STATE OF CALIFORNIA

The Resources Agency

Department of Water Resources

BULLETIN No. 146

SAN JOAQUIN COUNTY GROUND WATER INVESTIGATION

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RONALD REAGAN
Governor
State of California

WILLIAM R. GIANELLI
Director
Department of Water Resources

FOREWORD

This bulletin is the result of a two and one-half year study of ground water occurrence, movement, and quality in San Joaquin County. The study is a culmination of requests from local county agencies and individuals, and activity of the Department of Water Resources over the last 15 years.

Past reports of the Department generally have dealt with parts of the County, or specific problems. This report discusses the relationship of ground water occurrence and movement to ground water quality in the entire County, with the exception of the Delta area which has not been studied in the same detail as the rest of the County.

Ground water has been almost the sole source of water for domestic, municipal and industrial water supply in the County, and is used extensively for agricultural supply. Knowing that ground water will continue to be vital to the economy of the County, and will play an important role in the ultimate county water supply, the Advisory Water Commission of San Joaquin County Flood Control and Water Conservation District, on October 31, 1962, requested that this Department study conditions affecting ground water quality in the County. A general authority for this type of project is given in Section 229 of the Water Code, which states the Department may "... investigate conditions of the quality of all waters within the State, and may recommend any steps which might be taken to improve or protect the quality of such waters ...".

A Department report entitled "Proposed Investigation" was presented to the Advisory Water Commission on August 1, 1963. The scope, objectives, work program, and costs of the proposed study included in that report were supported by the County and were authorized as part of the Department budget in 1964-65. The primary concept in this planning program was to look at the ground water problem from a countywide standpoint. This recognized that ground water deficiencies and quality problems were expanding across local water agency lines and the scattered local problems of ten years earlier were linking together into a common problem of water quality degradation.

County participation in this study was principally through a five-man advisory committee appointed by the Advisory Water Commission. The project staff and this committee held periodic meetings to coordinate and guide this study toward its objectives, which were (1) to evaluate ground water occurrence, movement, and quality; (2) define ground water problems; and (3) recommend remedial measures which could alleviate the ground water quality problems in the County.

In meeting these objectives, the study also provides the knowledge of ground water quality, occurrence, and movement necessary for planning to obtain maximum benefit through conjunctive use of ground and surface waters in the County.

William R. Gianelli

William R. Gianelli, Director
Department of Water Resources
The Resources Agency
State of California
June 30, 1967

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Many individuals and companies in San Joaquin County, as well as federal, state, and local agencies, contributed assistance and data for this ground water study. Their co-operation is gratefully acknowledged. The following are specially mentioned:

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The committee assigned by the Advisory Water Commission to assist and guide this study, consisting of Robert L. Clark, Chairman, Charles B. Wong, Herbert A. Paul, Grahame Ridley, and William R. Gianelli

The City of Stockton for providing office space

Data and information from the following have been helpful in completing this investigation:

California Water Service Company
California State Department of Conservation
- Division of Mines and Geology
- Division of Oil and Gas

Cities of Escalon, Lodi, Manteca, Tracy and Stockton
Communities of French Camp and Lathrop
Irrigation and Water Districts
- Stockton and East San Joaquin Water Conservation District
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- South San Joaquin Irrigation District

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Pacific Gas and Electric Company
Shell Oil Company
Texas Company, Incorporated
United States Government
- Bureau of Reclamation
- Corps of Engineers
- Geological Survey
- Sharpe Army Depot
- Weather Bureau

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SUMMARY

The vast ground water basin underlying the Great Central Valley has furnished a significant portion of San Joaquin County's water supply for many years. The more than 745,000 acre-feet of ground water pumped annually in San Joaquin County is almost the sole source of water for domestic and industrial use, and supplies an important part of the County's agricultural and rural water. The importance of ground water to crops, manufactured products, and other economic factors in the County make it imperative that the continuing use of ground water be protected.

During the past decade marked changes in ground water quality have been observed in certain areas and it was agreed by county and state officials that a ground water investigation should be undertaken to determine causes of degradation, and to evaluate the future utilization of ground water within the County.

To further define factors affecting ground water movement and quality, a rather extensive geologic study was included in this investigation. The nonwater-bearing formations in San Joaquin County include the east side basement complex, the west side Franciscan Group, the Undifferentiated Cretaceous Formation west of Tracy, the Eocene Undifferentiated Formation east of the County, the Undifferentiated Eocene in the southwest portion of the County, the Miocene east side Valley Springs Formation, and the west side San Pablo Group. The Valley Springs Formation is the only one of these formations exposed at the surface on the east side of the County.

The water-bearing formations include the Mehrten Formation, the Laguna Formation, the Tulare Formation, Flood Basin Deposits, the Victor Formation, alluvial fan deposits, and stream channel deposits. The Mehrten Formation appears to be somewhat confined, at least in the Stockton area. The Laguna Formation is an east side unit which outcrops in the rolling hills areas from Farmington northward.

The Tulare Formation acts as a major reservoir for pumping in the west side of the County. A clay layer, the Corcoran Clay, occurs at the top of the formation and confines underlying fresh water. The eastern limit of the Corcoran Clay is about at the San Joaquin River and confined water conditions attributable to the Corcoran Clay are not found east of the River. The Tulare Formation is moderately permeable and most of the larger irrigation, industrial, and municipal wells west of the River obtain water from below the Corcoran Clay.

Flood Basin Deposits occur in the Delta area of San Joaquin County and the trough portion of the basin. The Victor Formation occurs on the east side of the County, is about 15 miles wide and extends the length of the County.

In the alluvial fans of the Mokelumne and Stanislaus Rivers, the soil profiles are composed of sandy loam and silt loam and, because of their proximity to streams, and other characteristics, these areas were considered best for ground water recharge. None of the soils has a high infiltration rate. Some areas on the Calaveras River fan are also suitable for recharge. The best areas for recharge are generally the more easterly portions of the fans; however, due to the extremely slow movement of ground water, it takes many years for the effects of recharge to reach the Stockton area.

During this investigation no apparent geologic barriers to the normal lateral movement of ground water were found. The aquifers producing water supplies for the Stockton area are separated from the land surface by sediments that are low in permeability, which limit or minimize any local recharge from the land surface. Exposed faults, which may extend to great depths, exist on the west side of the County, and these faults could act as an avenue for poor quality waters (very high in boron) to rise from the underlying mineralized sources.

A previous Department of Water Resources study has discussed a "barrier concept" to control lateral ground water movement near Stockton. Additional data obtained in this study indicates that ground water is free to move at a rate dictated by geologic and hydraulic factors and that the "barrier concept" should be reconsidered.

To more fully evaluate causative factors for water quality problems in the County, a hydrologic balance was determined within the boundary areas defined in Chapter II. The hydrologic balance was calculated for a 14-year period, from 1950-51 to 1963-64. The study included the components of water supply which are precipitation, surface water inflow, fresh water import, subsurface inflow; and the components of water use and disposal which are consumptive use, surface outflow, waste water, and fresh water export. As a result of extensive study of all of these factors, it was determined that under 1964 cultural conditions the mean annual ground water overdraft was about 123,000 acre-feet. During the 14-year base period the water table dropped over 60 feet in the Collegeville area and about 40 feet in the Stockton and north Stockton areas. Only local areas of the County escaped a drop in the water table. The area where ground water levels are below sea level has expanded from approximately 44,000 acres, in 1950, to approximately 184,000 acres, in 1964.

The principal sources of good quality ground water in San Joaquin County are streams originating in the Sierras and rainfall on the eastern portion of the County. The entire east half of the County is supplied by these sources. In the southwestern portion of the County, near Tracy, there is a small but important area of good quality ground water. This water is generally below the Corcoran Clay and probably is recharged mainly from Sierra streams south of the county line. The City of Tracy, many industries, and the Tracy Defense Depot, rely on this deeper zone as their principal supply. Many localized areas or "islands" of poor quality water are found in this area and could be caused by gravel packed wells which penetrate the Corcoran Clay and are occasionally perforated in all producing zones from the surface down. These wells allow the poor quality waters overlying the Corcoran Clay to intermix through the gravel envelope and, during periods of nonpumping, descend into the deeper usable formations, resulting in quality degradation. Local small areas of good quality ground water are found adjacent to the San Joaquin River, with recharge probably occurring from that source. The remaining ground water areas within the County are generally of somewhat marginal quality.

During this investigation the base of fresh water was generally determined, and in some areas (such as beneath the City of Stockton) the fresh water sediments were found to be almost a thousand feet thick. North of the Calaveras River and south of Stockton, toward Lathrop, sediments are only about one-half that depth, and wells drilled below the base of fresh water generally have quality problems.

The Delta area within San Joaquin County generally contains unusable ground water; however, there are a few local exceptions where lenses of fresh water, probably supplied by channel seepage, are found.

In the Tracy area, the deeper zones (below the Corcoran Clay) generally produce good water. Extremely unpredictable quality may be found above the clay layer, and wells drilled in shallow depths may produce from poor quality "pockets".

In the past the Stockton area has had an abundant supply of good quality ground water; however, the continued use and increased draft have developed a ground water depression, resulting in an easterly migration of the poor quality ground waters of the Delta.

Analysis of data from many wells in this area indicates that the 300 ppm chloride line is moving easterly into the Stockton area at a rate of about 150 feet per year.

To investigate all possible sources of poor quality water in the Stockton area many records were obtained relating to gas wells and other deep wells. Although isolated quality problems could be associated with some of these deeper wells it is doubtful that a widespread quality problem could be attributable to this source.

The overdraft on the ground water basin has resulted in a subsidence problem. The greatest rate of subsidence (one-tenth of a foot per year) was found to occur in the Stockton and French Camp areas. Locations of the major areas of subsidence coincide with the greatest changes in ground water levels and it is believed that the primary cause of subsidence is the dropping ground water level.

Local and seemingly unrelated ground water quality problems were found in the Lathrop-French Camp area. Historic problems have been reported from west of Highway 50 and it appears that this poor quality water originates principally from the Delta and, again, is attributable to concentrated pumping in certain areas.

Localized conditions of high hardness were found in the Manteca area and it is believed that these sources exist only at shallow depths, perhaps in perched water tables. Such water is usually poor in quality, typically high in hardness, and has little protection from surface contamination due to the shallow depths.

During the 14-year hydrologic study period the Collegeville area, far removed from the Delta, experienced a 60-foot drop in ground water levels without any associated quality problems. The Stockton area, bordering the Delta, experienced quality deterioration following a drop of only 40 feet in the ground water levels. This confirms that the quality problem in the Stockton area is attributable to the easterly migration of poor quality ground waters underlying the Delta.

It appears desirable that a ground water basin management plan be prepared to alleviate the ground water quality problem developing in the Stockton area. Such a management plan could consider the different techniques already used in several coastline areas of California to correct sea water intrusion, and determine if any of these are appropriate for this area.

This report includes information and cost figures relating to artificial recharge projects in other areas. However, it is unlikely that the overdraft and quality problem along the west side of Stockton can be corrected by artificial recharge in, or near, the Stockton area since soils are fine grained and thick enough to preclude rapid infiltration, and land costs would be prohibitive.

It is almost certain that no improvement in ground water quality in the Stockton area can be realized until measures are undertaken to alleviate the overdraft or to replenish ground water supplies. The increased use of imported water is one alternative which is already under consideration by various agencies in the County. Use of imported water in the Stockton area could cause a reduction in the pumping draft which probably would be beneficial in controlling the intrusion of poor quality waters from the west.

CONCLUSIONS

It is concluded that:

1. Several areas within the County, particularly the Stockton area, an area east of Collegeville, an area between the San Joaquin River and Highway 50, and others, can no longer depend solely on ground water and existing surface importation to meet water demands. Negotiations have already been started to augment present water supplies.

2. As a result of declining ground water levels poor quality water is moving east along a 16-mile front on the east side of the Delta. The degradation in quality is particularly evident in the Stockton area where the saline front is moving eastward at a rate estimated at 140 to 150 feet per year. This rate may accelerate under increased pumping, and ground water monitoring should be continued.

3. In the areas of Lathrop and French Camp, ground water degradation has been observed in local "pockets"; however, the problem is not continuous along a front. This localized intrusion of saline waters is probably caused by concentrated pumping in certain areas where the depressed ground water table has apparently induced an easterly "fingering" of poor quality ground waters from the Delta.

4. In the Tracy area the upper formations generally produce poor quality water. The underlying better quality water is frequently degraded by wells perforated in all formations. Gravel packed wells in this area also allow the interchange of water from different aquifers and permit the possibility of degradation.

5. The Manteca area has many wells which pump water high in hardness. Although data is scant, the hardness probably originates from perched water tables at shallow depths.

6. A reduction of the pumping draft appears to be the only feasible way to correct the quality problem in the Stockton area. This would necessitate the importation of water to this area.

7. Recharge projects, or water spreading in the eastern agricultural areas, will benefit the falling ground water levels and alleviate overdraft conditions in the basin. However, the quality problems in the Stockton area and the areas to the north and south, cannot wait for the slow beneficial effects of rising ground water levels to arrive from the eastern recharge areas.

8. Artificial recharge projects in the Stockton area could not employ the basin method, due to the relative impermeability of the underlying soils. Replenishment of the producing formations underlying the Stockton area, by injection wells, may not be economically practical, mainly due to the high cost of constructing enough recharge wells to be effective, and the high degree of treatment required for the injection water.

RECOMMENDATIONS

1. In the Stockton area ground water pumping should be reduced to halt the easterly migration of poor quality waters from the Delta area. A reduction in the pumping draft would necessitate importation of additional waters and current negotiations should be expedited to accomplish this objective.

2. As an interim or temporary measure, rearrangement of the present pumping pattern in the Stockton area should be considered so that the major withdrawals are distributed over a broader area to the east.

3. The County should adopt and enforce well construction and abandonment standards to protect good quality aquifers from degradation by improperly constructed or abandoned wells.

4. A continuing ground water monitoring program should be established and maintained by local agencies to determine the rate of advance of the saline front, and to determine the effectiveness of future remedial actions.

5. To properly manage the surface and ground waters within San Joaquin County it appears desirable that a single local governmental agency be responsible for coordinating all studies and activities relating to water planning, development, and management.

STATE OF CALIFORNIA
The Resources Agency
DEPARTMENT OF WATER RESOURCES

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ABSTRACT

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Poor quality ground water was found to exist in many areas of San Joaquin County as a result of several factors. In the area in and around Tracy the upper aquifers are brackish and wells drilled into the deeper formations are frequently gravel packed and perforated in all producing zones. This results in poor quality water as the waters in all aquifers intermix through the gravel envelope. In the Lathrop and French Camp areas local pumping concentrations have caused poor quality ground water underlying the delta to "finger" into these localized zones resulting in "pockets" of poor quality ground water. In the Manteca area, local waters are frequently high in hardness. These waters are generally obtained from shallow zones of perched water which are more easily affected by surface sources of degradation. In the area around Stockton, over a 16-mile front along the periphery of the delta area, ground water has been degraded by salinity intrusion. Degradation (as indicated by a 300 ppm chloride line) is moving easterly at a rate of about 140 to 150 feet per year and wells behind this advancing front generally produce poor quality water and are soon abandoned. /RECOMMENDATIONS: Ground water pumping in the Stockton area should be reduced, which may necessitate importation of water to this area. Rearrangement of the pumping patterns should be considered to distribute withdrawals over a broader area. Well construction standards should be established in areas where gravel packed wells allow interchange of poor quality waters into usable formations. Ground water monitoring should be undertaken to determine movement of the saline front and to evaluate effectiveness of remedial measures. A single local agency should be responsible for the planning and coordination of all studies relating to water in San Joaquin County.

CHAPTER I

GEOLOGY

A knowledge of the three dimensional geologic framework of San Joaquin County is a necessary prelude to the application of hydrologic and engineering concepts to the solution of local water problems. Studies involving ground water particularly depend upon an evaluation of the geologic aspects of a ground water basin. Previous reports on the county have been selective or local in describing the geologic environment through which ground water moves.

This chapter defines, with written description and pictorial augmentation, the pertinent geologic parameters governing ground water in San Joaquin County. The text includes information on the composition, water properties, and areal extent of the aquifers, the geologic structure of the area, a description of the ground water basin, soils, and geologic history. Maps and cross sections were constructed to clarify and support the text.

In defining the subsurface geology of the county, some 650 water well logs and 275 gas well electric logs were studied. Field work with respect to geology, was limited to reconnaissance investigation of formations to obtain qualitative estimates of permeability to augment subsurface data. In addition, approximately 1800 water well performance tests conducted by the Pacific Gas and Electric Company were analyzed. Geology pertinent to the hydrologic investigation of the eastside of the county is developed in Chapter II. References cited in the text are keyed to the bibliography by a number in parentheses, such as (5).

General Geologic Framework

San Joaquin County lies within the Great Central Valley and Coast Ranges geomorphic provinces of California. The low position of this area, dictated by the structural adjustments between regional land masses, represents an isostatic compensation to the mountain building activities of the Sierra Nevada and Coast Ranges.

The isostatic compensation delineates the concurrent downwarping of the valley separating these two rising mountain masses. Sediments, eroded from the bordering highlands, are carried into the basin where they add their weight to the sequence already there. As a result, this mass sinks under the burden. To adjust, the mountains rise and are eroded further, thus contributing a virtually continuous supply of material to the basin until the chain of events is broken. Faulting and folding commonly occur during the sinking as a means of stress relief.

The final result is a concentration of a sedimentary sequence of gravels, sands, silts, and clays within the downwarped basin, along with associated folds and faults. These sediments contain voids which permit the passage of subsurface water. They are thus an important source of water supply, storage, and distribution.

Regional Stratigraphic Setting

The Quaternary and late Tertiary deposits of San Joaquin County are of considerable economic importance since they contain within their boundaries one of the county's most important assets -- a large quantity of good quality ground water. These deposits are grouped into formations which are described in a subsequent part of this chapter (See Plates 2A and 2B). As a rule, the younger sediments are of continental origin and are discontinuous in their depositional pattern, with the exception of the Corcoran Clay of the Tulare formation. These sediments consist of a heterogeneous sequence of gravel, sand, silt, and clay.

Beneath the sediments containing good quality water, and in the San Joaquin Delta adjacent to them, are a sequence of sediments containing brackish to saline waters. The formations into which these sediments, consisting of gravel, sand, silt, and clay, are grouped, will be described briefly later. The bulk of the sedimentary sequence in the county is of marine origin. It is of economic importance because the natural gas fields in the study area have their sources in these marine sediments. A marine sequence can be detrimental to fresh water in acting as an extensive source of supply of poor quality water which enters the fresh water system under the proper hydraulic conditions. Though not usable now, there may be future economic worth in these poor quality waters for cooling, saline conversion to fresh water, or for disposal of wastes within the sediments.

Regional Structural Setting

San Joaquin County lies near the axis of a regional geosyncline, with a gently dipping east flank and a fairly steeply-dipping west flank. In the deeper marine measures, lesser synclines and anticlines of small areal extent are superimposed on this major structure, particularly in the Delta portion of the county.

Many faults disrupt the continuity of the older sediments. However, the tectonic forces which caused the configurations and strong anomalies in the older marine sediments were quiescent or much less effective after the deposition of the fresh water-bearing sediments. These forces are evidenced only by homoclinal uplift along the flanks of the basin and restricted faulting along the west border.

There is no discernible evidence of faulting or structural irregularities in the fresh water sediments on the eastside, other than the homoclinal gently dips (Plates 3, 4, and 5). The steeper dips of the westside and some faulting are indications of the greater structural activity of the Coast Ranges (Plate 5).

None of these, however, appear to have an undesirable effect upon ground water storage or movement. Man-made disruptions of historical normal water flow paths overshadow any possible effects due to faulting or folding.

Physiography and Geologic History

In this section, the inferred historical and present land forms of San Joaquin County, their areal distribution, and their effect on direction of movement, origin, and quality changes of water are discussed. The salient features of geologic history are also developed.

San Joaquin County is included in parts of two geomorphic provinces, the Great Central Valley and the Coast Ranges. In addition, it is adjacent to and affected by a third, the Sierra Nevada. Within the county, major land forms are present, including foothills, terraces, alluvial plains, basins, flood plains, and the river forms which traverse and drain the county. Land shapes are mostly the products of erosion, but forms due to sedimentation and earth movements are also included in the definition of the term.

Past Land Forms

Configurations of past land forms are inferred chiefly from a study of rock distributions through interpretation of drillers' logs and from the projection of phenomena associated with current land forms into the past.

Using a combination of the present arrangement of land forms, geologic sections, and subsurface lithologic descriptions, isopach maps (Plates 6A, 6B, 7A, 7B) were constructed. These maps suggest that ancient feeder streams fluctuated across the predecessor to what is now the Victor flood plain, with main paths of flow which possibly extended into the Delta beyond where the present sloughs (such as Disappointment, Sycamore, and Hog) are located. This is assumed on the valid premise that high sand and gravel concentrations will occur in the vicinity of a stream while finer material such as clay and silt are more typical of areas distant from the stream proper.

Based on this, the isopach maps from 0 to 50 feet depth (Plates 6A, 6B) and 50 to 100 feet depth (Plates 7A, 7B) show the same general southwest-northeast sediment trend that the streams tend to show today. Isopach thicks (where contouring shows the most sand to be present) can be roughly connected to show this lineation. The maps indicate that stream positions are not static through time, but sweep back and forth in response to conditions present at any given moment. Although similar maps were not made of depth intervals greater than 100 feet, the continental environmental relationships among all the formations suggest that a similar situation should exist at depth.

The implication of this is that there is a decided northeast-southwest directional trend to the sediments of San Joaquin County, excluding possibly the Delta area where data is not extensive enough to support any conclusion. These maps show that recharge is most easily accomplished within the areas of the Mokelumne and Stanislaus Rivers since broad patterns of sand are developed there. The maps also suggest that waters of poor quality would most easily move in these northeast-southwest directions under proper hydraulic gradients.

The isopach maps (Plates 6A, 6B, 7A, 7B) indicate the same general conditions in the southwest portion of the county (Tracy area) with preferential depositional direction toward the northeast. Detailed data is not available for the Delta but, based on analogy with other areas, sediment configuration can be inferred. The chief influence on older land forms in the Delta would be Pleistocene glaciation.

Prior to the last (Wisconsin) glacial stage, some 15,000 to 60,000 years ago, an interval of warmer climate existed. The glaciers were much smaller than they now are, and sea level was about 100 feet above its present position. Much of the topographically lower part of the county was covered by layers of fine grained flood basin deposits. The lateral extent of these deposits is unknown, but they undoubtedly formed re-entrants up the major stream valleys which drained the

Sierras and Coast Ranges.

During the Wisconsin glacial stage, sea level fell some 300 feet. As a result of this, stream gradients and erosive power were increased, and large portions of the flood plain deposits were removed. Following the Wisconsin stage (during the last 15,000 to 18,000 years) the glaciers retreated, and the level of the sea rose to its present position. As sea level rose, stream gradients were lowered and gravels and sands were deposited along their courses. During the last 5,000 to 7,000 years, sea level has remained fairly static, grade has been established, and the main rivers have developed meander patterns. As a result, natural levees and flood plains of fine material which slope away from the rivers have been created.

Present Land Forms

The present land forms of San Joaquin County can be described in detail and with greater accuracy than can the past land forms which largely have to be inferred.

The eastern portion of the county consists of dissected alluvial uplands corresponding generally with exposures of the Laguna and Mehrten formations and overlain and buttressed by a topographically lower alluvial plain which coincides roughly with the Victor and younger alluvium formation (see Plates 2A, 2B, 3, 4, 5). The higher alluvial uplands slope basinward about 15-25 feet per mile and represent, at their higher levels, the development of the Laguna and Arroyo Seco surfaces and at their lower levels the oscillations of the Mokelumne and Stanislaus Rivers.

Dissection of the alluvial upland surface from what was probably originally a piedmont or flat plain, has resulted in a system of gently rolling hills and valleys. The effect of this system upon water has been twofold: older soils have been thoroughly developed, decreasing the ability of water to infiltrate due to hardpan development, and steeper slopes have increased runoff gradient, thus lowering the time that rainfall remains on and penetrates the surface.

Following the formation of the Laguna surface, a period of downcutting across the two main streams, the Mokelumne and Stanislaus (and to a lesser extent, the Calaveras), and channeling occurred with deposition on the relatively flat, undissected plain on which the Victor and alluvium formation is now lying.

The early portions of this surface were formed by fans which coalesced and spread out from their apexes at the entrances to the valley. The present eastern boundary of this unit is at about 90 feet elevation. These fans have a relatively shallow dip toward the basin of about 10 feet per mile. At present they are slightly dissected by such lesser streams (usually intermittent) as Bear and Littlejohns, pointing to the fact that they are currently under mild degradation. The effect of this land form on surface water is to decrease the rapidity of runoff and offer a better surface for the infiltration of rainfall and stream water.

Superimposed on both of the above land forms are the stream channels, entrenched into both the Laguna and Victor surfaces and acting as recharge avenues to these lower formations. These channels vary in width from about 1/10 of a mile to almost two miles. Their effect on water is to channel it into restricted avenues on its passage across the basin. This channel form usually has relatively coarse rock types which offer easy percolation and infiltration of waters to underlying formations.

Within the central portion of the basin is the delta land form. This has been an almost perennially saturated environment into which excess runoff has flowed. As a result, it is commonly flat-lying with virtually no topographic expression. Sediments carried into this portion of the basin are generally fine grained, due to the weak carrying capacity of the traversing waters. However, during high velocity flow periods considerable amounts of sand, and occasionally gravel, have been carried along streams into the delta to form avenues for the migration or movement of enclosed waters (see Plates 3, 4, 5).

In the Tracy area, land forms are similar to those on the east side and resulting relationships are as described for the east side units. Preferential northeasterly sediment directions are present (Plates 6B and 7B).

Geologic History

The geologic formations of San Joaquin County range over a wide spectrum of geologic time (Table 1) extending from Recent to Pre-Cretaceous. During this time a sequence of continental and marine gravels, sands, silts, and clays were laid down upon metamorphosed sediments and volcanics and upon granitic rocks. Interruptions in the sedimentary depositional cycle occurred several times as volcanic activity, uplift, faulting and/or folding, and glaciation altered the physical environment and relationships of the sediments.

The Central Valley has been a sedimentary trough since Pre-Cretaceous times, bordered by highlands similar to those which lie adjacent to it on the east and west today. During much of its early life, however, this trough was open to the sea and the sediments carried into it from the antecedent Sierras and island or peninsular-like Coast Ranges sources, were deposited under marine conditions (see Table 1 for a tabular synopsis of marine and non-marine formations). These marine conditions persisted into middle Tertiary times. The bulk of the sedimentary sequence in the County is of this marine origin.

In late Tertiary times, the sedimentation changed from marine to continental, due to the retreat of the sea before a regionally rising land mass. Intermittent vulcanism deposited first rhyolitic, then andesitic lavas and agglomerates across the highlands in the Sierras and these became the source materials for sedimentary formations such as the Valley Springs and Mehrten. Along the west side sedimentation originated from the Coast Ranges. During latest Tertiary time, over valley portions of the County, fresh and brackish-water lakes were formed within which extensive, uniform clay intervals were deposited. These clay deposits have been termed the Corcoran Clay. In addition, adjustments of mountain masses and the valley floor accelerated erosion, and continental sediments formed deltas and fans at the apex of river valleys. Glaciation in Pleistocene time resulted in steepening of stream gradients with resulting erosion of valley sediments along these stream valleys. When the glaciers retreated their melted waters caused a rise in sea level and resulted in backfilling of the eroded stream valleys to about present levels. Processes of erosion and deposition are still in effect today.

Stratigraphy and Water-Bearing Characteristics

This section describes in detail the sediments of San Joaquin County, their surface and subsurface distribution, composition, age, relationships to one

TABLE I

GENERALIZED STRATIGRAPHIC COLUMN of SAN JOAQUIN COUNTY WITH WATER BEARING CHARACTERISTICS

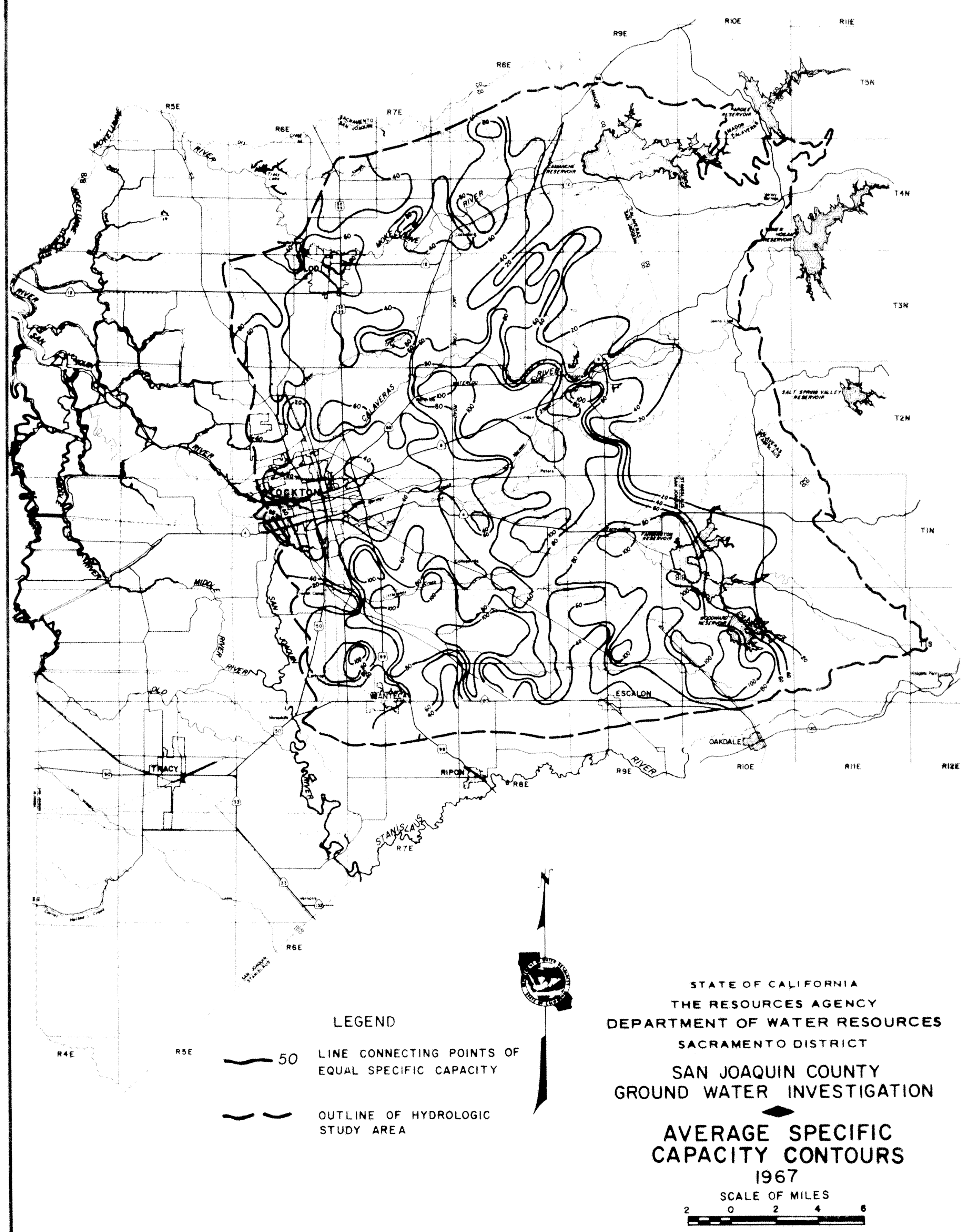
System	Series	Formation & Map Symbol	Location Thickness Maximum (ft)	Rock Characteristics and Environment	Water-Bearing Properties
Quaternary	Recent	Stream Channel Deposits (Qsc)	Westside Eastside	Continental unconsolidated gravel, and coarse to medium sand deposited along present stream channels.	High permeability, Unimportant to ground water except as avenue for percolation to underlying fms.
	Recent to Late Pleistocene	Alluvial Fan Deposits (Qal)	Westside (0-150±)	Continental fan deposits-heterogeneous, discontinuous mixtures of gravel, sand, silt, clay.	Moderate to locally high permeabilities. Unconfined aquifers.
		Recent Alluvium and Victor (Qalv)	Eastside (0-150±)	Continental fan and interfan material, locally some basin types. Lenticular gravel, sand, silt, clay.	Moderate permeabilities. Unconfined aquifers.
	Recent to Pliocene	Flood Basin Deposits (Qb)	Westside Eastside)-1400±	Continental basinal equivalent of Laguna, Tulare & younger fms. Clay, silt & sand, organic in part.	Generally low permeabilities, saturated environment, unconfined to confined.
	Plio-Pleistocene	Tulare (QT_t)	Westside 0-1400±	Continental semiconsolidated clay, sand, gravel. Contains Corcoran Clay Member.	Moderate permeability, generally unconfined above Corcoran Clay confined below Corcoran Clay.
Tertiary	Plio-Pleistocene	Laguna (QTl)	Eastside 0-1000±	Continental, semi-to unconsolidated silt, sand & gravel, poorly sorted, includes Arroyo Seco Gravel pediment of Mokelumn R. area.	Moderate permeability. Unconfined to locally semi-confined. Restricted perched bodies in some areas
	Mio-Pliocene	Mehrten (Tm)	Eastside 0-600±	Continental andesitic derivatives of silt, sand and gravel & their indurated equivalents; tuff; Breccia; agglomerate.	Moderate permeability to high where "Black Sands" occur. Confined to unconfined. Saline west of Stockton.
	Upper Miocene	San Pablo Group (Tsp)	Westside 0-1000±	Continental to marine massive sandstone and shale. Westside equivalent of Mehrten and Valley Springs fms, in part.	Low permiability. Saline in part. Essentially nonwater bearing except along fractures and joints.
	Miocene	Valley Springs (Tvs)	Eastside 0-500±	Continental to marine (?) rhyolitic ash, clay, sand & gravel and their indurated equivalents.	Low permeability. Saline in Stockton area. Not considered as significant in ground water studies.
	Eocene	Eocene Undifferentiated (Te)	Westside ?	Marine shale, siltstone and sandstone.	Contains saline waters except where flushed in outcrop areas. Unimportant to fresh water basin except as possible contaminant source.
Cretaceous	Cretaceous	Cretaceous Undifferentiated (K)	Westside ?	Marine shale, siltstone and sandstone.	Contains saline waters, Unimportant to fresh water basin except as possible contaminant source.
Pre-cretaceous	Jurassic	Franciscan Group, Undifferentiated	Westside ?	Marine shale, sandstone, chert metamorphics, serpentine.	Unimportant to fresh water basin except as possible contaminant source.

NOTE: Areal distribution and configuration of these formations are shown on Plates 2A, 2B

? Indeterminate in Outcrop

another, and their water-bearing properties. The description of these rocks is based on their nature in the outcrop as determined from published literature and reconnaissance field work, and in the subsurface as indicated by water well drillers' logs and gas well electric logs. Summary information on each of the outcropping formations is obtainable from Table 1. Plates 2A and 2B indicate the areal geology of San Joaquin County. Three geologic sections (Plates 3, 4, and 5) give a visual indication of subsurface sand and gravel distribution in the younger formations as well as structural information, while the isopach maps (Plates 6A, 6B, 7A, and 7B) detail the areal distribution of sands and gravels from surface down to 100-foot depth of the area of investigation. For ease in cataloging and describing the formations, they have been grouped into nonwater-bearing and water-bearing units. Particular problem areas associated with these sediments are described in Chapter IV.

Figure 1 shows the average specific capacity of wells of the hydrologic study area. This map was developed by averaging, for alternate sections of land, the specific capacities obtained from 1800 Pacific Gas and Electric Company tests, and contouring the results. The map is meant to indicate only average specific capacities in the area since wells of various depth were included in the averaging.



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SAN JOAQUIN COUNTY
GROUND WATER INVESTIGATION

AVERAGE SPECIFIC CAPACITY CONTOURS
1967

It may be noted that some of the lowest specific capacities are in the Stockton area. These are in part due to selective perforating of wells to avoid poor water quality intervals. Specific yields and sand percentages in this area are approximately the same as in adjacent higher specific capacity areas (Appendix 3 and Plate 4). The east-west trend of the contouring in the Stockton area, and its configuration, suggest it is independent of any "barrier".

Nonwater-bearing Formations

Formations grouped here include the east side basement complex, the west side Franciscan group, the undifferentiated Cretaceous formations west of Tracy, the Eocene Ione formation east of the County, the undifferentiated Eocene in the southwest portion of the County, and the Miocene east side Valley Springs formation and west side San Pablo group. With the exception of the Valley Springs formation, the above-named east side units are not exposed at the surface in San Joaquin County. The west side formations are all exposed in outcrop west of Tracy.

The term "nonwater-bearing" is meant to indicate only that these formations have limited water producing capabilities as compared to the usual agricultural or domestic well drilled into the fresh water-bearing series. Additionally, formations containing waters of marine origin are included in this category.

Basement Complex. The basement complex, commonly called the bedrock series, outcrops from 5 to 10 miles east of the County, dipping beneath the sediments in the County at about 4 degrees (350+ feet per mile). The rocks grouped in this unit include resistant, fractured, microstructured and metamorphosed sedimentary rocks, metamorphosed volcanic rocks, ultrabasic igneous rocks, and granitic igneous rocks.

The basement complex contains many small scale faults and fractures which offer passage to water, but the amount transmitted is considered negligible. The chief influence of these rocks on San Joaquin County is in offering limited interception of water during its traverse down the streams to the sedimentary sequence, and in contributing to the dissolved solids of the waters. It is assumed that subsurface flow across the contact between the basement complex and the sedimentary rocks is negligible and can be considered as zero for determining subsurface inflow into the ground water area. The control exercised by the basement complex on the hydrologic study boundary is discussed in Chapter II.

