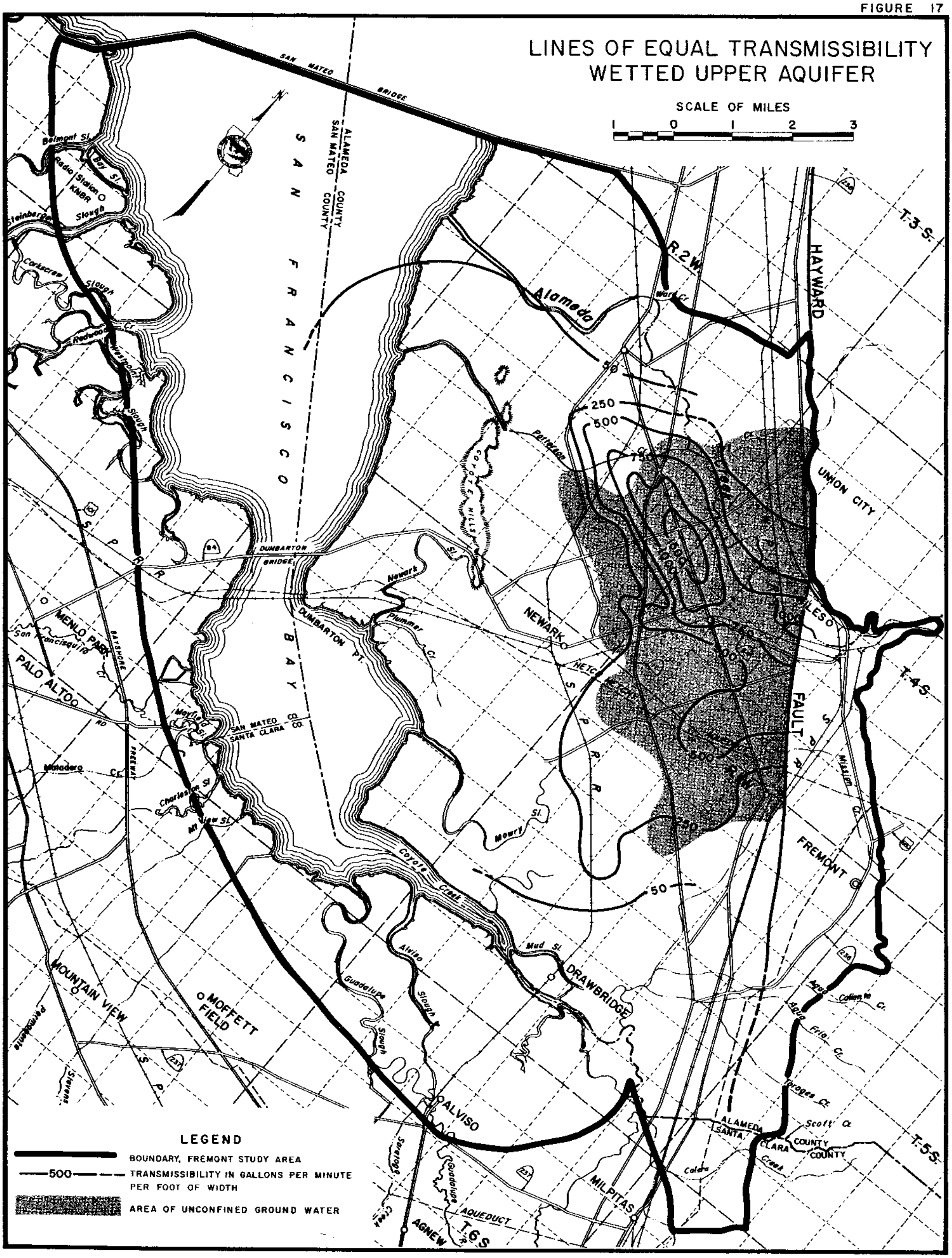
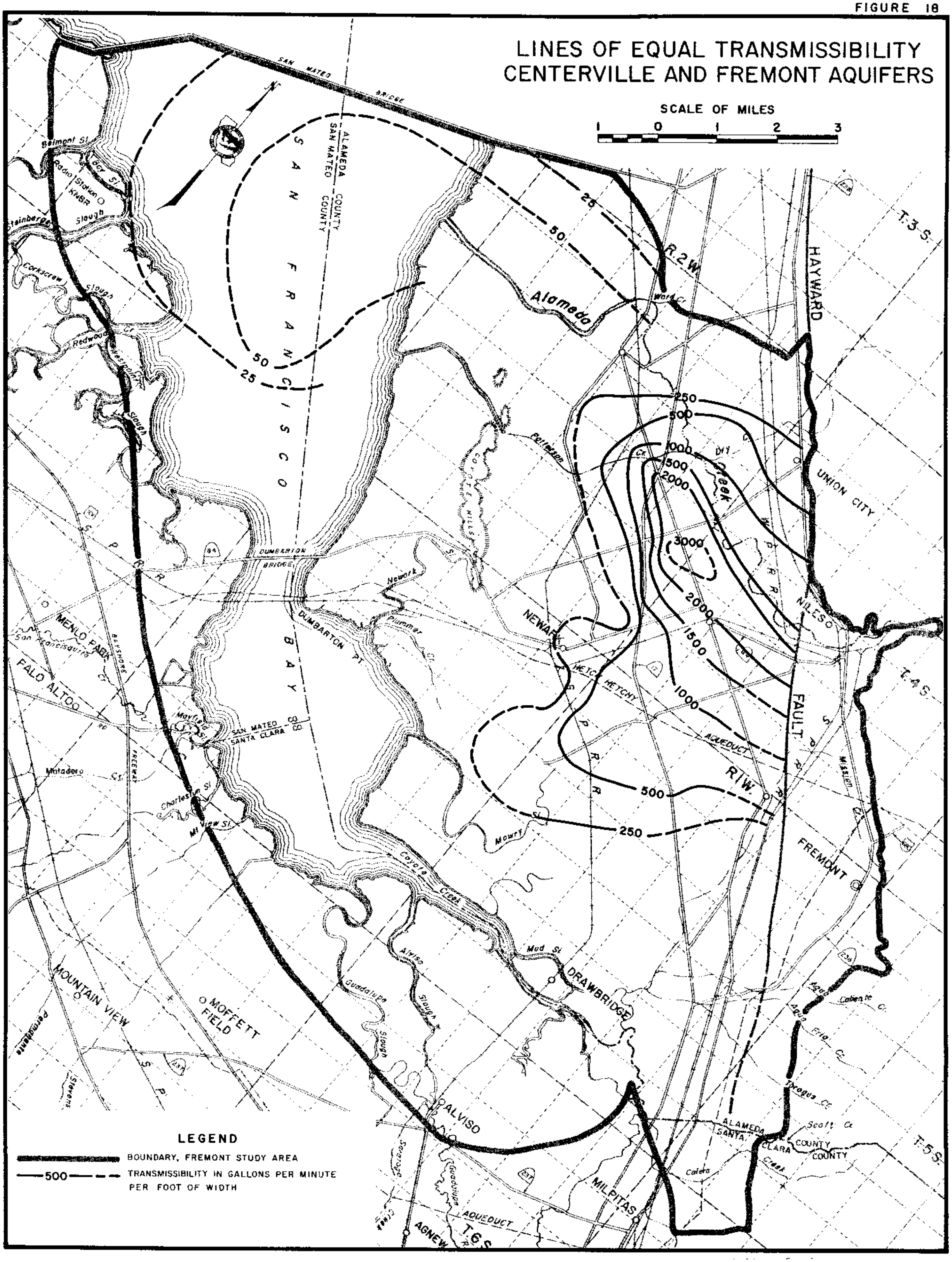


FIGURE 17



LINES OF EQUAL TRANSMISSIBILITY
WETTED UPPER AQUIFER

FIGURE 18



LINES OF EQUAL TRANSMISSIBILITY CENTERVILLE AND FREMONT AQUIFERS

Transmissibility Across Hayward Fault

The Hayward fault is a partial barrier to the movement of ground water. The transmissibility of this barrier was not known prior to this investigation, so it had to be determined. In order to determine the transmissibility of the Hayward fault, the following application of Darcy's Law was used:

$$Q = K\,I\,A \quad \text{(Darcy's Law)}$$

but $I = \dfrac{h - h_o}{L}$

$A = tJ$

and $K = \dfrac{T}{t}$

then by substitution and solving for $\dfrac{TJ}{L}$ gives

$$\frac{TJ}{L} = \frac{Q}{h - h_o}$$

where Q = flow across the fault
K = permeability of the fault zone
I = hydraulic gradient across the fault
A = cross-sectional area of fault barrier
$h - h_o$ = change in head across the fault
L = effective width of fault
t = saturated depth of fault zone
J = horizontal width
T = transmissibility of fault zone
$\frac{TJ}{L}$ = transmissive factor of fault zone

Modifications During Modeling

During verification of the ground water basin model it was necessary to change some of the values of transmissibility coefficient, storage coefficient and specific yield. The only changes of consequence were those made to the specific yield values in the upper aquifer. The final values of specific yield were sixty percent of the original values. By Nodes (Figure 20) the changes were A - from 10 to 6 percent; B, C, and G - from 30 to 18 percent; D, E, and F - from 35 to 21 percent; H - from 25 to 15 percent; and J through R - from 20 to 12 percent.

Appendix D

WATER QUALITY ANALYSES

WATER QUALITY ANALYSES

The information presented in Tables 20 and 21 is the basis of computation of the amount of sea water intrusion which has occurred in the study area. Tables 22 through 25 present historic changes in the character of ground water for the period 1962-67.

TABLE 20

Chloride Content of Water Quality Samples
Centerville-Fremont Aquifer

State Well Number	Date	Chlorides in p.p.m.	State Well Number	Date	Chlorides in p.p.m.
4S/1W 7N1	10-1-62	84	4S/1W 28N1	2-16-65	210
	2-18-65	84		3-16-65	208
	3-15-65	84	34P1	9-26-62	72
17E5	10-1-62	100		2-16-65	91
	2-17-65	129		3-17-65	95
	3-15-65	134	4S/2W 10M1	10-1962	60
18N2	9-16-62	228		3-26-65	30
	2-18-65	284	14P7	8-23-62	64
	3-15-65	294		2-16-65	80
19A2	10-2-62	228		3-16-65	87
	2-18-65	262	21G1	10-1-62	48
	3-17-65	218		3-3-65	87
20E2	10-2-62	204		3-16-65	101
	2-23-65	139	24L1	10-1-62	184
	3-22-65	114		2-18-65	850
28N1	10-1-62	116		3-16-65	850

TABLE 21

Chloride Content of Water Quality Samples
Newark Aquifer

State Well Number	Date	Chlorides in p.p.m.	State Well Number	Date	Chlorides in p.p.m.
4S/1W 18G1	11-27-62	196	4S/2W 11A2	9-27-62	64
	2-18-65	296		2-18-65	63
	3-15-65	296		3-16-65	53
19A1	11-27-62	624	13R5	8-20-62	1748
	2-18-65	143		2-16-65	128
	3-17-65	150		3-17-65	112
19E1	3-2-66	360	14P2	3-2-66	5210
19F1	9-16-62	572		3-1967	5630
	2-23-65	214	15C2	2-8-66	1640
	3-17-65	164		3-1967	1680
19J2	11-27-62	720	23A4	2-18-66	3210
	2-18-65	258		3-1967	3400
	3-17-65	242	23F1	3-1-66	3570
19L3	10-3-62	672		3-1967	2380
	2-18-65	845	24H2	11-6-62	844
	3-25-65	830		2-16-65	1280
20C4	11-27-62	104		3-15-65	420
	2-18-65	76	26E2	3-2-66	650
	3-15-65	80		3-1967	35
20E1	11-27-62	500	26G2	2-10-66	380
	2-23-65	104		3-1967	315
	3-17-65	126	26M4	2-10-66	700
20N3	11-27-62	1096	27R1	2-10-66	1355
	2-18-65	85		3-1967	2115
	3-30-65	88	34E1	3-1967	6000
28D9	11-27-62	76	34G1	2-28-66	480
	2-16-65	73	5S/1W 3Q2	9-26-62	64
	3-16-65	72		2-16-65	52
28R1	9-26-62	80		3-17-65	52
	2-16-65	116	4F1	2-11-66	2120
	3-16-65	108		3-1967	2090
29F2	3-3-66	1370	6C4	2-25-66	975
	3-1967	630	8P3	2-4-66	150
29F3	3-4-66	1235	5S/2W 1E7	2-2-66	95
	3-1967	770		3-1967	25
29G2	3-3-66	80	1K1	2-3-66	60
	3-1967	85	2F1	11-26-62	684
30E4	2-28-66	930		2-16-65	1210
	3-1967	970	12C1	2-24-66	18000
30J4	3-2-66	4700		3-1967	17400
	3-1967	4100	2L1	9-28-67	13000
4S/2W 10Q3	10-2-62	304	7K1	9-27-67	29600
	2-16-65	345	12D1	9-27-67	23800
	3-26-65	410	21B3	9-29-67	18800