Franciscan Group, Undifferentiated. This sequence of rocks outcrops in the southwestern part of the County (Plate 2B). It consists of metamorphosed sediments, serpentine, and bedded marine sandstones and shale which locally plunge nearly vertically into the sedimentary trough of the valley. The Franciscan group is in fault contact with the adjacent sedimentary sequence and apparently was brought up from considerable depth along the fault. This unit is relatively unimportant to the ground water basin except for its minimal holding capacity and as a possible adverse quality source. Boron, associated with the Franciscan formation, may rise along faults and migrate into the trough areas of the ground water basin.

Cretaceous, Undifferentiated. The Cretaceous formations occur in the subsurface across virtually the entire basin, although they are exposed in outcrop only in the southwest corner of the County. Rocks of this age produce much of the gas in southern San Joaquin County (fields producing from Cretaceous formations include Lathrop, Southwest Vernalis, Vernalis, McMullin Ranch, and Tracy).

The unit consists of sandstone, siltstone and shale of marine origin. It is generally unimportant to the fresh ground water basin except as a potential source of quality degradation by saline waters.

Eocene, Undifferentiated. Eocene marine sediments underlie virtually all of San Joaquin County north of the Stockton fault, an extensive deep subsurface structural feature (Plates 2A and 2B). They are not exposed in the outcrop to the east of the County, feathering out in the subsurface beneath the foothills area. On the west side they outcrop in a small area about 10 miles south of Tracy. Sediments of this formation are prolific gas producers in central and northern San Joaquin County (from such fields as Roberts Island, McDonald Island and Lodi).

The unit consists of sandstone, siltstone and shale of marine origin. In some limited areas on the perimeter of the basin, fresh waters have flushed out the saline waters. The effect of the Eocene sediments on the fresh ground water basin may be as a source of pollution through improperly constructed wells, movement along faults, or by migration because of hydrostatic or lithostatic pressures.

Valley Springs Formation. The Valley Springs formation is exposed in outcrop in the easternmost portion of the County and extends into the subsurface in the Delta area. It is equivalent in part to the west side San Pablo group. The formation dips into the valley on the order of two degrees (180 feet per mile) and is generally too deep for economic productivity by water wells in the main agricultural and urban areas of the basin.

The Valley Springs formation consists of deposits of possibly marine to continental origin and comprising rhyolitic ash, clay, sand, and gravel as well as their indurated equivalents. The marine phases of the formation are confined to the deeper areas in and adjacent to the Delta. The fresh water phases are limited to the eastern part of the County where the formation rises above the base of fresh water. Limited study of the unit suggests that sand and clay layers within it are more continuous than are the similar types in the overlying fresh water-bearing formations. Waters within this unit are confined and show piezometric characteristics. A reconnaissance of the outcropping formation suggests that it, in general, has low permeability, although it produces limited quantities of water in some of the near-surface areas of the east side (Plates 3 and 4). In the Stockton area, the formation underlies sediments containing poor quality water which is saline in nature.

San Pablo Group. The San Pablo group is an outcropping west side Miocene formation which plunges steeply into the trough of the valley (Plate 5). It extends in outcrop as a wide band of rock in a northwest-southeast pattern (Plate 2B) and is, at least in part, the west side equivalent of the east side Mehrten and Valley Springs formations. The unit consists of continental to marine massive sandstone and shale which, based on reconnaissance investigation of the outcrop, has estimated generally low permeability. The San Pablo group is essentially nonwater-bearing except along fractures and joints. It is considered relatively unimportant as a source of water supply.

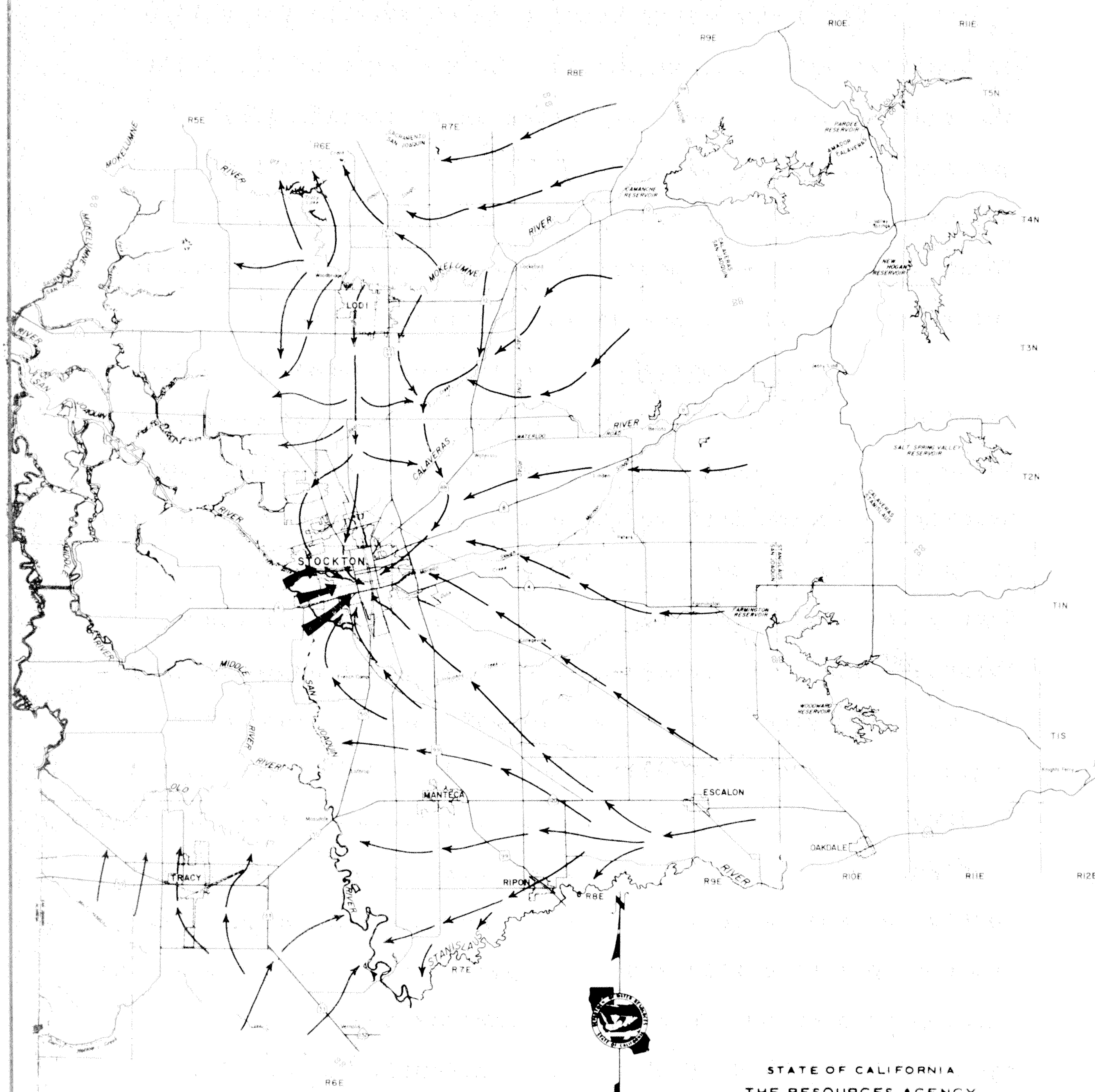
Water-bearing Formations

Within this grouping are placed all the fresh water-bearing units of San Joaquin County. They include the Mehrten formation, the Laguna formation, the Tulare formation, flood basin deposits, the Victor formation, alluvial fan deposits, and stream channel deposits.

The fresh water-bearing units overlie the saline or brackish water-bearing units. In the area of the Delta the equivalents of the fresh water units contain poor quality waters (Plates 3, 4, and 5). The direction of movement of these waters is shown on Figures 2 and 3. These maps were constructed by drawing flow lines normal to the water elevation lines shown on Figures 4 and 5.

Mehrten Formation. The Mehrten formation is here considered to be the oldest significant fresh water-bearing formation on the east side of the County, even though the underlying Valley Springs formation produces minor quantities. It is exposed at the surface in the easternmost part of the County where it forms readily identifiable, nearly flat-topped, hills. It plunges into the valley at approximately one to two degrees (90 to 180 feet per mile), reaching a depth at its upper surface of about 800 to 1000 feet in the Stockton area (Figure 6). West of the Stockton area it gradually flattens in dip until it is nearly flat-lying in the axial portion of the valley. In its plunge into the valley, the Mehrten formation thickens from approximately 400 feet in the outcrop to over 600 feet in the Stockton area. It is reported to be 1300± feet thick at McDonald Island (7).

The formation is composed of moderately to well indurated andesitic sand to sandstone, derived from Sierran andesitic flows and agglomerates and interbedded in discontinuous, irregular fashion, with conglomerate and



LEGEND

→ WATERS OF SIERRAN OR COAST RANGE ORIGIN

➡ WATERS SUBJECT TO DELTA INFLUENCE

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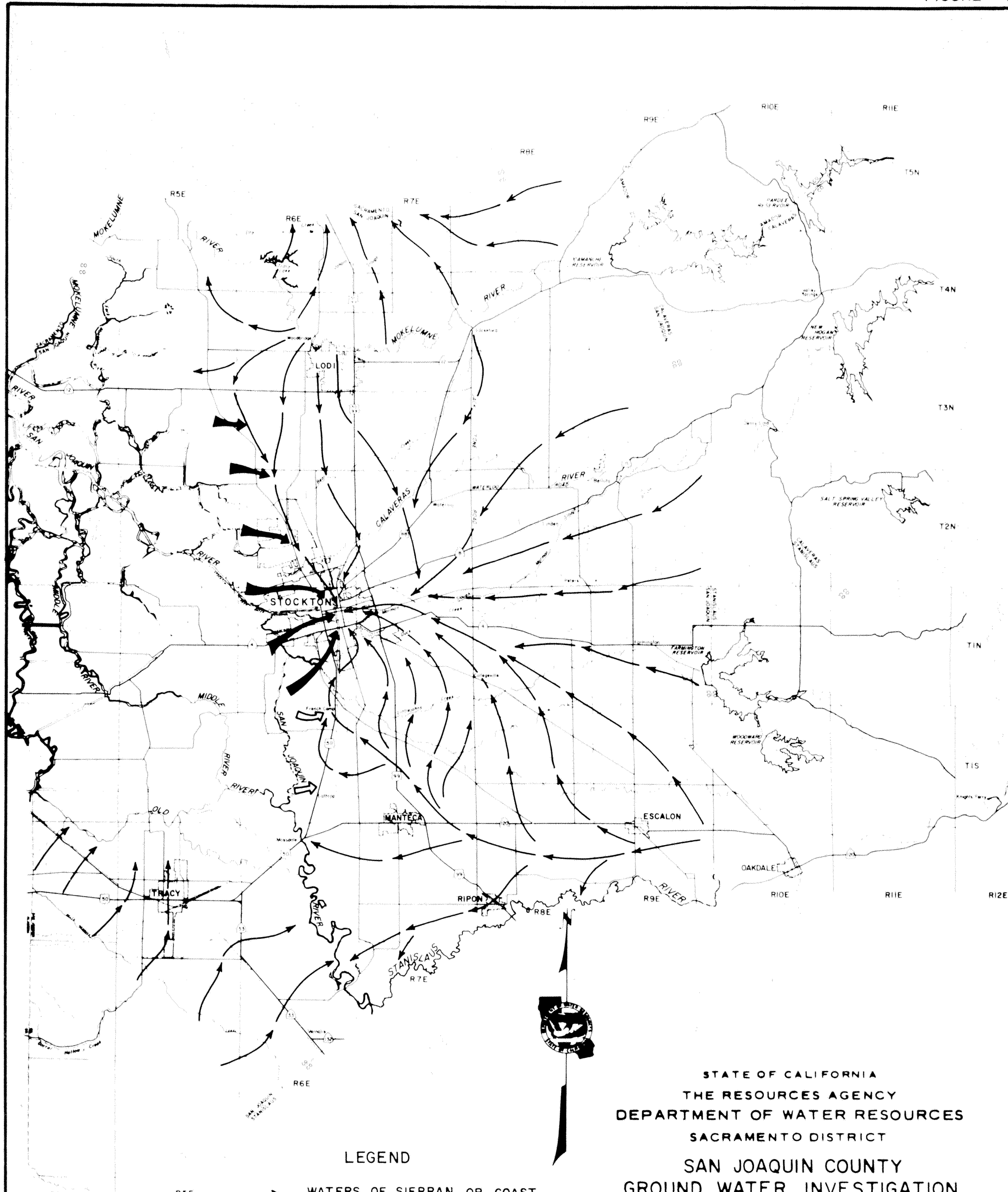
SAN JOAQUIN COUNTY
GROUND WATER INVESTIGATION

DIRECTION OF FREE GROUND WATER MOVEMENT ALONG ARBITRARILY SELECTED LINES FALL 1950

1967

SCALE OF MILES
2 0 2 4 6



LEGEND

- WATERS OF SIERRAN OR COAST RANGE ORIGIN
- WATERS SUBJECT TO DELTA INFLUENCE
- WATERS APPARENTLY SUBJECT TO DELTA INFLUENCE ON A LOCAL BASIS

STATE OF CALIFORNIA
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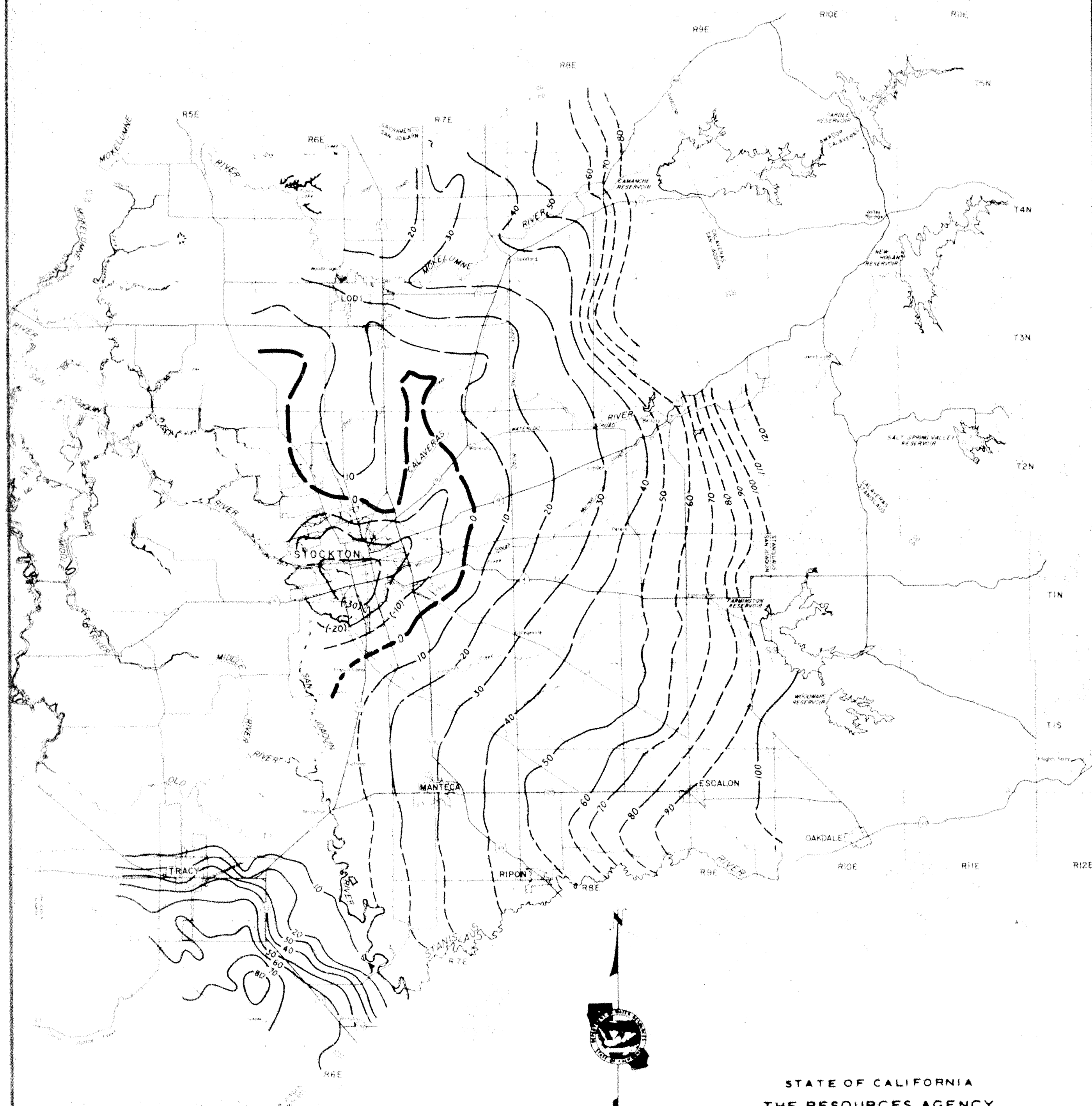
SACRAMENTO DISTRICT

SAN JOAQUIN COUNTY
GROUND WATER INVESTIGATION

DIRECTION OF FREE GROUND WATER MOVEMENT ALONG ARBITRARILY SELECTED LINES FALL 1964

1967

SCALE OF MILES
2 0 2 4 6



LEGEND

—10 ELEVATION OF WATER IN WELLS (SEA LEVEL DATUM)

– – 50 APPROXIMATE ELEVATION OF WATER IN WELLS (SEA LEVEL DATUM)

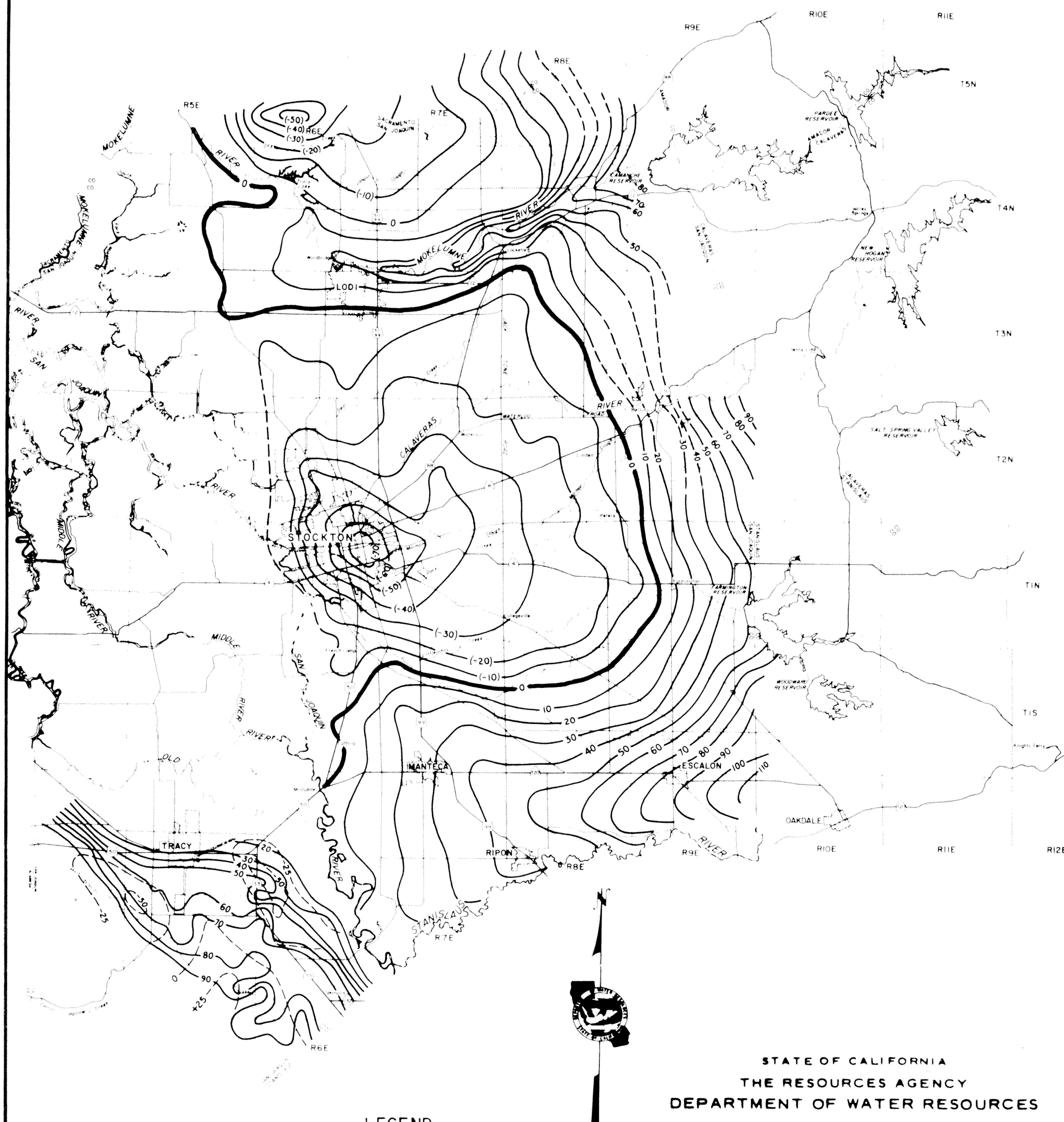
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SACRAMENTO DISTRICT

SAN JOAQUIN COUNTY
GROUND WATER INVESTIGATION

LINES OF EQUAL ELEVATION OF WATER IN WELLS FALL 1950

1967

SCALE OF MILES
2 0 2 4 6



LEGEND

—10 ELEVATION OF WATER IN WELLS (SEA LEVEL DATUM)

– – 50 APPROXIMATE ELEVATION OF WATER IN WELLS (SEA LEVEL DATUM)

~–25 ELEVATION OF PIEZOMETRIC WATER LEVEL IN WELLS-TRACY AREA (SEA LEVEL DATUM)

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SACRAMENTO DISTRICT

SAN JOAQUIN COUNTY
GROUND WATER INVESTIGATION

LINES OF EQUAL ELEVATION OF WATER IN WELLS FALL 1964

1967

SCALE OF MILES
2 0 2 4 6

tuffaceous siltstone and claystone beds (Plates 3, 4, and 5). Agglomerate and brecciated andesitic mudflows cap some of the more resistant hills and are occasionally discernible in subsurface cuttings. In the eastern portion of the County, wells penetrating the Mehrten apparently contain considerable sand and gravel or their indurated equivalents. Deep wells in the Stockton area indicate the upper portion of the Mehrten formation contains a high percentage of clay. This suggests that the upper portion of the unit may be finer grained than the middle or lower portion, with resulting pressure conditions. East of Jack Tone Road, a large number of wells produce from what are termed "black sands" by the well drillers. These members, although commonly described as hard, or as sandstones, by the drillers, are relatively permeable and commonly yield on the order of 1000 gallons per minute from wells.

The Mehrten formation appears to be semi-confined, at least locally in the Stockton area, due to the inferred extensive fine grained beds in its upper part. Wells producing from these sediments sometimes show irregular levels in head when compared to adjacent Laguna formation or Victor formation wells. These irregularities usually are not easily discernible in the spring when recovery has occurred, suggesting some degree of hydraulic continuity with overlying free water table sediments.

The permeability of the Mehrten formation is as varied as its lithology, ranging from high to low. Department of Water Resources analyses of a Mehrten sand taken from a well one mile downstream from Nimbus Dam on the American River, Sacramento County (Well 9N-7E-17NI) showed laboratory permeabilities of 501 and 438 gallons per day per square foot under constanthead test conditions. Field permeability tests of the right and left abutments of Camanche dam site on the Mokelumne River area (Township 4 North, Range 9 East, Sections 6 and 7) gave, respectively, permeabilities of 1.66 gallons per day per square foot (average) and 33-44 gallons per day square foot. A number of permeability tests were run by the Corps of Engineers on Mehrten sediments at the Farmington Flood Control dam. Values obtained ranged from a low of 0.1 to a high 375 gallons per day per square foot. It is apparent, then, that the Mehrten varies greatly in its ability to transmit water, but that the sands or sandstones can be high yield aquifers. Regional studies of the water producing capabilities of the Mehrten sands indicate the following:

*Gallons per minute	1000±
*Specific Capacity	40±
*Transmissibility	68000±

Natural recharge to the Mehrten formation is partly through the outcrop areas from rainfall, partly from streams crossing the exposed sections of the formation, and from waste water and irrigation return through the younger, overlying formations.

* These terms are defined in Appendix 2, Definition of Terms

Laguna Formation. The Laguna formation is an east side unit which outcrops in the gently rolling, hilly area from Farmington northward to Lockeford. At its western outcrop it is covered by the Victor formation and recent alluvium, but dips below these units into the subsurface at about one degree (90 feet per mile) and is extensively developed to the west as a subsurface formation. The Laguna formation unconformably overlies the Mehrten formation in the outcrop area (occasionally it is in contact with mapped Valley Springs formation) but to the west, in the area of the Delta, it appears to be in conformity, suggesting continuous deposition. It also is difficult to define the contacts of the Laguna formation with both the underlying Mehrten and overlying Victor formations in the Delta because of the similar nature of the sediments across the contacts. From the Mokelumne River area, the formation thickens from approximately 400 feet to approximately 1000 feet in the Stockton area (see Plate 4).

The Laguna formation is a Plio-Pleistocene, stream-laid, continental unit deposited subsequent to the andesitic episode represented by the Mehrten formation. A change in the source material is indicated by the nature of the sediments which contain sands and gravels and are nonvolcanic for the most part.

The Laguna formation varies both laterally and vertically in nature. The unit consists chiefly of stream laid discontinuous lenses of sand and silt with lesser amounts of clay and gravel. There are no regionally significant fine grained intervals which could cause water pressure conditions, although the heterogeneous nature of the sediments causes local semiconfinement. Included with the Laguna formation is the Arroyo Seco gravel, a thin unit exposed in outcrop adjacent to the Mokelumne River. It consists of weathered sand and resistant gravel and most probably represents a once extensive, ancient pediment (67). It is difficult to recognize in the subsurface as a separate unit, and so has been included with the discussion of the underlying Laguna formation.

The Laguna formation is very heterogeneous with lenticular sands of limited areal extent. Wells perforated in the Laguna formation also are commonly dually perforated in the overlying Victor formation and, in the eastern portion of the County, in the underlying Mehrten formation. Occasional minor perched water zones are encountered in the Laguna formation, particularly in the Mokelumne River area. Under these conditions it is expected that the yield of wells would vary, depending on location. Generally, though, yields and specific capacities are moderate, producing from an unconfined to locally semiconfined ground water system. Regionally, yields of 1500 gallons per minute have been reported from highly permeable beds, but average data for the formation are:

Gallons per Minute	900±
Specific Capacity	35±
Transmissibility	59,500±

The major producing area of the Laguna formation lies between the Delta and the lower foothills. East of the foothills the unit thins out rapidly and is relatively unimportant except as an avenue for recharge. Recharge to the Laguna formation is from streams traversing the outcrop area, from direct rainfall and from irrigation through infiltration and percolation.

The historical regional flow direction probably has been from northeasterly to southwesterly. However, man-induced deflections to this path are now evident (Figures 2 and 3).

Tulare Formation. The Tulare formation is a west side unit which outcrops as a thin band in the lower foothills of the Coast Ranges and plunges rapidly into the subsurface. It is the major reservoir for subsurface pumpage of water for the west side of the County. The formation dips on the order of 15 to 20 degrees into the subsurface from its outcrop area but flattens rapidly in the vicinity of Tracy. It varies from zero feet in thickness at the outcrop, to 1400± feet in thickness in the area of the Delta. It is equivalent, at least in part, to the east side Laguna formation.

The Tulare formation is composed of continental, semiconsolidated, poorly sorted, discontinuous deposits of clay, silt, and gravel. A regionally extensive clay layer, termed the Corcoran Clay of the Tulare formation (Plate 5) occurs near the top of the Tulare formation and confines the underlying fresh water deposits. Its extent and configuration are documented in several publications (49 and 63). This clay, usually logged as "blue clay" by the drillers, is a lake deposit containing high concentrations of diatoms. It is relatively free of nonclay lithologies except on its perimeter or where the larger sierran streams have breached its eastern border with sand and gravel deposits. The thickness of the Corcoran Clay in the Tracy area varies from near zero to about 150± feet. Its eastern limit, in San Joaquin County, is about at the San Joaquin River (Figure 15). Therefore, confined water conditions attributable to the Corcoran Clay do not occur east of the San Joaquin River.

The Tulare formation is moderately permeable in both its confined portion below the Corcoran Clay and unconfined part above the Clay. Most of the larger irrigation wells, the industrial and the municipal wells obtain their water supply from below the Corcoran Clay. The small domestic wells often obtain their supply from above the confining clay. The water quality differences above and below this confining unit are discussed in greater detail in Chapter III.

High water yields have been reported from the unit below the Corcoran Clay. Wells within the City of Tracy below the Corcoran Clay indicate the following:

Gallons per Minute	3,000±
Specific Capacity	50±
Transmissibility	99,500±

Observations of piezometric water levels suggest that the direction of movement of water below the Corcoran

Clay is from the south and southeast with a probably Sierran origin. Minor amounts may be contributed from Coast Range waters or by leakage from above the Corcoran Clay. Recharge to the sediments above the Corcoran Clay is chiefly from the Coast Ranges' creeks, from rainfall, and from irrigation. This latter has resulted in waterlogging in some areas such as New Jerusalem and a net increase in ground water levels over the last ten years.

Flood Basin Deposits. Within this unit are included the Delta equivalents of the Laguna, Tulare, Victor, and Recent formations. As such, the term "Flood Basin Deposits" has a geographic connotation. The lithologies of this formation occur in the Delta area of San Joaquin County, the trough portion of the basin. The beds here are relatively flat-dipping, and generally conformable with one another, indicating that deposition has been virtually continuous.

Sediments in this formation are basinward, fine grained forms of the Laguna, Tulare, Victor, and Recent formations and therefore range in age from Pliocene to Recent. They are generally much finer grained with a higher percentage of fine sand and clays than their depositional equivalents to the east and west. Occasional gravel beds occur along the present water ways and are probably representative of the type of underlying lithology distribution. The various cross sections (Plates 4, 5, and 6) indicate that sand bodies can reasonably be expected at depth even in the central portion of the Delta.

Occasional pockets of fresh water are found in the Delta deposits, but generally speaking the formation contains poor quality water. The reason for this is not clear, but it is suggested here that the area has historically been topographically low and thus the avenue through which all the drainage waters of the San Joaquin Valley have moved. It has been subjected on numerous occasions to tidal influences from Pacific Ocean waters. The glacial stages and interstages (described under Past Land Forms) have also undoubtedly played a role in creating the present quality environment.

Victor Formation. The Victor formation occurs on the east side of the County as a band approximately 15 miles wide and extending the length of the County. The unit dips very gently to the west, with its upper surface lying approximately parallel to the present land surface. The unit interfingers and blends into the Flood Basin deposits to the west with no apparent abruptness (Plates 6 and 7).

The Victor formation is heterogeneous in outcrop and in the subsurface, with no apparent extensive clay layers to act as confining bodies. It is generally coarser grained than the underlying Laguna formation, especially around the flood plains of the Mokelumne and Stanislaus Rivers, but is somewhat clayey in the interfan areas. Sand and gravel are dominant in the fanal areas while clay, silt, and sand are dominant in the interfanal areas. However, there are local clay layers in the Manteca area causing perched water. The Victor formation is usually difficult to delineate from the underlying Laguna formation since they are both composed of similar lithologies derived from the Sierra granitics, metamorphics, and volcanics.

Because the Victor formation is limited in thickness, most wells penetrate it into deeper intervals. This is particularly true where the water table lies some distance below the surface. Most of the irrigation wells draw from the deeper formations. Therefore, it is difficult to obtain well characteristics from other than small domestic wells. Tests of some of the shallower wells, which also probably tap in part the underlying Laguna formation, give the following general data:

Gallons per Minute	650±
Specific capacity	60±
Transmissibility	87,600±

The unit is Pleistocene in age, but has included with it recent sediments not differentiated on the geologic map (Plates 2A and 2B). The sediments of this formation are fan and flood plain deposits derived from a Sierran source, and were deposited during the period of the formation of the Laguna terraces in the eastern part of the County.

Recharge to the Victor formation is by rainfall, return irrigation, and from waters of the traversing streams.

Alluvial Fan Deposits. These sediments are a west side unit of areally wide extent, but rather thin depth (0 to 150± feet), consisting of continental, unconsolidated fanal material derived from the Coast Ranges. The lithology is composed of a heterogeneous mixture of discontinuous sand, gravel, silt, and clay deposits.

The unit is under free water table influence and is tapped dominantly by small domestic wells. Numerical data were not obtained on production capabilities but reconnaissance field investigations indicate it is moderately to locally highly permeable. Recharge is by infiltration and percolation of rainfall, irrigation practices, and from the flow of the Coast Range intermittent streams, chiefly Corral Hollow Creek.

Stream Channel Deposits. The stream channel deposits consist chiefly of sand and gravel with lesser silt and clay. Based on visual field inspection, these sediments are considered to be generally highly permeable, but because they are commonly above the water table and of limited vertical and areal extent, they are useful only as avenues for the infiltration and percolation of water to underlying formations.

Features Affecting Ground Water Movement

There are no apparent significant shallow or deep geologic barriers to the normal lateral movement of ground water in San Joaquin County within the ground water basin. However, some features such as the east side tilt of sediments and fine grained units at depth (Plates 3, 4, and 5) and the west side Corcoran Clay and syncline (Plate 5) influence the direction and rate of movement.

Structural features in any ground water basin commonly affect the rate and direction of ground water movement. Faults, homoclinal dip, synclines, and anticlines cause local alterations in the regional patterns of water movement and by redirecting, or modifying the paths of movement can also affect the quality. These structural features are not often apparent at the surface, being only indirectly observable by abrupt changes in water table or piezometric levels, by sudden changes in ion concentrations, or by recognizable changes in elevation or thickness of lithology types.

The regional features in the San Joaquin County area are the Sierra Nevada and the gentle western dip on its valleyward flank, the relatively flat-lying synclinal portion of the lower valley, and the more abruptly eastward-dipping flank of the Coast Ranges on the west.

The County is considered seismically quiet, with only one reported earthquake epicenter of magnitude greater than 4.0 on the Richter scale between 1934 and 1961 (DWR 1963). This suggests that faulting that might extend upward into the near-surface sediments in the ground water basin is minor.

<u>Deep Structures</u>

The deep structures in San Joaquin County apparently have little effect upon the movement of water in the ground water basin, although some of the west side faults may contribute to quality deterioration.

The deep tectonic structure of San Joaquin County is the Delta part of the regional geosyncline on which are superimposed lesser anticlines and synclines, noses, faults, and warps. These lesser structures are developed in marine formations and are the collecting areas for the gas accumulations represented by such fields as Lathrop, Tracy, McDonald Island, and Roberts Island.

Several large subsurface faults traverse the area, chief of which is the Stockton fault, with an alignment somewhat parallel to a line between Stockton and Tracy (Plates 2A and 2B) and with a displacement of several thousand feet. This fault does not extend up into the nonmarine sediments of the ground water basin.

Exposed faults, probably extending to considerable depth, are present on the west side of the County, but these are out of the main ground water basin. Chief among these is the Black Butte fault (Plate 5) which may act as an avenue for boron rising along the fault from underlying Franciscan rocks being picked up by near-surface waters, and spreading laterally into the ground water basin.

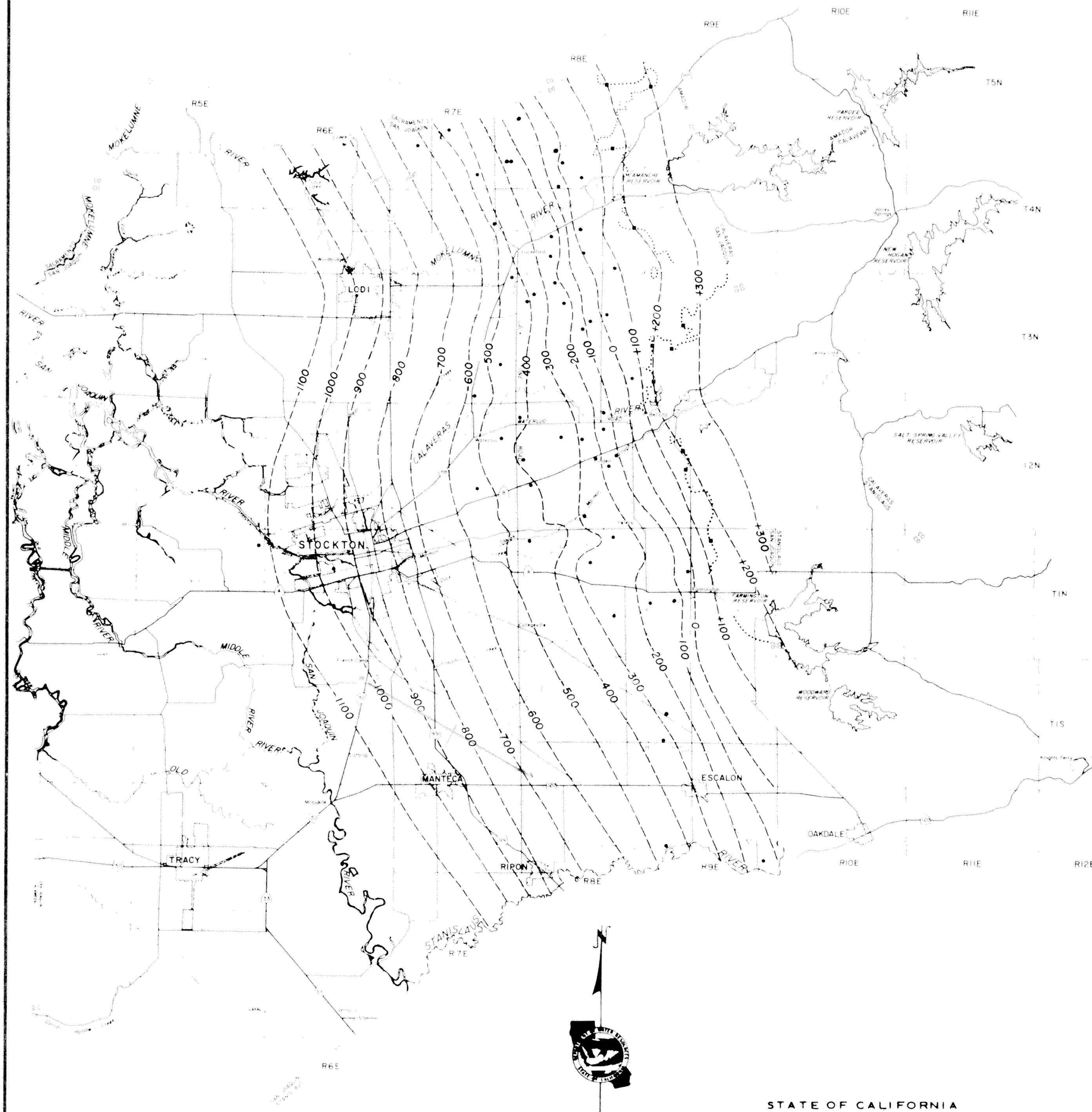
Shallow Structures

Several shallow tectonic structures affect the direction of but do not stop ground water movement in San Joaquin County. These structures generally lie east and west of the Delta.

On the east side, the homoclinal dip of the sediments influence the water to move in a southwesterly direction under natural, uninhibited conditions. However, man-induced deflections to this direction are evident in the wide range of flow paths which exist today (see Figures 2 and 3).

The younger formations apparently extend across the Delta in structural continuity under a nearly flat structural gradient. Structure contours on the top of the Mehrten formation (Figure 6) indicate that no irregularities exist on the east side of the valley as far as the Delta. In a sedimentary basin it would be expected that only normal (perpendicular) faulting would occur in a structural system of one or two degree dips. There is no evidence that even this kind of faulting exists in the shallow, fresh water-bearing sediments on the east side of the County or within the flat-lying system of the Delta.

The west side of the County is influenced by a sequence of steeper dipping sediments than those on the east side. Under natural conditions water would flow northeast, toward the Delta, from the southwest. No sizable faults, except for those evident in outcrop, are apparent in this ground water portion of the basin. Several small faults have been isolated during the digging of the Delta-Mendota canal, but these have no obvious widespread effect on ground water movement or quality (4). However, the presence of boron in much of the west side water suggests that boron



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

SAN JOAQUIN COUNTY
GROUND WATER INVESTIGATION

STRUCTURE CONTOURS
TOP OF MEHRTEN FORMATION
1967

SCALE OF MILES
2 0 2 4 6

LEGEND

- -100 LINE CONNECTING POINTS OF EQUAL ELEVATION (SEA LEVEL DATUM)
- ● SUBSURFACE CONTROL POINT FROM DRILLER'S LOG
- ■ SURFACE CONTROL POINT ON MEHRTEN CONTACT
- .... OUTCROPPING UPPER CONTACT OF MEHRTEN

may rise along faults such as the Black Butte fault, and then enter the ground water basin either directly or from surface waters traversing Franciscan terrain on their paths to the Delta along the intermittent west side streams such as Corral Hollow Creek.

Lithologic Barriers

In a previous study by this Department of the Stockton area (11) the concept of a "barrier effect" to lateral ground water movement was proposed and has gained widespread acceptance. This concept was based on data gathered over a limited time period. Additional data gathered in the present investigation suggests that this concept should be reconsidered. The background and current information leading to a reevaluation of the environmental situation in the west portion of Stockton is developed in detail in the chapter titled "Problem Areas". The conclusion is that no barrier to the eastward lateral movement of ground water exists in the Stockton area, that water is free to move at a rate dictated by the geologic and current hydraulic parameters governing the area.

Free vertical movement of water is inhibited adjacent to the Delta in the eastern portion of the County below the top of the Mehrten formation and in the lower portions of the Laguna formation. This is suggested both by the subsidence which occurs in the Stockton area and by indications of local semiconfined ground water conditions. The heterogeneous nature of the sediments results in differences in head between water levels in these semiconfined units and the water table levels. However, over long periods of time, adjustment to equilibrium with the water table takes place, indicating general hydraulic continuity.

In the Tracy area, the Corcoran Clay impedes the vertical movement of water except where it has been breached by wells. Water below the Corcoran Clay moves from points of high piezometric pressure to points of low piezometric pressure. The presence of the Corcoran Clay has not been definitely established east of the San Joaquin River or north of Tracy.

Soils

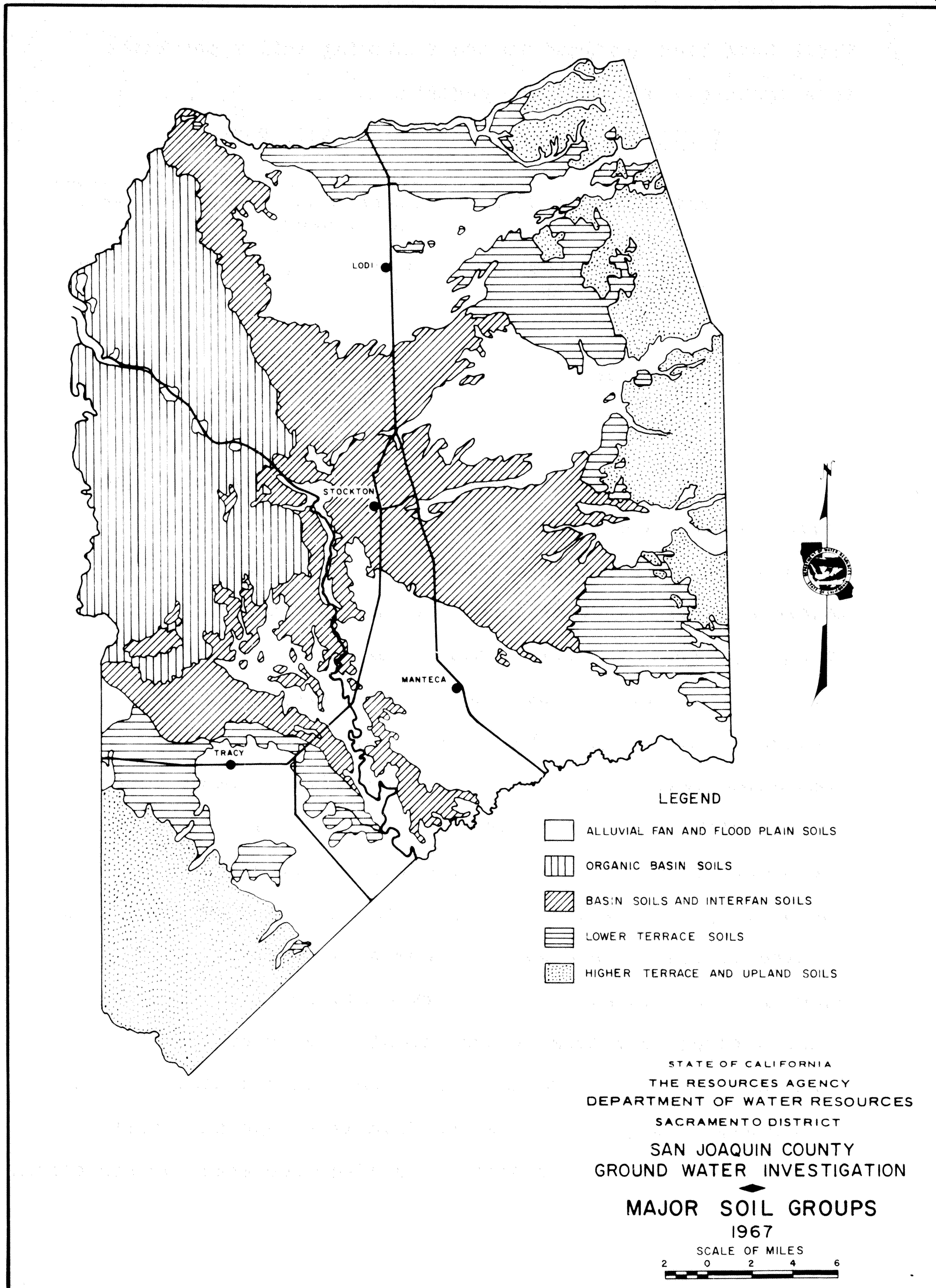
Soil is defined as the earth material which has been so modified and acted upon by physical, chemical, and biological agents that it will support rooted plants. The study of soils is germane to any geologic and hydrologic investigation since soils commonly control the rate at which surface waters can penetrate through the zone of aeration to the ground water table. The soil types of San Joaquin County have been described in a number of publications (76). Soil studies usually extend down to a depth of six feet.

The soils of San Joaquin County can be grouped into five main categories. These are:

1. Alluvial fan and flood plain soils
2. Organic basin soils
3. Basin soils
4. Lower terrace soils
5. Higher terrace and upland soils

These groupings, in part, coincide with the geologic formations as shown on Plates 2A and 2B, but since one is based on soil description and the other is based on rock or sediment description there are expected areas of divergence. Figure 7 shows the areal distribution of the five soil types in the County, modified from Weir (76).

Infiltration rates are related to soil types. The infiltration rate of a soil is a measure of how rapidly surface water can infiltrate into the soil belt and start movement down into the intermediate belt before reaching the zone of saturation. Infiltration rates have not been directly established for the soils of San Joaquin County by either the Department of Water Resources or by other agencies. Therefore, only qualitative values have been assigned although the probable quantitative rate has been listed in parentheses as a numerical reference. These qualitative rates are meant only to indicate general relationships among the five major soil groups. Infiltration rate data for various soil types in California were obtained from the United States Department of Agriculture, Agricultural Research Service and from Department of Water Resources bulletins and office reports.


LODI
STOCKTON
MANTECA
TRACY
LEGEND
ALLUVIAL FAN AND FLOOD PLAIN SOILS
ORGANIC BASIN SOILS
BASIN SOILS AND INTERFAN SOILS
LOWER TERRACE SOILS
HIGHER TERRACE AND UPLAND SOILS
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SACRAMENTO DISTRICT
SAN JOAQUIN COUNTY
GROUND WATER INVESTIGATION
MAJOR SOIL GROUPS
1967
SCALE OF MILES
2 0 2 4 6

Rates have been assigned to the following soil types based on a synthesis of the above reports.

Infiltration Rate	Soil Texture
High (greater than 2"/hr.)	Coarse sand, sand, fine sand, loamy sand, loamy fine sand, coarse sandy loam
Intermediate (between 2"/hr. and 0.6"/hr.)	Sandy loam, fine sandy loam, loam
Low (less than 0.6"/hr.)	Silt loam, sandy clay loam, clay loam, silty clay loam, silty clay, sandy clay, clay

The alluvial fan and flood plain deposits of San Joaquin County are grouped into four main areas, three bounding the main eastern streams, the Mokelumne, the Calaveras, and the Stanislaus, and the fourth adjacent to the foothills south of Tracy. These areas have the best infiltration rates in the County, exclusive of the peat locales in the Delta. The soils of the Mokelumne and Stanislaus fans have youthful soil profiles of sandy loam to loam with common areas of silt loam. There is a tendency for these soils to coarsen toward the apexes of the fans. The soil types show little compaction and slight accumulation of lime or clay. Hardpan development is minimal. In general, they belong in the intermediate infiltration rate group although portions of the deposits described as silt loam have low rates. Because of their soil profile, proximity to streams, and general freeness from waterlogging, these intervals are considered best for surface recharge investigation.

The soils of the Calaveras fan and the west side fan near Tracy have deeper profiles of loam and clay loam and are darker and heavier than the Stanislaus and Mokelumne River fan soils. This may be due to their source areas being restricted to metamorphic or pre-Tertiary sedimentary material, whereas the Mokelumne and Stanislaus Rivers receive large contributions from a granitic source. Based on assigned infiltration rates, the soils of these fans and flood plains, in general, belong in the low group.

The organic basin soils are restricted to the lower Delta portion of San Joaquin County. Peat, muck, and clay loam are terms commonly applied to soils in this group. The organic basin soils are variable in their infiltration capacity. Where peat is the dominant soil constituent, infiltration rates are high. Where clastics such as muck and clay loams occur, rates are low.

The interfan and basin soils lie between the Mokelumne, Calaveras, and Stanislaus fans, in a northwesterly trending belt north of Tracy and around the periphery of the organic basin soils. These soils generally have well developed profiles, medium to heavy texture, and underlying fairly well compacted subsoils. Locally, hardpan overlies silty to silty clay loams. These soils have low infiltration rates based on their soil texture.

The terrace and upland soils have low infiltration rates based on textures defined by Weir (76). The terrace soils have profiles containing moderately dense accumulations of clay and claypan, relatively near the surface. These act as essentially impervious barriers to the local downward movement of water, although root holes and other breaks permit some infiltration. The upland soils consist essentially of residual materials derived from the underlying parent rock and are commonly rather thin.

Summarizing, it is noteworthy that none of the soils, as defined by Weir, can be placed in the high infiltration rate category. For purposes of artificial recharge by surface methods (see Chapter V) the best areas for infiltration are the fans of the Mokelumne, Calaveras, and Stanislaus Rivers, and the fan south of Tracy.

CHAPTER II

HYDROLOGY

This chapter presents the significant hydrologic phenomena that influence the chemical degradation of water in the study area. The origin and movement of water, the quantitative methods of evaluating the water supply, use and disposal, and the results and applications of these evaluations are presented. A detailed discussion is given of the ground water movement and storage in the San Joaquin County area and the implication of these factors with respect to the water supply for the overlying cultural development.

Hydrologic Balance Studies

A hydrologic balance study considers all the significant factors related to the determination of water conditions in a specific area. The precise determination of all sources of inflow and outflow from an area where the boundaries can be fairly well defined (hydrologically) should enable the calculation of the surplus or deficiency. In actual practice the values for many of the conditions cannot be precisely determined and certain assumptions or estimates must be made in order to arrive at a realistic understanding of the hydrology of the basin. For certain factors, such as seepage from surface streams, fairly realistic values can be determined by using the measured flow at an upstream and downstream station and computing the seepage. Of course, in this one example, many things, such as evaporation and diversions, must also be known (or estimated) before seepage can be determined. Many other factors in the hydrologic balance are more difficult to accurately determine and the engineer must rely on his judgment and experience to arrive at a reasonable value.

As a result of this need to estimate and apply engineering judgment, the hydrologic balance is never an exact determination. The final answer is no more accurate than some of the individual estimates that were used to compute it. Consequently, it is not realistic to imply that the final answer is precise.

It is also unrealistic to assume that hydrology studies should not be undertaken due to this lack of precision. The determination of overdraft, based on a hydrologic balance, provides an order of magnitude sufficient to initiate further engineering studies of corrective measures.

Hydrologic Basin Area

The continual hydrologic cycle consists of migration of water from the sea as evaporation to the atmosphere where it is carried over the land by winds. These water-laden winds carry the moisture which first falls on the land surface then flows back to the sea in rivers or percolates into the ground. Even the water that seeps into the ground is ultimately destined to find its way back to its place of birth, the sea.

The concept of the hydrologic cycle applied to the San Joaquin County area leads to the conclusion that the flow of water through the area is an ever-changing, dynamic process. To understand this process, it is necessary to solve the "equation of hydrologic equilibrium" which states:

Inflow - Outflow = Change in Storage

This equation simply states that a balance must exist between that water flowing into or out of the area and that stored within it. However, before this statement has meaning, the boundaries of the area to which the equation is to be applied must be carefully drawn, and the time period of study must be defined. The boundaries of the study area and the study period are discussed in the following sections.

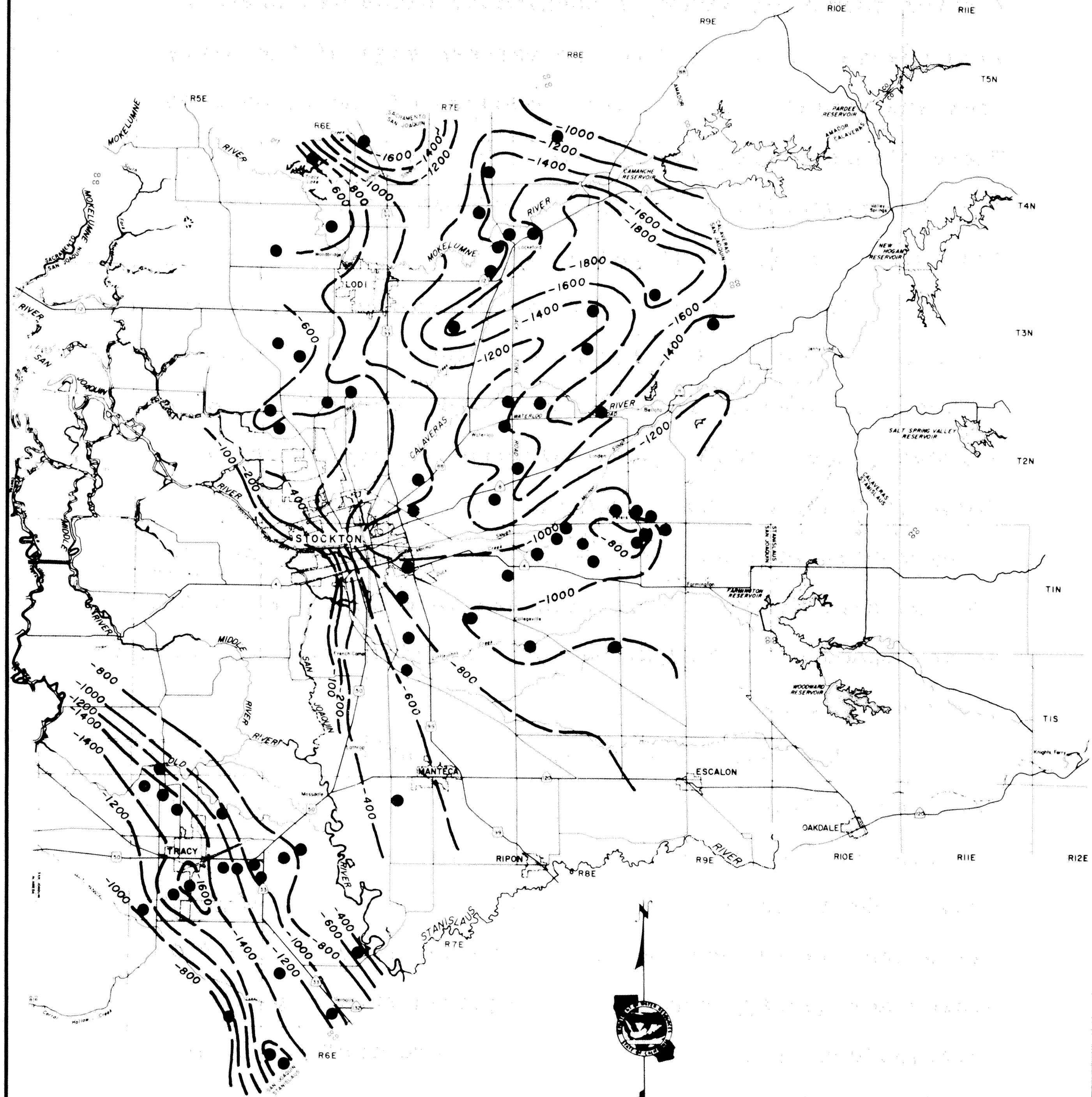
The unit of time used for calculations of inflow and outflow is the water-year, October 1 through September 30. Values for this unit time are referred to as "annual" amounts in the following text. The values reported in the text are all rounded to the nearest thousand acre-feet. The gauged values are more accurate than the estimated values.

Hydrologic Study Area Boundaries

One of the preludes to a ground water hydrologic study is the choice of the basin boundaries. As a general premise it was decided in delineating the San Joaquin County study area to exclude the Tracy and Delta areas since no overdraft problems were evident there.

The physical boundaries were then fixed so as to minimize errors in those portions of the hydrologic equation least subject to accurate quantitative analysis. Chief among these is subsurface flow across the vertical subsurface projection of the boundary. This factor must be estimated solely from indirect evidence and is therefore probably the weakest part of the hydrologic equilibrium equation, although its percentage contribution to the total balance may be low as in San Joaquin County. Therefore, the eastern, northern, and southern boundaries were defined so as to have zero cross-flow. The western boundary could not be fixed along a vertical plane of zero cross-flow; therefore,quantities of water movement across this front had to be determined for the hydrologic equation. The area included within the study is approximately 586,000 acres.

The eastern boundary of the study area was placed at the contact between the main body of valley sediments and the Sierran "basement complex". There is essentially zero subsurface flow across this contact. This interface also forms, in part, the basal boundary of the study area. Most of the basal boundary coincides with the base of fresh water (Figure 8). However, where the trace of the



LEGEND

——400 LINE CONNECTING POINTS OF EQUAL ELEVATION (SEA LEVEL DATUM) ON BASE OF FRESH WATER, ALL CONTOURS APPROXIMATE

● LOCATION OF WELL WITH ELECTRIC LOG CONTROL

BASE OF FRESH WATER – DEPTH BELOW WHICH WATER OF POOR QUALITY OCCURS AT ALL INTERVALS AS DETERMINED BY CHLORIDE CONCENTRATION THAT EXCEED 300 MG/L

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SACRAMENTO DISTRICT

SAN JOAQUIN COUNTY
GROUND WATER INVESTIGATION

CONTOURS ON
BASE OF FRESH WATER
1967

SCALE OF MILES
2 0 2 4 6

intersection of the base of fresh water and the top of the Mehrten formation occur, a horizontal plane was drawn for each township involved, to the western edge of the study area and represents the basal boundary of the study area. These planes vary from -700 to -900 feet subsea. Therefore, all deep producing wells are, in effect, included within the defined study area boundaries.

The northern border was determined on both water level and topographic information. Where ground water level controls existed (Figures 4 and 5) the boundary was along a ground water saddle. The easternmost levels are in Township 4 North, Range 8 East. East of this area a major topographic ridge was used to define the northern perimeter. The southern boundary selection was made like that on the north, based on a combination of subsurface water level and topographic control.

The western boundary was somewhat arbitrarily fixed, as shown on Plates 1A and 1B, in order to (1) avoid crossing the San Joaquin River in several places with concomitant loss of data control, (2) to make use of the westernmost historical water level data, (3) to be assured of maximum subsurface geology control for required subsurface flow calculations, and (4) to include the overdraft portion of the basin.

Hydrologic Base Period

Because of data limitations and costs of hydrologic studies, a short, recent time must be selected for a base period which is representative of the long-time hydrological conditions. The base period should begin and conclude after a series of dry years to minimize the differences in quantities of ground water in transit in the zone of aeration at the beginning and ending of the base period. A base period must also be chosen on the basis of the availability of records for the period.

Precipitation is the ultimate basis of supply of water in any watershed. It is an index of the availability of water in both the basin and its tributary areas. Because of this, an analysis was performed on the long-term precipitation record at Stockton, to establish a base period which would fulfill the requirements mentioned above. The long-term period from 1910-11 to 1963-64 was chosen for analysis. Mean precipitation for this period was 14.28 inches.

On the basis of this analysis a 14-year base period, 1950-51 to 1963-64, was selected. During this base period, so-called wet, average, and dry years occur. The period is recent, includes current physical and cultural conditions, and encompasses a period of available records. Also, it begins and ends after a series of dry years. The mean precipitation is 14.69 inches and compares closely with the long-term mean precipitation of 14.28 inches.

Water Supply, Use, and Disposal

Water Supply

Water supply, as used in this investigation, is water that enters the ground water basin from its tributary areas combined with precipitation that falls on the basin surface. The components of water supply are precipitation, surface inflow, fresh water import, and subsurface flow. The average annual water supply was 1,870,000 acre-feet for the 14-year base period. Annual water supply is presented in Table 2.

Pumped ground water is commonly considered as water supply; however, for this analysis it is not considered since it cancels out of the equation of hydrologic equilibrium. This item will be discussed in detail later in this chapter.

Precipitation. The average precipitation on the basin ranged from 11.50 inches at Manteca to 19.81 inches at Camp Pardee for the 14-year base period. The average precipitation over the entire basin was 15.71 inches and amounts to an average annual volume of 767,000 acre-feet. This is 41 percent of the total average annual water supply. The year 1957-58 recorded the highest volume of rainfall for the base period, 1,278,000 acre-feet. The lowest annual volume was 518,000 acre-feet, and occurred during the year 1959-60. In general, the years prior to 1957-58 were wet years while those following were dry years.

Data used for estimating annual volume of precipitation were obtained from the United States Weather Bureau and the Department of Water Resources. After inspecting the various stations for location and length of record, records for 14 rain gauge stations were selected to calculate the annual precipitation volume for the base period. Corrections and estimations of missing records were accomplished by a correlation with 10 reliable local stations for which complete and accurate records were available. The locations of rain gauging stations used in this study are shown on Plate 1A and 1B.

The Thiessen Method was used to calculate the volume of rainfall for each year. This method entails constructing a polygon of influence about each rain gauge station. The area for each polygon is then multiplied by the annual depth of rainfall for the corresponding station. For each year, the volume of precipitation computed for each polygon is summed to obtain the total annual volume of precipitation for the entire basin.

A check was made of several annual amounts to test the reliability of the values obtained by the Theissen Method. This check was accomplished by constructing isohyetal maps, measuring the area between each isohyet, and multiplying by the average isohyet rainfall value. The result is the volume of rainfall for the year. A comparison between the Thiessen Method and the Isohyetal Method resulted

TABLE 2

WATER SUPPLY
SAN JOAQUIN COUNTY GROUND WATER BASIN*

In Thousands of Acre-Feet

Year	Precipitation	Fresh Water Import	Surface Inflow	Sub-surface Flow**	Annual Water Supply
1950-51	939	323	1,419	-2	2,679
1951-52	1,054	365	1,592	-2	3,009
1952-53	646	381	635	-2	1,661
1953-54	593	320	533	-2	1,445
1954-55	743	317	419	-2	1,477
1955-56	1,020	354	1,496	-2	2,868
1956-57	652	370	579	-2	1,599
1957-58	1,278	376	1,339	-2	2,991
1958-59	604	361	324	-2	1,287
1959-60	518	363	240	-1	1,120
1960-61	581	287	179	-1	1,046
1961-62	656	420	530	+3	1,609
1962-63	895	360	860	+18	2,134
1963-64	557	384	260	+51	1,252
14-year average	767	356	743	+4	1,870

*Area is shown on Plates 1A and 1B.
**Subsurface Flow are combined (-) meaning net outflow (+) meaning net inflow. It includes poor quality as well fresh water.

in a difference of less than one percent. Since this range in error is less than the errors inherent in measurement, the Thiessen Method values were adopted.

Surface Water Inflow. Surface water inflow consists of that water which enters the ground water basin in natural channels or in the form of runoff over the land surface. There are two major rivers, the Mokelumne and the Calaveras, that flow into the basin. The Stanislaus River is outside the study basin, therefore, it does not contribute water directly to the basin. Each of these rivers has a gauging station adjacent to the basin boundary as shown on Plates 1A and 1B. Runoff into the basin from the Rock Creek and Littlejohns Creek watersheds was estimated by correlating rainfall with the gauged flow from Littlejohns Creek at Farmington which lies downstream from the confluence of the two creeks. There are several watersheds smaller than the Rock Creek and Littlejohns Creek watersheds, which also supply runoff into the basin across the eastern boundary of the study area. These are small enough to be considered negligible. Because of the flatness of the terrain on the north, south, and western boundaries, and the near coincidence of topographic divides to these boundaries, runoff across these boundaries was assumed negligible.

The average annual surface inflow contributed by the Mokelumne River was 572,000 acre-feet, or about 77 percent of the total average annual surface water inflow during the 14-year base period. The 1951-52 annual surface inflow into the study area basin of 1,592,000 acre-feet was the maximum surface inflow during the base period.

The minimum occurred in 1960-61 and was 179,000 acre-feet. Surface inflow accounted for 40 percent of total water supply. Annual amounts of total surface inflow, tabulated in Table 2, were determined from published records of the United States Geological Survey and the Department of Water Resources.

Fresh Water Import. Imported fresh water is water brought into the basin by means of man-made conveyances. East Bay Municipal Utility District and the South San Joaquin and Oakdale Irrigation Districts, are the only agencies which import water into the basin.

East Bay Municipal Utility District imports and also exports water via the Mokelumne aqueduct. This aqueduct has its origins in Pardee Reservoir and is completely piped throughout its length in San Joaquin County. There are no releases of any consequence. Since imports equal exports, the Mokelumne aqueduct did not enter any of the import-export calculations.

South San Joaquin Irrigation District and Oakdale Irrigation District import water by means of the South San Joaquin Canal. Waters diverted from the Stanislaus River into the South San Joaquin Canal are measured by the United States Geological Survey near Knights Ferry. Oakdale Irrigation District draws part of the water in the canal, and the remainder flows to the Woodward Reservoir where it is stored for subsequent use by the South San Joaquin Irrigation District.

Fresh water import has averaged about 356,000 acre-feet a year during the base period. Since 1961, this average has increased approximately 34,000 acre-feet per annum. This increase in imports is the result of increased surface water storage capacity on the upper Stanislaus River.

Subsurface Flow. In previous reports covering hydrologic investigations of San Joaquin County, subsurface flow was treated as a residual in the hydrologic equation. That is, all other elements of the equation were summed and the quantity of water needed for the balance was assumed to be subsurface flow. In this study, subsurface flow was calculated directly, using the ground water form of Darcy's equation. The boundaries of the ground water study area were deliberately chosen to minimize subsurface flow into the basin (see Hydrologic Study Area Boundaries, Plates 1A and 1B). Therefore, subsurface flow theoretically occurs only across the western boundary and, in several years, the westernmost part of the northern boundary.

Quantities of subsurface flow were calculated for those years for which maps were available, using Darcy's equation

$$Q = PIA$$

Subsurface flow of years for which no maps were available is based on interpolation and extrapolation of data. Subsurface flow (Q) is in acre-feet. Permeability (P) of the saturated thickness of sediments was obtained by assigning values based on permeability and aquifer tests of similar sediments in other areas. The slope or hydraulic gradient (I) was obtained from published water table contour maps and was assumed to occur over the entire year. The area (A) is the product of length of boundary across which subsurface flow takes place, and depth of sediments. Elevation of the base of the sediments varied from -700 to -900 (sea level datum) as explained in the section titled Hydrologic Study Area Boundaries.

Flow across the entire length of the study area boundary is not and has not been unidirectional over the 14-year study period. Inspection of Figures 2 and 3 show that there are segments along the western perimeter across which outflow occurred while other segments were subjected to inflow. Furthermore, this selective flow direction situation has been dynamic rather than static. The subsurface flow tabulated in Table 2 is net subsurface flow (net flow = inflow - outflow).

Net fresh water subsurface flow was estimated to be 7,000 acre-feet outflow, in 1950-51. This has steadily decreased to the point where the net subsurface flow of fresh water actually became inflow. At the end of the study period, 1963-64, net subsurface flow of fresh water was estimated to be 2,000 acre-feet inflow. The average annual net subsurface flow of fresh water was 3,000 acre-feet outflow for the 14-year study period.

Net poor quality subsurface flow was estimated to be 5,000 acre-feet inflow the first year of the study period, 1950-51. This has increased in volume, especially in the later years of the investigation. In 1963-64, there was approximately 49,000 acre-feet net subsurface inflow of poor quality water. For the 14-year study period the average annual subsurface flow of poor quality water was 7,000 acre-feet inflow.

The reason, of course, for the increase in subsurface inflow is the dramatically lowered water elevation (maximum of 40± feet) in the 16 mile portion of the western boundary centered at Stockton. An approximately 65 percent increase in ground water extractions in the Stockton area in the last 14 years was a contributing factor to the water level decline. The result has been a steepening of the hydraulic gradient (Plate 4, Figures 4 and 5) which increases the flow of Delta waters toward the east.

Water Use and Disposal

The components of water use and disposal are consumptive use, surface outflow, waste water export, and fresh water export. The average annual amount of water use and disposal for the base period was 1,936,000 acre-feet. Table 3 presents seasonal water use and disposal.

Consumptive Use. Consumptive use is water that is used by plants through transpiration, water evaporated from soil, and evaporation from open water surfaces. Water consumption and evaporation in urban and nonvegetative types of land use are also included.

Total consumptive use of irrigated crops and native vegetation were determined by using an existing machine computing program. This approach is similar to the Soil Budget Method used in Bulletin 113. Basically the approach assumes there are two sources of water for the plants' consumption. These are precipitation and applied water. Excess water from either of these two sources is stored in the soil as soil moisture to the point of soil saturation. The plant is then assumed to draw water from either the stored moisture in the soil, or to draw from the precipitation which falls on the soil, or from the water which is applied to the soil.

The method required monthly precipitation input. These monthly values were obtained by breaking the annual precipitation obtained for the basin, as discussed under Precipitation, into monthly values using the Stockton precipitation record as an index.

During the irrigation season it is assumed the monthly potential consumptive use is completely satisfied. If there is not sufficient soil moisture or precipitation, the deficit is made up by applied waters. The remainder of the year, the plant has only precipitation and soil moisture to draw from. If these are deficient, then the monthly potential consumptive use is not satisfied.

TABLE 3

WATER USE AND DISPOSAL
SAN JOAQUIN COUNTY GROUND WATER BASIN*

In Thousands of Acre-feet

Year	Consumptive Use	Waste Water Export	Fresh Water Export	Surface Outflow	Annual Water Use & Disposal
1950-51	1,163	19	148	1,333	2,663
1951-52	1,188	19	148	1,493	2,848
1952-53	1,147	21	186	446	1,800
1953-54	1,168	22	163	316	1,669
1954-55	1,151	21	137	298	1,607
1955-56	1,145	22	163	1,396	2,726
1956-57	1,167	22	150	411	1,750
1957-58	1,293	23	145	1,348	2,809
1958-59	1,148	22	147	211	1,528
1959-60	993	23	149	89	1,254
1960-61	1,053	23	105	61	1,242
1961-62	1,059	22	159	386	1,626
1962-63	1,277	24	149	739	2,189
1963-64	1,097	23	129	135	1,384
14-year average	1,146	22	148	618	1,936

*Area is shown on Plates 1A and 1B.

Land use for each year of the base period was estimated, using countywide annual crop acreages published in the Agricultural Commissioner's Annual Report and a comprehensive land use survey conducted by this Department during 1958. Urban land use was estimated with the aid of census reports. Potential consumptive use employed in the estimation of consumptive use were those used in the 1966 United States Bureau of Reclamation-Department of Water Resources Joint Hydrology Study.

Average annual consumptive use for the base period was approximately 1,146,000 acre-feet. In 1959-60 there was a minimum consumptive use of 993,000 acre-feet and in 1957-58 there was maximum consumptive use of 1,293,000 acre-feet. Consumptive use accounts for about 60 percent of the water used in or disposed from the study area.

Surface Outflow. There are six principal rivers and creeks that carry runoff from the San Joaquin County Water Basin. These are the Mokelumne River, Bear Creek, Stockton diverting canal via the Calaveras River, Calaveras River, French Camp Slough, and Duck Creek. The location of gauging stations on these channels are shown on Plates 1A and 1B.

The average annual surface water outflow was about 618,000 acre-feet for the 14-year base period. Of this, the Mokelumne accounts for approximately 70 percent. The maximum total annual surface water outflow was 1,493,000 acre-feet for 1951-52, and the minimum total annual surface water outflow was 61,000 acre-feet for 1960-61.

Waste Water. The cities of Stockton and Lodi are the two major exporters of waste water in the basin. Stockton transports its effluent across the San Joaquin River to a series of ponds on Roberts Island. Lodi transports its treated effluent to a series of ponds several miles to the west of Lodi.

Annual waste water export, as reported by the exporters, has increased from 19,000 acre-feet in 1950-51 to 23,000 acre-feet in 1963-64. This gradual increase in waste water export reflects the gradual increase in population.

Fresh Water Export. Fresh water export from the basin results from exports by the Woodbridge Irrigation District and the South San Joaquin Irrigation District. Because of the necessity of selecting the basin boundaries to simplify calculations of other components of water supply use and disposal, fresh water export is more of a result of the location of the basin's boundaries than a depletion of the basin's water supply.

The basin boundaries divide these irrigation districts in two, crossing numerous ungauged irrigation ditches and delivery canals. Water exported by Woodbridge Irrigation District, which diverts water from the Mokelumne River, and South San Joaquin Irrigation District, which imports water from the Stanislaus River, was determined by proportional area and checked by comparison of consumptive use in each portion of the Districts.