TABLE 22

Representative Analysis of Well Water
Newark Aquifer

State Well Number	4S/1W-18M7				
Date	9-62	10-64	9-65	9-66	9-67
Constituent					
Calcium, ppm	374	164	146	171	304
Magnesium, ppm	184	103	62	77	130
Sodium, ppm	108	72	60	68	110
Potassium, ppm	4.1	3.9	3.0	3.0	
Carbonate, ppm	0	0	0	0	0
Bicarbonate, ppm	51	81	220	193	251
Sulfate, ppm	23	56	66	30	
Chloride, ppm	1280	580	360	468	798
Nitrate, ppm	9.3	4.6	3.4	14	
Fluoride, ppm	0.3				
Boron, ppm	0.3	0.0	0.3	0.4	0.3
Silica, ppm	17				
Total Hardness, ppm	1690	834	620	743	1293

TABLE 23

Representative Analysis of Well Water
Centerville-Fremont Aquifer

State Well Number	4S/1W-28D4				
Date	9-62	10-64	9-65	9-66	9-67
Constituent					
Calcium, ppm	143	88	79	76	70
Magnesium, ppm	52	38	33	33	30
Sodium, ppm	61	44	44	43	45
Potassium, ppm	2.5	2.2	2.6	2.1	
Carbonate, ppm	0	11	13	0	17
Bicarbonate, ppm	257	260	250	281	239
Sulfate, ppm	63	78	70	66	
Chloride, ppm	309	105	91	77	78
Nitrate, ppm	4.1	4.0	2.5	1.4	
Fluoride, ppm	0.1				
Boron, ppm	0.6	0.5	0.6	0.7	0.4
Silica, ppm	14				
Total Hardness, ppm	573	378	335	326	298

TABLE 24

Representative Analysis of Well Water
Lower Aquifer

State Well Number	4S/1W-30E3			
Date	9-62	10-64	9-65	9-67
Constituent				
Calcium, ppm	19	44	71	148
Magnesium, ppm	7.7	16	18	40
Sodium, ppm	131	78	93	92
Potassium, ppm	1.8	1.8	2.2	
Carbonate, ppm	8	0	12	0
Bicarbonate, ppm	208	166	184	225
Sulfate, ppm	54	46	48	
Chloride, ppm	90	111	160	327
Nitrate, ppm	1.2	2.4	2.5	
Fluoride, ppm	0.3	0	0	
Boron, ppm	0.4	0.4	0.3	0.2
Silica, ppm	21			
Total Hardness, ppm	79	174	250	534

TABLE 25

Representative Analysis of Well Water
Above Hayward Fault

State Well Number	4S/1W-21P6				
Date	12-63	12-64	9-65	9-66	6-67
Constituent					
Calcium, ppm	63	58	53	60	56
Magnesium, ppm	29	26	26	25	24
Sodium, ppm	43	45	46	42	46
Potassium, ppm	1.7	1.5	1.8	1.4	1.5
Carbonate, ppm	0	0	0	10	9
Bicarbonate, ppm	269	240	256	234	239
Sulfate, ppm	72	57	55	58	69
Chloride, ppm	55	66	43	58	41
Nitrate, ppm	3.9	2.3	7.0	4.6	6.6
Fluoride, ppm	0.3				
Boron, ppm	0.7	0.6	0.6	0.6	0.6
Silica, ppm	16				
Total Hardness, ppm	278	250	239	252	240

Appendix E

MATHEMATICAL GROUND WATER MODEL

MATHEMATICAL GROUND WATER MODEL

A test of the validity of assumptions and calculations made in an inventory of supply to, and withdrawals from, a ground water basin is the matching of theoretical water levels against the historical water levels. A mathematical model was developed to accomplish the verification. The model was programmed on a general purpose analog computer with additional work being done by a digital computer.

For the purposes of the evaluation only, the areas containing significant amounts of water-bearing material were included in the model area. Successful evaluation of the model area required a mathematical solution of the general equation of hydrologic equilibrium.

The mathematical model is a tool to simulate the actual conditions which are present in the ground water basin. The basin is divided into nodal areas (nodes), each node being of a homogeneous nature.

Ground Water Equation

A generalized ground water equation which defines the storage, transmissive, and water flow characteristics of a ground water basin, first developed for the Los Angeles Coastal Plain, is used in this investigation and model development.

Appendix C describes the transmissive (TJ/L) and storage factors (AS) as determined from pump tests in the study area.

By combining the general continuity equation and Darcy's Law:

Inflow-outflow = Change in storage (continuity equation)

$Q = KAI = TWI$ (Darcy's Law)

where:
- Q = flow
- K = permeability coefficient
- A = saturated area
- I = hydraulic gradient
- T = transmissibility coefficient
- W = width through which water moves
- $KA = TW$

For any general unit area within the ground water basin, we have:

$$\sum\left[(h_i - h_B/L_{iB})T_{iB}J_{iB}\right] + A_BQ_B = A_BS_Bdh_B/dt$$

Subsurface flow + surface flow = storage change, where:

h_B = water level elevation associated with general unit area (node) B, in feet.

h_i = water level elevation associated with a unit area (node) adjacent to area B, in feet.

L_{iB} = distance between nodes of area i and B, in feet.

T_{iB} = transmissibility at midpoint between areas B and i, in acre-feet per year per foot.

J_{iB} = width through which the subsurface flow occurs between B and i areas, in feet.

Q_B = rate of net surface inflow and outflow of general unit area B, in acre-feet/year/acre.

S_B = representative specific yield of sediments in general area (node) B. (Storage coefficient.)

t = time, in years.

A schematic sketch of the generalized ground water flow equation is shown on Figure19.

Selection of Nodal Pattern

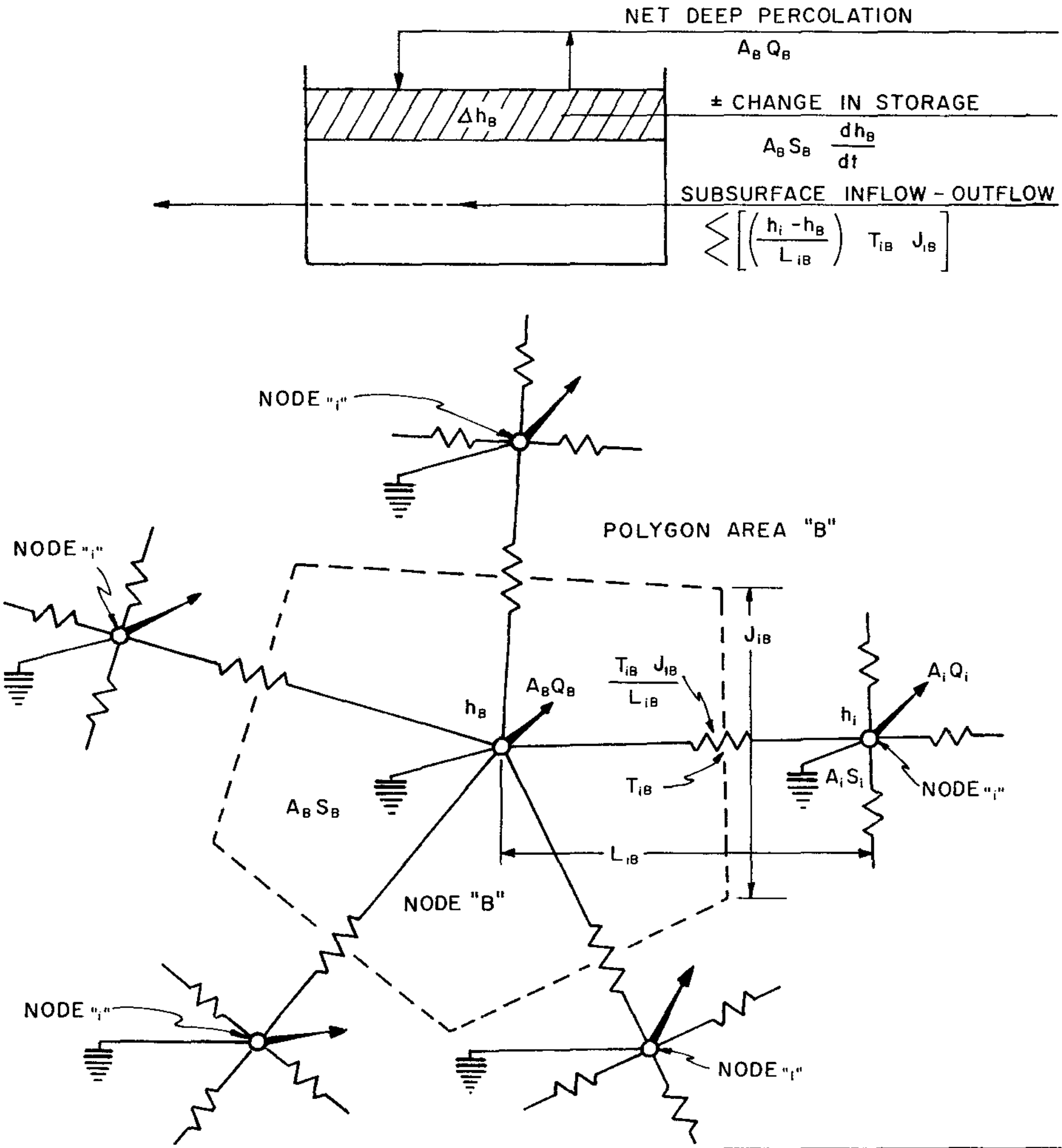
In selection of the nodal patterns, the following conditions are considered: the geologic data which are available, the hydrology of the area, and a general working knowledge of the study area.

Since limited continuity exists between the model area and adjacent cones and ground water areas, the model boundaries were located along the line of the least continuity where the ground water movement is the least. The east boundary of the model is at the base of the Diablo Highlands. The south boundary crosses Avliso and Guadalupe Sloughs near Alviso. The west boundary is established near the west side of the San Francisco Bay. The north boundary being arbitrarily established at the San Mateo Bridge. The control nodes inside the model boundary are determined from the geology and hydrology of the area. Since each control node would represent the characteristics of the nodal area, they are located closer together where rapid changes occurred in the characteristics. Thus, they are located closer together near the Hayward fault where the water levels change rapidly.

EQUATIONS

INFLOW − OUTFLOW = ± CHANGE IN STORAGE

$$\sum \left[\left(\frac{h_i - h_B}{L_{iB}} \right) T_{iB} \; J_{iB} \right] + A_B Q_B = A_B S_B \; \frac{dh_B}{dt}$$



SCHEMATIC SKETCH OF GENERALIZED GROUND WATER FLOW EQUATION

In the westerly half of the model area under the San Francisco Bay, the nodes are located greater distances apart because water level data are not available for these areas and geologic and hydrologic conditions are more uniform. The Theisen method is used to determine the polygons.

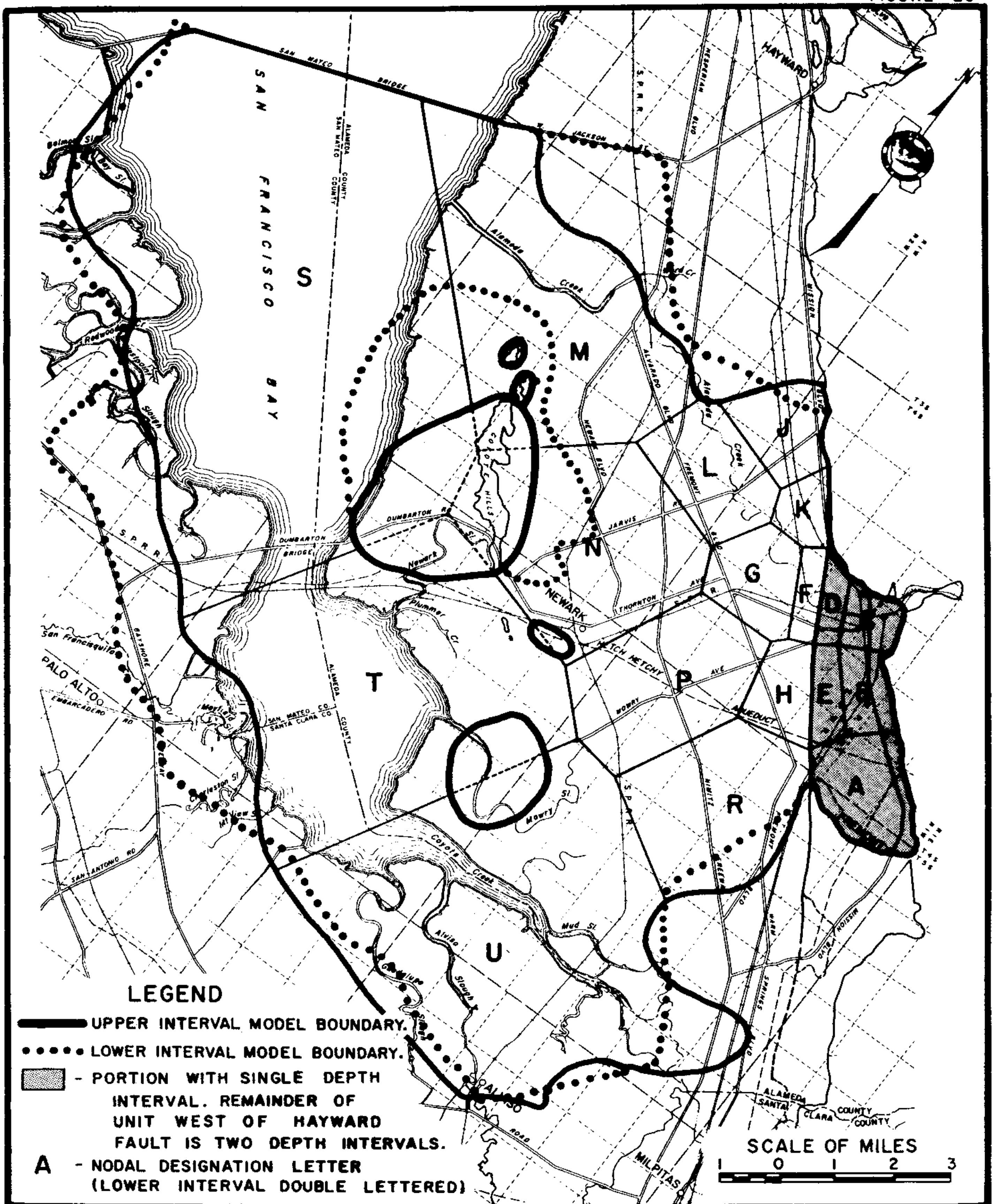
One control nodal area boundary was established along the Hayward fault and another nearly along the Coyote Hills, as these lines represent partial barriers to ground water movement. Since the basin east of the fault is not layered in depth, the nodes are a single layer. All nodes west of the fault are separated into two layers because the Newark aquifer is not continuous with the Centerville and the lower aquifers. The final nodal pattern is shown on Figure 20.

Testing the Reliability of the Mathematical Model

Testing the reliability of the model consists of matching the water level elevations generated by the computer for each node with hydrographs of historical water level elevations for the corresponding node.

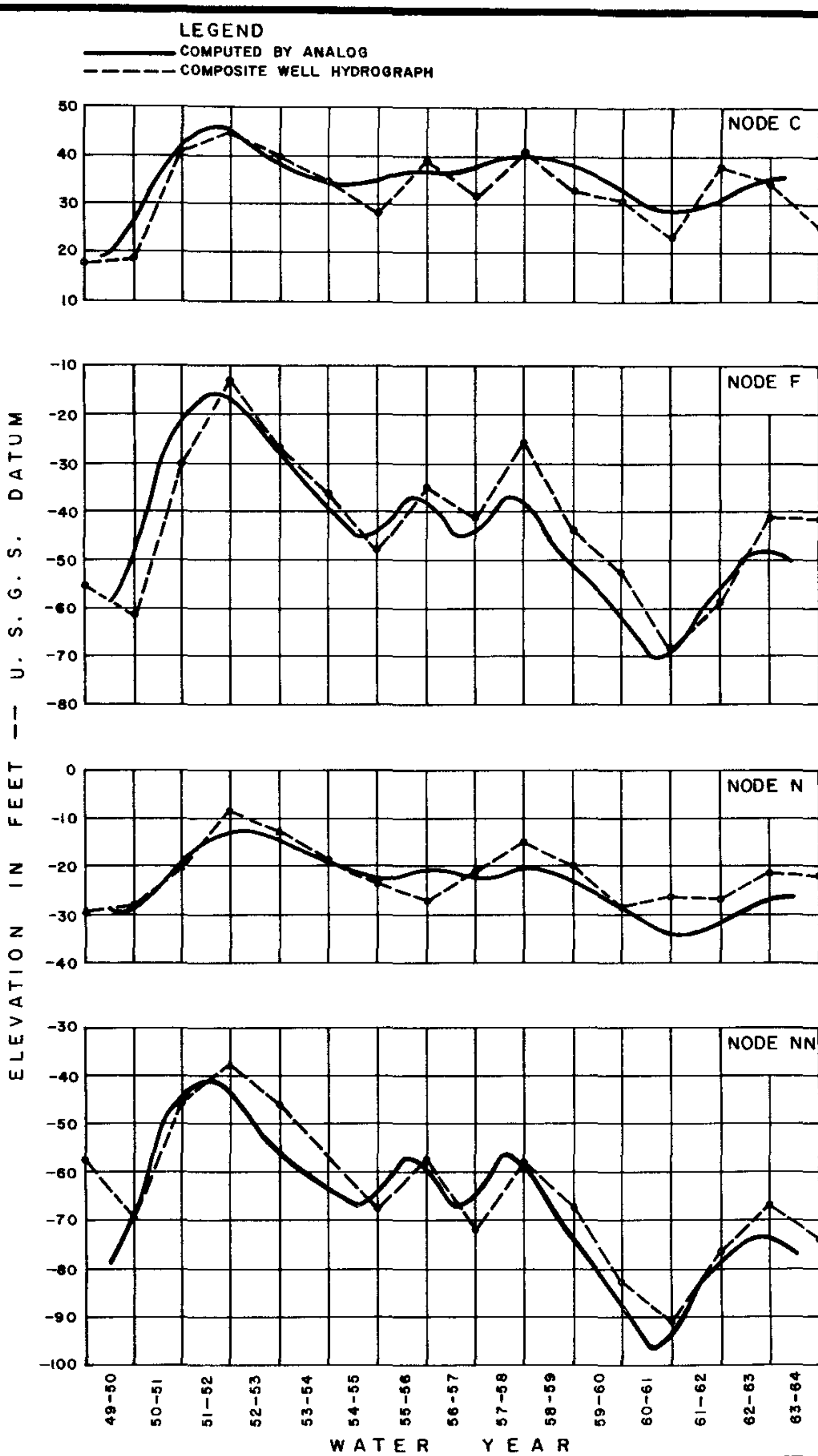
The first trial was made using the best estimates of inflow, outflow, transmissibility, and storage factor. The sensitivity of the model to changes in these items was tested by varying the values assigned to one item and holding all the others fixed. A series of changes in transmissibility, specific yield, and net inflow were made to bring about the best match of water levels. Changes made during modeling were then checked against the original data and it was determined that the answers were within the probable range of values. Comparison of computer output with historical water levels are shown on Figure 21.

The major results of modeling were the reduction of transmissibility values, the verification of salt water inflow estimates and the increase in recharge from streamflow. The changes, although significant, resulted in values that were within the range of expected variation.