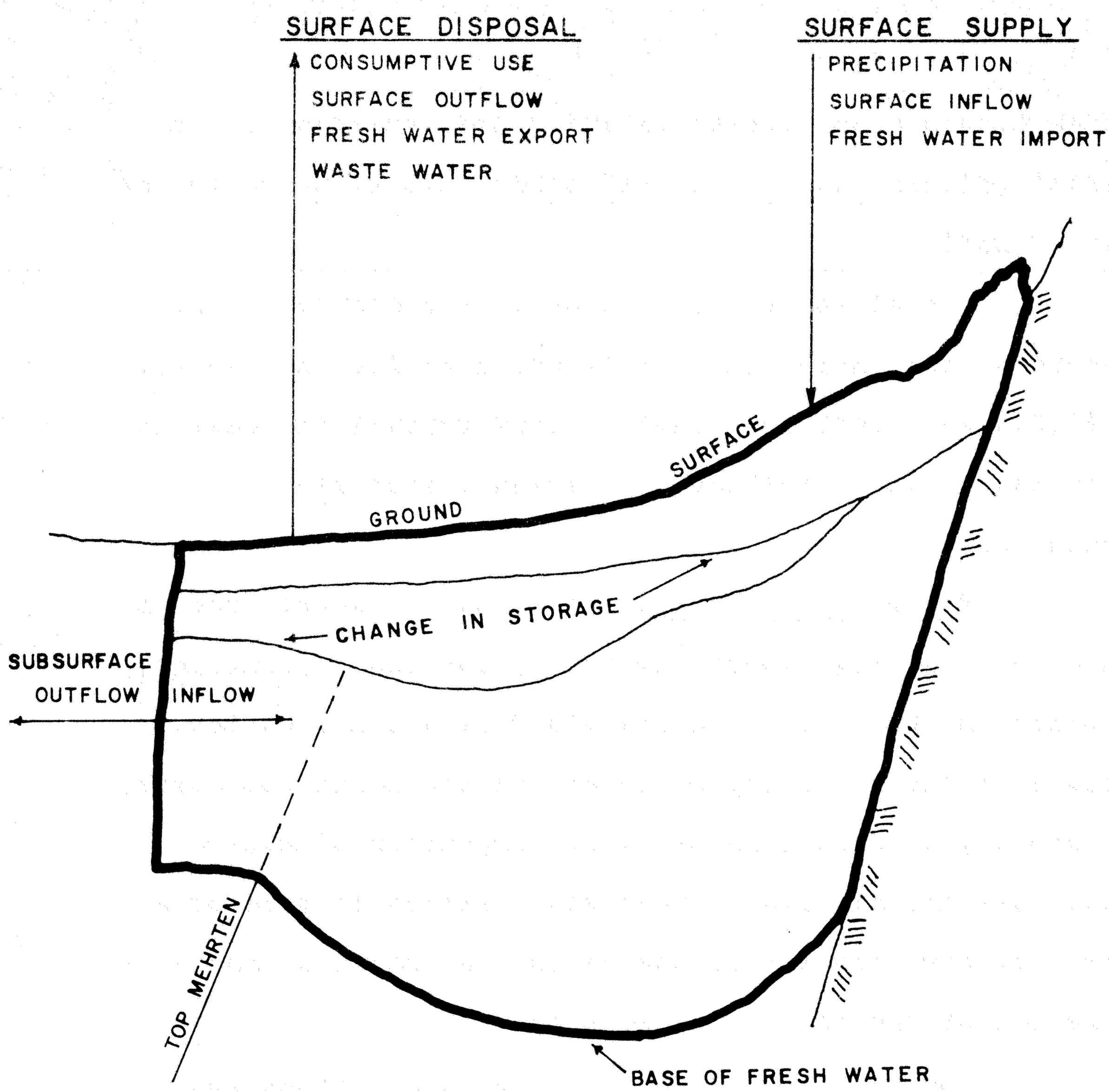


Figure 9 THE GROUND WATER BASIN AS A FREE BODY

Water Supply Surplus or Deficiency

Because a balance must exist between water entering or leaving the water-bearing portion of the study area, and water stored within it, the general equation of hydrologic equilibrium, stated at the beginning of this chapter, may be expressed as:

Water Supply - Water Use and Disposal =
Water Supply Surplus or Deficiency

and illustrated in Figure 9. In general, this equation expresses the change in ground water storage in the zone of aeration and the zone of saturation since the water supply, use, and disposal is estimated as a ground surface input or output to the basin. This is called the "water supply inventory method". For this investigation, the items of water supply, use and disposal were calculated on an annual basis. Consequently, because of a relatively shallow zone of aeration and permeable materials, and because of the selection of the base period, it may be assumed that changes in the water storage in the zone of aeration (see Figure 10) are negligible. As a result, the annual water supply surplus or deficiency can be equated to change in storage in the zone of saturation.

An independent method is available for estimating change in storage in the zone of saturation and for this report it is called "the specific yield method". Briefly, change in storage by this method consists of multiplying the area by the annual change in water level. This product is then multiplied by the specific yield of the interval over which the change in water level occurs.

Results in determining ground water change in storage by the two methods were compared. When there was a difference between the two methods, individual components of water supply, use, and disposal, as well as the change in storage by specific yield, were tested for confidence and adjusted accordingly, to bring the two methods into equilibrium (see Appendix 6).

The results of the adjusted balance (See Appendix 6) indicate that there was a mean annual water supply deficiency of 66,000 acre-feet. Because of the assumptions discussed above, this amount represents an average annual decrease in storage of 66,000 acre-feet. It is cautioned that this water supply deficiency is an average amount and does not represent present needs in the basin. The basin has undergone a cultural change over the 14-year base period and increased population and development will result in a need for more water. These needs will be discussed in the ground water overdraft section.

Ground Water Movement and Storage

The geologic environment and nature of the sedimentary materials within the ground water basin were presented in Chapter I. The implications of these factors, with respect to ground water movement and storage, are presented below.

Water Movement in the Zone of Aeration

Water that falls or that flows onto the basin surface is either evaporated, used by plants through transpiration, flows out of the basin, or percolates into the soil. The soil water is consumed to support plant life, or the water moves downward in the zone of aeration (Figure 10). Gravity is the principal force that moves the water downward until it eventually reaches the zone of saturation.

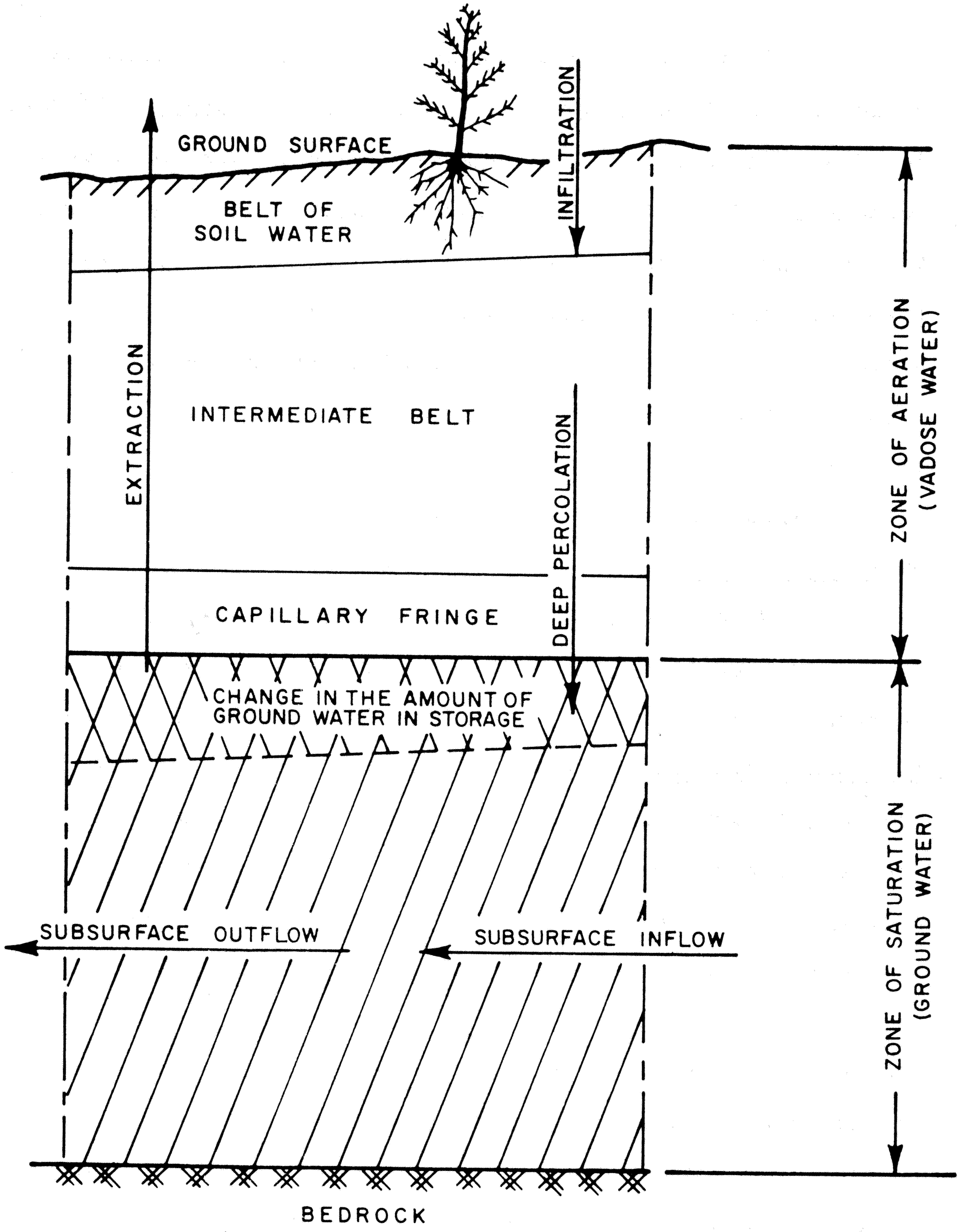


DIAGRAM SHOWING
GENERALIZED HYDROLOGIC ELEMENTS OF SUBSURFACE WATER

As mentioned previously, the zone of aeration is relatively shallow in the San Joaquin area, averaging 70 feet in 1964. In addition, the surface sediments are relatively permeable. Consequently, it can be assumed that the travel time of water through the zone of aeration is short, less than one year. This means that it can be assumed that annual surface inputs to the zone of aeration are annual inputs to the zone of saturation, which is the zone of interest for this investigation since it is only from the zone of saturation that water can be extracted.

Water Movement in the Zone of Saturation

Water moves in the zone of saturation from points of higher head to points of lower head. The direction of movement of water can be determined from contour maps (Lines of Equal Elevation of Water in Wells, Figures 4 and 5). However, before a definitive statement can be made about ground water movement in the San Joaquin County area, the geologic environment must be carefully evaluated. Geologic evidence and water well data indicate that the water table in the San Joaquin County area behaves essentially as a free ground water basin. Local clay layers and local subsidence in the Stockton area suggest there may be minor local pressure effects. That is, water levels measured in some wells are perhaps piezometric heads rather than free ground water levels. These effects, however, are considered local and negligible in the total basin picture.

Because of heavy ground water withdrawals in the Stockton area, a ground water "pumping hole" has been developed. The ground water levels are lower in the Stockton area than in the surrounding region. As a result, ground water flows toward Stockton from the areas of recharge along the Mokelumne River, the Sierra foothills, and the area north of the Stanislaus River. In addition, the pumping hole in the Stockton area causes an eastward ground water gradient such that inferior quality ground waters are moving into the Stockton area from the Delta. The movement and nature of these waters will be discussed in detail in Chapter III. The effects of this "hole" under Stockton were mentioned in the section on Subsurface Flow and will be discussed in detail under Problem Areas (Chapter IV).

Inflow and Outflow at the Zone of Saturation

Water entering or leaving the zone of saturation may be considered as deep percolation to the zone of saturation or as ground water extractions from the zone of saturation. A knowledge of the magnitude of these quantities will aid considerably in understanding the hydrology of the basin but are not used in determinations of overdraft.

To calculate deep percolation and ground water extractions, ground water pumpage data is needed. However, an attempt to collect this data disclosed that the cost of compiling ground water pumpage data was beyond the means of this investigation. Therefore, a rough estimate was made instead by assuming a gross basin efficiency for the basin and using information developed for estimates of water supply, use, and disposal. A description of the estimations of deep percolation and ground water extractions is presented below.

Deep Percolation. Deep percolation is defined as water that percolates beyond the aeration zone and that reaches the zone of saturation. The components of deep percolation for this report are: streambed percolation, deep percolations of precipitation that falls on the basin surface, and deep percolation of delivered water. Deep percolation of delivered water consists of waste water percolation, and percolation of applied water together with conveyance losses. Percolation in streambeds and from precipitation are natural means of ground water recharge while deep percolation of delivered water is an incidental ground water recharge.

The difference between delivered water disposal and delivered water supply is deep percolation of delivered water (Figure 11). Delivered water disposal was estimated by summing the seasonal consumptive use of applied water, waste water production, and return flow from irrigation.

A gross basin efficiency of 75 percent was assumed on the basis of estimated efficiencies for other similar basins. An annual deep percolation of delivered

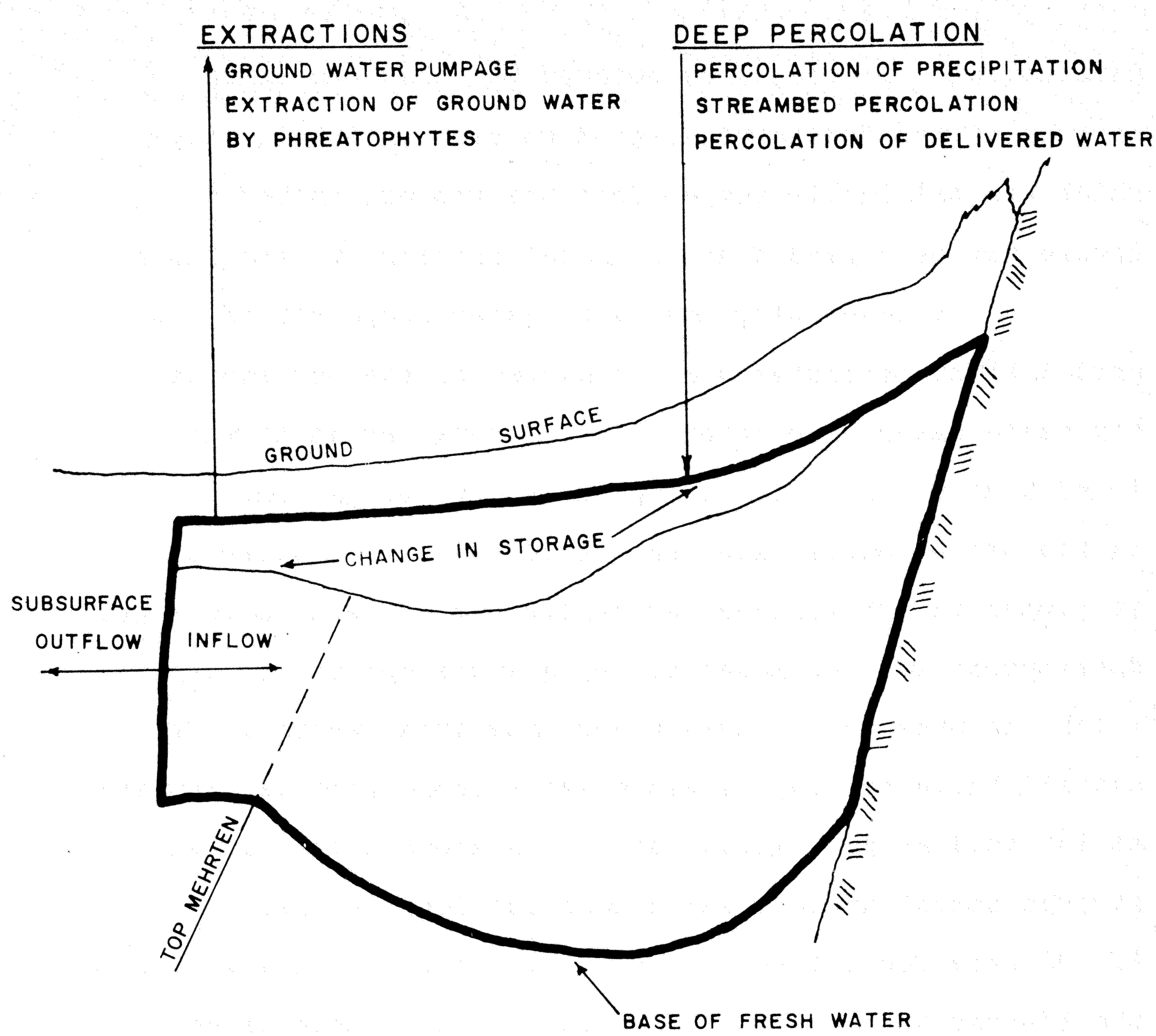


Figure II THE ZONE OF SATURATION AS A FREE BODY

water supply, which includes both surface water and pumped ground water, was calculated by dividing delivered water disposal by the basin efficiency, giving delivered water supply, then subtracting out delivered water disposal. As a result, a mean annual deep percolation of delivered water of 260,000 acre-feet was obtained. This amounts to about 35 percent of 675,000 acre-feet, the total deep percolation. It should be pointed out that the major portion of the delivered water deep percolation is water which was originally pumped from the ground, therefore it should not be regarded as an annual recharge to the basin.

In developing the waste water component of deep percolation, estimates were developed of the per capita day waste water production. In the rural areas it was found that prior to 1960, approximately 100 gallons per capita day of waste water was developed, while after 1960 it jumped to 145 gallons per capita day. Urban waste water development was estimated as 195 gallons per capita day, which includes both domestic and industrial wastes. The overall basin per capita waste water production is estimated as 160 gallons per capita day. This amounts to a total average annual waste water production for the basin of 42,000 acre-feet, based on the 1950 and 1960 census. During the 14-year base period the annual average waste water exported was 22,000 acre-feet. This means that approximately 20,000 acre-feet of waste water percolated into the ground water each year.

Deep percolation from stream flow and precipitation was estimated from stream gauging station records and the calculated annual volume of precipitation supply to the basin and disposal of these quantities. Supply is equal to surface inflow plus precipitation minus surface diversions in the basin, and disposal is equal to surface outflow plus consumptive use of precipitation minus irrigation return flow. The mean annual deep percolation from these sources was about 415,000 acre-feet for the 14-year base period, or about 65 percent of the total deep percolation. It is of interest to note that the mean seasonal deep percolation contributed by flow in the Mokelumne River was about 134,000 acre-feet, or about 33 percent of the natural deep percolation.

Ground Water Extractions. Ground water extractions from the zone of saturation result from pumped ground water extractions by man, and extractions by nature. The only natural extractions are by deep-rooted water-loving plants, which are insignificant in San Joaquin County. Therefore, these extractions can be considered as negligible. Consequently, the ground water extractions discussed here are by ground water pumpage.

As mentioned earlier, ground water pumpage was not easily available for compiling; therefore, it was estimated by subtracting the estimated deep percolation and net subsurface flow from water supply surplus or deficiency (see Figure 11). The values were checked by subtracting consumptive use of precipitation and surface water and imported water from the total consumptive use. This resulted in a rough check on the ground water extractions which compared reasonably with the calculated values.

It is estimated that the average annual ground water pumpage in the study area was 745,000 acre-feet for the

14-year base period. Of this, about 58,000 acre-feet were for urban uses. Approximately 92 percent of the total average annual pumpage was used for rural and agricultural purposes.

Ground Water Storage and Change in Storage

The determinations of ground water storage capacity and change in ground water storage are based on an analysis of well logs, water level measurements, and specific yield of the various types of sediments within the study area. In this analysis, a specific yield is assigned to each sediment type in all available logs in a township and the average specific yield for each increment of depth in the township is then determined (Appendix 3). These average specific yield values are multiplied by the volume increment of sediment in the township to determine storage capacity of the township (Appendix 4) in increments of 20 feet.

The total available ground water storage capacity from 20 feet below the land surface to the base of the ground water basin, as previously defined, is about 42,400,000 acre-feet. The total volume of sediments is 579,900,000 acre-feet, therefore, the average specific yield for the entire ground water basin study area is 7.3 percent.

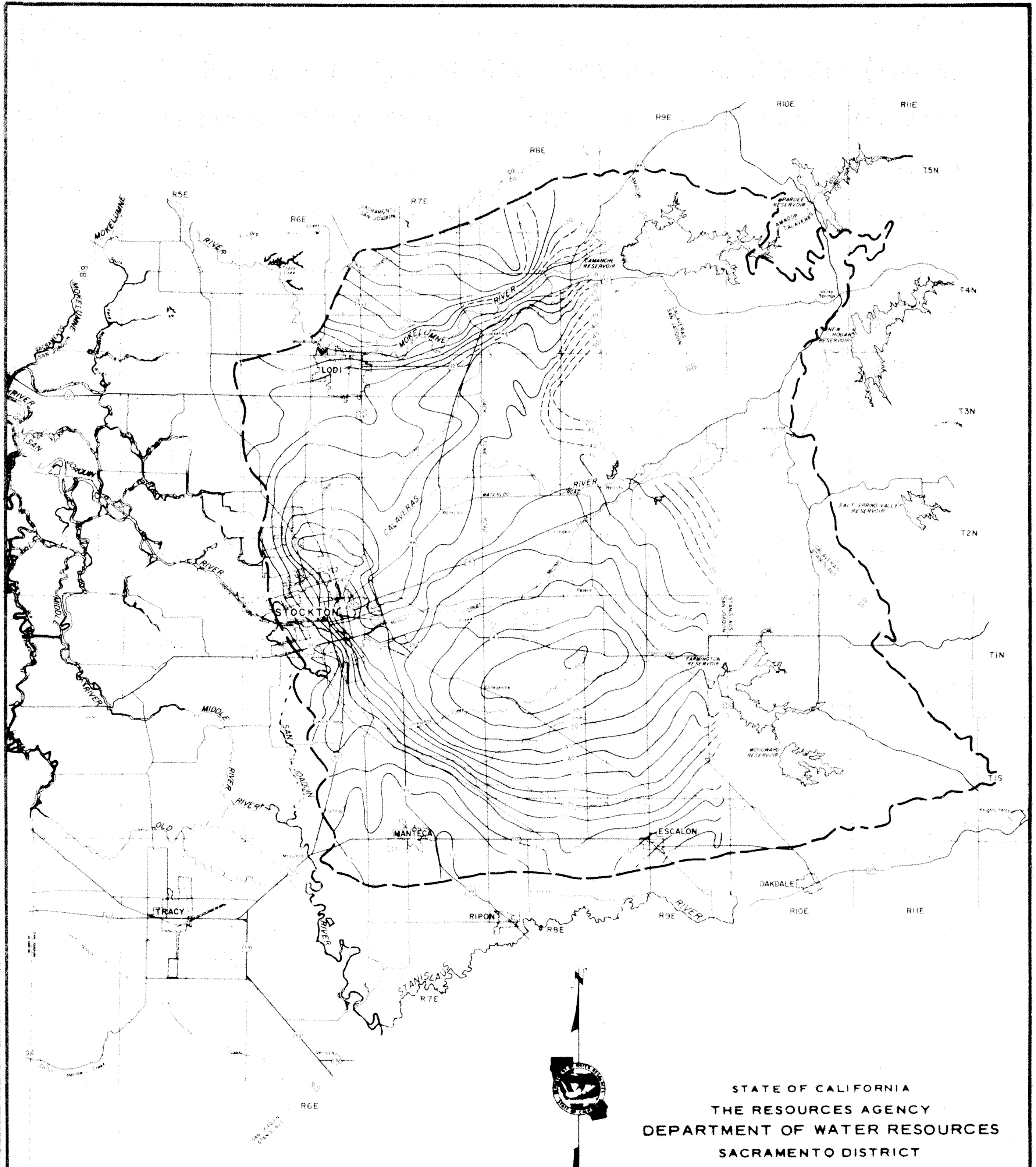
Change in ground water storage can be calculated also by the specific yield method. Here the weighted average change in water level for a township from year to year (fall to fall, as determined from water wells) is multiplied by the weighted average specific yield of the interval over which the change occurred to obtain the change in storage in acre-feet of water. The algebraic sum of all township changes is the total change in storage over the basin.

Figure 12 shows the change in ground water level in wells over the 14-year study period. Plates 8A and 8B indicate the change in water storage in feet of water. With these Plates, it is possible to determine the approximate change in storage in acre-feet of water of any given area over the 14-year study period. This is done by taking subareas between contour lines and multiplying this figure by the average change in feet of water for the subareas. A summation of all subareas gives the total change in acre-feet of water.

The closures on Plates 8A and 8B are the areas where the most water has been removed, as compared to Figure 12 which shows areas of maximum change in elevation of water in wells. Variations in configuration between the two enclosures are due to changes in specific yield with area and depth. It is worthwhile noting that an area of closure, not apparent on Figure 12 except by a broadening of contours, has developed southeast of Lodi near the intersection of Jack Tone and Eight Mile roads.

Ground Water Overdraft

Ground water overdraft is defined for this report



LEGEND

— 50 LINE CONNECTING POINTS OF EQUAL CHANGE IN ELEVATION OF WATER, IN FEET. DASHED WHERE APPROXIMATE

— — OUTLINE OF HYDROLOGIC STUDY AREA

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

SAN JOAQUIN COUNTY
GROUND WATER INVESTIGATION

LINES OF EQUAL CHANGE IN ELEVATION OF WATER FALL 1950 TO FALL 1964 IN FEET

1967

SCALE OF MILES

2 0 2 4 6

as the average annual decrease in fresh ground water in storage during a long time period under a particular set of physical conditions that affect the water supply, use, and disposal in the basin. The water and climate conditions during the 14-year base period are considered as equivalent to conditions during the long time period. The physical conditions affecting the supply, use, and disposal of water are considered as the cultural and physical conditions that existed in 1964 in San Joaquin County. These assumptions fix the mean annual amounts of supply, use, and disposal at one level for the 14-year base period. These assumptions also fix the place and manner in which the water supply is applied, used, and disposed.

Mean annual precipitation is not affected by cultural conditions; therefore, the mean annual precipitation under 1964 conditions is equal to the historical average annual precipitation. The average annual surface water inflow under 1964 conditions was estimated by adjusting historical mean annual surface inflow. Surface water inflow has decreased because of an increase in diversions from Pardee Reservoir on the Mokelumne River. Since 1959, East Bay Municipal Utility District has increased their flows through the Mokelumne aqueduct from Pardee Reservoir, by an average of 48,700 acre-feet per year. This problem has been alleviated since 1964 by the completion of Camanche reservoir.

East Bay Municipal Utility District built this facility to meet their legal requirements toward water demands in the Mokelumne River below Pardee Reservoir, and to permit an increase in exports from the Mokelumne River. Since the mean annual surface inflow under historical conditions already reflects a portion of the decrease in inflow, the average decrease in surface water inflow due to these diversions was adjusted by 31,000 acre-feet per year for determining overdraft under 1964 conditions. Accordingly, the average annual surface inflow under cultural 1964 conditions is 712,000 acre-feet.

Water imported by Oakdale and South San Joaquin Irrigation Districts for use both inside and outside the study basin had increased an average of 34,000 acre-feet per year since 1961 as a result of completion of the several dams on the Stanislaus River. More water is available for irrigation in the summer months. Consequently, the average annual fresh water imports under 1964 cultural conditions are estimated as 390,000 acre-feet.

Exports of fresh water by South San Joaquin and Oakdale Irrigation Districts to areas outside the study boundary increased annually by 22,000 acre-feet as a result of increased imports. Therefore, fresh water export for 1964 average annual cultural conditions were determined to be 170,000 acre-feet. Waste water export has gradually increased in relation to the population increase. Under 1964 cultural conditions waste water exports were therefore taken as the 1963-64 waste water outflow.

Mean annual consumptive use of precipitation and of applied water that would have occurred under 1964 cultural conditions is 1,204,000 acre-feet. This amount was estimated by applying average historical unit consumptive use values to 1964 land use which was projected from the 1958 Department Survey as explained under Consumptive Use.

Surface outflow under 1964 conditions has undergone a cultural change, due essentially to the decrease in surface water inflow under 1964 conditions. To determine the decrease in surface outflow for 1964 conditions, a ratio of the average surface outflow and inflow for the Mokelumne River, where the decrease has occurred, during the base period was multiplied by the difference between mean annual surface inflow and annual surface inflow under 1964 cultural conditions. The surface water outflow for 1964 cultural conditions was determined to be 595,000 acre-feet.

Subsurface flow items require a more complicated adjustment because the hydrologic balance considers both poor and good quality waters. In determining overdraft only good quality waters are considered. Therefore, for purposes of the overdraft calculations historic net fresh water subsurface flow is shown on Table 4 as 3,000 acre-feet outflow. The net fresh subsurface flow for 1964 conditions was taken as that which occurred in 1964, 2,000 acre-feet inflow.

TABLE 4

MEAN ANNUAL OVERDRAFT IN THE SAN JOAQUIN COUNTY
GROUND WATER BASIN UNDER 1964 CONDITIONS

In Thousands of Acre-Feet

Items of Total Water Supply and Disposal	Mean Annual Amount Under 1964 Conditions	Mean Annual Amount Under Historical Conditions	Difference	Decrease In Ground Water Storage
Average Annual Decrease in Ground Water Storage during Base Period under Historical Conditions				66
Average Annual Change of Fresh Water Storage Due to Poor Quality Water Intrusion under Historic Conditions				7
True Average Annual Decrease in Fresh Ground Water Storage During Base Period				73
Fresh Water Supply				
Precipitation	767	767	0	
Surface inflow	712	743	-31	
Fresh water import	390	356	+34	
Net subsurface flow	+2	-3	+5	
TOTAL SUPPLY	1,871	1,863	+8	-8
Fresh Water Disposal				
Consumptive use	1,204	1,146	+58	
Surface outflow	595	618	-23	
Waste water export	23	22	+1	
Fresh water export	170	148	+22	
TOTAL DISPOSAL	1,992	1,934	+58	+58
Annual Overdraft (mean Annual Change in Storage During Base Period under 1964 Conditions				123

A change in fresh water storage did occur during the base period due to the intrusion of poor quality waters along the western boundary, which is in addition to the 66,000 acre-feet shown in the hydrologic balance. An adjustment of 7,000 acre-feet representing the average annual change in storage during the base from that source is also included. This brings the true annual decrease in ground water storage to 73,000 acre-feet.

The annual amounts of water supply, use, and disposal under 1964 cultural conditions and historical conditions are summarized in Table 4. The mean seasonal overdraft on the ground water basin, under 1964 cultural conditions, was estimated as 123,000 acre-feet.

New Hogan Reservoir, with an expected average yield of 55,900 acre-feet per year for irrigation, will have a definite effect upon the overdraft conditions if the waters are applied in those areas of overdraft. It should be pointed out the value reflects old as well as new waters. This new supply of water did not enter the calculations of overdraft because it was not available until after the close of the study period.

CHAPTER III

WATER QUALITY

Introduction

The quality of ground water is principally dependent on and controlled by the physical nature of the basin, as described in Chapter I, and the source, quantity, and movement of the water as described in Chapter II. This means that the quality of water pumped from a well of any depth, anywhere in the basin, can be roughly predicted if the items in the first two chapters are defined and understood well enough.

The quality of ground water has been and will continue to be the prime consideration to anyone seeking a water supply in the County for most any purpose. Ground water is available almost everywhere, with only a very few areas where pumping lifts or quantity would be an important limiting consideration.

To have any assurance of reasonable quality water when a new well is drilled, or to maintain quality in an existing well or well field, it is essential to know the existing quality conditions and predict possible future changes.

This chapter shows the chemical makeup of the ground water and how it affects beneficial uses, the sources of both good quality ground water and inferior quality waters, also the direction and rate of movement of poor quality ground waters.

Criteria and Standards

Use and desirability of a water supply is dependent upon its quality. If the supply comes from the ground water basin, several aspects of quality are generally eliminated from concern since ground water is almost always free from turbidity, algae problems, changes in temperature, sudden changes in quality and pathogenic bacteria. However, in most large municipal systems chlorination of the supply is provided as an added safeguard.

The fact that ground water can be used just as it is pumped from the ground, and the fact that it is available at relatively shallow depths almost everywhere in the County make ground water preferred to surface water in this area for domestic and industrial use.

The one limiting factor to the use of ground water in San Joaquin County is its tendency to dissolve mineral salts. Unlike surface water, which does not appreciably increase in salt content except with use, ground water picks up minerals while in transit. From the time water enters the ground it continues to add to its mineral load while at the same time changing its mineral proportions.

As ground water percolates from areas of recharge to areas of withdrawal, mineral salts are dissolved from the formations through which the water moves. The chemical and physical nature of the formation determines in part the makeup of mineral salts in solution and the total amount.

The amount and type of mineral salts affect and limit the uses to which the water is put. The most prominent feature of dissolved mineral salts in ground water is a phenomenon which is called "hardness". This hardness characteristic is a chemical property that has only slight effect on the taste of water. In general, water users report that hardness improves the flavor. Hardness in water is not a great concern to use of water for irrigation; in fact, hard water is superior to soft water for irrigation. (78)

The primary concern with hardness in water is from domestic, municipal, and industrial users. These users complain primarily of the following hardness problems:

1. Interference with soap efficiency, and residue left by action of soap and hardness properties;

2. Formation of scales in boilers, water heaters, pipes, and utensils.

In addition, many industrial users have specific objections to hardness in water because of interference with particular processes or adverse effects on products. Hardness in water is quite common and widespread; it has several undesirable effects but it can be removed or reduced to acceptable limits for most purposes with slight additional cost on both municipal and individual levels. For this reason, in this report, hardness is not considered as a serious water quality problem.

An approximate hardness measure of the water obtained at any point in the County is available in this Department's Bulletin 74-5 "Water Well Standards: San Joaquin County" Plate No. 10.

Hardness is caused by the presence of calcium and magnesium ions dissolved in the water.

Besides hardness, there are other mineral constituents that make up a dissolved salt load of a water supply. Some of these constituents affect the desirability of the water supply for domestic use only. Some affect irrigation uses only, but most are of concern to general water uses.

Water quality and criteria standards have been developed for most uses of water. These standards are in the form of suggested to mandatory requirements that govern desirability or use of water.

The U. S. Public Health Service has developed a set of "drinking water standards" to be used in interstate commerce. These criteria have been adopted by the California State Department of Public Health and also can serve as a guide for the suitability of a water supply for individual homes. These standards are reproduced in Appendix 5.

There are several sets of criteria published for use to evaluate water for irrigation. The standards that this Department uses are included in Appendix 5. Irrigation water quality criteria are of a general nature and many additional factors must be considered such as climate, soil, irrigation methods, and type of crop. The County Farm Advisor can be helpful in adaption of these criteria to actual field situations.

As mentioned previously, industries have numerous different quality requirements for water supply. A good discussion of these demands can be found in "Water Quality Criteria" (38).

In the following paragraphs, the ground water quality existing in various areas of the County is discussed and the various general constituents contained are compared against these previously mentioned standards and an evaluation made on the suitability of the supply for the various intended uses.

Ground Water of Good Mineral Quality

East Side Sources. The principal source of ground water of good mineral quality is from streams originating in the Sierras and infiltration of rainfall on the eastern portion of the County. These sources feed the ground water basin beneath the entire east half of the County. The three rivers flowing westward out of the Sierras are particularly important for at least three reasons, which are:

1. The volume of water contributed as recharge. (The mean annual deep percolation of stream flow and precipitation was about 415,000 acre-feet for the 14-year base period.)

2. The good chemical nature of the streams.

3. Nature of the deposits comprising the ground water basin were determined by the streams.

Another source of native ground water of good quality is located in the southwestern portion of the County, near Tracy. This water generally occurs beneath the Corcoran Clay and is probably recharged from Sierra streams south of the County line.

Minor areas of native ground water of good quality are supplied from the San Joaquin River, close to its banks. The remaining ground water areas of the County are generally of inferior quality and will be described later.

The most significant sources of recharge are the Mokelumne and Stanislaus Rivers which contribute the major portion of water volume and drain areas that are in large part of granitic origin. The Calaveras River and smaller eastside streams contribute a minor volume and drain areas composed almost entirely of metamorphic and volcanic rocks.

Rivers whose source is from granitic drainage basins tend to have lower dissolved mineral salt content than those from volcanic or metamorphic areas. This can be seen in a comparison in surface water quality on the Mokelumne and Calaveras Rivers where the former has less than one-half the total salt content of the latter (25). This difference is less evident in the Stanislaus River probably because return irrigation water causes quality changes in the lower portion of the river.

In surface streams originating in the Sierras, the bicarbonate ion is the predominant anion, and for the Mokelumne and Stanislaus Rivers calcium and sodium cations are usually prominent, whereas the Calaveras River usually has a predominance of calcium and magnesium cations.

Streams that recharge the ground water body beneath the Corcoran Clay cannot be identified but must be similar in quality to the Mokelumne and Stanislaus Rivers.

The quality of the San Joaquin River in this area is quite variable but at times when it contributes most to recharge (during high flows) the quality is good; however, the areas where it provides recharge in this County are believed to be extremely minor.

In the Delta the many surface channels and sloughs provide some local recharge to very small localized ground water bodies; however, this is minor and the effect limited in extent since only local lenses of fresh water are found. A further discussion of the Delta ground water is included later.

After water infiltrates into the ground and moves through the deposited sediments its mineral content is slowly altered by contact with these sediments. The nature of the chemical change is related to the types of sediments which are dependent to some extent on the nature of the material the streams have eroded from the drainage basin and have deposited as alluvial fill.

The different mineral content of recharge water, the different sediments through which the ground water percolates, and the different rates and volumes of water moved are responsible for the differences in quality of ground water that is found in the various areas of the County.

Since only slight differences exist in quality of the east side streams and alluvial deposits developed by these streams, and because of the intermixing of flow in the entire eastern portion of the County, there are only slight variations in quality of ground water in this area. This difference is evidenced by slight changes in proportioning of the three prominent cations, calcium, magnesium, and sodium. The bicarbonate ion is almost always the major constituent of the anions.

During the westward migration of ground water a natural softening process takes place through a gradual exchange of calcium and magnesium, the hardness causing elements, for the sodium ion. This phenomena is complex and subject to many variations; however, it is a fairly consistent fact that the further away and deeper in the sediments the water has migrated, the softer the water seems to be. An example of this can be seen in the Stockton area where the percent sodium (the ratio of sodium to other cations) in wells below 400 feet deep generally is greater than 50 and often around 75, whereas wells with depths less than 400 feet have percent sodium less than 50. Of course, percent sodium is related to the water hardness and of great interest to municipal water users.

Geochemical diagrams have been prepared showing the general chemical nature of the ground water. These diagrams are included with the three geologic cross sections on Plates 3, 4 and 5. They show the proportion of chemical constituents that make up the dissolved salt content of the ground water. Trends and changes can be seen as the water migrates towards the Delta area. The graphs show differences in ground water that would not be easily detected from the analysis sheet. Changes in chemical character of ground water were compared with diagrams of surface water, sea water, Delta surface and ground water, and many waters from outside the area of study.

The total dissolved solids concentration in ground water in this eastern portion of the County ranges slightly higher than the surface water, with ranges from 175 to 600 ppm with the higher concentrations generally occurring at shallow depths (less than 100 feet).

The chloride ion has been used in this report and many others as an indicator of the overall mineral quality of ground water. This is probably because the ion is easy to test for, and is usually not affected by exchange like the cations. Also, chloride ion is very abundant in most sources of polluted water or waters of high salinity. For instance, sea water has about 19,000 ppm of chloride ion.

For this area (from east side recharge) ground water of good mineral quality will probably not have chloride concentrations in excess of 75 ppm. If the chloride concentration is in excess of 75 it is quite likely that at least part of the supply comes from sources other than east side runoff. In many samples examined from the Stockton-Lathrop area when the 75 ppm value is exceeded, the chloride content of a well supply continues to increase, since the source of the high chlorides (Delta ground water) becomes a major contributor. Many times this increase was ultimately responsible for the abandonment of the well.

Nature of ground water of good mineral quality which is supplied from east side sources can roughly be summarized as follows:

1. The ground water has no constituent present that would interfere or limit its use for all of the uses commonly found in the area, with the exception of possibly hardness which was discussed previously.

2. The total dissolved solids range generally between 175 and 500 ppm with chloride concentration usually below 75 ppm.

3. Areas of ground water recharge principally by the Mokelumne and Stanislaus Rivers would probably have slightly better quality than those recharged from the Calaveras or other local eastside streams.

<u>Tracy Area</u>. In the southwestern portion of the County, near Tracy, a small but important area of ground water of good mineral quality exists. This ground water body can roughly be described as existing below the Corcoran

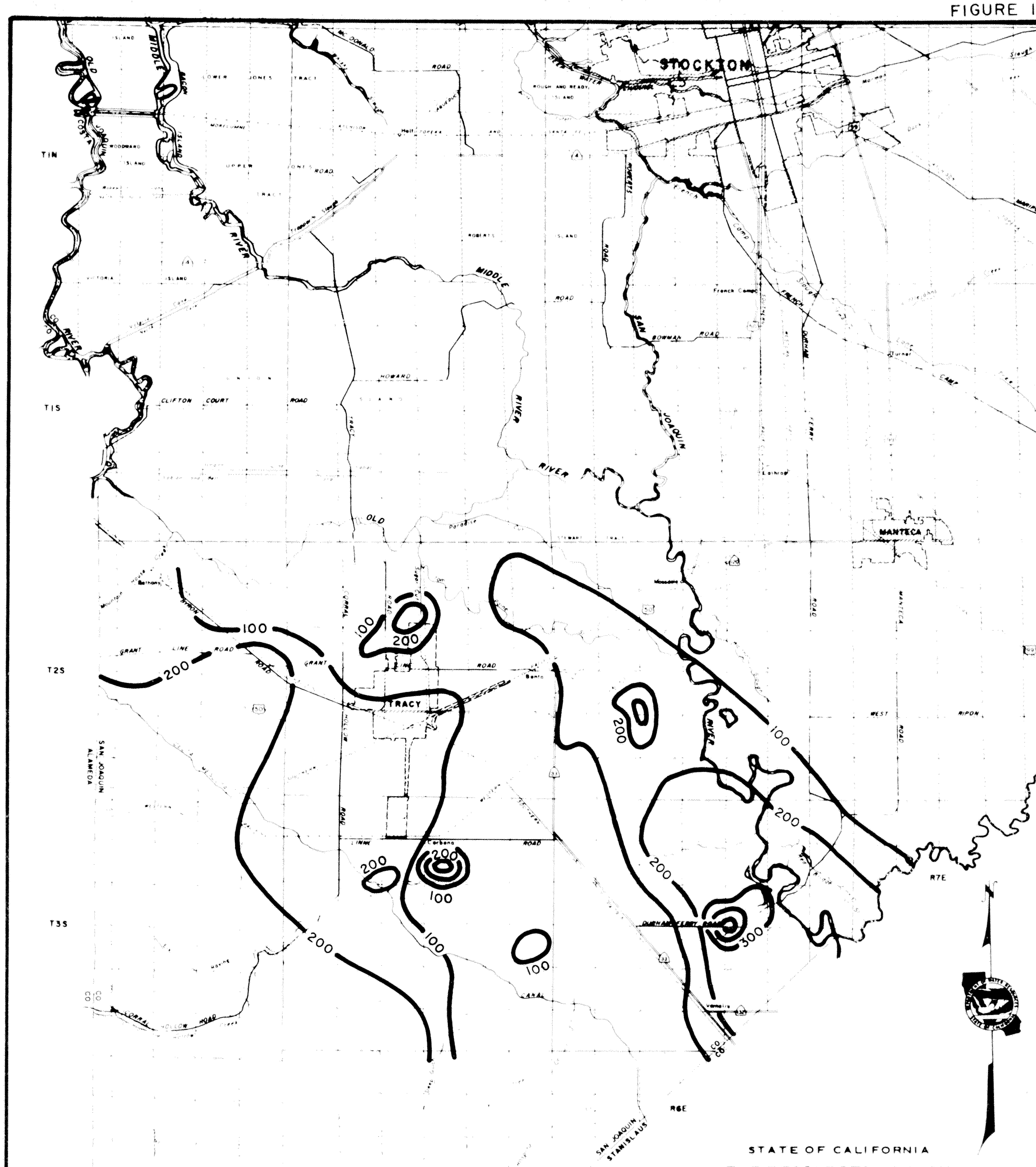
Clay; however, the same water can be found at about the same depth interval in areas just beyond where the Corcoran Clay is thought to pinch out.

The source of this water is difficult to trace but it is believed that around 1916 (63), ground water in this confined zone moved northward toward the Delta. At the present time, limited data indicate that movement of water is toward areas of heavy withdrawal of ground water (see Figure 5).

Water beneath the Corcoran Clay is in most places of different character and concentration than the overlying waters. Generally these waters are higher in sodium percentage and lower in mineral content than the overlying waters, and are lower in mineral content than that of the local west side streams. The increase in sodium proportionate to calcium and magnesium is more than likely due to cation exchange reactions of sodium ions on the clay particles in an equivalent trade (63). This phenomenon is called "natural softening" and is similar to the reaction occurring in the previously described east side recharge area.

The ground water in this zone is different from the previously described "east side source water; principally in the larger proportion of sulfates in solution and small but significant increase in boron concentrations. Both sulfate and boron in these deep waters beneath the Tracy area showed increases in the direction of the upper (shallow) aquifers in the area.

FIGURE 13



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

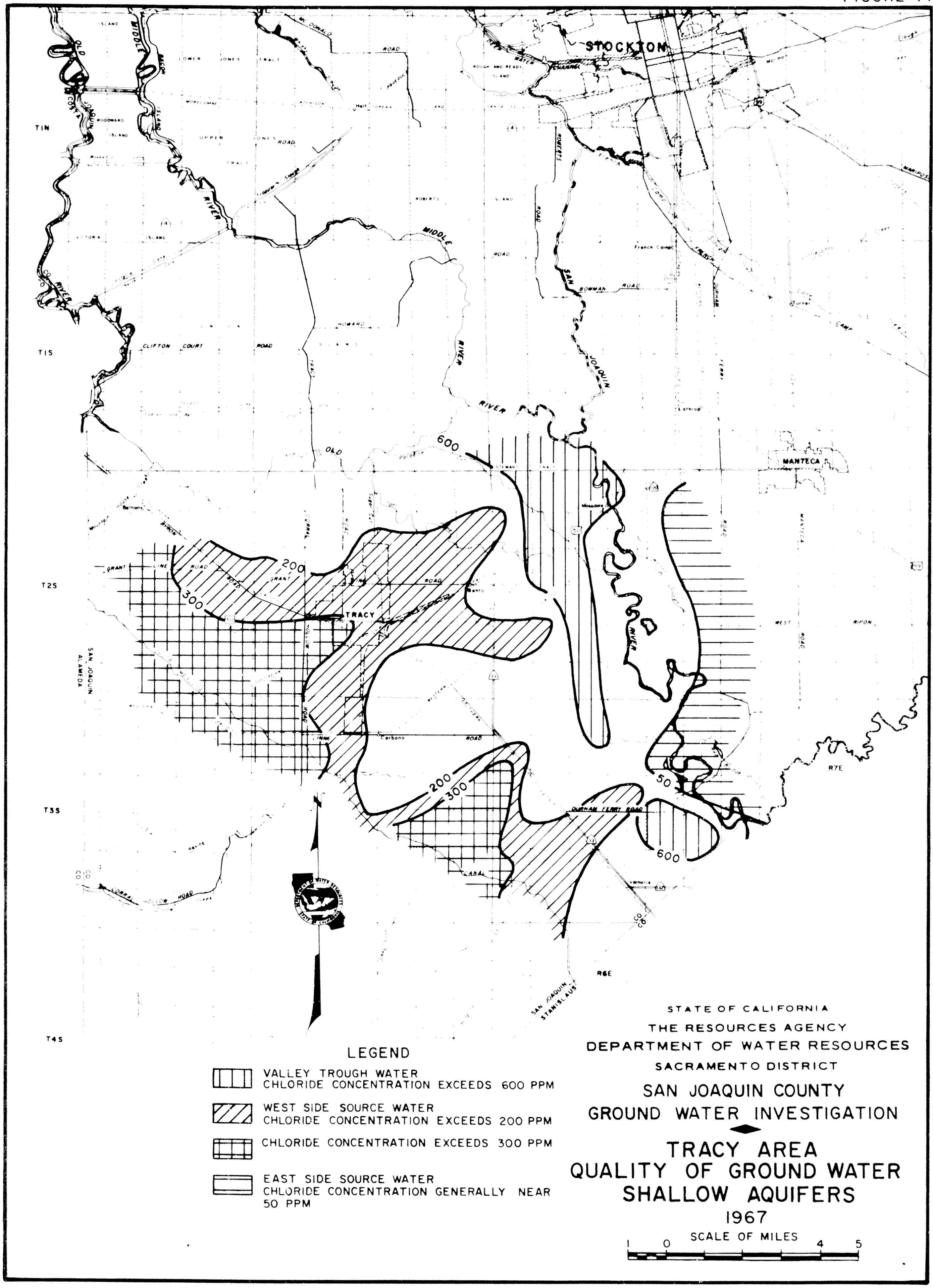
SAN JOAQUIN COUNTY
GROUND WATER INVESTIGATION

TRACY AREA
QUALITY OF GROUND WATER
DEEP AQUIFERS
1967

SCALE OF MILES
1 0 4 5

LEGEND

100 LINES OF EQUAL CHLORIDE CONCENTRATION FROM WELLS IN PARTS PER MILLION


STOCKTON
TRACY
MANTECA
600
200
300
50
600
LEGEND
VALLEY TROUGH WATER
CHLORIDE CONCENTRATION EXCEEDS 600 PPM
WEST SIDE SOURCE WATER
CHLORIDE CONCENTRATION EXCEEDS 200 PPM
CHLORIDE CONCENTRATION EXCEEDS 300 PPM
EAST SIDE SOURCE WATER
CHLORIDE CONCENTRATION GENERALLY NEAR 50 PPM
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SACRAMENTO DISTRICT
SAN JOAQUIN COUNTY
GROUND WATER INVESTIGATION
TRACY AREA
QUALITY OF GROUND WATER
SHALLOW AQUIFERS
1967
SCALE OF MILES
1 0 4 5

The City of Tracy, many industries, and the Tracy Defense Depot rely on this deep zone for their supply. Many agricultural wells penetrate the Corcoran Clay and in the past it was common practice to gravel pack wells and perforate in all the producing zones, from the surface down. In the last few years many quality problems have been experienced, mainly from these multiple aquifer agricultural wells. It is believed that the principal source of trouble is from the upper aquifer that yields less desirable water than the lower aquifer. This can be seen in Figures 13 and 14, and a further discussion of the quality of the upper aquifer appears in the following sections.

Figure 13 shows ground water quality in the lower aquifer as interpreted from well samples. The results can only be approximated due to the difficulty in determining the source of the water produced in many of the deep wells. It is often not known for sure whether a well is producing only from the upper or the lower aquifer, or whether it is a mixture or a result of leakage into the well.

Areas of poor quality shown on Figure 13 appear to be a result of leakage or interconnection between the upper and lower aquifer. These appear on the Figure as islands. Many of the islands are results of only one well sample and may not actually mean that the lower zone is degraded over several hundred acres.

An exception to this is the increase in salinity of the ground water toward the southeast along the trough of the Valley. In this area, the quality interpretation is supported by other reports covering areas south of the County line (47 and 63). These reports confirm that the trough of the Valley contains ground water of very inferior quality along an extensive area.

The lower zone produces good quality water for domestic and agricultural use, within the rough boundaries shown on Figure 13. The pumping demand on this zone is high and the water pressure surface is pulled down during the summer and fall of every year. The trend over the years has been a lowering of the pressure surface. The lowering pressure levels in the lower zone can increase the threat of degradation since this zone is surrounded from above, below, to the west, to the north, and to the southeast by waters of inferior quality. The result of this lowering on the supply and future supply of the area cannot be evaluated at this time; however, the United States Geological Survey, Water Resource Division, in cooperation with this Department is currently conducting a ground water investigation covering the west side area, which incorporated this portion of the Tracy area south down to about the Gustine area.

The east side source and the Tracy area, or zone, which have been described above, are the only extensive areas where ground water of good mineral quality suitable for most all desired used can be obtained. These two areas cover a major portion of the County.

Minor Areas. Minor localized areas were ground water is of suitable quality can be found along portions of the San Joaquin River, under many of the Delta islands, and in many of the small foothill valleys. None of these areas is extensive enough to be shown on maps; however, they provide a limited supply to several homes and other uses.

Native Ground Water of Inferior Mineral Quality

Within the County boundaries there are several areas, or zones, of ground water of inferior water quality. These ground water bodies are important because of their areal extent, high salinity, and/or close proximity to important ground water supplies.

Base of Fresh Water

The most extensive area of inferior quality ground water is that existing below the "base of fresh water". Contours drawn on the base of fresh water are shown in Figure 8. These lines are based on interpretation of electric logs of gas wells or exploratory wells, but some water wells were used.

Matching of contour lines was made on the north and south of the County line, with contour lines plotted from other reports.

For this report, the base of fresh water is defined as the depth below which quality is always worse than a certain determined limit. This limit is generally picked at about 300 ppm of chloride content. Below the depth where 300 ppm is reached, quality generally continues to increase in salinity, frequently approaching and sometimes exceeding the salinity of sea water.

The ground water below the base of fresh water is often referred to as connate water. Connate water is water entrapped in the interstices of the sedimentary rock at the time the rock was deposited. This water has since been subjected to alterations due to long exposure to the formation and possible dilution or concentration through time. This means that connate water usually would be found in marine formations, but not always.

It can be seen from the geologic cross section that the contours on the base of fresh water do not always follow formation boundaries. This is because the base of fresh water contours are determined solely on quality of water.

One possible explanation of the base of fresh water cutting across formation boundaries is that the saline water, or connate water, has been partly flushed by fresh water in some areas, or the saline water has invaded previously fresh water zones.

The imaginary surface shown by the base of fresh water contours fixes an approximate lower boundary of the fresh water supply. In some areas the fresh water sediments are almost a thousand feet thick, such as beneath the City of Stockton, whereas the areas north of the Calaveras River and south of Stockton, towards Lathrop, are only about half that depth. If wells penetrate below this surface, trouble usually results.

Problems develop from heavy pumping of a well or well field even though the well or wells may bottom considerably above the base of fresh water. What generally causes this trouble is a cone of depression or pressure relief resulting from pumping wells in a formation where there is good vertical permeability relative to horizontal permeability. This would allow the more dense connate water to rise up through the formation in response to the diminished fresh water head above, due to pumping. This situation is not believed to have occurred anywhere in the County.

The base of fresh water contours as shown on Figure 8, are an approximate lower limit to the fresh ground water supply available within the County. They are not precise enough in any area to be considered as a lower limit of well exploration, but serve as a good limit for planning. If a new well depth comes close to the boundary it is advisable to take quality samples. Results of the sampling, and new data from petroleum exploration should be compiled and used for periodic improvement and updating of the contour map.

Delta Area

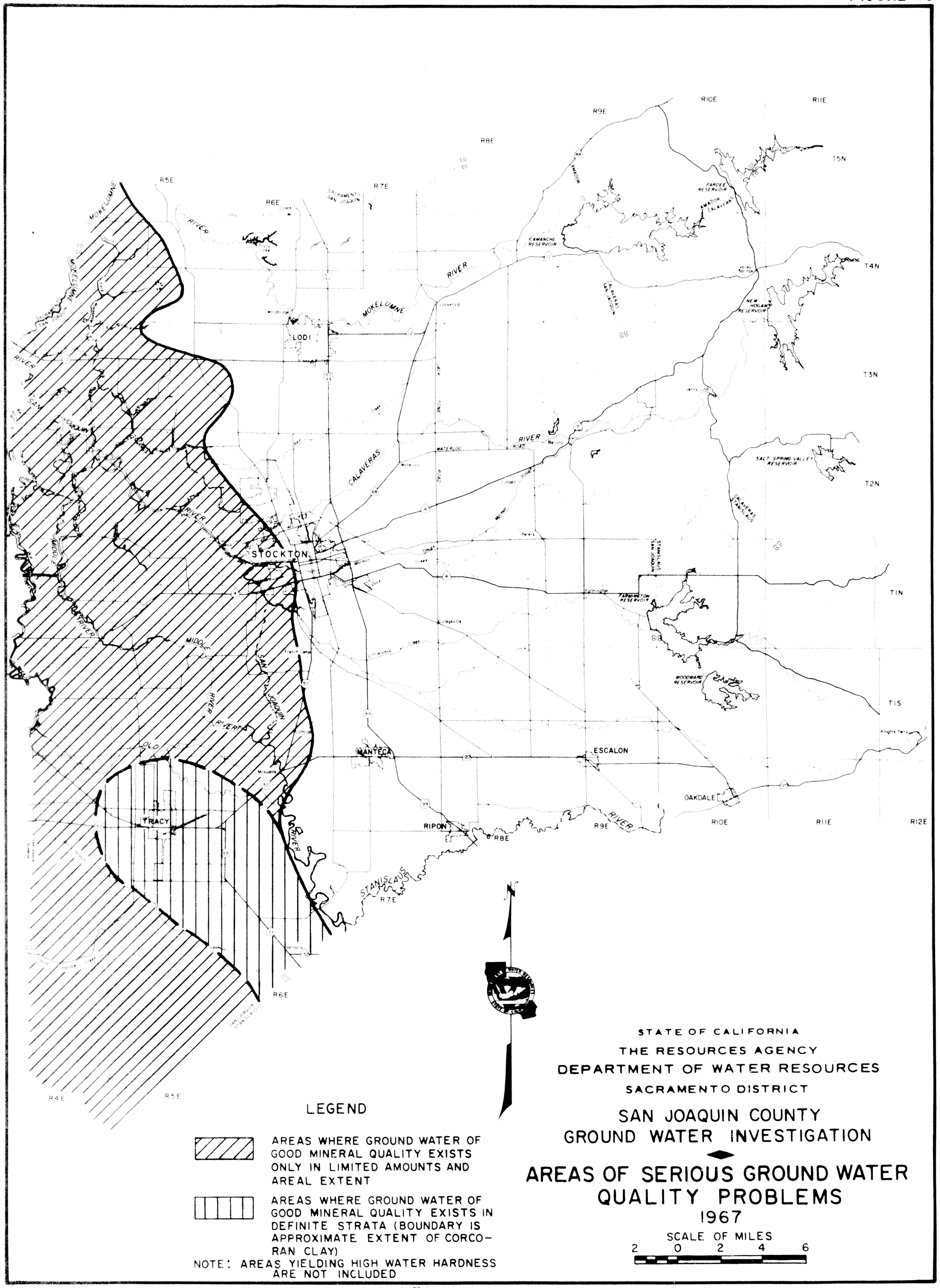
The Delta within San Joaquin County generally contains ground water of undesirable mineral quality throughout its entire surface area and from just below ground surface to the depth of unconsolidated sediments (see Figure 15). The few exceptions are local lenses of fresh water which are probably supplied from seepage from the Delta channels, and areas in the northwest portion of the County, where surplus surface water and ground water from the Mokelumne River system have probably flushed out or diluted poor quality ground waters.

The origin of the inferior quality ground waters in the Delta is still a matter of speculation. There are several possible reasons for the poor quality waters underlying the Delta. Among these, the following seem more likely; however, there is no agreement on which source, or combination of sources, is most probable:

1. Poor quality water may have accumulated in the trough of the valley and then moved northward to be squeezed out of the trough by higher water levels or pressure from the south.

2. A source of the inferior water in the Delta could be rising connates. These connates, deposited with the Deltaic sediments, are subject to pressure from surrounding areas and consequent upward movement in the Delta. The comparison of ratios of Delta ground water constituents with those of saline connates, indicates that this could be a possibility.

FIGURE 15


R10E
R11E
R9E
R8E
R7E
R6E
R5E
R4E
R12E
T5N
T4N
T3N
T2N
T1N
T1S
PARDEE RESERVOIR
CAMANCHE RESERVOIR
NEW HOGAN RESERVOIR
SALT SPRING VALLEY RESERVOIR
FARMINGTON RESERVOIR
WOODWARD RESERVOIR
MOKELUMNE
RIVER
CALAVERAS
SAN JOAQUIN
MIDDLE
STANISLAUS
OLD
LODI
STOCKTON
MANTECA
ESCALON
OAKDALE
RIPON
TRACY
LEGEND
AREAS WHERE GROUND WATER OF GOOD MINERAL QUALITY EXISTS ONLY IN LIMITED AMOUNTS AND AREAL EXTENT
AREAS WHERE GROUND WATER OF GOOD MINERAL QUALITY EXISTS IN DEFINITE STRATA (BOUNDARY IS APPROXIMATE EXTENT OF CORCORAN CLAY)
NOTE: AREAS YIELDING HIGH WATER HARDNESS ARE NOT INCLUDED
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SACRAMENTO DISTRICT
SAN JOAQUIN COUNTY
GROUND WATER INVESTIGATION
AREAS OF SERIOUS GROUND WATER QUALITY PROBLEMS
1967
SCALE OF MILES
2 0 2 4 6

3. Tidal action causes flow reversal and salinity intrusion in the Delta waterways. Seepage of these saline waters into the ground water could account for the poorer mineral quality; however, an examination of Figure 16 shows that intrusion of the 1000 ppm chloride line has never reached some areas of the Delta where ground water salinity is almost twice this value.

Tracy Area

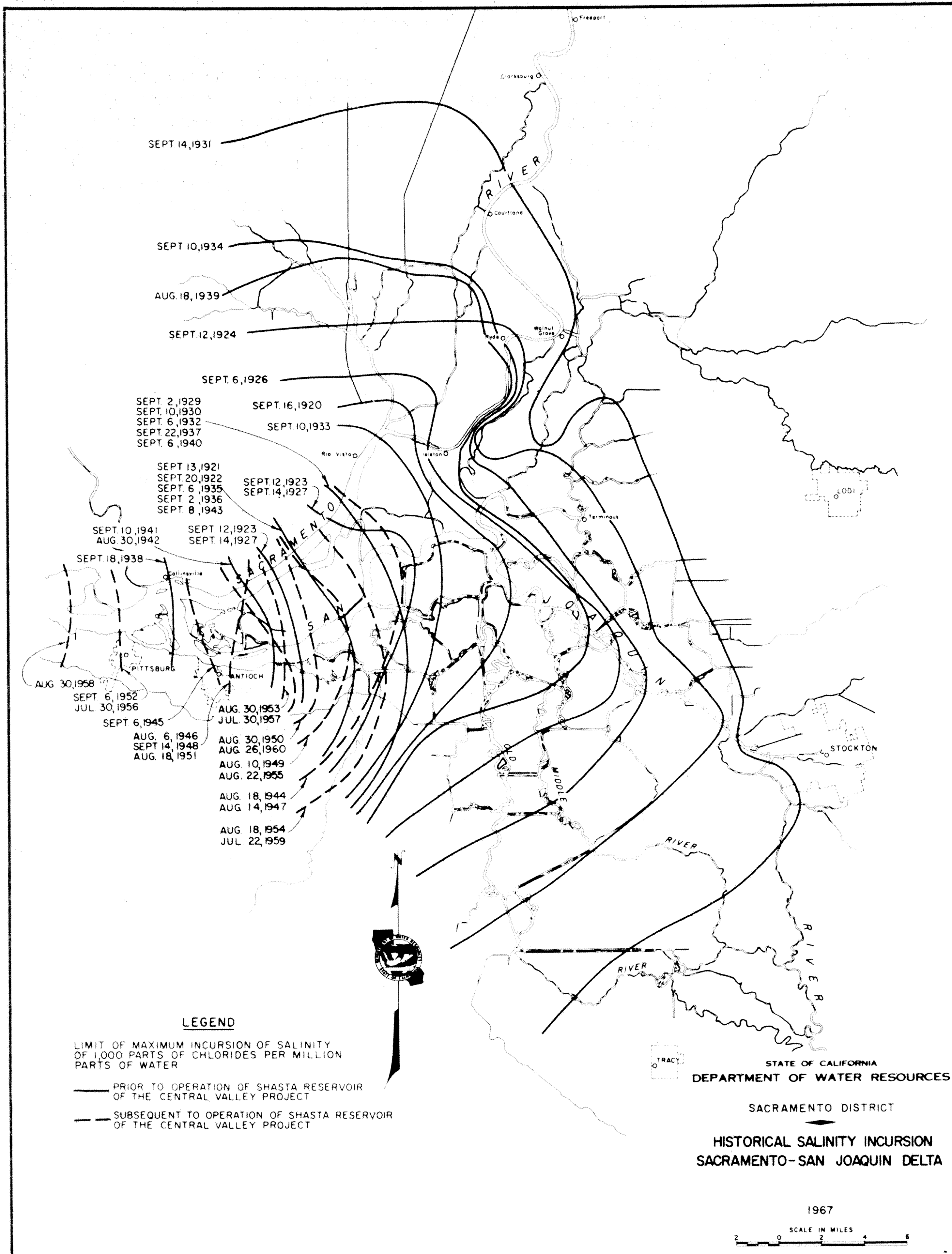
As mentioned previously, there are roughly two separate producing zones in the Tracy area. The quality of the lower zone was described earlier in this chapter as the area of "Native Good Quality Ground Water". This zone which exists generally below the Corcoran Clay, lies between the base of fresh water and the upper zone.

The quality in the upper zone (above the Corcoran Clay) is quite variable as a result of several different sources of recharge. These sources are evident in the map of water level elevation shown in Figure 5. The water quality map of this upper zone (Figure 14) reflects the ground water level contours to some extent.

The quality is shown by plotting the chloride ion concentration of well samples yielded from the zone above the Corcoran Clay or, where the clay is not present, from about the same depth interval.

Interpretation of ground water quality was based on analysis of total mineral salt content but is depicted by the chloride ion concentration. On Figure 14 the chloride concentration contours are separated into three areas based on the nature of the chemical makeup and movement shown by

FIGURE 16



Freeport
Clarksburg
RIVER
Courtland
Walnut Grove
Ryde
Rio Vista
Isleton
Terminous
LODI
Collinsville
PITTSBURG
ANTIOCH
SACRAMENTO
SAN JOAQUIN
OLD
MIDDLE
RIVER
STOCKTON
TRACY
SEPT 14,1931
SEPT 10,1934
AUG 18,1939
SEPT 12,1924
SEPT 6,1926
SEPT 16,1920
SEPT 10,1933
SEPT 2,1929
SEPT 10,1930
SEPT 6,1932
SEPT 22,1937
SEPT 6,1940
SEPT 13,1921
SEPT 20,1922
SEPT 6,1935
SEPT 2,1936
SEPT 8,1943
SEPT 12,1923
SEPT 14,1927
SEPT 10,1941
AUG 30,1942
SEPT 12,1923
SEPT 14,1927
SEPT 18,1938
AUG 30,1958
SEPT 6,1952
JUL 30,1956
SEPT 6,1945
AUG 6,1946
SEPT 14,1948
AUG 18,1951
AUG 30,1953
JUL 30,1957
AUG 30,1950
AUG 26,1960
AUG 10,1949
AUG 22,1955
AUG 18,1944
AUG 14,1947
AUG 18,1954
JUL 22,1959
LEGEND
LIMIT OF MAXIMUM INCURSION OF SALINITY OF 1,000 PARTS OF CHLORIDES PER MILLION PARTS OF WATER
PRIOR TO OPERATION OF SHASTA RESERVOIR OF THE CENTRAL VALLEY PROJECT
SUBSEQUENT TO OPERATION OF SHASTA RESERVOIR OF THE CENTRAL VALLEY PROJECT
STATE OF CALIFORNIA
DEPARTMENT OF WATER RESOURCES
SACRAMENTO DISTRICT
HISTORICAL SALINITY INCURSION
SACRAMENTO-SAN JOAQUIN DELTA
1967
SCALE IN MILES
2 0 2 4 6

the water level contours. The separation between the two general areas of high chloride concentrations are made on slight differences between proportions of sulfate and chloride ion. In other words, it is believed that the inferior quality upper zone water is a result of two separate sources. Principally, the Coast Range supplies ground water which is high in chloride, sulfate, and boron. This is shown on Figure 14 as two arms of high chloride concentration spreading from the hills on the west towards Tracy, and on the south towards Durham Ferry Road. A secondary source of inferior quality water is believed to exist as a narrow strip along the west edge of the San Joaquin River. This water has many qualities similar to the Delta ground water. It is felt that it is a result of a residual of ground water forced out of the trough of the valley to the south.

The third zone of water quality shown on Figure 14 is the area to the east of the 50 ppm chloride contour line, which approximately follows the river from north to south. This water is generally of good mineral quality and is part of the east side source water described previously. It is important to remember that Figure 14 represents only generalized ground water quality and its main purpose is to indicate probable sources or areas of inferior quality water.

CHAPTER IV

PROBLEM AREAS

This chapter contains discussions of the water quality, hydrologic and geologic parameters for particular areas of the County in which problems did or may develop.

Stockton Area

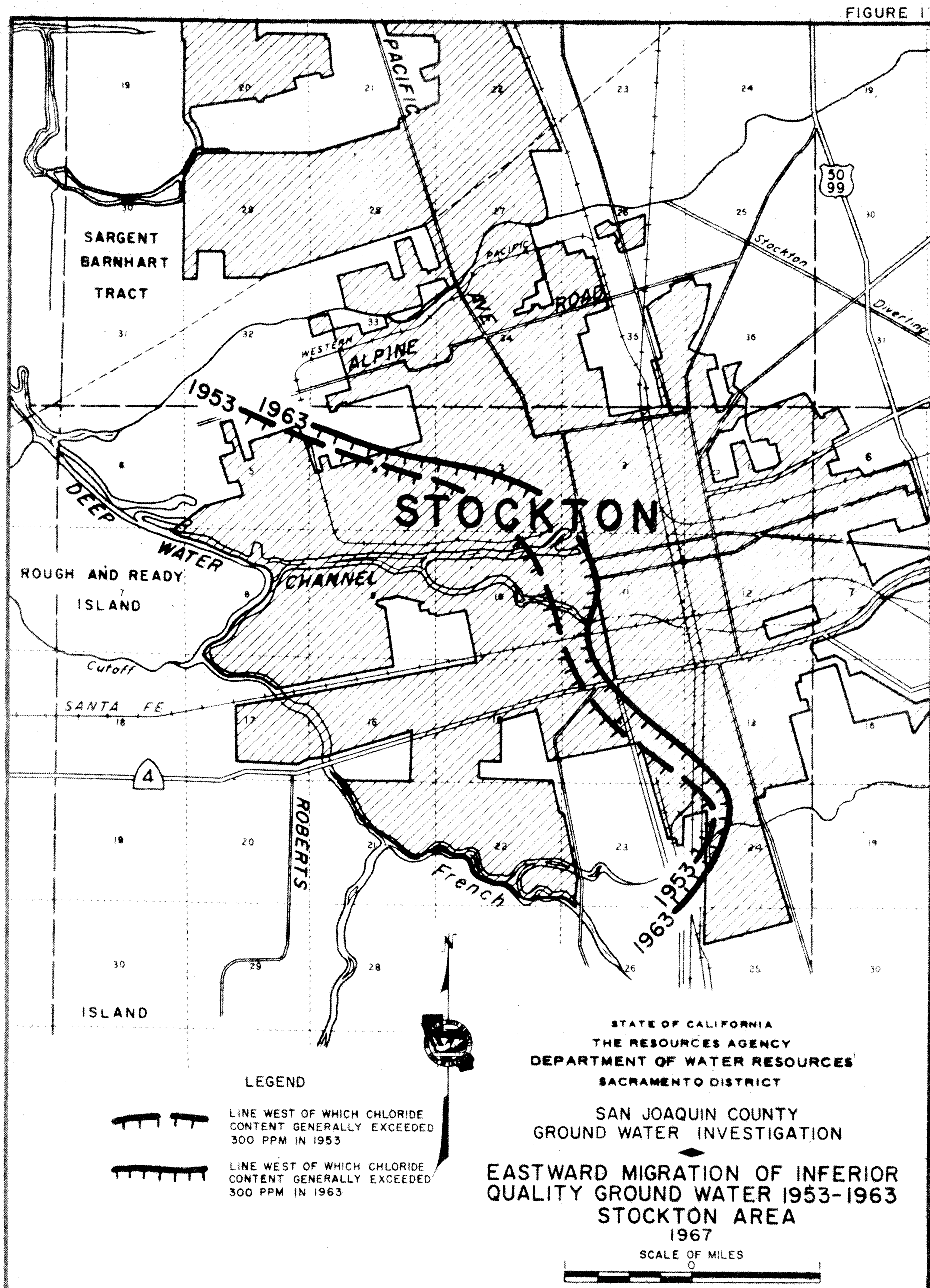
Stockton is the pivotal area of San Joaquin County, so the protection of its water supply is of paramount economic importance to all county residents. Historically, the Stockton area has had an abundant supply of good quality ground water. However, there is clearly a present danger that this supply is being slowly encroached upon by the poor quality waters underlying the Delta.

Previous studies (11) have indicated that a "barrier effect" exists between the poor quality chloride waters on the west and the good quality waters flowing into the Stockton area from Sierran sources to the east. Results of the present investigative program indicate that no such barrier exists; that, in fact, poor quality waters are migrating into the Stockton area from the west at a rate governed by the laws of fluid mechanics, the constant geologic parameters, and the variable current hydraulic parameters by which ground water is controlled. There are no lithologic, structural, or apparent consistent hydraulic discontinuities which would stop the incursion of water in an easterly direction from the Delta.

The problem of poor quality water encroachment has been developing in Stockton for some time but it has been most noticeable in the last several years as shown on figures and plates included in this report.

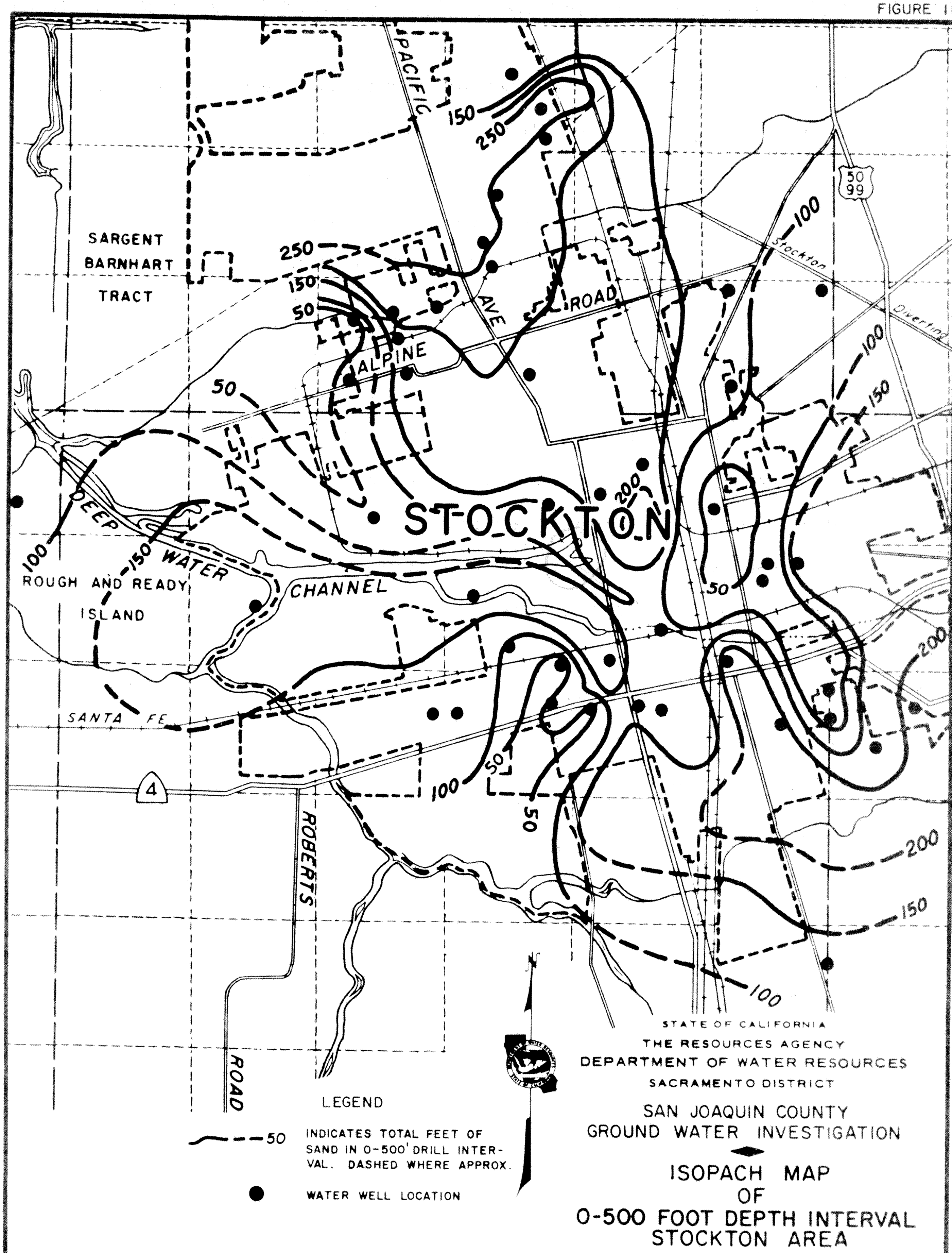
One of the ways to trace the movement of water, both with respect to direction and apparent velocity, is by observing the course and amount of decrease or increase of chloride ion concentration, with time, in a well network. In the Stockton area, a number of wells are present on which excellent long-term chemical data are available. By charting the chloride content of critical wells against time and against distance from a base line (here chosen as the 300 parts per million chloride quality line for 1953) an indication of chloride increase is obtained. Analyses of data from these wells indicate that poor quality chloride waters are locally moving into the Stockton area at a lateral rate of 140 to 150 feet per year. Figure 17 illustrates the approximate position of the 300 parts per million chloride line in 1953 and in 1963. Fair agreement was obtained by checking the flow rate by use of the Darcy flow equation.