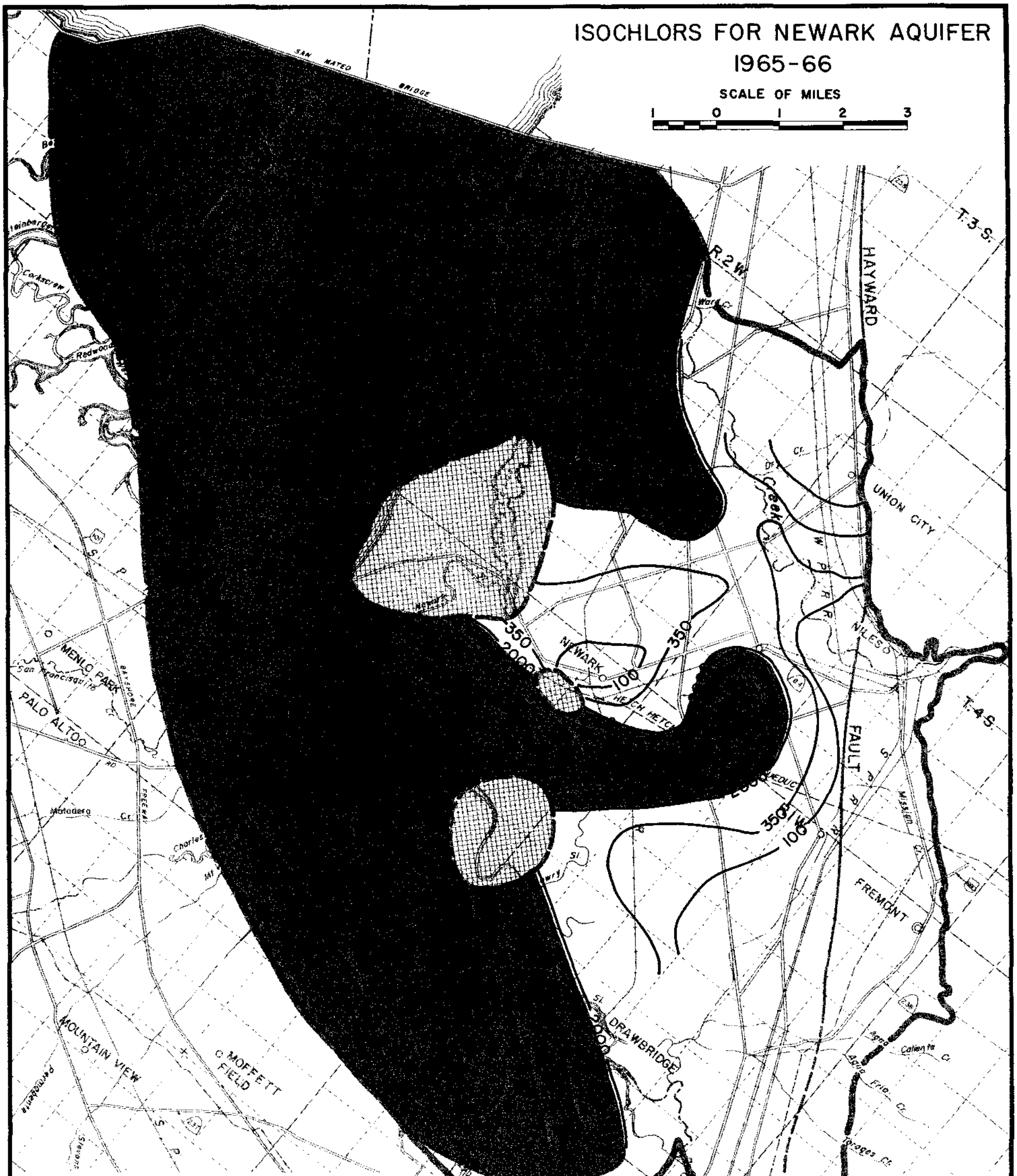
NODAL PATTERN FOR MATHEMATICAL MODEL

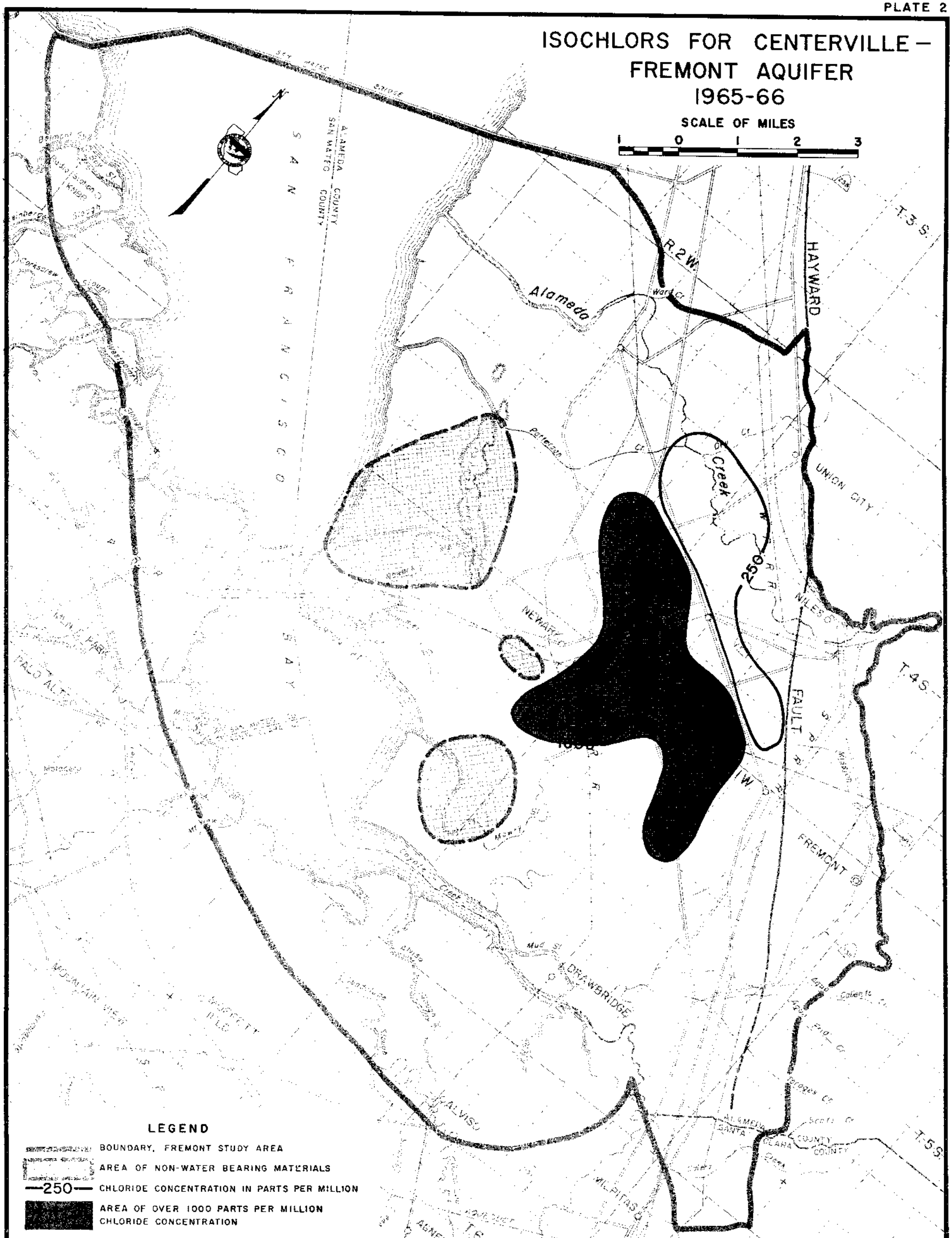
FIGURE 21

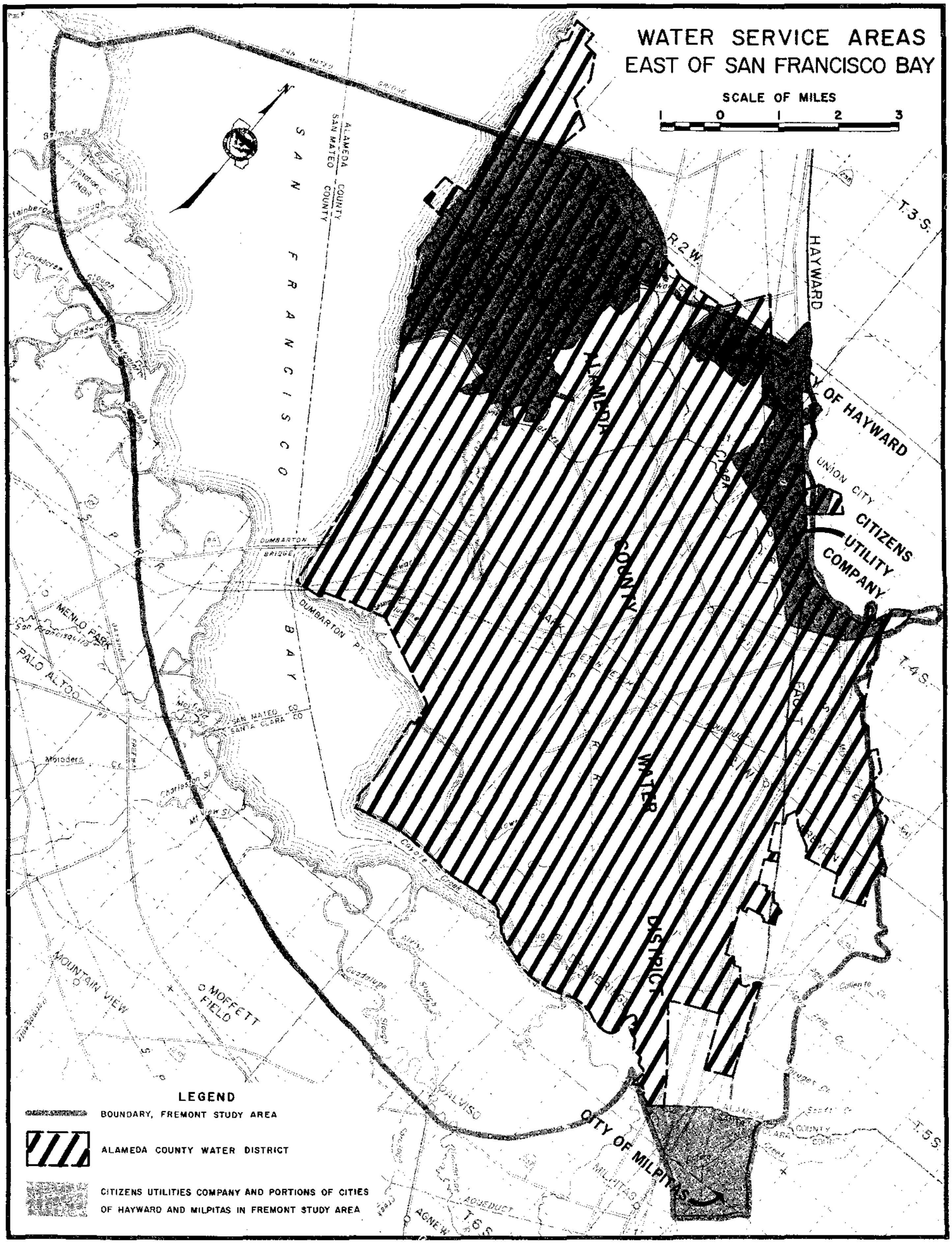


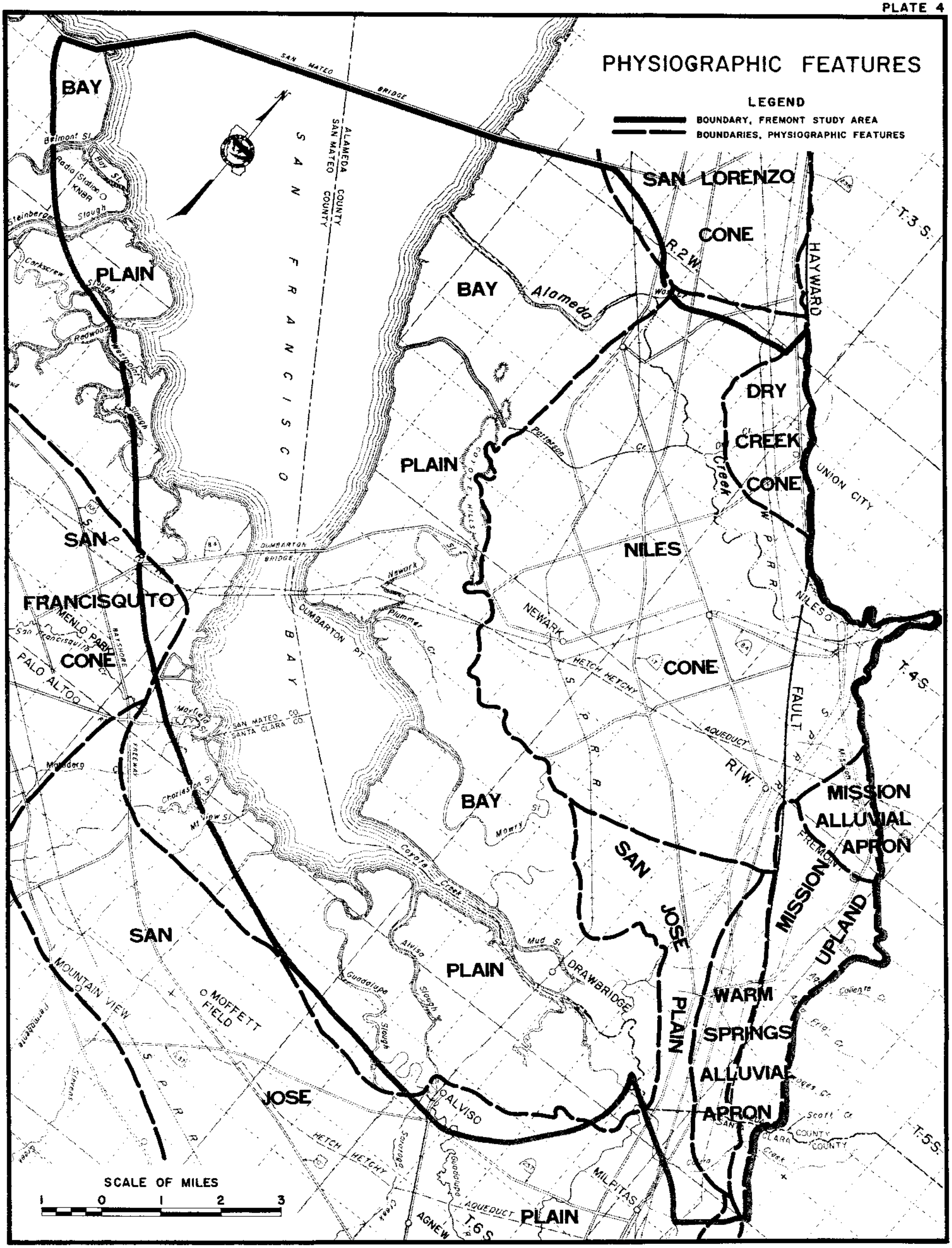
COMPOSITE WELL HYDROGRAPHS

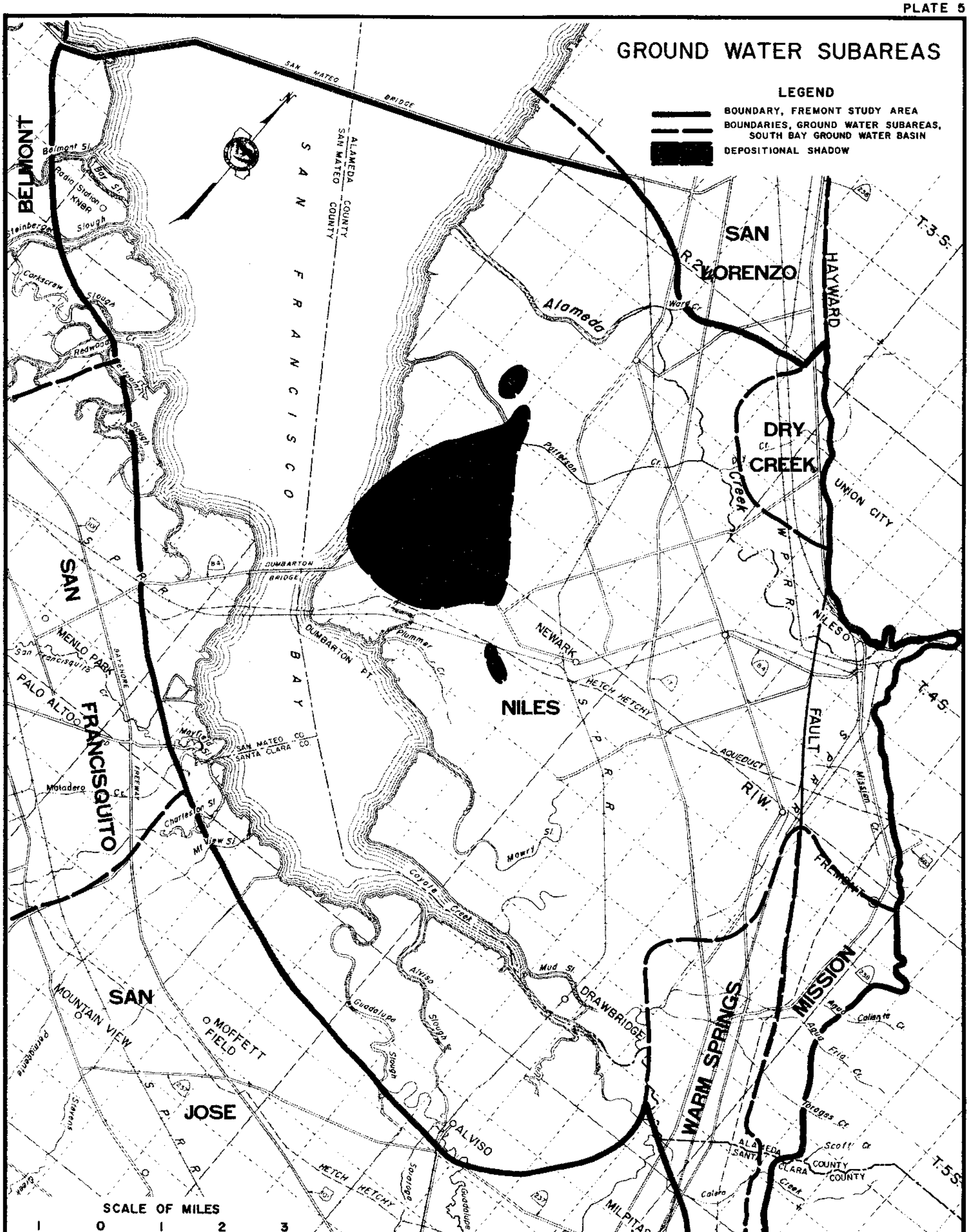
P L A T E S

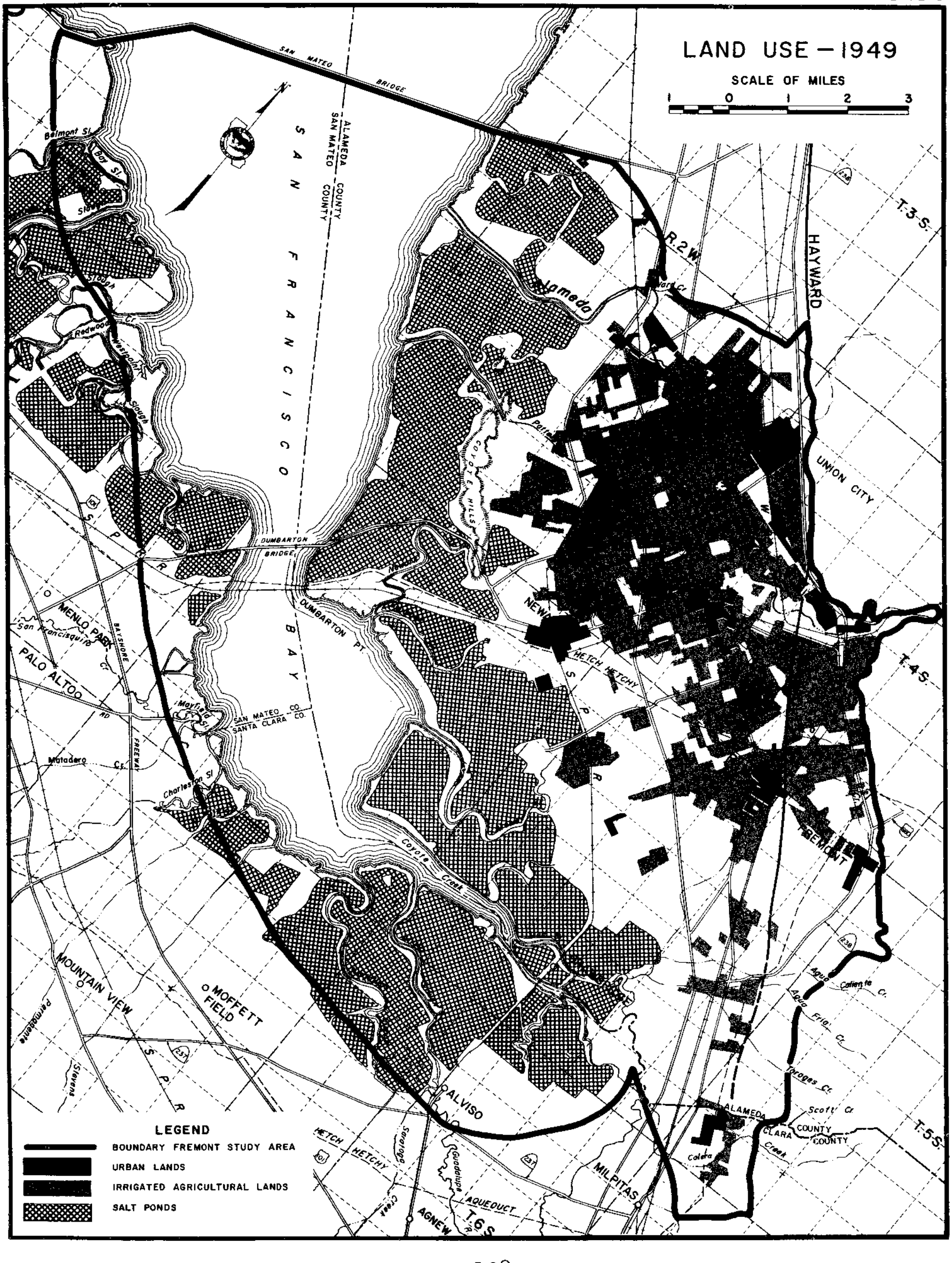

ISOCHLORS FOR NEWARK AQUIFER
1965-66
SCALE OF MILES
1 0 1 2 3
SAN MATEO BRIDGE
R.2 W.
T.3 S.
HAYWARD
UNION CITY
NILES
T.4 S.
FAULT
FREMONT
NEWARK
MENLO PARK
PALO ALTO
MOUNTAIN VIEW
MOFFETT FIELD
DRAWBRIDGE
MILPITAS
ALAMEDA COUNTY
SANTA CLARA COUNTY
T.5 S.
AQUEDUCT
350
2000
100
LEGEND