It is interesting to note on Figure 17 that the greatest separation between the time-chloride lines is in the area of the deep water channel, and that expansion is apparently in a direction north of east rather than


PACIFIC
SARGENT
BARNHART
TRACT
ROUGH AND READY
ISLAND
DEEP WATER CHANNEL
STOCKTON
ALPINE
ROAD
WESTERN PACIFIC
Stockton Diverting
SANTA FE
Cutoff
ROBERTS
French
ISLAND
1953
1963
LEGEND
LINE WEST OF WHICH CHLORIDE CONTENT GENERALLY EXCEEDED 300 PPM IN 1953
LINE WEST OF WHICH CHLORIDE CONTENT GENERALLY EXCEEDED 300 PPM IN 1963
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SACRAMENTO DISTRICT
SAN JOAQUIN COUNTY
GROUND WATER INVESTIGATION
EASTWARD MIGRATION OF INFERIOR QUALITY GROUND WATER 1953-1963
STOCKTON AREA
1967
SCALE OF MILES

south of east toward the deepest closing contour of the cone of depression (Figures 4, 5). (The lowest closing contour of the cone is located just northeast of the intersection of South Wilson Way and East Charter Way). This observation is partly explained by the influence of geology on the direction of water movement. Figure 18 shows that there is more sand concentrated in this immediate direction than toward the southeast. This figure may also explain in part the tendency of the two end portions of the lines on Figure 17 to bunch in toward one another, since sand concentrations are less here. However, the major control on the configuration of these quality lines is pumping pattern and quantity of water withdrawn.

The geologic configuration of sediments in the Stockton area is demonstrated on Figure 18 which shows the amount of sand in the upper 500 feet of drill depth as determined from an analysis of drillers' logs. The individual sand beds could be of any thickness. All the sand beds in the surface, to 500-foot drill depth, were added to arrive at the thicknesses in the control wells used for contouring. The contours indicate the amounts of sand expected at different points in the area of the map. This figure demonstrates that there is no basis for expecting a lithologic "barrier". If one were present there would be no sand on one side compared to significant amounts of sand on the other side. This premise is further supported by



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

SAN JOAQUIN COUNTY
GROUND WATER INVESTIGATION

ISOPACH MAP
OF
0-500 FOOT DEPTH INTERVAL
STOCKTON AREA
1967

Plate 4 in which no significant abrupt decrease in sand or gravel beds is evident in the Stockton area. In fact, on the section, wells just west of El Dorado Street indicate a local increase in gravel in the Laguna formation.

While deposited sediments normally are progressively finer grained from source to place of farthest transit (from the Sierras to the Delta) there is generally no sharp break in sediment grain size unless an impediment exists which blocks orderly deposition. This impediment may be a fault, a topographic warp, a change in grade, or a change in environment (say from fresh water to saline water conditions). Furthermore, this impediment would have to exist over a significant vertical interval to be of importance in a ground water basin.

None of these situations appears applicable to the Stockton area. The absence of faulting is indicated by Figure 6. The absence of buried topographic warping is suggested by the undistorted configuration of ground water contours. The lack of change in grade or environment is indicated by the westward extension of sediments without noticeable interruption and by the known continental nature of the sediments. In addition to these, there is no indication of a barrier at other places in the Delta (37), Plates 3, 4 and 5.

If a "barrier" on the order of 2000 feet thick existed west of Stockton it would be expected that a feature of such magnitude would have fairly widespread lateral extent.

An additional complexity to the problem of intrusion of inferior quality ground water from the Delta is that eastward movement varies with depth. Most of the data used to compute rate of intrusion were from wells producing mostly from below about 150 feet.

There is very little data within the City of Stockton on the zone from the surface down to 150-200 feet. However, based on historic records, and sampling south of the City, it is believed that this shallow zone has invaded farther eastward and at a greater rate than the lower strata. This accounts for many of the past difficulties in trying to interpret the water quality changes. A more detailed description of this phenomenon is included in discussion of the Lathrop-French Camp area.

The old abandoned gas wells in the Stockton area have long been considered a possible source of degradation. Report No. 7 by a predecessor of this Department (11), published in 1955, investigated this subject. The findings were that 34 abandoned gas wells were located; of these, 16 were properly sealed, two were probably adequately sealed and the 15 remaining were either filled with debris, open, or their condition unknown.

The only one of these wells that indicated that it was causing pollution problems, was a well that was located in an inaccessible site on the Stockton State

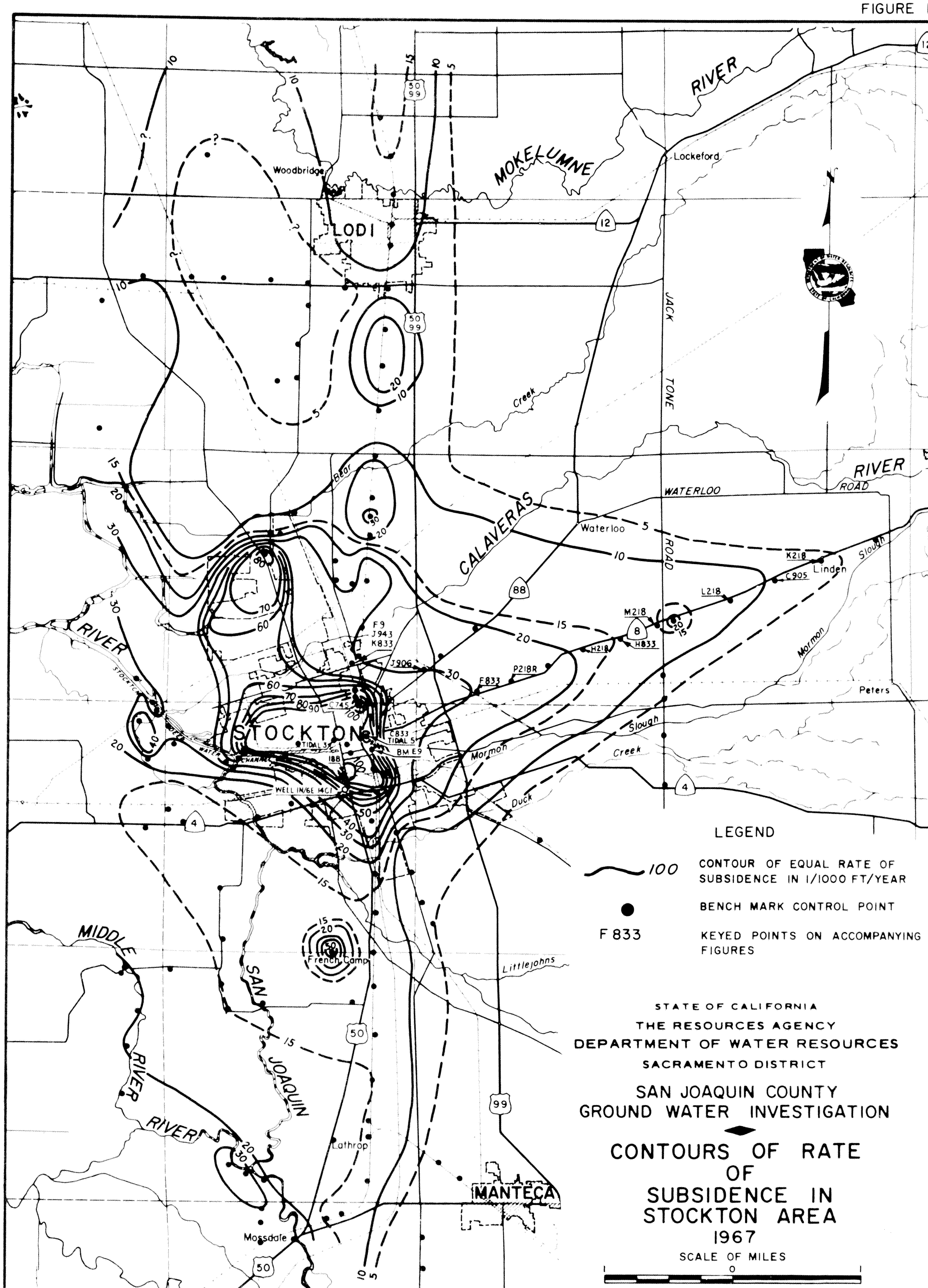
Hospital Grounds. Here the degradation was limited to a few local wells. Recent sampling indicate that there has been no change in status since 1955.

Historic records indicate that there were many more gas wells drilled than the 34 found in 1955. Many more were drilled deep, probably into high pressure saline water-bearing formations, but never completed. Any of these wells could be the source of problems similar to the situation at the State Hospital. However, these wells would not cause extensive areas of degradation.

One of the byproducts of the overdraft situation in Stockton is a subsidence problem. The rate of subsidence in the Stockton area is shown on Figure 19. The figure was constructed by taking the difference in ground elevation between the first and last year of data at a control point and dividing this by the number of intervening years. It, therefore, does not show any increasing rates of subsidence with time, but solely the average over the given span of years.

It will be noted that the configuration of the subsidence contouring is similar to that of the change in ground water levels over the 14-year hydrologic base period (Figure 12) in the Stockton area. It is believed that the primary cause of the subsidence is the overdraft of ground water. Subsidence of selected stations in the Stockton area are shown on Figure 20. The increased rate of

FIGURE 19


MOKELUMNE
RIVER
Lockeford
Woodbridge
LODI
JACK
TONE
ROAD
Creek
Bear
CALAVERAS
RIVER
WATERLOO
ROAD
Waterloo
Linden
Slough
Mormon
Peters
Creek
Duck
STOCKTON
TIDAL 3
TIDAL 5
BM E9
WELL IN/6E 14C1
F9
J943
K833
J906
F833
P218R
H218
H833
M218
L218
K218
C905
C745
C833
188
French Camp
Littlejohns
MIDDLE
RIVER
SAN
JOAQUIN
RIVER
Lathrop
MANTECA
Mossdale
LEGEND
100 CONTOUR OF EQUAL RATE OF SUBSIDENCE IN 1/1000 FT/YEAR
BENCH MARK CONTROL POINT
F 833 KEYED POINTS ON ACCOMPANYING FIGURES
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SACRAMENTO DISTRICT
SAN JOAQUIN COUNTY
GROUND WATER INVESTIGATION
CONTOURS OF RATE OF SUBSIDENCE IN STOCKTON AREA
1967
SCALE OF MILES

subsidence with time is indicated by the steeper slopes of more recent data (Figure 20). Points of time versus elevation of the bench mark at the station are connected by straight lines. The actual subsidence, if it could be plotted continuously, would be a smooth, curved line connecting these points. The relationship between elevation of a bench mark and the elevation of the water level in a nearby well is shown on Figure 21. The ratio of approximately 1:20 (i.e., one foot drop in ground surface to 20 feet decline in water levels) is on the same order of magnitude as other parts of the San Joaquin Valley where land subsidence has been definitely correlated to withdrawals of ground water. This figure indicates that the cause of subsidence can be most obviously assigned to water withdrawal. This is particularly so, since the other major reasons for subsidence (peat oxidation, gas and oil withdrawal) are not applicable to this situation. Tectonic activity is a possible cause of subsidence, but its contribution is believed to be relatively minor here.

Lathrop-French Camp Area

The Lathrop-French Camp area has for some time experienced local, seemingly unrelated, ground water quality problems. This area roughly includes the land lying between the San Joaquin River and Airport Way (Durham Ferry Road), bounded on the north by French Camp Slough and on the south by Highway 120, encompassing about 30 square miles.

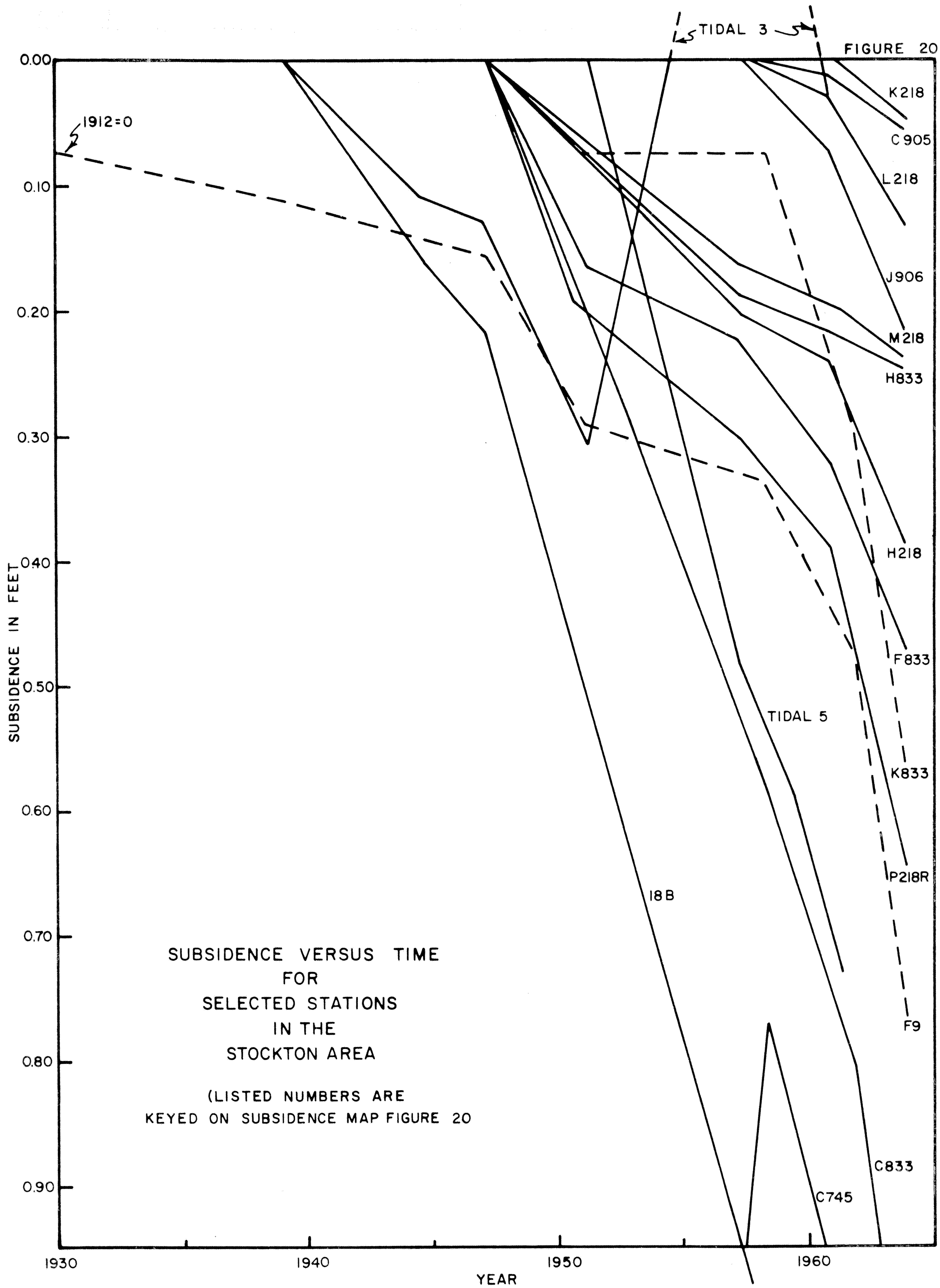
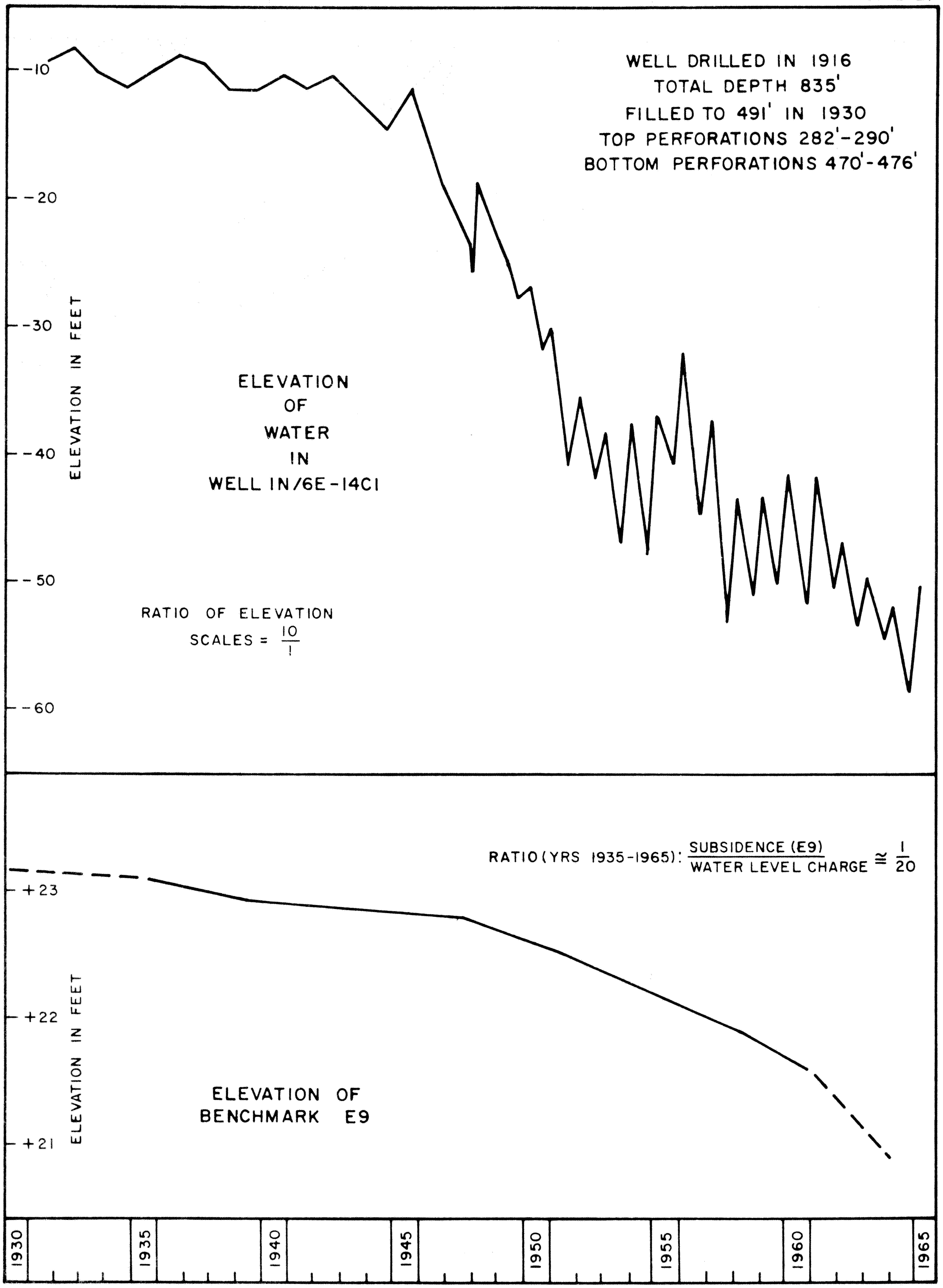


FIGURE 20
TIDAL 3
1912=0
K218
C905
L218
J906
M218
H833
H218
F833
TIDAL 5
K833
P218R
18B
F9
C833
C745
SUBSIDENCE VERSUS TIME
FOR
SELECTED STATIONS
IN THE
STOCKTON AREA
(LISTED NUMBERS ARE
KEYED ON SUBSIDENCE MAP FIGURE 20
SUBSIDENCE IN FEET
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1930
1940
1950
1960
YEAR


WELL DRILLED IN 1916
TOTAL DEPTH 835'
FILLED TO 491' IN 1930
TOP PERFORATIONS 282'-290'
BOTTOM PERFORATIONS 470'-476'
ELEVATION OF WATER IN WELL 1N/6E-14C1
RATIO OF ELEVATION SCALES = 10/1
ELEVATION IN FEET
-10
-20
-30
-40
-50
-60
RATIO (YRS 1935-1965): SUBSIDENCE (E9) / WATER LEVEL CHARGE ≅ 1/20
+23
+22
+21
ELEVATION IN FEET
ELEVATION OF BENCHMARK E9
1930
1935
1940
1945
1950
1955
1960
1965

Agricultural, industrial, and residential uses are beginning to compete for space. Ground water is relied on exclusively to supply the growing needs of these uses.

Historic quality problems have been reported from ranchers west of Highway 50, portions of the County Hospital complex, and the area near the intersection of Highways 50 and 120. Results of ground water samples and water level measurements obtained during this study indicate that the causes and effects of ground water degradation of the entire area are related.

The source of inferior quality ground water is principally from the Delta, the cause for movement eastward is due to local depression in the ground water levels due to high concentrations of pumping in certain areas. The areas showing water level depression and growing water quality problems are roughly the same. The lowering of water levels in the area can be seen by comparing the eastward shift of zero (sea level) contour between the lines of equal elevation of water levels for 1950 and 1964 (Figures 4 and 5).

Also, Figures 2 and 3 for these same two years show recharge from the Delta area. The black arrows cover a three-mile front in 1950 and over a 16-mile front in 1964.

Historic quality and water level records are too inadequate to make any estimates of future extent or rate of eastward intrusion of inferior quality ground water.

However, it is not expected that the intrusion could ever advance eastward beyond Airport Way, with the possible exception of the area near the south boundary of the City of Stockton. This is due to the ground water ridge extending northwest from the Stanislaus River.

Tracy Area

The ground water quality problems in Tracy (see Figures 13 and 14) were briefly described in the previous Chapter when the lower aquifers of good mineral quality and the upper aquifers of generally inferior water quality were outlined.

The problems in the Tracy area seem to be a result of poor knowledge of where the good quality and inferior quality ground waters exist, their extent, movement, and source.

The most common type of well problem has been due to gravel packed wells, producing from every strata in an area where the upper aquifers are supplying undesirable water. Many of these wells probably produced a composite of marginal or unsuitable quality water from the start. Others have probably degraded since construction, due to rising levels in the upper aquifers and falling levels in the lower aquifers. This effect would tend to cause proportionally more production from the upper strata in these multi-aquifer wells.

A few problems appear to be the result of the wells penetrating into the base of fresh water. A well in the area south of Carbona could be of this type (see Figure 13).

Manteca Area

During the investigation, several complaints about high hardness were received from individuals pumping water in the vicinity of Manteca. Upon investigating, it was found that the City wells and many other important wells had total hardness that did not exceed about 200 ppm. Further sampling and a search of records resulted in analysis that showed quite high total hardness concentrations, up to 617 ppm. These high values are unique, and much greater than that expected from eastside recharge.

Although information on the wells samples is scant, it is believed that this uniquely high hardness is present only at shallow depths. A perched water zone is thought to be the cause. The existence of this perched water zone can be partly verified by data shown on Plate 6B and Figure 5. The plate indicates extensive amounts of clay in the surface, down to 50 feet in depth, and Figure 5 shows high water table in this area.

Perched water tables are usually undesirable as a source of domestic water. The quality is usually poor, with typical high hardness, and there is little protection from surface contamination due to shallow depth to water. This problem is not shown on Figure 5 since it is mainly due to high hardness and this type of problem is not included, by earlier discussion.

Collegeville Area

A glance at Figure 12 will disclose that the area of greatest change in water level in the 14-year hydrologic study period within the study area occurred in the Collegeville area, and yet it has no significant quality problem. This is because it is so far removed from the Delta that there is no present influence of Delta waters. Furthermore, the base of fresh water (Figure 8) is at such depth as to be of no current concern.

CHAPTER V

POSSIBLE SOLUTIONS TO PROBLEMS

Artificial Recharge

The easterly movement of the poor quality water underlying the Delta has been caused by a lowering of the water table in areas east of the Delta. This declining water table results from increasing use of ground water with insufficient inflow to meet the demand. The problem could be corrected if the inflow of ground water were also to increase as withdrawals increase. During the course of this investigation, the possibility of using artificial recharge has been considered as a means of restoring ground water levels.

The underground storage of water has several advantages over surface storage. The cost of artificially recharging a basin may be less than the cost of construction and maintenance of surface reservoirs of similar capacity.

Recharge, in its broadest meaning, is the replenishment of ground water resources through both natural and artificial means. If the volume of recharge to a basin is increased, the safe yield is also increased. The term "artificial recharge", as used in California, refers to the replenishment of ground water storage through works provided primarily for that purpose. The term is related to but separate from "incidental recharge" which occurs through normal water-use activities such as irrigation, or "natural recharge", which takes place by infiltration and percolation of stream runoff and rainfall.

Methods of Artificial Recharge

Artificial recharge projects involve one or a combination of the following six methods. The first five methods are most applicable to nonurban areas where land values are comparatively low. The last method is useful in high land value areas or where near-surface geology precludes use of surface spreading methods.

1. Basin Method. This method involves the construction of artificial dikes or levees as a means of impounding water in a natural depression or series of depressions. The basins are constructed with the upper basin used for desilting of water before it passes through the system.

2. Pit Method. Here are included the constructed "basin-like pit" and the abandoned borrow pit. The former has a higher silt tolerance than regular basins because the silt usually settles rapidly, leaving the side walls relatively free for infiltration of water. The latter type usually requires relatively silt-free water unless its sides are steep because of difficulty in removing silt from the sides as well as the bottom of the pit.

3. Modified Stream Bed. Runoff can be conserved in part, through regulation of flow rates by upstream dams, by construction of small temporary check dams or dikes designed to spread the flow over the entire width of the channel (thereby reducing stream velocity past any given reach), or by levelling, scarifying, or simply widening the channel to increase the area of infiltration.

4. Ditches and Furrows. This infiltration method involves the construction of various types of flat-bottomed ditches or furrows which act as avenues for infiltration at the same time that they convey water through the system.

5. Flooding Method. Water in the form of a thin sheet is allowed to flow over the land surface.

This method is most applicable to gentle, uniform slopes with erosion-preventing vegetative cover.

6. Injection Wells. Injection wells (or recharge wells) are simply a reversal of pumping wells with water being pumped into the formation instead of out of it. This method is largely confined to areas where high land costs or extensive, thick, clay members of low permeability near the surface render other methods impractical or inadvisable.

The well injection method is comparatively more expensive than the other five methods describe. Extensive preliminary studies are mandatory, and continuing operation and maintenance are required.

Application of Artificial Recharge to San Joaquin County

All of the artificial recharge methods discussed above can be applied at various locations in San Joaquin County. Use of a specific method depends on local geologic, hydrologic, and cost factors.

One method of correcting the quality problem which exists along the west side of the Stockton area is by injecting good quality water directly in the subsurface. Surface methods of rechange are probably not feasible because soils are fine grained and thick enough to preclude rapid infiltration of surface waters and land costs for the extensive areas needed to infiltrate water at a rate to match the influx of poor quality waters would be prohibitive. Development of recharge surface infiltration areas north, east and south of the metropolitan area where the proper geology exists would require the passage of many years, under the most favorable conditions, before water would reach the cone of depression in the City, since lateral movement of ground water is slow (on the order of tens to hundreds of feet per year).

Induced Pumping Trough

One method to block the eastward migration of inferior quality ground water from the Delta is the pumping of poor quality Delta ground water at a rate equal to the encroachment volume. In theory, a line of discharge wells could create a depression or trough along the Delta area into which would flow poor quality waters from the west, as well as good water from the east. The ultimate aim of this system would be to shift the primary cone of depression, now centered northwest of the intersection of South Wilson Way and East Charter Way, to the trough created by the discharge wells, thus permitting good quality water to re-occupy the part of the basin east of the line of pumping wells.

One of the primary problems associated with this method is the disposal of the pumped poor quality waters. Direct discharge to the Delta could be objectionable to the downstream users. Other considerations for handling pumped water are:

1. Spreading grounds to the west for evaporation;
2. A combination of spreading and discharge into the river system.

Cutoff Curtain
(Subsurface Impermeable Membrane)

A possible, but expensive, means of blocking the eastward movement of poor quality Delta waters into the Stockton area would be to construct a subsurface cutoff wall. This would involve either (1) the digging of a deep, long trench, and backfilling it with an impervious material such as clay or grout, or (2) the drilling of wells spaced in such a manner that a continuous grout curtain is created. This technique has application where water is moving through a shallow, sediment-filled, subsurface gorge bounded on either side and at the base by impervious formation. However, it appears that technical difficulties preclude use of the cutoff wall method in the Stockton area where distances of many miles and depths of hundreds of feet must be considered.

Rearrangement of Pumping Pattern
(Reduction of Pumping in Critical Areas)

Consideration should be given to the rearrangement of pumping patterns in the Stockton area as an aid in reducing the intrusion of poor quality water. A reduction of pumping of good quality water in the western part of the basin would aid in bringing water levels up and thus increase the head against the poor quality intervals. An upward change in the level of the cone of depression would reduce the gradient on the west side and slow the rate of intrusion and, if the rise were great enough, would aid in repelling further intrusion.

Importation of Water
(Replenishment of Basin)

Use of imported water is already being considered by various agencies in the County. Agencies within the County are well underway in negotiating with the United States Bureau of Reclamation for imported water.

Use of imported water would reduce the need for excessive pumping of ground water and, in the Stockton area, would be beneficial in reducing the poor quality intrusion problem.

Recharge Costs in Other Areas

As a guideline for determining artificial recharge or fluid barrier costs in San Joaquin County, general information and estimated costs are presented for several Southern California projects.

Dominguez Gap Barrier Project

The Dominguez Gap Barrier Project is located in a highly urbanized part of western Los Angeles County between the Palos Verdes Hills on the west and the Dominguez-Signal Hill trend on the east. The object of the proposed project is to prevent further saline encroachment from the Pacific Ocean into the ground water basin. Pertinent general data are: length of barrier line, approximately 4.5 miles; estimated initial water requirement, 14,000 acre-feet per year; number of recharge wells, 22; number of observation wells, 42 existing and 38 proposed; supply pipeline, approximately 4 miles long.

Costs cited in Table 5 are estimated for the 7-year period, 1965-1972. To demonstrate that capital costs are initially high while operation and maintenance costs are low until the project is operational, a tabulation of percentages of total costs for major items is given in Table 6. A comparison of estimated capital and operation and maintenance costs is made between the Dominguez Gap project and the West Coast Basin project in Table 7.

TABLE 5

DOMINGUEZ GAP BARRIER PROJECT COSTS

	7-year total
Capital Costs Observation wells, recharge wells, supply pipeline (engineering, construction, connection); distribution pipeline (engineering, construction); chlorination station (right of way, engineering, construction); engineering (design of observation and recharge wells and administering and reviewing other engineering plans)	$2,110,000
Purchase of Water	$1,014,000
Operation and Maintenance	$ 792,000
Total estimated project cost for 7 years	$3,916,000

TABLE 6

PERCENTAGES OF TOTAL COSTS OF MAJOR ITEMS FOR EACH YEAR OF DOMINGUEZ GAP PROJECT

	65-66	66-67	67-68	68-69	69-70	70-71	71-72
Capital Costs	1%	20%	66%	13%	-	-	-
Purchase of Water	-	-	-	12%	35%	26%	27%
Operation and Maintenance	-	3%	11%	16%	23%	23%	24%
Total Project Cost	1%	11%	38%	13%	14%	11%	12%

West Coast Basin Experimental Project

The West Coast Basin Experimental Project was located in the cities of Manhattan Beach and Hermosa Beach, Los Angeles County, California. The object of the project was to engage in investigational work and design criteria for correction or prevention of damage to underground waters of the State, by sea water intrusion in the West Coast Basin of Los Angeles County and other critical areas. Expenditures reimbursible by the State were determined for the period October 1951 through December 1953. Based on analysis of the project, a tabulation of estimated costs for a similar project under similar circumstances, but with the knowledge gained from the primary investigation converted to cost savings, is shown in Table 7. The cost comparison with the Dominguez Gap Barrier Project is also tabulated here.

Data are not readily available to explain with certainty the large differences in capital costs of the two projects. The most obvious differences as shown on Table 7, exclusive of 1953 versus 1965 increases in prices, are supply and distribution pipeline costs, and recharge and observation well costs. The data do indicate that careful engineering studies are necessary for each artificial recharge or barrier project.

TABLE 7

COMPARISON OF ESTIMATED CAPITAL AND OPERATION AND MAINTENANCE COSTS**
OF DOMINGUEZ GAP AND WEST COAST BASIN BARRIER PROJECTS

Capital Costs per Mile	Dominguez Gap Project		West Coast Basin Experimental Project	
Preliminary Planning and Design	*		$ 5,000	
Geologic Investigation	*		6,000	
Supply Pipeline	$112,500		Water Assumed Available at Dist. Point	
Distribution Pipeline	128,000		56,000	
Recharge Wells	88,000	(Approx. 5 Wells)	52,500	(7 wells)
Observation Wells	78,000	(Approx. 8 Wells)	27,000	(12 Wells)
Transmissibility Tests	*		5,200	(7 Wells)
Recharge Well Appurtenances	*		7,000	(7 Wells)
Measuring Equipment	*		5,000	
Field Office and Chlorinator Housing, Chlorinator Equipment	11,000		5,000	
Miscellaneous Right of Way	4,500		*	
Engineering Design of Observation and Recharge Wells and Administering and Reviewing other Engineering Plans	31,000		*	
Totals	$453,000		$168,700	
10 Percent Contingency	*		16,900	
Total Capital Cost	$453,000	per Mile	Say $186,000	per Mile
Operation and Maintenance (Annual)				
Supervision and Operation Personnel	*		10,000	
Routine Project Maintenance and Miscellaneous Material	*		4,000	
Recharge Well Redevelopment	*		3,500	(3-1/2 Wells
Chlorine	*		4,500	
Well Sampling Operations	*		5,000	
Water Analysis and Related Laboratory Work	*		2,000	
Totals	$ 25,100		$ 29,000	
10 Percent Contingency	*		2,900	
Total Operation and Maintenance Cost (Annual)	Say $ 25,000	per year/ per mile	Say $ 32,000	per year/ per mile

* Not detailed, or included in other items
** Note that water costs not included here

West Coast Basin Barrier Project

The West Coast Basin Barrier Project is located in the cities of Manhattan Beach and Hermosa Beach. The present (1963) barrier is approximately 1-1/2-miles long and includes the area of the West Coast Basin Experimental Project described above. Data are available on recharge well costs and redevelopment costs. These are:

1. The actual recharge well cost for one 1960 well drilled to a total depth of 270 feet was $36.80 per foot. This figure does not include connection costs to a supply line.

2. The cost estimate for a contract for 13 recharge wells of reverse rotary type, using asbestos-cement pipe, were:

   $42.50 per foot for 9 wells averaging 335 feet deep

   $42.70 per foot for 4 dual-type wells averaging 560 feet deep

These figures include all costs of drilling, furnishing and installing casing, furnishing and setting plastic tremie pipes, well development (but not water disposal) and an underground vault, connection with the main supply line including necessary valves, meters, and other miscellaneous header devices. The dual-well cost also includes the packer and its activating appurtenances.

Redevelopment costs of the project varied, but as of 1963, were on the order of $1500 per well. The average frequency of redevelopment for seven, gravel-packed, cable-tool drilled, steel cased wells was 20 months, with a frequency range of 9 to 32 months.

Alamitos Barrier Project

The Alamitos Barrier Project is located approximately on the Los Angeles-Orange County line east of Bixby Ranch Hill in southern California. Cost data is for the 1965-1966 fiscal year.

A total of 4,076.3 acre-feet of water was injected at a cost of $63.17 per acre-foot, of which $21.00 per acre-foot was the price of purchased water. In addition, 2,429.3 acre-feet of saline water were pumped at a cost of $13.86 per acre-foot. These costs do not include capitalized cost of the injection facilities, injection and observation wells. They also do not include the additional cost of purchased water paid as a result of the subsidy for conservation water (about $15.00 per acre-foot). Nor do they include the additional cost of purchased water included in the Metropolitan Water District property tax.

APPENDIX 1

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APPENDIX 2

DEFINITION OF TERMS

The following terms used in this report are defined as follows:

Acre-foot - the volume of water which covers one acre to a depth of one foot (one acre-foot = 43,560 cubic feet = 325,851 gallons).