BOUNDARY, FREMONT STUDY AREA
AREA OF NON-WATER BEARING MATERIALS
350 CHLORIDE CONCENTRATION IN PARTS PER MILLION
AREA OF OVER 2000 PARTS PER MILLION CHLORIDE CONCENTRATION

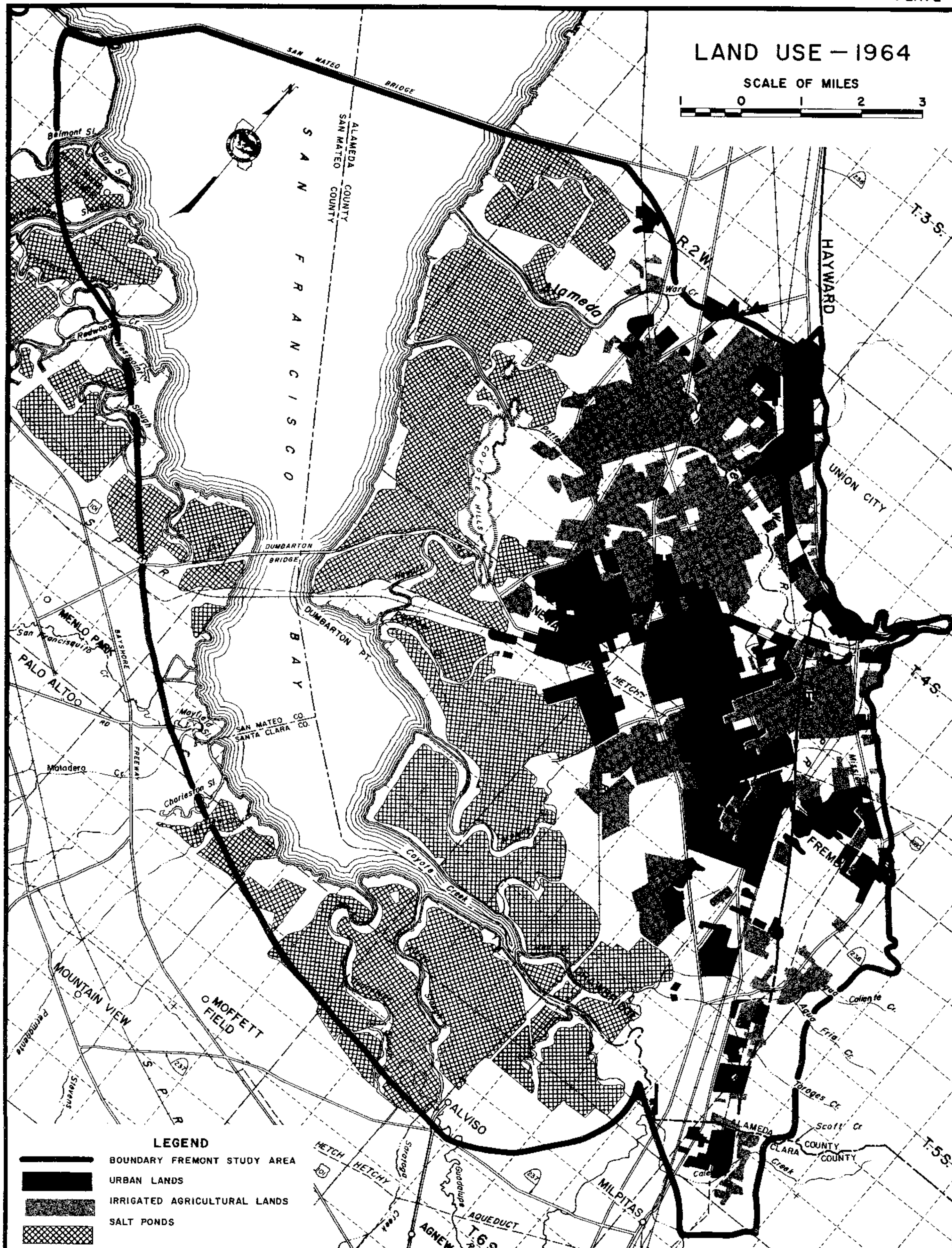

ISOCHLORS FOR CENTERVILLE - FREMONT AQUIFER 1965-66
SCALE OF MILES
1 0 1 2 3
SAN FRANCISCO BAY
ALAMEDA COUNTY
SAN MATEO COUNTY
HAYWARD
R.2W.
T.3S.
T.4S.
T.5S.
Alameda
UNION CITY
NILES
FAULT
FREMONT
NEWARK
DRAWBRIDGE
ALVISO
MILPITAS
250
1000
LEGEND
BOUNDARY, FREMONT STUDY AREA
AREA OF NON-WATER BEARING MATERIALS
—250— CHLORIDE CONCENTRATION IN PARTS PER MILLION
AREA OF OVER 1000 PARTS PER MILLION CHLORIDE CONCENTRATION