Anion - an ion that moves, or that would move, toward an anode; hence nearly always synonomous with negative ion.

Anticline - the term applied to strata which dip in opposite directions from a common ridge or axis, like the ridge of a house.

Applied water - the water delivered to the farmer's headgate or to an urban house meter, or its equivalent. This term excludes precipitation.

Aquiclude - (1) A geologic formation so impervious that, for all practical purposes, it completely obstructs the flow of ground water (although it may be saturated with water itself) and completely confines other strata with which it alternates in deposition. A shale or very impervious tight clay is an example. (2) An areally extensive body of saturated but relatively impermeable material that functions as an upper or lower aquifer boundary and does not yield appreciable quantities of water to wells or to adjacent aquifers.

Aquifer - (1) A geologic formation or stratum containing water in its voids or pores that may be removed economically and used as a source of water supply. Unconsolidated alluvial deposits of sand and gravel, and permeable sandstones are examples of water-bearing strata. (2) A body of saturated relatively permeable material that conducts significant ground water flow and is capable of yielding water to wells in economic quantities.

Aquifuge - a rock which contains no interconnected openings and, therefore, neither absorbs or transmits water. A massive hard granite is an example.

Aquitard - (1) A geologic formation of a rather impervious and semiconfining nature which transmits water at a very slow rate compared to the aquifer. Over a large area of contact, however, it may permit the passage of large amounts of water between adjacent aquifers which it separates from each other. Clay lenses interbedded with sands, if thin enough, may form aquitards. (2) A body of saturated material of relatively low permeability that impedes ground water movement and does not yield freely to wells, but which may transmit appreciable water to or from adjacent aquifers, and where sufficiently thick, may function as an important ground water storage unit.

Artesian leakage - the slow percolation of water from artesian formations into the confining materials of a less permeable but not strictly impermeable character. Such percolation causes a reduction in artesian pressure, depending on the relative impermeability of the materials in the confining formations.

Artesian water - ground water that is under sufficient pressure to rise above the level at which it is encountered in a well, but which does not necessarily rise to or above the surface of the ground.

Artificial recharge - defined as the water that is added to the ground water basin through facilities primarily designed for that purpose, such as through spreading basins and injection wells.

Basement - a series of rocks generally with complex structure beneath the dominantly sedimentary sequence. These rocks essentially contain no water.

Base of fresh water - the depth below which water of poor quality occurs at all intervals. Some poor quality zones may occur above this level in the normally fresh water interval, but no good quality water should be expected below this depth. (Chlorides generally exceed 300 mg/l).

Cation - an ion that moves, or that would move, toward a cathode; nearly always synonomous with positive ion.

Clastics - a term applied to rocks composed of fragmental material derived from pre-existing rocks and mechanically transported to its place of deposition. Examples are sands and clays.

Cone of depression - the water surface in the water-bearing formation within the area of influence of a pumping well. It resembles the shape of a cone with its apex at the pumping level in the well.

Confined ground water - a body of ground water that is immediately overlain by material sufficiently impervious to sever free hydraulic connection with overlying water, and that moves under gradient or pressure caused by the differences in head between the intake, or forebay area, and the discharge area of the confined water body.

Connate water - water entrapped in the interstices of a sedimentary rock at the time it was deposited. This water may be fresh, brackish, or saline in character. Because of the dynamic geologic and hydrologic conditions in California, this definition has been modified in practice to apply to water in older formations even though the water may have been altered in quality since the rock was originally deposited.

Consumptive use of water - water consumed by vegetative growth in transpiration and building plant tissue, and water evaporated from adjacent soil, from water surfaces, and from foliage. It also includes water similarly consumed and evaporated by urban and nonvegetative types of land use.

Deep percolation - the movement of water into the zone of saturation from the intermediate belt.

Delivered water - the sum of the applied water and any conveyance losses within a study area in delivering this water.

Dip - the angle at which a formation, stratum, or any planar feature is inclined from the horizontal.

Drawdown - the change in water surface elevation in a well as the result of pumping ground water.

Flow line - a line along which a drop of water would move. The drop of water travels from points of high energy to points of low energy by the shortest route possible. Under water table conditions the direction of travel is at right angles to the line of equal elevation of water in wells.

Formation - any assemblage of rocks which have some character in common, whether of origin, age, or composition.

Free ground water - water in interconnected interstices in the zone of saturation down to the first impervious barrier, moving under the control of the water table slope.

Geohydrology - the science dealing with subsurface water.

Gravel packed well - a well in which gravel is placed in the annular space to increase the effective diameter and to prevent the entrance of fine-grained sediments.

Ground water - subsurface water in the zone of saturation.

Ground water basin - an area underlain by permeable materials. The permeable materials must be water-bearing, i.e., generally capable of furnishing a water supply of acceptable quality to wells of moderately heavy draft (100 gpm or more). The basin includes both the surface area and the underlying permeable materials.

Ground water storage - that stage of the hydrologic cycle during which water occurs as ground water in the zone of saturation, including that part of such stage when water is passing through the zone of aeration and entering or leaving storage.

Homocline - a general name for any block of bedded rocks all dipping in the same direction.

Hydraulic conductivity - hydraulic conductivity is used in a specific sense to mean the rate of transmissibility of water through soil in feet per day, assuming a hydraulic gradient of unity, which is essentially the same value as the coefficient of permeability.

Hydraulic gradient - under unconfined ground water conditions, the slope of the profile of the water table. Under confined ground water conditions, the line joining the elevations to which the water would rise in wells if they were perforated in the aquifer.

Hydrologic cycle - the complete cycle of phenomena through which water passes, commencing as atmospheric water vapor, passing into liquid and solid form as precipitation, thence along or into the ground surface, and finally again returning to the form of atmospheric water vapor by means of evaporation and transpiration.

Impermeable-Impervious - having a texture that does not permit water to move through it perceptibly under the head differences ordinarily found in subsurface water.

Infiltration - the flow of a fluid into a substance through pores or small openings. It connotes flow into a substance in contradistinction to the word percolation, which connotes flow through a porous substance.

Ion - an atom or group of atoms with an electric charge.

Isopach map - a map indicating by means of contour lines the varying thickness of an assemblage or subassemblage of rocks. The shape of the assemblage is indicated by the distribution of contours.

Isostatic compensation - an equilibrium condition in which elevated masses such as continents and mountains are compensated by a mass deficiency in the crust beneath them. The compensation for depressed areas is by a mass excess.

Monocline - a succession of beds dipping in one direction.

Overdraft - continuing decrease in the amount of ground water in storage over a long time period, under a particular set of physical conditions, affecting the supply, use, and disposal of water in the ground water basin.

Pediment - a gently sloping plane eroded at the foot of steep slopes or cliffs. See (67) for details.

Percolation - the movement, or flow, of water through the interstices, or the pores, of a soil or other porous media.

Permeability - the permeability of rock is its capacity for transmitting a fluid. Degree of permeability depends upon the size and shape of the pores, the size and shape of their interconnections, and the extent of the interconnections.

Sedimentary - clastic rock, as gravel, sand, and clay formed of fragments of other rock, transported from their source of origin and commonly laid down from a water environment.

Soil - that earth material which has been so modified by physical, chemical and biological agents that it will support rooted plants. Its thickness is variable, ranging from a few inches to more than six feet.

Specific capacity - the amount of water, in gallons per minute, which a well will yield per foot of drawdown.

Specific yield - the ratio of the volume of water a saturated sediment will yield by gravity drainage to the total volume of the sediment and water prior to draining, usually expressed in percent.

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

Syncline - a fold in rocks in which the strata dip inward from both sides toward the axis. The opposite of anticline.

Thiessen method - a method used to determine the amount of precipitation on an area by constructing polygons, or areas of influence, about each rain gaging station. The polygon is formed by the perpendicular bisectors of the straight lines joining adjacent gaging stations. When using this method, it is assumed the depth of precipitation within the polygon is equal to the depth of precipitation at the corresponding gaging station.

Transmissibility - as used in this report, transmissibility was obtained from a modification of the Thiem equilibrium formula presented by Thomasson (75). This method allows for a rapid determination of transmissibility based on specific capacity.

$T = 1{,}990 \frac{Q}{SW}$ (1,990 = factor for confined aquifer conditions)

$T = 1{,}460 \frac{Q}{SW}$ (1,460 = factor for water table conditions)

$T = 1{,}700 \frac{Q}{SW}$ (1,700 = factor, average)

T = transmissibility in gallons per day per foot

$\frac{Q}{SW}$ = specific capacity

This method is a useful and fairly reliable procedure based on a check of reliable pumping tests. It appears to give values fairly close to well pumping tests.

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

Transpiration - the exhalation of water vapor from the stomata of plant leaves and other surfaces.

Unconfined ground water - ground water that is not immediately overlain by impervious materials and that moves under control of the water table.

Unconformity - a surface of erosion or nondeposition, usually the former, that separates older rock from overlying younger rock.

Vadose water - subsurface water occurring in the zone of aeration.

Water table - the surface of ground water at atmospheric pressure in an unconfined aquifer. This is revealed by the levels at which water stands in wells penetrating the unconfined aquifer.

Zone of aeration - the zone in which the interstices of the functional permeable rocks are not filled (except temporarily) with water. The water is under pressure less than atmospheric.

APPENDIX 3

ESTIMATED AVERAGE WEIGHTED SPECIFIC YIELD VALUES BY DEPTH INCREMENTS BELOW GROUND SURFACE FOR SAN JOAQUIN COUNTY GROUND WATER INVESTIGATION HYDROLOGIC STUDY.

These estimated specific yield values were finalized in 1961 from the average weighted specific yield of the material in each 20 foot zone as shown by available logs, and covering the acreages shown under Appendix 4. **This table is a portion of the print out from the 650 Computer Program #284.**

SPECIFIC YIELD VALUES ASSIGNED TO WATER-BEARING SEDIMENTS IN SAN JOAQUIN COUNTY, CALIFORNIA

Material	Specific yield (percent)
Gravel; sand and gravel; and related coarse gravelly deposits	25
Sand, medium to coarse-grained, loose, and well-sorted	25
Fine sand; tight sand; tight gravel; and related deposits	10
Silt; gravelly clay; sandy clay; sandstone, conglomerate; and related deposits	5
Clay and related very fine grained deposits	3
Crystalline bedrock (fresh)	0

APPENDIX 3

ESTIMATED AVERAGE WEIGHTED SPECIFIC YIELD VALUES BY DEPTH INCREMENTS BELOW GROUND SURFACE SAN JOAQUIN COUNTY GROUND WATER INVESTIGATION

DEPTH INCREMENT BELOW GROUND SURFACE	SPECIFIC YIELD IN PERCENT FOR INDICATED TOWNSHIP AND RANGE						DEPTH INCREMENT BELOW GROUND SURFACE	SPECIFIC YIELD IN PERCENT FOR INDICATED TOWNSHIP AND RANGE					
	1N/6E	1N/7E	1N/8E	1N/9E	1N/10E	1N/11E		1N/6E	1N/7E	1N/8E	1N/9E	1N/10E	1N/11E
0- 20	4.59	3.95	6.89	5.46	6.33	8.00*	500-520	5.90	7.40	8.10	7.50	8.00*	8.00*
20- 40	7.33	5.80	6.36	8.68	3.00	8.00*	520-540	7.00	18.13	4.00	5.00	8.00*	8.00*
40- 60	8.36	7.20	7.97	7.58	4.75	8.00*	540-560	5.00	8.00*	3.83	5.00	8.00*	8.00*
60- 80	9.57	7.93	7.10	8.97	4.50	8.00*	560-580	10.00*	8.00*	4.17	10.00	8.00*	8.00*
80-100	7.26	7.18	6.18	6.71	5.63	8.00*	580-600	10.00*	8.00*	3.33	8.00*	8.00*	8.00*
100-120	6.46	6.86	7.98	6.63	4.25	8.00*	600-620		8.00*	3.17	8.00*	8.00*	
120-140	9.02	7.78	9.49	6.05	4.50	8.00*	620-640		8.00*	10.07	8.00*	8.00*	
140-160	6.44	9.14	9.41	5.77	5.13	8.00*	640-660		8.00*	5.83	8.00*	8.00*	
160-180	9.10	8.24	7.21	5.44	4.13	8.00*	660-680		8.00*	7.50	8.00*	8.00*	
180-200	10.07	6.39	6.10	6.38	3.00	8.00*	680-700		8.00*	8.33	8.00*	8.00*	
200-220	13.08	7.25	6.44	7.60	3.75	8.00*	700-720		8.00*	11.67	8.00*	8.00*	
220-240	13.04	6.34	4.16	7.37	7.25	8.00*	720-740		8.00*	5.75	8.00*	8.00*	
240-260	11.52	5.34	4.46	6.61	4.75	8.00*	740-760		8.00*	12.50	8.00*	8.00*	
260-280	8.51	8.37	4.49	6.11	4.25	8.00*	760-780		8.00*	8.00*	8.00*	8.00*	
280-300	8.37	9.14	5.27	7.36	5.00	8.00*	780-800		8.00*	8.00*	8.00*	8.00*	
300-320	8.06	7.18	4.90	6.16	5.00	8.00*	800-820		8.00*	8.00*	8.00*	8.00*	
320-340	9.42	9.69	3.63	5.18	6.00	8.00*	820-840		8.00*	8.00*	8.00*	8.00*	
340-360	7.78	4.18	5.75	5.38	8.00	8.00*	840-860		8.00*	8.00*	8.00*	8.00*	
360-380	6.61	5.65	4.62	3.50	6.63	8.00*	860-880		8.00*	8.00*	8.00*	8.00*	
380-400	9.23	4.58	5.23	3.88	9.75	8.00*	880-900		8.00*	8.00*	8.00*	8.00*	
400-420	8.72	6.20	7.12	3.73	5.00	8.00*	900-920		8.00*	8.00*	8.00*	8.00*	
420-440	7.93	3.80	6.09	5.95	8.00*	8.00*	920-940		8.00*	8.00*	8.00*	8.00*	
440-460	6.13	5.12	5.63	6.60	8.00*	8.00*	940-960		8.00*	8.00*	8.00*	8.00*	
460-480	7.06	5.50	6.29	7.47	8.00*	8.00*	960-980		8.00*	8.00*	8.00*	8.00*	
480-500	5.69	3.67	6.76	7.50	8.00*	8.00*	980-1000		8.00*	8.00*	8.00*	8.00*	

*Specific Yield value estimated

APPENDIX 3 (contd.)

ESTIMATED AVERAGE WEIGHTED SPECIFIC YIELD VALUES BY DEPTH INCREMENTS BELOW GROUND SURFACE SAN JOAQUIN COUNTY GROUND WATER INVESTIGATION

DEPTH INCREMENT BELOW GROUND SURFACE	SPECIFIC YIELD IN PERCENT FOR INDICATED TOWNSHIP AND RANGE				
	2N/6E	2N/7E	2N/8E	2N/9E	2N/10E
0- 20	6.24	4.67	4.56	4.42	9.00*
20- 40	8.61	5.36	5.98	8.24	9.00*
40- 60	8.71	6.09	6.11	4.86	9.00*
60- 80	9.45	7.16	5.65	4.26	9.00*
80-100	7.91	6.40	5.25	4.25	9.00*
100-120	6.96	6.00	4.83	4.23	9.00*
120-140	6.41	5.61	4.82	4.44	9.00*
140-160	7.16	5.38	4.80	5.80	9.00*
160-180	7.96	5.08	4.01	6.35	9.00*
180-200	10.60	5.85	4.63	5.25	9.00*
200-220	9.45	5.25	4.22	6.46	9.00*
220-240	13.18	5.22	5.52	6.50	9.00*
240-260	11.45	6.03	4.79	8.00	9.00*
260-280	8.54	5.60	4.56	7.29	9.00*
280-300	8.02	5.69	4.76	5.50	9.00*
300-320	11.10	4.60	5.54	5.33	9.00*
320-340	8.67	4.07	5.70	4.81	9.00*
340-360	9.51	4.93	5.34	5.00	9.00*
360-380	6.59	4.76	5.25	5.92	9.00*
380-400	7.25	5.80	5.75	4.60	9.00*
400-420	7.73	4.57	4.26	4.40	9.00*
420-440	9.48	3.91	5.79	4.40	9.00*
440-460	8.79	6.48	6.36	4.20	9.00*
460-480	8.43	4.74	6.23	4.50	9.00*
480-500	5.57	6.18	4.22	4.50	9.00*

DEPTH INCREMENT BELOW GROUND SURFACE	SPECIFIC YIELD IN PERCENT FOR INDICATED TOWNSHIP AND RANGE				
	2N/6E	2N/7E	2N/8E	2N/9E	2N/10E
500- 520	8.34	4.21	4.52	8.90	9.00*
520- 540	5.31	6.40	6.83	7.00	9.00*
540- 560	5.70	4.38	5.38	4.75	9.00*
560- 580	3.53	4.40	8.86	10.00	9.00*
580- 600	17.30	5.40	4.16	5.00	9.00*
600- 620	9.60	8.70	4.80	10.33	9.00*
620- 640	9.00*	7.01	5.83	11.67	9.00*
640 660		6.17	9.60	11.00	9.00*
660- 680		18.00	5.17	7.17	9.00*
680- 700		10.00	10.00	3.50	9.00*
700- 720		10.00	8.00*	6.20	9.00*
720- 740		8.00*	8.00*	7.00	9.00*
740- 760		8.00*	8.00*	8.00	9.00*
760- 780		8.00*	8.00*	8.75	9.00*
780- 800		8.00*	8.00*	5.63	9.00*
800- 820		8.00*	8.00*	3.00	9.00*
820- 840		8.00*	8.00*	3.00	9.00*
840- 860		8.00*	8.00*	3.00	9.00*
860- 880		8.00*	8.00*	8.00*	9.00*
880- 900		8.00*	8.00*	8.00*	9.00*
900- 920		8.00*	8.00*	8.00*	
920- 940		8.00*	8.00*	8.00*	
940- 960		8.00*	8.00*	8.00*	
960- 980		8.00*	8.00*	8.00*	
980-1000		8.00*	8.00*	8.00*	

*Specific yield value estimated

APPENDIX 3 (contd.)

ESTIMATED AVERAGE WEIGHTED SPECIFIC YIELD
VALUES BY DEPTH INCREMENTS BELOW GROUND SURFACE
SAN JOAQUIN COUNTY GROUND WATER INVESTIGATION

DEPTH INCREMENT BELOW GROUND SURFACE	SPECIFIC YIELD IN PERCENT FOR INDICATED TOWNSHIP AND RANGE					DEPTH INCREMENT BELOW GROUND SURFACE	SPECIFIC YIELD IN PERCENT FOR INDICATED TOWNSHIP AND RANGE				
	3N/6E	3N/7E	3N/8E	3N/9E	3N/10E		3N/6E	3N/7E	3N/8E	3N/9E	3N/10E
0- 20	6.03	6.15	4.22	5.00	3.40	500- 520	15.10	4.73	14.10	8.00*	9.00*
20- 40	8.69	8.17	4.73	5.00	11.80	520- 540	25.00	8.00	6.80	8.00*	9.00*
40- 60	10.70	10.51	5.10	5.00	20.60	540- 560	25.00	6.15	3.00	8.00*	9.00*
60- 80	9.21	10.23	4.81	5.00	11.80	560- 580	25.00	3.00	3.35	8.00*	9.00*
80-100	6.92	9.62	6.18	5.00	18.40	580- 600	25.00	3.00	5.60	8.00*	9.00*
100-120	7.60	8.30	6.79	5.00	13.00	600- 620	25.00	3.00	8.00*	8.00*	
120-140	6.29	9.99	6.09	7.50	6.60	620- 640	22.75	3.00	8.00*	8.00*	
140-160	6.75	6.94	4.81	7.50	3.00	640- 660	10.00	3.20	8.00*	8.00*	
160-180	8.21	7.18	4.48	7.50	3.00	660- 680	10.00*	6.60	8.00*	8.00*	
180-200	6.94	6.79	3.85	7.50	14.00	680- 700	10.00*	9.00*	8.00*	8.00*	
200-220	6.79	5.72	3.93	7.50	3.00	700- 720	10.00*	9.00*	8.00*	8.00*	
220-240	8.66	5.74	3.99	7.50	3.00	720- 740	10.00*	9.00*	8.00*	8.00*	
240-260	8.60	3.86	4.38	6.50	3.00	740- 760	10.00*	9.00*	8.00*	8.00*	
260-280	3.63	6.18	4.56	7.00	3.00	760- 780	10.00*	9.00*	8.00*	8.00*	
280-300	7.30	8.45	5.43	7.50	3.00	780- 800	10.00*	9.00*	8.00*	8.00*	
300-320	10.33	3.45	5.85	4.00	3.00	800- 820	10.00*	9.00*	8.00*	8.00*	
320-340	4.10	4.60	7.18	7.50	3.00	820- 840	10.00*	9.00*	8.00*	8.00*	
340-360	4.10	4.93	5.46	12.84	9.00*	840- 860	10.00*	9.00*	8.00*	8.00*	
360-380	9.65	4.60	4.14	10.00	9.00*	860- 880	10.00*	9.00*	8.00*	8.00*	
380-400	3.00	6.11	6.71	10.00	9.00*	880- 900	10.00*	9.00*	8.00*	8.00*	
400-420	11.80	7.40	4.03	3.70	9.00*	900- 920	10.00*	9.00*	8.00*	8.00*	
420-440	17.85	4.93	6.14	3.00	9.00*	920- 940	10.00*	9.00*	8.00*	8.00*	
440-460	14.00	5.80	6.26	3.00	9.00*	940- 960	10.00*	9.00*	8.00*	8.00*	
460-480	5.20	5.27	10.88	3.00	9.00*	960- 980	10.00*	9.00*	8.00*	8.00*	
480-500	7.40	4.73	4.50	3.00	9.00*	980-1000	10.00*	9.00*	8.00*	8.00*	

*Specific Yield value estimated

APPENDIX 3 (contd.)

ESTIMATED AVERAGE WEIGHTED SPECIFIC YIELD
VALUES BY DEPTH INCREMENTS BELOW GROUND SURFACE
SAN JOAQUIN COUNTY GROUND WATER INVESTIGATION

DEPTH INCREMENT BELOW GROUND SURFACE	SPECIFIC YIELD IN PERCENT FOR INDICATED TOWNSHIP AND RANGE				DEPTH INCREMENT BELOW GROUND SURFACE	SPECIFIC YIELD IN PERCENT FOR INDICATED TOWNSHIP AND RANGE			
	4N/6E	4N/7E	4N/8E	4N/9E		4N/6E	4N/7E	4N/8E	4N/9E
0- 20	5.56	4.53	3.64	3.25	500- 520	5.20	8.98	8.45	8.00*
20- 40	6.45	5.69	5.39	3.00	520- 540	3.33	8.10	5.16	8.00*
40- 60	8.25	7.56	4.64	3.00	540- 560	4.30	10.14	8.94	8.00*
60- 80	10.66	8.46	5.24	9.65	560- 580	10.11	7.25	4.48	8.00*
80-100	9.37	8.51	5.19	9.03	580- 600	9.00*	11.58	4.13	8.00*
100-120	8.31	7.10	6.50	3.63	600- 620	9.00*	3.85	3.68	8.00*
120-140	8.22	5.71	5.38	8.00*	620- 640	9.00*	6.25	6.50	8.00*
140-160	7.37	5.54	5.77	8.00*	640- 660	9.00*	4.75	3.00	8.00*
160-180	6.05	6.36	4.76	8.00*	660- 680	9.00*	3.00	3.00	8.00*
180-200	6.59	4.27	6.09	8.00*	680- 700	9.00*	19.50	13.00	8.00*
200-220	8.18	7.17	6.66	8.00*	700- 720	9.00*	17.30	8.00*	8.00*
220-240	6.84	6.83	6.84	8.00*	720- 740	9.00*	8.00*	8.00*	8.00*
240-260	7.10	7.50	7.01	8.00*	740- 760	9.00*	8.00*	8.00*	8.00*
260-280	6.56	5.21	5.40	8.00*	760- 780	9.00*	8.00*	8.00*	8.00*
280-300	9.22	5.85	5.77	8.00*	780- 800	9.00*	8.00*	8.00*	8.00*
300-320	8.87	6.80	6.15	8.00*	800- 820	9.00*	8.00*	8.00*	8.00*
320-340	8.50	5.78	5.20	8.00*	820- 840	9.00*	8.00*	8.00*	8.00*
340-360	8.50	5.38	6.84	8.00*	840- 860	9.00*	8.00*	8.00*	8.00*
360-380	9.43	6.33	12.00	8.00*	860- 880	9.00*	8.00*	8.00*	8.00*
380-400	11.25	5.79	11.13	8.00*	880- 900	9.00*	8.00*	8.00*	8.00*
400-420	5.20	5.63	10.39	8.00*	900- 920	9.00*	8.00*	8.00*	8.00*
420-440	4.47	4.90	8.12	8.00*	920- 940	9.00*	8.00*	8.00*	8.00*
440-460	3.00	7.99	11.44	8.00*	940- 960	9.00*	8.00*	8.00*	8.00*
460-480	3.00	5.91	10.50	8.00*	960- 980	9.00*	8.00*	8.00*	8.00*
480-500	5.20	5.84	7.64	8.00*	980-1000	9.00*	8.00*	8.00*	8.00*

*Specific Yield value estimated

APPENDIX 3 (contd.)

ESTIMATED AVERAGE WEIGHTED SPECIFIC YIELD
VALUES BY DEPTH INCREMENTS BELOW GROUND SURFACE
SAN JOAQUIN COUNTY GROUND WATER INVESTIGATION

DEPTH INCREMENT BELOW GROUND SURFACE	SPECIFIC YIELD IN PERCENT FOR INDICATED TOWNSHIP AND RANGE			
	5N/7E	5N/8E	5N/9E	5N/10E
0- 20	5.77	5.73	3.00	9.00*
20- 40	7.61	9.94	3.00	9.00*
40- 60	7.11	9.40	7.40	9.00*
60- 80	8.25	14.21	6.30	9.00*
80-100	7.57	4.51	6.30	9.00*
100-120	6.95	6.79	11.80	9.00*
120-140	6.71	5.54	3.50	9.00*
140-160	6.60	5.17	21.33	9.00*
160-180	6.75	8.43	8.00*	9.00*
180-200	6.15	5.35	8.00*	9.00*
200-220	5.59	5.28	8.00*	9.00*
220-240	5.68	4.69	8.00*	9.00*
240-260	6.03	4.66	8.00*	9.00*
260-280	6.03	3.25	8.00*	9.00*
280-300	5.06	4.50	8.00*	9.00*
300-320	5.89	12.13	8.00*	9.00*
320-340	5.20	14.49	8.00*	9.00*
340-360	5.28	14.08	8.00*	9.00*
360-380	5.12	9.46	8.00*	9.00*
380-400	6.18	11.53	8.00*	9.00*
400-420	5.29	4.80	8.00*	9.00*
420-440	5.49	3.00	8.00*	9.00*
440-460	5.78	4.80	8.00*	9.00*
460-480	5.27	4.00	8.00*	9.00*
480-500	6.29	4.00	8.00*	

DEPTH INCREMENT BELOW GROUND SURFACE	SPECIFIC YIELD IN PERCENT FOR INDICATED TOWNSHIP AND RANGE		
	5N/7E	5N/8E	5N/9E
500- 520	7.37	4.00	8.00*
520- 540	5.65	5.00	8.00*
540- 560	6.06	5.00	8.00*
560- 580	6.55	11.00	8.00*
580- 600	5.14	5.00	8.00*
600- 620	5.11	5.00	8.00*
620- 640	6.48	8.00*	8.00*
640- 660	5.30	8.00*	8.00*
660- 680	5.25	8.00*	8.00*
680- 700	5.25	8.00*	8.00*
700- 720	4.80	8.00*	8.00*
720- 740	5.17	8.00*	8.00*
740- 760	5.43	8.00*	8.00*
760- 780	5.10	8.00*	8.00*
780- 800	3.00	8.00*	8.00*
800- 820	5.80	8.00*	
820- 840	3.00	8.00*	
840- 860	5.80	8.00*	
860- 880	8.00*	8.00*	
880- 900	8.00*	8.00*	
900- 920	8.00*	8.00*	
920- 940	8.00*	8.00*	
940- 960	8.00*	8.00*	
960- 980	8.00*	8.00*	
980-1000	8.00*	8.00*	

*Specific yield value estimated

APPENDIX 3 (contd.)

ESTIMATED AVERAGE WEIGHTED SPECIFIC YIELD
VALUES BY DEPTH INCREMENTS BELOW GROUND SURFACE
SAN JOAQUIN COUNTY GROUND WATER INVESTIGATION

DEPTH INCREMENT BELOW GROUND SURFACE	SPECIFIC YIELD IN PERCENT FOR INDICATED TOWNSHIP AND RANGE					
	1S/6E	1S/7E	1S/8E	1S/9E	1S/10E	1S/11E
0- 20	8.74	9.72	11.28	10.83	8.63	13.00
20- 40	11.08	10.91	14.11	9.60	3.63	10.00
40- 60	11.06	9.65	12.37	5.85	5.93	3.50
60- 80	14.72	12.00	12.73	6.30	5.03	4.00
80-100	9.22	9.43	11.81	5.28	7.80	3.00
100-120	3.00	8.75	11.20	4.05	3.82	5.25
120-140	12.90	15.12	7.94	3.60	4.25	5.00
140-160	25.00	8.85	6.26	6.80	8.80	11.80
160-180	14.00	7.59	6.94	11.88	5.13	21.25
180-200	3.00	10.00	7.48	15.10	8.07	10.00
200-220	3.00	10.00*	3.20	4.80	8.53	10.00
220-240	10.00*	10.00*	3.54	3.70	16.75	10.00
240-260	10.00*	10.00*	3.40	3.00	7.40	9.30
260-280	10.00*	10.00*	6.98	4.10	7.40	14.00
280-300	10.00*	10.00*	6.18	4.10	25.00	5.00
300-320	10.00*	10.00*	4.95	3.53	15.10	5.00
320-340	10.00*	10.00*	3.40	11.50	3.00	5.00
340-360	10.00*	10.00*	3.35	3.00	5.80	5.00
360-380	10.00*	10.00*	4.83	3.00	3.00	5.00
380-400	10.00*	10.00*	4.63	3.00	3.80	5.00
400-420	10.00*	10.00*	3.93	10.86	3.40	8.75
420-440	10.00*	10.00*	3.07	9.00*	7.20	6.50
440-460	10.00*	10.00*	3.00	9.00*	4.40	3.00
460-480	10.00*	10.00*	3.00	9.00*	21.33	3.00
480-500	10.00*	10.00*	5.00	9.00*	10.00*	10.00*

DEPTH INCREMENT BELOW GROUND SURFACE	SPECIFIC YIELD IN PERCENT FOR INDICATED TOWNSHIP AND RANGE				
	1S/6E	1S/7E	1S/8E	1S/9E	1S/10E
500- 520		10.00*	10.05	9.00*	10.00*
520- 540		10.00*	3.00	9.00*	10.00*
540- 560		10.00*	5.00	9.00*	10.00*
560- 580		10.00*	12.80	9.00*	10.00*
580- 600		10.00*	3.00	9.00*	10.00*
600- 620		10.00*	9.00*	9.00*	
620- 640		10.00*	9.00*	9.00*	
640- 660		10.00*	9.00*	9.00*	
660- 680		10.00*	9.00*	9.00*	
680- 700		10.00*	9.00*	9.00*	
700- 720		10.00*	9.00*	9.00*	
720- 740		10.00*	9.00*	9.00*	
740- 760		10.00*	9.00*	9.00*	
760- 780		10.00*	9.00*	9.00*	
780- 800		10.00*	9.00*	9.00*	
800- 820		10.00*	9.00*		
820- 840		10.00*	9.00*		
840- 860		10.00*	9.00*		
860- 880		10.00*	9.00*		
880- 900		10.00*	9.00*		
900- 920		10.00*	9.00*		
920- 940		10.00*	9.00*		
940- 960		10.00*	9.00*		
960- 980		10.00*	9.00*		
980-1000		10.00*	9.00*		

*Specific Yield value estimated

APPENDIX 3 (contd.)

ESTIMATED AVERAGE WEIGHTED SPECIFIC YIELD
VALUES BY DEPTH INCREMENTS BELOW GROUND SURFACE
SAN JOAQUIN COUNTY GROUND WATER INVESTIGATION

DEPTH INCREMENT BELOW GROUND SURFACE	SPECIFIC YIELD IN PERCENT FOR INDICATED TOWNSHIP AND RANGE					
	2S/6E	2S/7E	2S/8E	2S/9E	2S/10E	2S/11E
0- 20	11.81	10.26	13.63	13.39	9.15	10.41
20- 40	14.61	8.38	12.48	18.69	10.23	10.72
40- 60	13.82	10.99	13.86	13.55	9.84	11.28
60- 80	12.56	10.15	12.81	13.46	9.73	11.49
80-100	10.36	3.79	12.48	14.29	8.33	9.18
100-120	12.48	5.29	8.54	15.09	5.75	6.05
120-140	11.96	5.25	6.63	8.17	4.70	5.60
140-160	10.80	7.68	7.95	3.83	5.01	5.09
160-180	18.12	3.00	6.30	4.25	5.94	5.82
180-220	17.56	3.00	5.75	3.93	5.56	6.83
200-220	14.06	3.00	3.92	3.35	4.34	7.50
220-240	14.59	3.00	3.00	4.10	4.10	7.75
240-260	10.06	4.40	4.86	8.50	4.47	8.33
260-280	10.63	14.50	3.50	15.65	5.50	6.50
280-300	6.78	10.00	4.47	4.00	4.09	3.00
300-320	6.53	10.00	7.40	5.00	4.02	3.00
320-340	7.16	10.00	3.00	5.00	4.39	3.00
340-360	7.35	10.00	3.00	5.00	5.68	6.15
360-380	7.31	8.00	9.00*	15.00	5.27	3.00
380-400	4.82	9.00*	9.00*	4.50	7.29	3.00
400-420	7.60	9.00*	9.00*	5.00	5.14	3.00
420-440	10.76	9.00*	9.00*	5.00	7.92	3.00
440-460	7.80	9.00*	9.00*	5.00	6.39	7.40
460-480	8.42	9.00*	9.00*	5.00	9.79	3.00
480-500	7.70	9.00*	9.00*	5.00	4.19	6.50

DEPTH INCREMENT BELOW GROUND SURFACE	SPECIFIC YIELD IN PERCENT FOR INDICATED TOWNSHIP AND RANGE					
	2S/6E	2S/7E	2S/8E	2S/9E	2S/10E	2S/11E
500- 520	6.60	9.00*	9.00*	5.00	9.63	3.00
520- 540	7.42	9.00*	9.00*	5.00	5.25	3.00
540- 560	9.73	9.00*	9.00*	5.00	10.88	4.40
560- 580	13.67	9.00*	9.00*	5.00	7.51	3.00
580- 600	8.25	9.00*	9.00*	5.00	8.00	3.00
600- 620	10.95	9.00*	9.00*	3.00		4.40
620- 640	14.00	9.00*	9.00*	5.00		3.00
640- 660	6.50	9.00*	9.00*	5.00		13.42
660- 680	5.00	9.00*	9.00*	5.00		8.00*
680- 700	16.25	9.00*	9.00*	5.00		8.00*
700- 720	10.13	9.00*	9.00*	9.00*		
720- 740	11.33	9.00*	9.00*	9.00*		
740- 760	6.50	9.00*	9.00*	9.00*		
760- 780	11.00	9.00*	9.00*	9.00*		
780- 800	11.50	9.00*	9.00*	9.00*		
800- 820	7.38	9.00*	9.00*	9.00*		
820- 840	10.00*	9.00*	9.00*	9.00*		
840- 860	10.00*	9.00*	9.00*	9.00*		
860- 880	10.00*	9.00*	9.00*	9.00*		
880- 900	10.00*	9.00*	9.00*	9.00*		
900- 920				9.00*		
920- 940				9.00*		
940- 960				9.00*		
960- 980				9.00*		
980-1000				9.00*		

*Specific Yield value estimated

APPENDIX 3 (contd.)

ESTIMATED AVERAGE WEIGHTED SPECIFIC YIELD
VALUES BY DEPTH INCREMENTS BELOW GROUND SURFACE
SAN JOAQUIN COUNTY GROUND WATER INVESTIGATION

DEPTH INCREMENT BELOW GROUND SURFACE	SPECIFIC YIELD IN PERCENT FOR INDICATED TOWNSHIP AND RANGE	
	2S/12E	2S/13E
0- 20	25.00	10.00*
20- 40	25.00	10.00*
40- 60	8.50	10.00*
60- 80	3.00	10.00*
80-100	5.70	10.00*
100-120	5.00	10.00*
120-140	5.00	10.00*
140-160	5.00	10.00*
160-180	5.00	10.00*
180-200	5.00	10.00*
200-220	5.00	10.00*
220-240	12.50	10.00*
240-260	5.00	10.00*
260-280	8.00	10.00*
280-300	5.00	10.00*
300-320	7.50	10.00*
320-340	5.00	10.00*
340-360	10.00*	10.00*
360-380	10.00*	10.00*
380-400	10.00*	10.00*
400-420		
420-440		
440-460		
460-480		
480-500		

*Specific Yield value estimated

APPENDIX 4

ESTIMATED STORAGE CAPACITY VALUES IN ACRE-FEET BY DEPTH INCREMENTS BELOW GROUND SURFACE FOR SAN JOAQUIN COUNTY GROUND WATER INVESTIGATION HYDROLOGIC STUDY

These estimated storage capacity values were finalized in 1961 using the average weighted specific yield values of Appendix 3 for the acreages shown.

This table is a portion of the print out from the 650 Computer Program #284.