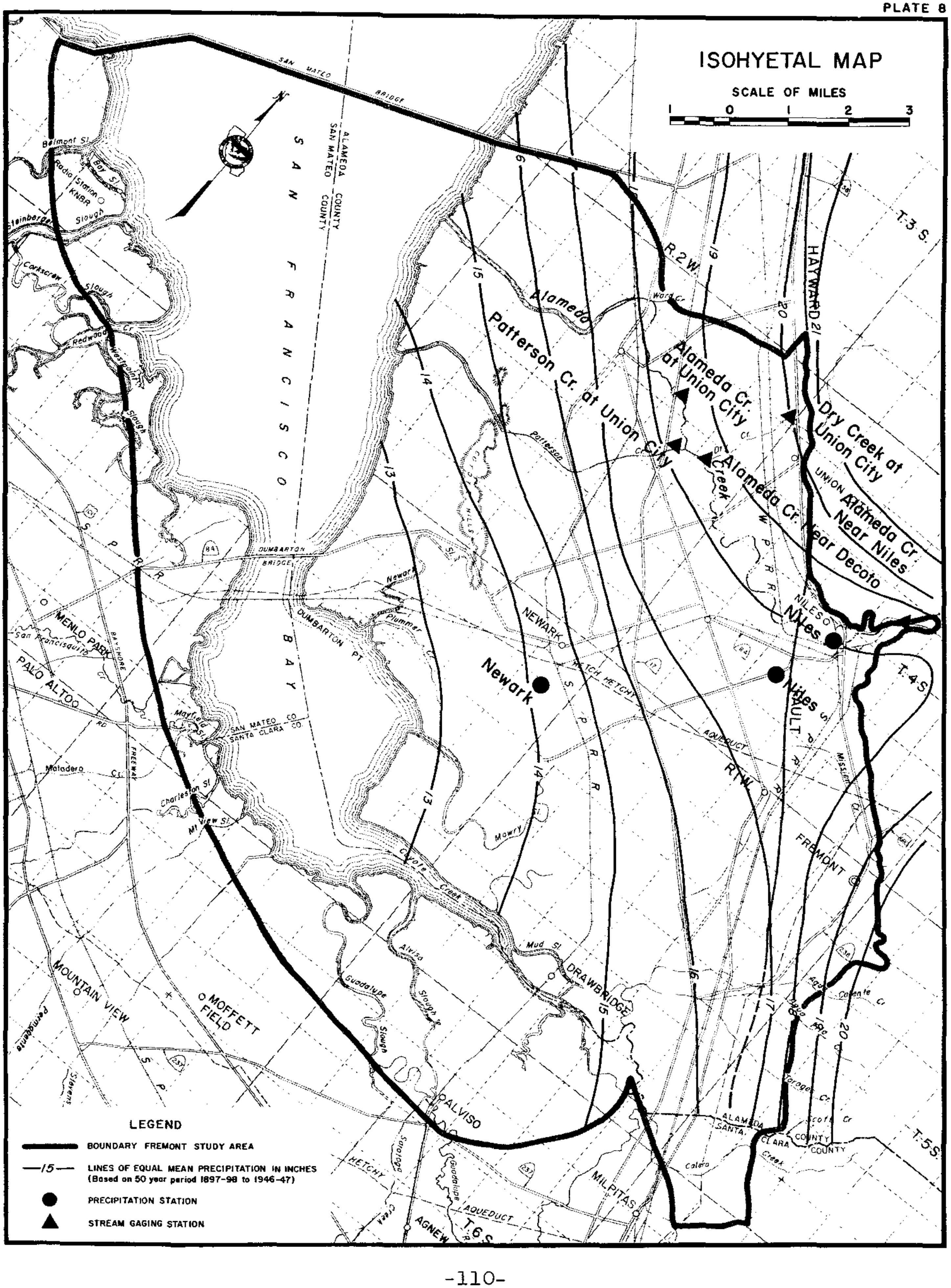

WATER SERVICE AREAS
EAST OF SAN FRANCISCO BAY
SCALE OF MILES
1 0 1 2 3
SAN FRANCISCO BAY
ALAMEDA COUNTY
SAN MATEO COUNTY
ALAMEDA COUNTY WATER DISTRICT
CITY OF HAYWARD
UNION CITY
CITIZENS UTILITY COMPANY
CITY OF MILPITAS
HAYWARD
R.2 W.
T.3 S.
T.4 S.
T.5 S.
T.6 S.
DUMBARTON BRIDGE
DUMBARTON PT.
MENLO PARK
PALO ALTO
MOUNTAIN VIEW
MOFFETT FIELD
ALVISO
MILPITAS
AGNEW
AQUEDUCT
SAN MATEO CO.
SANTA CLARA CO.
Coyote Creek
Guadalupe Slough
Charleston Sl.
S. P. R. R.
LEGEND
BOUNDARY, FREMONT STUDY AREA
ALAMEDA COUNTY WATER DISTRICT
CITIZENS UTILITIES COMPANY AND PORTIONS OF CITIES OF HAYWARD AND MILPITAS IN FREMONT STUDY AREA


PHYSIOGRAPHIC FEATURES
LEGEND
BOUNDARY, FREMONT STUDY AREA
BOUNDARIES, PHYSIOGRAPHIC FEATURES
BAY
PLAIN
SAN FRANCISQUITO CONE
SAN JOSE PLAIN
SAN LORENZO CONE
DRY CREEK CONE
NILES CONE
MISSION ALLUVIAL APRON
MISSION UPLAND
WARM SPRINGS ALLUVIAL APRON
SAN JOSE PLAIN
SAN FRANCISCO BAY
SAN MATEO BRIDGE
DUMBARTON BRIDGE
ALAMEDA COUNTY
SAN MATEO COUNTY
HAYWARD FAULT
UNION CITY
NEWARK
NILES
FREMONT
ALVISO
DRAWBRIDGE
MILPITAS
AGNEW
MOFFETT FIELD
MOUNTAIN VIEW
PALO ALTO
MENLO PARK
HETCH HETCHY AQUEDUCT
R.2 W.
R.1 W.
T.3 S.
T.4 S.
T.5 S.
T.6 S.
SCALE OF MILES
1 0 1 2 3

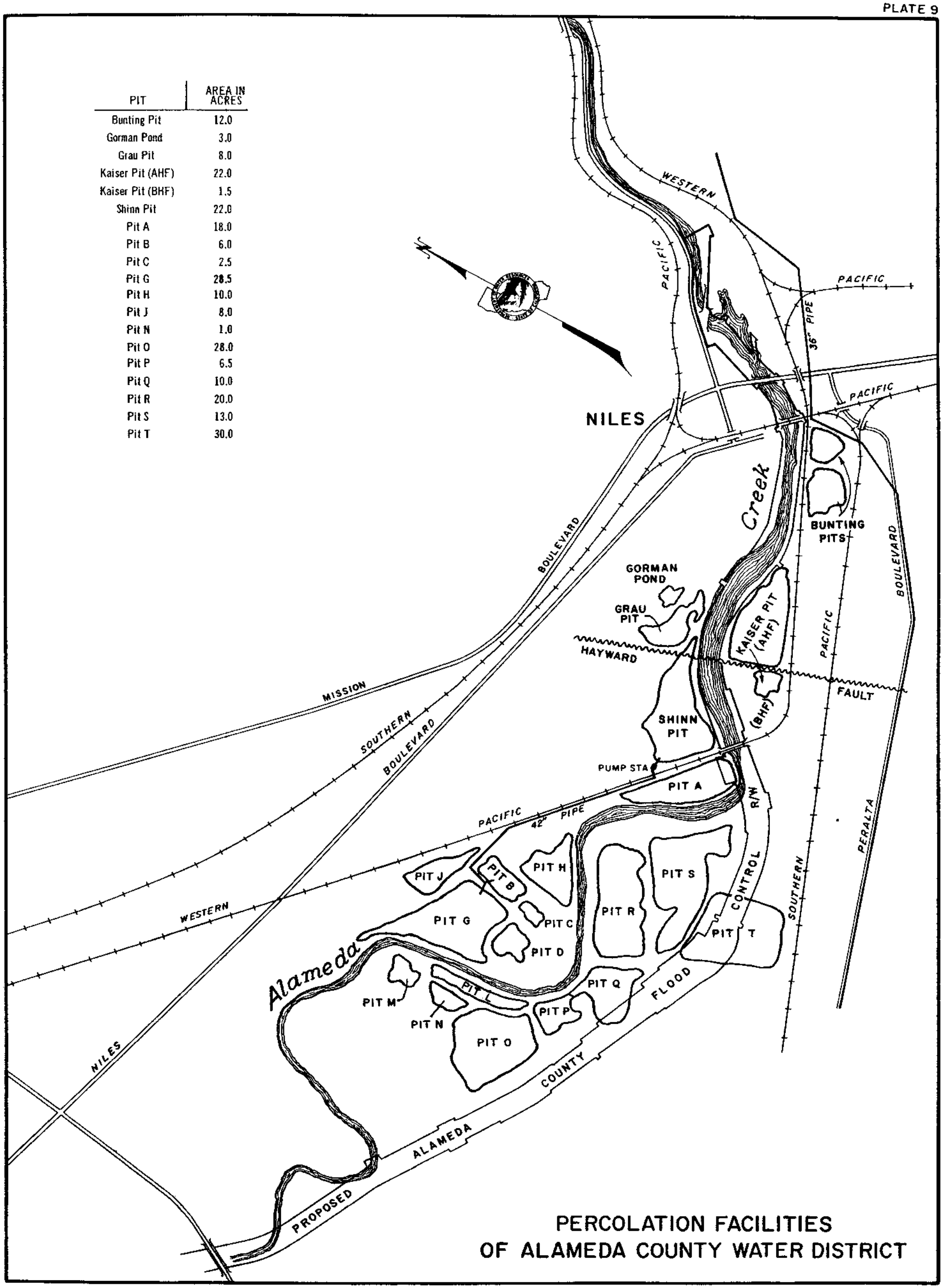

GROUND WATER SUBAREAS
LEGEND
BOUNDARY, FREMONT STUDY AREA
BOUNDARIES, GROUND WATER SUBAREAS, SOUTH BAY GROUND WATER BASIN
DEPOSITIONAL SHADOW
BELMONT
SAN LORENZO
HAYWARD
DRY CREEK
NILES
SAN FRANCISQUITO
MISSION
WARM SPRINGS
SAN JOSE
BERRYESSA
SAN FRANCISCO BAY
SAN MATEO BRIDGE
DUMBARTON BRIDGE
ALAMEDA COUNTY
SAN MATEO COUNTY
NEWARK
UNION CITY
FREMONT
MENLO PARK
PALO ALTO
MOUNTAIN VIEW
MOFFETT FIELD
ALVISO
DRAWBRIDGE
MILPITAS
HETCH HETCHY AQUEDUCT
HAYWARD FAULT
T.3 S.
T.4 S.
T.5 S.
SCALE OF MILES
1 0 1 2 3


LAND USE — 1949
SCALE OF MILES
1 0 1 2 3
SAN MATEO BRIDGE
ALAMEDA COUNTY
SAN MATEO COUNTY
SAN FRANCISCO BAY
HAYWARD
UNION CITY
NEWARK
FREMONT
DUMBARTON BRIDGE
DUMBARTON PT.
MENLO PARK
PALO ALTO
MOUNTAIN VIEW
MOFFETT FIELD
ALVISO
MILPITAS
AGNEW
Coyote Creek
COYOTE HILLS
HETCH HETCHY AQUEDUCT
SAN MATEO CO.
SANTA CLARA CO.
ALAMEDA COUNTY
SANTA CLARA COUNTY
T.3 S.
T.4 S.
T.5 S.
T.6 S.
R.2 W.
LEGEND
BOUNDARY FREMONT STUDY AREA
URBAN LANDS
IRRIGATED AGRICULTURAL LANDS
SALT PONDS

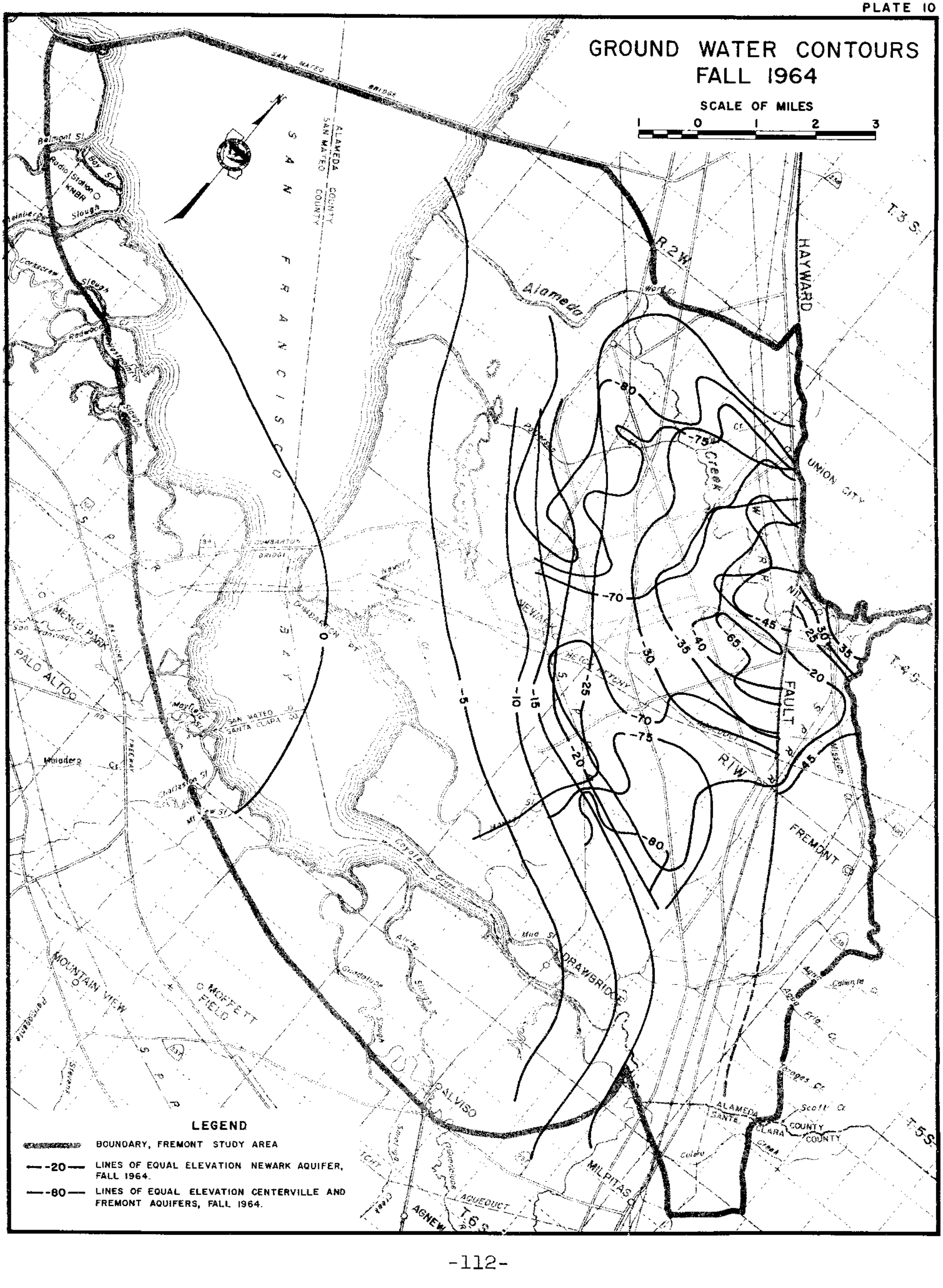

LAND USE — 1964
SCALE OF MILES
1 0 1 2 3
LEGEND
BOUNDARY FREMONT STUDY AREA
URBAN LANDS
IRRIGATED AGRICULTURAL LANDS
SALT PONDS
SAN MATEO BRIDGE
SAN FRANCISCO BAY
ALAMEDA COUNTY
SAN MATEO COUNTY
DUMBARTON BRIDGE
DUMBARTON PT.
SAN MATEO CO.
SANTA CLARA CO.
MENLO PARK
PALO ALTO
MOUNTAIN VIEW
MOFFETT FIELD
ALVISO
MILPITAS
AGNEW
HAYWARD
UNION CITY
ALAMEDA COUNTY
SANTA CLARA COUNTY
R.2W.
T.3.S.
T.4.S.
T.5.S.
T.6.S.
Belmont Sl.
Redwood Cr.
Alameda
Coyote Creek
COYOTE HILLS
HETCH HETCHY AQUEDUCT
Matadero Cr.
Charleston Sl.
San Francisquito Cr.
BAYSHORE FREEWAY
Mayfield
Ward Cr.
Agua Caliente Cr.
Agua Fria Cr.
Toroges Cr.
Scott Cr.
Guadalupe
Stevens

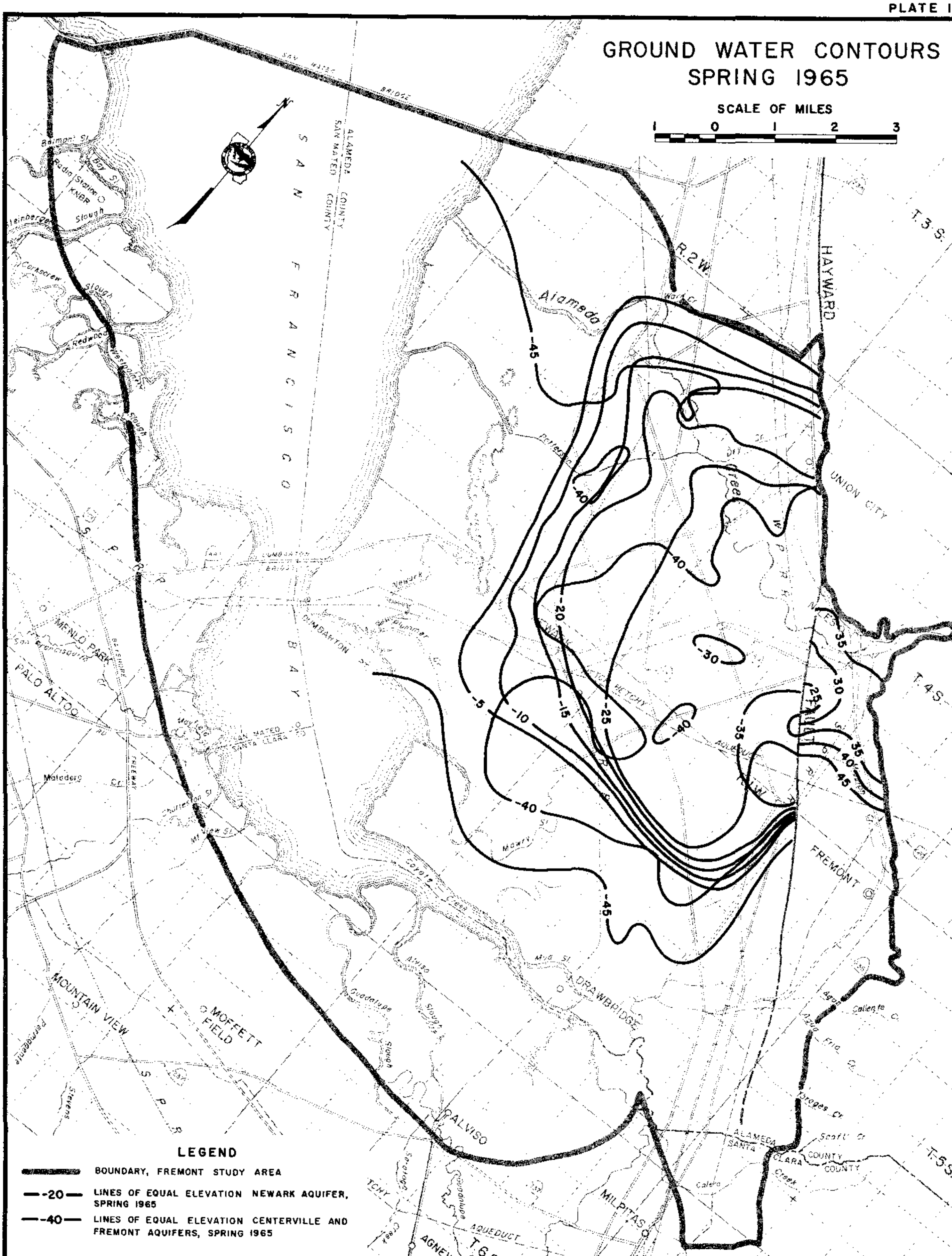

ISOHYETAL MAP
SCALE OF MILES
1 0 1 2 3
LEGEND
BOUNDARY FREMONT STUDY AREA
15 LINES OF EQUAL MEAN PRECIPITATION IN INCHES (Based on 50 year period 1897-98 to 1946-47)
PRECIPITATION STATION
STREAM GAGING STATION
Patterson Cr. at Union City
Alameda Cr. at Union City
Dry Creek at Union City
Alameda Cr. Near Decoto
Alameda Cr. Near Niles
Newark
Niles
SAN FRANCISCO BAY
SAN MATEO BRIDGE
DUMBARTON BRIDGE
ALAMEDA COUNTY
SAN MATEO COUNTY
MENLO PARK
PALO ALTO
MOUNTAIN VIEW
MOFFETT FIELD
ALVISO
MILPITAS
AGNEW
FREMONT
DRAWBRIDGE
HAYWARD FAULT
T.3 S.
T.4 S.
T.5 S.
T.6 S.
R.2 W.
R.1 W.
13
14
15
16
17
18
19
20
21

PIT	AREA IN ACRES
Bunting Pit	12.0
Gorman Pond	3.0
Grau Pit	8.0
Kaiser Pit (AHF)	22.0
Kaiser Pit (BHF)	1.5
Shinn Pit	22.0
Pit A	18.0
Pit B	6.0
Pit C	2.5
Pit G	28.5
Pit H	10.0
Pit J	8.0
Pit N	1.0
Pit O	28.0
Pit P	6.5
Pit Q	10.0
Pit R	20.0
Pit S	13.0
Pit T	30.0

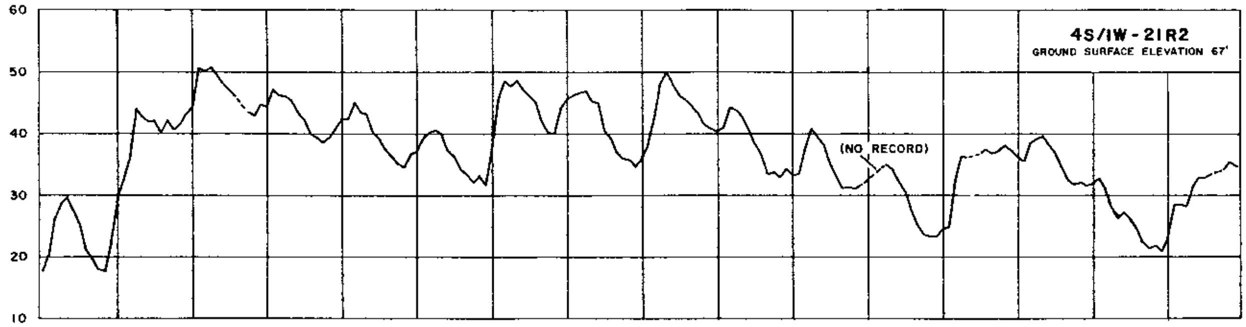


PERCOLATION FACILITIES OF ALAMEDA COUNTY WATER DISTRICT

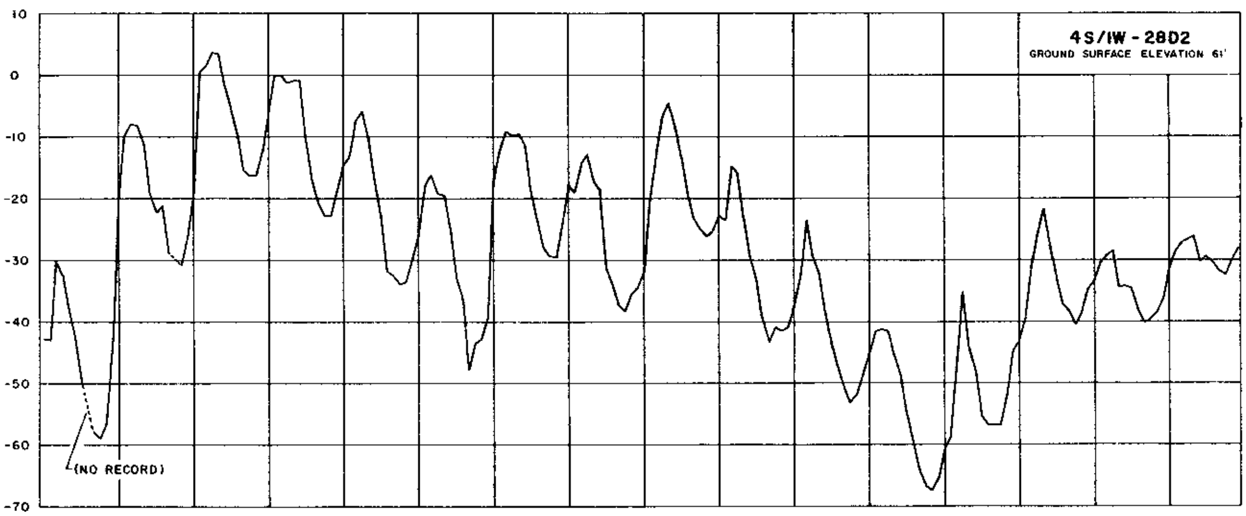

GROUND WATER CONTOURS
FALL 1964
SCALE OF MILES
1 0 1 2 3
SAN FRANCISCO BAY
ALAMEDA COUNTY
SAN MATEO COUNTY
SAN MATEO BRIDGE
HAYWARD
UNION CITY
FREMONT
NILES
FAULT
NEWARK
MENLO PARK
PALO ALTO
MOUNTAIN VIEW
MOFFETT FIELD
ALVISO
MILPITAS
AGNEW
DRAWBRIDGE
R.2W.
T.3S.
T.4S.
T.5S.
T.6S.
ALAMEDA COUNTY
SANTA CLARA COUNTY
Alameda Creek
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
-65
-70
-75
-80
20
25
30
35
45
LEGEND
BOUNDARY, FREMONT STUDY AREA
-20 LINES OF EQUAL ELEVATION NEWARK AQUIFER, FALL 1964.
-80 LINES OF EQUAL ELEVATION CENTERVILLE AND FREMONT AQUIFERS, FALL 1964.


GROUND WATER CONTOURS
SPRING 1965
SCALE OF MILES
1 0 1 2 3
LEGEND
BOUNDARY, FREMONT STUDY AREA
-20 LINES OF EQUAL ELEVATION NEWARK AQUIFER, SPRING 1965
-40 LINES OF EQUAL ELEVATION CENTERVILLE AND FREMONT AQUIFERS, SPRING 1965
SAN FRANCISCO BAY
HAYWARD
UNION CITY
FREMONT
MENLO PARK
PALO ALTO
MOUNTAIN VIEW
MOFFETT FIELD
ALVISO
MILPITAS
DRAWBRIDGE
NEWARK
DUMBARTON
ALAMEDA COUNTY
SAN MATEO COUNTY
SANTA CLARA COUNTY
T.3 S.
T.4 S.
T.5 S.
T.6 S.
R.2 W.
-45
-40
-30
-20
-25
-15
-10
-5
-35
35
30
25
40
45

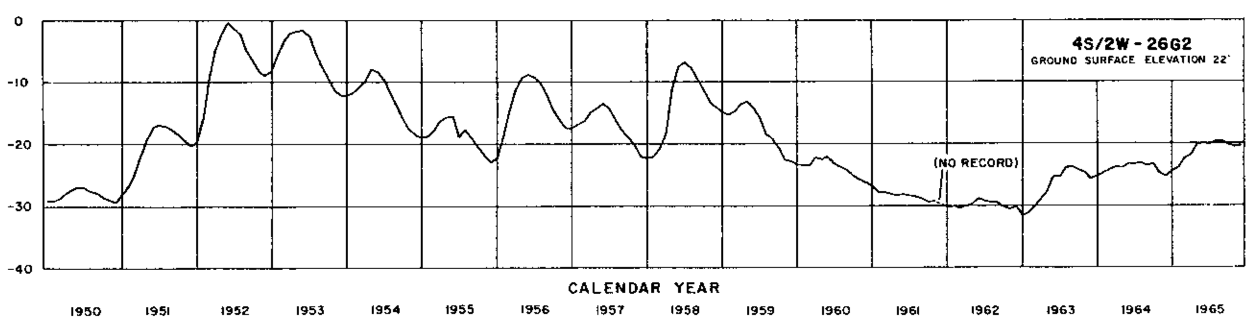
ELEVATION IN FEET — U.S.G.S. DATUM



FREE GROUND WATER EAST OF HAYWARD FAULT

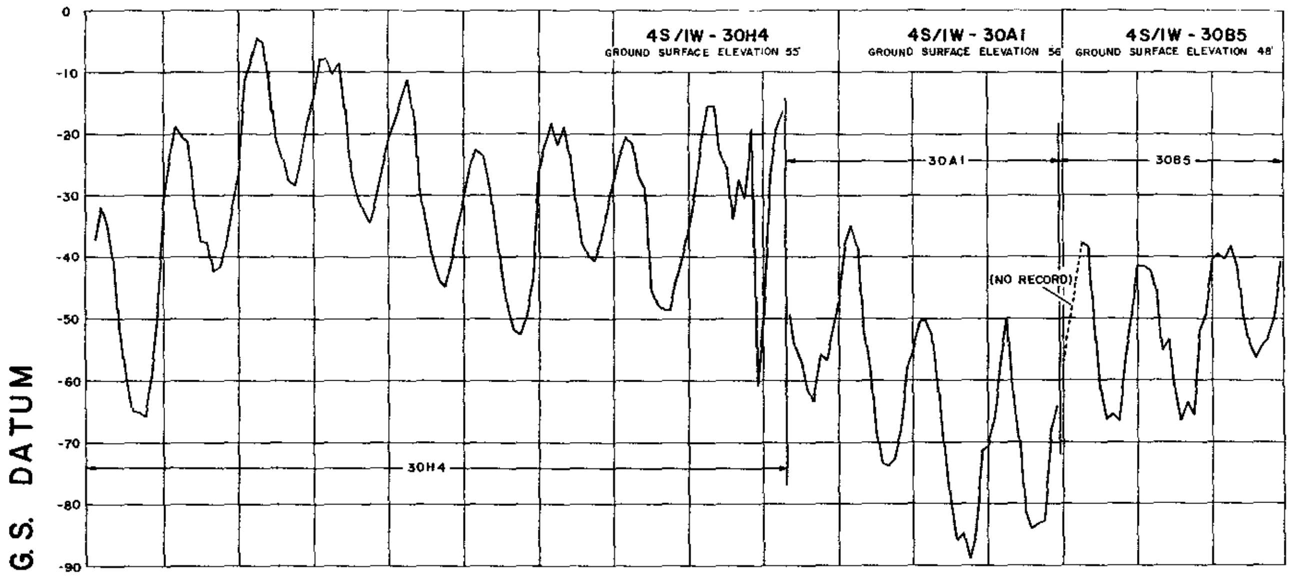


FREE GROUND WATER WEST OF HAYWARD FAULT - NEWARK AQUIFER

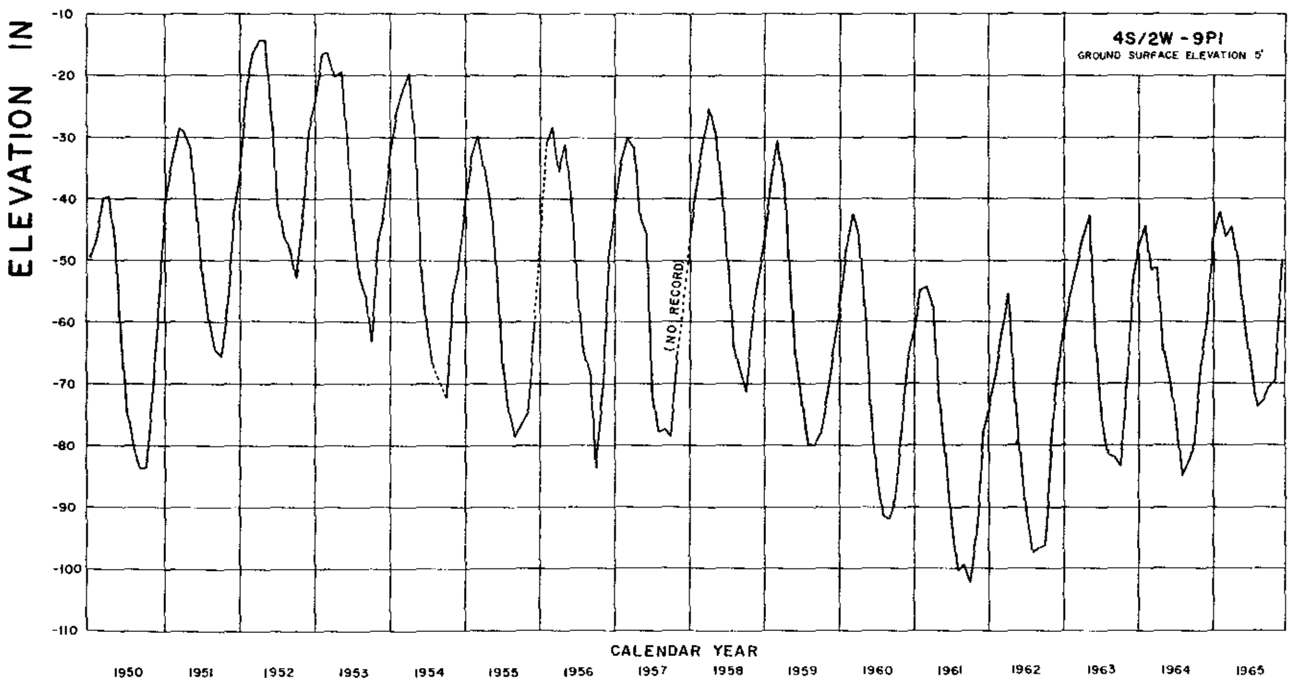


CONFINED GROUND WATER WEST OF HAYWARD FAULT - NEWARK AQUIFER

HYDROGRAPHS AT SELECTED WELLS



CONFINED GROUND WATER WEST OF HAYWARD FAULT - CENTERVILLE AQUIFER



CONFINED GROUND WATER WEST OF HAYWARD FAULT - LOWER AQUIFER

HYDROGRAPHS AT SELECTED WELLS