APPENDIX 4

ESTIMATED STORAGE CAPACITY VALUES IN ACRE-FEET BY DEPTH INCREMENT BELOW GROUND SURFACE SAN JOAQUIN COUNTY GROUND WATER INVESTIGATION

DEPTH INCREMENT BELOW GROUND SURFACE	Estimated Storage Capacity Values for Indicated Township and Range: 1N/6E	1N/7E	1N/8E	1N/9E	1N/10E	1N/11E
TOWNSHIP ACREAGE USED FOR THIS STUDY	10,560	22,941	22,963	23,245	21,993	4,026
0- 20	9,694	18,123	31,643	25,384	27,843	6,442*
20- 40	15,481	26,612	29,209	40,353	13,196	6,442*
40- 60	17,656	33,035	36,603	35,239	20,893	6,442*
60- 80	20,212	36,384	32,607	41,702	19,794	6,442*
80-100	15,333	32,943	28,382	31,195	24,764	6,442*
100-120	13,644	31,475	36,649	30,823	18,694	6,442*
120-140	19,050	35,696	43,584	28,126	19,794	6,442*
140-160	13,601	41,936	43,216	26,825	22,565	6,442*
160-180	19,219	37,807	33,113	25,291	18,166	6,442*
180-200	21,268	29,319	28,015	29,661	13,196	6,442*
200-220	27,625	33,264	29,576	35,332	16,495	6,442*
220-240	27,540	29,089	19,105	34,263	31,890	6,442*
240-260	24,330	24,501	20,483	30,730	20,893	6,442*
260-280	17,973	38,403	20,621	28,405	18,694	6,442*
280-300	17,677	41,936	24,203	34,217	21,993	6,442*
300-320	17,023	32,943	22,504	28,638	21,993	6,442*
320-340	19,895	44,460	16,671	24,082	26,392	6,442*
340-360	16,431	19,179	26,407	25,012	35,189	6,442*
360-380	13,960	25,923	21,218	16,272	29,163	6,442*
380-400	19,494	21,014	24,019	18,038	42,886	6,442*
400-420	18,417	28,447	32,699	17,341	21,993	6,442*
420-440	16,748	17,435	27,969	27,662	35,189*	6,442*
440-460	12,947	23,492	25,856	30,683	35,189*	6,442*
460-480	14,911	25,235	28,887	34,728	35,189*	6,442*
480-500	12,017	16,839	31,046	34,868	35,189*	6,442*

DEPTH INCREMENT BELOW GROUND SURFACE	Estimated Storage Capacity Values for Indicated Township and Range: 1N/6E	1N/7E	1N/8E	1N/9E	1N/10E	1N/11E
500-520	12,461	33,953	37,200	34,868	35,189*	6,442*
520-540	14,784	83,184	18,370	23,245	35,189*	6,442*
540-560	10,560	36,706*	17,590	23,245	35,189*	6,442*
560-580	21,120*	36,706*	19,151	46,490	35,189*	6,442*
580-600	21,120*	36,706*	17,590	37,192*	35,189*	6,442*
600-620		36,706*	14,559	37,192*	35,189*	
620-640		36,706*	46,247	37,192*	35,189*	
640-660		36,706*	26,775	37,192*	35,189*	
660-680		36,706*	34,445	37,192*	35,189*	
680-700		36,706*	38,256	37,192*	35,189*	
700-720		36,706*	53,596	37,192*	35,189*	
720-740		36,706*	26,407	37,192*	35,189*	
740-760		36,706*	57,408	37,192*	35,189*	
760-780		36,706*	36,741*	37,192*	35,189*	
780-800		36,706*	36,741*	37,192*	35,189*	
800-820		36,706*	36,741*	37,192*	35,189*	
820-840		36,706*	36,741*	37,192*	35,189*	
840-860		36,706*	36,741*	37,192*	35,189*	
860-880		36,706*	36,741*	37,192*	35,189*	
880-900		36,706*	36,741*	37,192*	35,189*	
900-920		36,706*	36,741*	37,192*	35,189*	
920-940		36,706*	36,741*	37,192*	35,189*	
940-960		36,706*	36,741*	37,192*	35,189*	
960-980		36,706*	36,741*	37,192*	35,189*	
980-1000		36,706*	36,741*	37,192*	35,189*	

*Storage capacity value from estimated specific yield

APPENDIX 4 (contd.)

ESTIMATED STORAGE CAPACITY VALUES IN ACRE-FEET
BY DEPTH INCREMENT BELOW GROUND SURFACE
SAN JOAQUIN COUNTY GROUND WATER INVESTIGATION

DEPTH INCREMENT BELOW GROUND SURFACE	2N/6E	2N/7E	2N/8E	2N/9E	2N/10E
TOWNSHIP ACREAGE USED FOR THIS STUDY	17,774	22,669	22,943	23,837	12,534
	ESTIMATED STORAGE CAPACITY VALUES FOR INDICATED TOWNSHIP AND RANGE				
0- 20	22,182	21,173	20,924	21,072	22,561*
20- 40	30,607	24,301	27,440	39,283	22,561*
40- 60	30,962	27,611	28,036	23,170	22,561*
60- 80	33,593	32,462	26,843	20,309	22,561*
80-100	28,118	29,016	24,090	20,261	22,561*
100-120	24,741	27,203	22,163	20,166	22,561*
120-140	22,786	25,435	22,117	21,167	22,561*
140-160	25,452	24,392	22,025	27,651	22,561*
160-180	28,296	23,032	18,400	30,273	22,561*
180-200	37,681	26,523	21,245	25,029	22,561*
200-220	33,593	23,802	19,364	30,797	22,561*
220-240	46,852	23,666	25,329	30,988	22,561*
240-260	40,702	27,339	21,979	38,139	22,561*
260-280	30,358	25,389	20,924	34,754	22,561*
280-300	28,509	25,797	21,842	26,221	22,561*
300-320	39,458	20,855	25,421	25,410	22,561*
320-340	30,820	18,453	26,155	22,931	22,561*
340-360	33,806	22,352	24,503	23,837	22,561*
360-380	23,426	21,581	24,090	28,223	22,561*
380-400	25,772	26,296	26,384	21,930	22,561*
400-420	27,479	20,719	19,547	20,977	22,561*
420-440	33,700	17,727	26,568	20,977	22,561*
440-460	31,247	29,379	29,183	20,023	22,561*
460-480	29,967	21,490	28,587	21,453	22,561*
480-500	19,800	28,019	19,364	21,453	22,561*

DEPTH INCREMENT BELOW GROUND SURFACE	2N/6E	2N/7E	2N/8E	2N/9E	2N/10E
	ESTIMATED STORAGE CAPACITY VALUES FOR INDICATED TOWNSHIP AND RANGE				
500-520	29,647	19,087	20,740	42,430	22,561*
520-540	18,876	29,016	31,340	33,372	22,561*
540-560	20,262	19,858	24,687	22,645	22,561*
560-580	12,548	19,949	40,655	47,674	22,561*
580-600	61,498	24,483	19,089	23,837	22,561*
600-620	34,126	39,444	22,025	49,247	22,561*
620-640	31,993*	31,782	26,752	55,636	22,561*
640-660		27,974	44,051	52,441	22,561*
660-680		81,608	23,723	34,182	22,561*
680-700		45,338	45,886	16,686	22,561*
700-720		45,338	36,709*	29,558	22,561*
720-740		36,270*	36,709*	33,372	22,561*
740-760		36,270*	36,709*	38,139	22,561*
760-780		36,270*	36,709*	41,715	22,561*
780-800		36,270*	36,709*	26,840	22,561*
800-820		36,270*	36,709*	14,302	22,561*
820-840		36,270*	36,709*	14,302	22,561*
840-860		36,270*	36,709*	14,302	22,561*
860-880		36,270*	36,709*	38,139*	22,561*
880-900		36,270*	36,709*	38,139*	22,561*
900-920		36,270*	36,709*	38,139*	
920-940		36,270*	36,709*	38,139*	
940-960		36,270*	36,709*	38,139*	
960-980		36,270*	36,709*	38,139*	
980-1000		36,270*	36,709*	38,139*	

*Storage capacity value from estimated specific yield

APPENDIX 4 (contd.)

ESTIMATED STORAGE CAPACITY VALUES IN ACRE-FEET
BY DEPTH INCREMENT BELOW GROUND SURFACE
SAN JOAQUIN COUNTY GROUND WATER INVESTIGATION

DEPTH INCREMENT BELOW GROUND SURFACE	3N/6E	3N/7E	3N/8E	3N/9E	3N/10E
TOWNSHIP ACREAGE USED FOR THIS STUDY	22,215	23,046	23,039	20,298	2,236
	ESTIMATED STORAGE CAPACITY VALUES FOR INDICATED TOWNSHIP AND RANGE				
0- 20	26,791	28,347	19,445	20,298	1,520
20- 40	38,610	37,657	21,795	20,298	5,277
40- 60	47,540	48,443	23,500	20,298	9,212
60- 80	40,920	47,152	22,164	20,298	5,277
80-100	30,746	44,341	28,476	20,298	8,228
100-120	33,767	38,256	31,287	20,298	5,814
120-140	27,946	46,046	28,062	30,447	2,952
140-160	29,990	31,988	22,164	30,447	1,342
160-180	36,477	33,094	20,643	30,447	1,342
180-200	30,843	31,296	17,740	30,447	6,261
200-220	30,168	26,365	18,109	30,447	1,342
220-240	38,476	26,457	18,385	30,447	1,342
240-260	38,210	17,792	20,182	26,387	1,342
260-280	16,128	28,485	21,012	28,417	1,342
280-300	32,434	38,948	25,020	30,447	1,342
300-320	45,896	15,902	26,956	16,238	1,342
320-340	18,216	21,202	33,084	30,447	1,342
340-360	18,216	22,723	25,159	52,125	4,025*
360-380	42,875	21,202	19,076	40,596	4,025*
380-400	13,329	28,162	30,918	40,596	4,025*
400-420	52,427	34,108	18,569	15,021	4,025*
420-440	79,308	22,723	28,292	12,179	4,025*
440-460	62,202	26,733	28,845	12,179	4,025*
460-480	23,104	24,290	50,133	12,179	4,025*
480-500	32,878	21,802	20,735	12,179	4,025*

DEPTH INCREMENT BELOW GROUND SURFACE	3N/6E	3N/7E	3N/8E	3N/9E	3N/10E
	ESTIMATED STORAGE CAPACITY VALUES FOR INDICATED TOWNSHIP AND RANGE				
500-520	67,089	21,802	64,970	32,477*	4,025*
520-540	111,075	36,874	31,333	32,477*	4,025*
540-560	111,075	28,347	13,823	32,477*	4,025*
560-680	111,075	13,828	15,436	32,477*	4,025*
580-600	111,075	13,828	25,804	32,477*	4,025*
600-620	111,075	13,828	36,862*	32,477*	
620-640	101,078	13,828	36,862*	32,477*	
640-660	44,430	14,749	38,862*	32,477*	
660-680	44,430*	30,421	36,862*	32,477*	
680-700	44,430*	41,483*	36,862*	32,477*	
700-720	44,430*	41,483*	36,862*	32,477*	
720-740	44,430*	41,483*	36,862*	32,477*	
740-760	44,430*	41,483*	36,862*	32,477*	
760-780	44,430*	41,483*	36,862*	32,477*	
780-800	44,430*	41,483*	36,862*	32,477*	
800-820	44,430*	41,483*	36,862*	32,477*	
820-840	44,430*	41,483*	36,862*	32,477*	
840-860	44,430*	41,483*	36,862*	32,477*	
860-880	44,430*	41,483*	36,862*	32,477*	
880-900	44,430*	41,483*	36,862*	32,477*	
900-920	44,430*	41,483*	36,862*	32,477*	
920-940	44,430*	41,483*	36,862*	32,477*	
940-960	44,430*	41,483*	36,862*	32,477*	
960-980	44,430*	41,483*	36,862*	32,477*	
980-1000	44,430*	41,483*	36,862*	32,477*	

*Storage capacity value from estimated specific yield

APPENDIX 4 (contd.)

ESTIMATED STORAGE CAPACITY VALUES IN ACRE-FEET
BY DEPTH INCREMENT BELOW GROUND SURFACE
SAN JOAQUIN COUNTY GROUND WATER INVESTIGATION

DEPTH INCREMENT BELOW GROUND SURFACE	TOWNSHIP ACREAGE USED FOR THIS STUDY			
	23,101	23,309	23,004	13,635
	ESTIMATED STORAGE CAPACITY VALUES FOR INDICATED TOWNSHIP AND RANGE			
	4N/6E	4N/7E	4N/8E	4N/9E
0- 20	25,688	21,118	16,747	8,863
20- 40	29,800	26,526	24,798	8,181
40- 60	38,117	35,243	21,348	8,181
60- 80	49,251	39,439	24,108	26,316
80-100	43,291	39,672	23,878	24,625
100-120	38,394	33,099	29,905	9,899
120-140	37,978	26,619	24,752	21,816*
140-160	34,051	25,826	26,547	21,816*
160-180	27,952	29,649	21,900	21,816*
180-200	30,447	19,906	28,019	21,816*
200-220	37,793	33,425	30,641	21,816*
220-240	31,602	31,840	31,469	21,816*
240-260	32,803	34,964	32,252	21,816*
260-280	30,309	24,288	24,844	21,816*
280-300	42,598	27,272	26,547	21,816*
300-320	40-981	31,700	28,295	21,816*
320-340	39,272	26,945	23,924	21,816*
340-360	39,272	25,080	31,469	21,816*
360-380	43,568	29,509	55,210	21,816*
380-400	51,977	26,992	51,207	21,816*
400-420	24,025	26,246	47,802	21,816*
420-440	20,652	22,843	37,358	21,816*
440-460	13,861	37,248	52,633	21,816*
460-480	13,861	27,551	48,308	21,816*
480-500	24,025	27,225	35,150	21,816*
500-520	24,025	41,863	38,877	21,816*
520-540	15,385	37,761	23,740	21,816*
540-560	22,177	47,271	41,131	21,816*
560-580	46,710	33,798	20,612	21,816*
580-600	41,582*	53,984	19,001	21,816*
600-620	41,582*	17,948	16,931	21,816*
620-640	41,582*	29,136	29,905	21,816*
640-660	41,582*	22,144	13,802	21,816*
660-680	41,582*	13,985	13,802	21,816*
680-700	41,582*	90,905	59,810	21,816*
700-720	41,582*	80,649	36,806*	21,816*
720-740	41,582*	37,294*	36,806*	21,816*
740-760	41,582*	37,294*	36,806*	21,816*
760-780	41,582*	37,294*	36,806*	21,816*
780-800	41,582*	37,294*	36,806*	21,816*
800-820	41,582*	37,294*	36,806*	21,816*
820-840	41,582*	37,294*	36,806*	21,816*
840-860	41,582*	37,294*	46,806*	21,816*
860-880	41,582*	37,294*	46,806*	21,816*
880-900	41,582*	37,294*	46,806*	21,816*
900-920	41,582*	37,294*	46,806*	21,816*
920-940	41,582*	37,294*	46,806*	21,816*
940-960	41,582*	37,294*	46,806*	21,816*
960-980	41,582*	37,294*	46,806*	21,816*
980-1000	41,582*	37,294*	46,806*	21,816*

*Storage capacity value from estimated specific yield

APPENDIX 4 (contd.)

ESTIMATED STORAGE CAPACITY VALUES IN ACRE-FEET
BY DEPTH INCREMENT BELOW GROUND SURFACE
SAN JOAQUIN COUNTY GROUND WATER INVESTIGATION

DEPTH INCREMENT BELOW GROUND SURFACE	TOWNSHIP ACREAGE USED FOR THIS STUDY			
	23,162	22,661	13,970	1,815
	ESTIMATED STORAGE CAPACITY VALUES FOR INDICATED TOWNSHIP AND RANGE			
	5N/7E	5N/8E	5N/9E	5N/10E
0- 20	26,729	25,970	8,382	3,267*
20- 40	35,253	45,050	8,382	3,267*
40- 60	32,936	42,603	20,676	3,267*
60- 80	38,217	64,403	17,602	3,267*
80-100	35,067	20,440	17,602	3,267*
100-120	32,195	30,774	32,969	3,267*
120-140	31,083	25,108	9,779	3,267*
140-160	30,574	23,431	59,596	3,267*
160-180	31,269	38,206	22,352*	3,267*
180-200	28,489	24,247	22,352*	3,267*
200-220	25,895	23,930	22,352*	3,267*
220-240	26,312	21,256	22,352*	3,267*
240-260	27,933	21,120	22,352*	3,267*
260-280	27,933	14,730	22,352*	3,267*
280-300	23,440	20,395	22,352*	3,267*
300-320	27,285	54,976	22,352*	3,267*
320-340	24,088	65,672	22,352*	3,267*
340-360	24,459	63,813	22,352*	3,267*
360-380	23,718	42,875	22,352*	3,267*
380-400	28,628	52,256	22,352*	3,267*
400-420	24,505	21,755	22,352*	3,267*
420-440	25,432	13,597	22,352*	3,267*
440-460	26,775	21,755	22,352*	3,267*
460-480	24,413	18,129	22,352*	3,267*
480-500	29,138	18,129	22,352*	

DEPTH INCREMENT BELOW GROUND SURFACE	ESTIMATED STORAGE CAPACITY VALUES FOR INDICATED TOWNSHIP AND RANGE			
	5N/7E	5N/8E	5N/9E	5N/10E
500-520	34,141	18,129	22,352*	
520-540	26,173	22,661	22,352*	
540-560	28,072	22,661	22,352*	
560-580	30,342	49,854	22,352*	
580-600	23,811	22,661	22,352*	
600-620	23,672	22,661	22,352*	
620-640	30,018	36,258*	22,352*	
640-660	24,552	36,258*	22,352*	
660-680	24,320	36,258*	22,352*	
680-700	24,320	36,258*	22,352*	
700-720	22,236	36,258*	22,352*	
720-740	23,950	36,258*	22,352*	
740-760	25,154	36,258*	22,352*	
760-780	23,625	36,258*	22,352*	
780-800	13,897	36,258*	22,352*	
800-820	26,868	36,258*		
820-840	13,897	36,258*		
840-860	26,868	36,258*		
860-880	37,059*	36,258*		
880-900	37,059*	36,258*		
900-920	37,059*	36,258*		
920-940	37,059*	36,258*		
940-960	37,059*	36,258*		
960-980	37,059*	36,258*		
980-1000	37,059*	36,258*		

*Storage capacity value from estimated specific yield

APPENDIX 4 (contd.)

ESTIMATED STORAGE CAPACITY VALUES IN ACRE-FEET
BY DEPTH INCREMENT BELOW GROUND SURFACE
SAN JOAQUIN COUNTY GROUND WATER INVESTIGATION

DEPTH INCREMENT BELOW GROUND SURFACE	TOWNSHIP ACREAGE USED FOR THIS STUDY						DEPTH INCREMENT BELOW GROUND SURFACE						
	14,517	22,621	22,905	23,283	23,251	20,953							
	ESTIMATED STORAGE CAPACITY VALUES FOR INDICATED TOWNSHIP AND RANGE							ESTIMATED STORAGE CAPACITY VALUES FOR INDICATED TOWNSHIP AND RANGE					
	1S/6E	1S/7E	1S/8E	1S/9E	1S/10E	1S/11E		1S/6E	1S/7E	1S/8E	1S/9E	1S/10E	1S/11E
0- 20	25,376	43,975	51,674	50,431	40,131	54,478	500-520		45,242*	46,039	41,909*	46,502*	
20- 40	32,170	49,359	64,638	44,703	16,880	41,906	520-540		45,242*	13,743	41,909*	46,502*	
40- 60	32,112	43,659	56,667	27,241	27,576	14,667	540-560		45,242*	22,905	41,909*	46,502*	
60- 80	42,738	54,290	58,316	29,337	23,391	16,762	560-580		45,242*	58,637	41,909*	46,502*	
80-100	26,769	42,663	54,102	24,587	36,272	12,572	580-600		45,242*	13,743	41,909*	46,502*	
100-120	25,202	39,587	51,307	18,859	17,764	22,001	600-620		45,242*	41,229*	41,909*		
120-140	29,731	68,406	36,373	16,764	19,763	20,953	620-640		45,242*	41,229*	41,909*		
140-160	24,360	40,039	28,677	31,665	40,992	49,449	640-660		45,242*	41,229*	41,909*		
160-180	25,492	34,339	31,792	55,320	23,856	89,050	660-680		45,242*	41,229*	41,909*		
180-200	13,094	45,242	34,266	70,315	37,527	41,906	680-700		45,242*	41,229*	41,909*		
200-220	14,720	45,242*	14,659	22,352	39,666	41,906	700-720		45,242*	41,229*	41,909*		
220-240	34,463	45,242*	16,217	17,229	77,891	41,906	720-740		45,242*	41,229*	41,909*		
240-260	40,648	45,242*	15,575	13,970	34,411	38,973	740-760		45,242*	41,229*	41,909*		
260-280	8,710	45,242*	31,975	19,092	34,411	58,668	760-780		45,242*	41,229*	41,909*		
280-300	8,710	45,242*	28,311	19,092	116,255	20,953	780-800		45,242*	41,229*	41,909*		
300-320	8,710	45,242*	22,676	16,438	70,218	20,953	800-820		45,242*	41,229*			
320-340	21,485	45,242*	15,575	53,551	13,951	20,953	820-840		45,242*	41,229*			
340-360	29,034*	45,242*	15,346	13,970	26,971	20,953	840-860		45,242*	41,229*			
360-380	29,034*	45,242*	22,126	13,970	13,951	20,953	860-880		45,242*	41,229*			
380-400	29,034*	45,242*	21,210	13,970	17,671	20,953	880-900		45,242*	41,229*			
400-420	29,034*	45,242*	18,003	50,571	15,811	36,668	900-920		45,242*	41,229*			
420-440	29,034*	45,242*	14,064	41,909*	33,481	27,239	920-940		45,242*	41,229*			
440-460	29,034*	45,242*	13,743	41,909*	20,461	12,572	940-960		45,242*	41,229*			
460-480	29,034*	45,242*	13,743	41,909*	99,189	12,572	960-980		45,242*	41,229*			
480-500	29,034*	45,242*	22,905	41,909*	46,502*	41,906*	980-100		45,242*	41,229*			

*Storage capacity value from estimated specific yield

ESTIMATED STORAGE CAPACITY VALUES IN ACRE-FEET
BY DEPTH INCREMENT BELOW GROUND SURFACE
SAN JOAQUIN COUNTY GROUND WATER INVESTIGATION

DEPTH INCREMENT BELOW GROUND SURFACE	2S/6E	2S/7E	2S/8E	2S/9E	2S/10E	2S/11E
TOWNSHIP ACREAGE USED FOR THIS STUDY	23,063	23,028	23,004	23,157	23,118	23,266
ESTIMATED STORAGE CAPACITY VALUES FOR INDICATED TOWNSHIP AND RANGE						
0- 20	54,475	47,253	62,709	62,014	42,306	48,440
20- 40	67,390	38,595	57,418	86,561	47,299	49,882
40- 60	63,746	50,616	63,767	62,755	45,496	52,488
60- 80	57,934	46,747	58,936	62,431	44,988	53,465
80-100	47,787	17,455	57,418	66,183	38,746	42,716
100-120	57,565	24,364	39,291	69,888	26,586	28,152
120-140	55,167	24,179	30,503	37,839	21,731	26,058
140-160	49,816	35,371	36,576	17,738	23,164	23,685
160-180	83,580	13,817	28,985	19,683	27,464	27,082
180-200	80,997	13,817	26,455	18,201	25,707	31,781
200-220	64,853	13,817	18,035	15,515	20,066	34,899
220-240	67,298	13,817	13,802	18,989	18,957	36,062
240-260	46,403	20,265	22,360	39,367	20,667	38,761
260-280	49,032	66,781	16,103	72,481	25,430	30,246
280-300	31,273	46,056	20,566	18,526	18,911	13,960
300-320	30,120	46,056	34,046	23,157	18,587	13,960
320-340	33,026	46,056	13,802	23,157	20,298	13,960
340-360	33,903	46,056	13,802	23,157	26,262	28,617
360-380	33,718	36,845	41,407*	69,471	24,366	13,960
380-400	22,233	41,450*	41,407*	20,841	33,706	13,960
400-420	35,056	41,450*	41,407*	23,157	23,765	13,960
420-440	49,632	41,450*	41,407*	23,157	36,619	13,960
440-460	35,978	41,450*	41,407*	23,157	29,545	34,434
460-480	38,838	41,450*	41,407*	23,157	45,265	13,960
480-500	35,517	41,450*	41,407*	23,157	19,373	30,246

DEPTH INCREMENT BELOW GROUND SURFACE	2S/6E	2S/7E	2S/8E	2S/9E	2S/10E	2S/11E
ESTIMATED STORAGE CAPACITY VALUES FOR INDICATED TOWNSHIP AND RANGE						
500-520	30,443	41,450*	41,407*	23,157	44,525	13,960
520-540	34,225	41,450*	41,407*	23,157	24,274	13,960
540-560	44,881	41,450*	41,407*	23,157	50,305	20,474
560-580	63,054	41,450*	41,407*	23,157	34,723	13,960
580-600	38,054	41,450*	41,407*	23,157	36,989*	13,960
600-620	50,508	41,450*	41,407*	13,894		20,474
620-640	64,576	41,450*	41,407*	23,157		13,960
640-660	29,982	41,450*	41,407*	23,157		62,446
660-680	23,063	41,450*	41,407*	23,157		37,226*
680-700	74,955	41,450*	41,407*	23,157		37,226*
700-720	46,726	41,450*	41,407*	41,683*		
720-740	52,261	41,450*	41,407*	41,683*		
740-760	29,982	41,450*	41,407*	41,683*		
760-780	50,739	41,450*	41,407*	41,683*		
780-800	53,045	41,450*	41,407*	41,683*		
800-820	34,041	41,450*	41,407*	41,683*		
820-840	46,126*	41,450*	41,407*	41,683*		
840-860	46,126*	41,450*	41,407*	41,683*		
860-880	46,126*	41,450*	41,407*	41,683*		
880-900	46,126*	41,450*	41,407*	41,683*		
900-920				41,683*		
920-940				41,683*		
940-960				41,683*		
960-980				41,683*		
980-1000				41,683*		

*Storage capacity value from estimated specific yield

APPENDIX 4 (contd.)

ESTIMATED STORAGE CAPACITY VALUES IN ACRE-FEET
BY DEPTH INCREMENT BELOW GROUND SURFACE
SAN JOAQUIN COUNTY GROUND WATER INVESTIGATION

DEPTH INCREMENT BELOW GROUND SURFACE	TOWNSHIP ACREAGE USED FOR THIS STUDY: 20,239	5,689
	ESTIMATED STORAGE CAPACITY VALUES FOR INDICATED TOWNSHIP AND RANGE	
	2S/12E	2S/13E
0- 20	101,195	11,378*
20- 40	101,195	11,378*
40- 60	34,406	11,378*
60- 80	12,143	11,378*
80-100	23,072	11,378*
100-120	20,239	11,378*
120-140	20,239	11,378*
140-160	20,239	11,378*
160-180	20,239	11,378*
180-200	20,239	11,378*
200-220	20,239	11,378*
220-240	50,598	11,378*
240-260	20,239	11,378*
260-280	32,382	11,378*
280-300	20,239	11,378*
300-320	30,359	11,378*
320-340	20,239	11,378*
340-360	40,478*	11,378*
360-380	40,478*	11,378*
380-400	40,478*	11,378*
400-420		
420-460		
460-480		
480-500		

*Storage capacity value from estimated specific yield

APPENDIX 5

WATER QUALITY CRITERIA

U. S. Public Health Service Drinking Water Standards, 1962
Reference (38)

Substance	Concentration in mg/l (ppm)
A. Maximum permissible concentration:	
Arsenic**	0.05
Barium	1.0
Cadmium	0.01
Chromium (hexavalent)	0.05
Copper	*
Cyanide**	0.2
Fluoride**	1.6 to 3.4#
Lead	0.5
Selenium	0.01
Silver	0.05
B. Recommended limiting concentrations (provided that other more suitable supplies are or can be made available)	
Alkyl benzene sulfonates	0.5
Arsenic**	0.01
Carbon chloroform extract	0.2
Chloride	250
Copper	1.0
Cyanide**	0.01
Fluoride**	0.8 to 1.7#
Iron	0.3
Manganese	0.05
Nitrate, as NO_3	45
Phenolic compounds, as phenol	0.001
Sulfate	250
Total dissolved solids	500
Zinc	5.0

*Maximum permissible concentrations were replaced by recommended limits after the 1925 standards

**These substances have both recommended limits and maximum permissible concentrations.

#Recommended limits and maximum permissible concentrations for fluoride vary with the annual average maximum daily air temperature.

Hardness Classification of W

Range of Hardness Expressed as $CaCO_3$ in mg/l (ppm)	Relative Classification
0-100	Soft
101-200	Moderately Hard
More than 200	Hard

Qualitative Classification of Irrigation Water

Class 1 - Regarded as safe and suitable for most plants under most conditions of soil and climate.

Class 2 - Regarded as possibly harmful for certain crops under certain conditions of soil or climate, particularly in the higher ranges of this class.

Class 3 - Regarded as probably harmful to most crops and unsatisfactory for all but the most tolerant.

Chemical Properties	Class 1 Excellent to Good	Class 2 Good to Injurious	Class 3 Injurious to Unsatisfactory
Total dissolved solids, in ppm	Less than 700	700 - 2000	More than 2000
Conductance, in micro-mhos at 25°C	Less than 1000	1000 - 3000	More than 3000
Chlorides, in ppm	Less than 175	175 - 350	More than 350
Sodium, in percent of base constituents	Less than 60	60- 75	More than 75
Boron, in ppm	Less than 0.5	0.5 - 2.0	More than 2.0

These criteria have limitations in actual practice. In many instances, water of a given quality may be wholly unsuitable for irrigation under certain conditions of use, and yet be completely satisfactory under other circumstances. Soil permeability, drainage, temperature, humidity, rainfall, and other conditions can alter the response of a crop to a particular quality of water.

Criteria for mineral quality of irrigation water have been developed by the Regional Salinity Laboratories of the United States Department of Agriculture in cooperation with the University of California. Because of diverse climatological conditions and the variation in crops and soils in California, only general limits of quality for irrigation waters can be suggested.

Conversion Factors Used in Water Analysis

Parts per Million (ppm) = Milligrams per Liter (mg/l)

These two are equivalent and used interchangeably for fresh and slightly brackish waters.

Grains per Gallon = 17.1 Parts per Million

If a value is given in grains per gallon, then 17.1 times this value will give the concentration in parts per million (hardness is often reported in grains per gallon).

$$\text{Equivalents per Million (epm)} = \frac{\text{Milligrams per Liter}}{\text{Equivalent Weight}}$$

Equivalents per million is equal to the mg/l (or ppm) divided by the equivalent weight of a particular ion. Equivalents per million is a convenient method of reporting, because one epm of any cation will combine exactly with one epm of any anion, i.e., one epm of calcium will combine with one epm of bicarbonate to form calcium bicarbonate.

$$\text{Percentage Reacting Value (r)} = \frac{\text{Percentage of any ion to its}}{\text{cation (or anion) total}}$$

This expression is used to demonstrate the chemical type and source of ground water.

APPENDIX 6

WATER SURPLUS OR DEFICIENCY AND CHANGE IN STORAGE BY SPECIFIC YIELD
SAN JOAQUIN COUNTY GROUND WATER INVESTIGATION *
(In thousand acre feet)

Year	WATER SUPPLY					WATER USE AND DISPOSAL					WATER SUPPLY SURPLUS OR DEFICIENCY		CHANGE IN STORAGE BY SPECIFIC YIELD	
	Precip-itation	Fresh Water Import	Surface Inflow	Subsurface** Inflow	Annual Supply	Consumptive Use	Waste Water Export	Fresh Water Export	Surface Outflow	Annual Seasonal Water Use and Disposal	Annual	Accumulation	Annual	Accumulation
1950-51	939	323	1,419	-2	2,679	1,163	19	148	1,333	2,663	+ 16	+ 16	- 9	- 9
1951-52	1,054	365	1,592	-2	3,009	1,188	19	148	1,493	2,848	+161	+ 177	- 13	- 22
1952-53	646	381	636	-2	1,661	1,147	21	186	446	1,800	-139	+ 38	-117	- 139
1953-54	593	320	534	-2	1,445	1,168	22	163	316	1,669	-224	- 186	-124	- 263
1954-55	743	317	419	-2	1,477	1,151	21	137	298	1,607	-130	- 316	- 90	- 353
1955-56	1,020	354	1,496	-2	2,868	1,145	22	163	1,396	2,726	+142	- 174	+ 45	- 308
1956-57	652	370	579	-2	1,599	1,167	22	150	410	1,750	-151	- 325	-115	- 423
1957-58	1,278	376	1,339	-2	2,991	1,293	23	145	1,348	2,809	+182	- 143	+ 56	- 367
1958-59	604	361	324	-2	1,287	1,148	22	147	211	1,528	-241	- 384	- 96	- 463
1959-60	518	363	240	-1	1,120	993	23	149	89	1,254	-134	- 518	-156	- 619
1960-61	581	287	179	-1	1,046	1,053	23	105	61	1,242	-196	- 714	-147	- 766
1961-62	656	420	530	+3	1,609	1,059	22	159	386	1,626	- 17	- 731	- 6	- 772
1962-63	896	360	860	+18	2,134	1,277	24	149	739	2,189	- 55	- 786	+ 14	- 758
1963-64	557	384	260	+51	1,252	1,097	23	129	135	1,384	-132	- 918	-160	- 918
TOTAL	10,737	4,981	10,407	+52	26,177	16,049	306	2,078	8,662	27,095	-918		-918	
14-Year Average	767	356	743	+4	1,870	1,146	22	148	618	1,936	-66		- 66	

* Area as shown on Plates 1A and 1B
** Subsurface inflow-outflow are combined under subsurface flow, (-) meaning outflow, (+) meaning inflow
It includes poor quality as well as fresh water

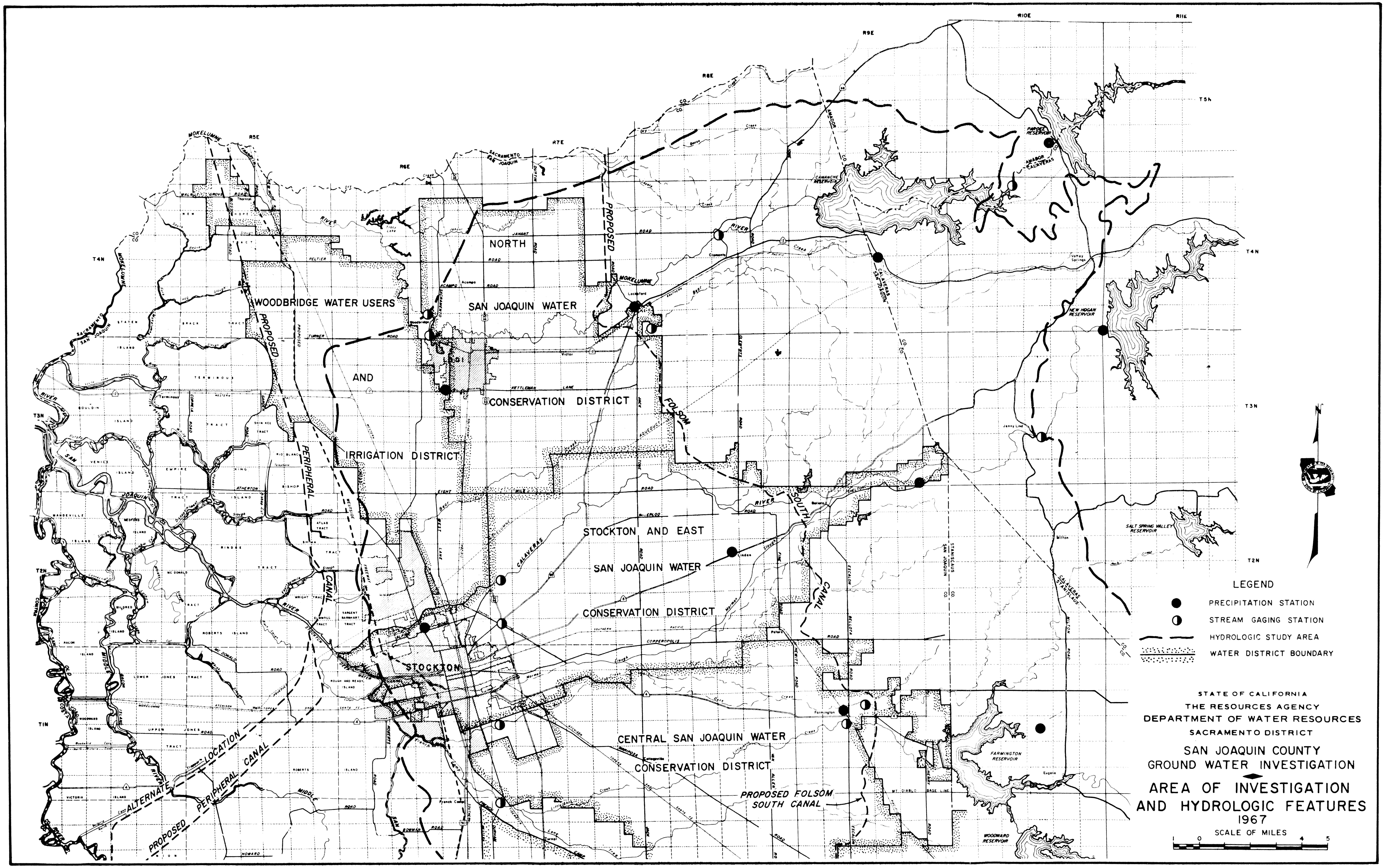
APPENDIX 7

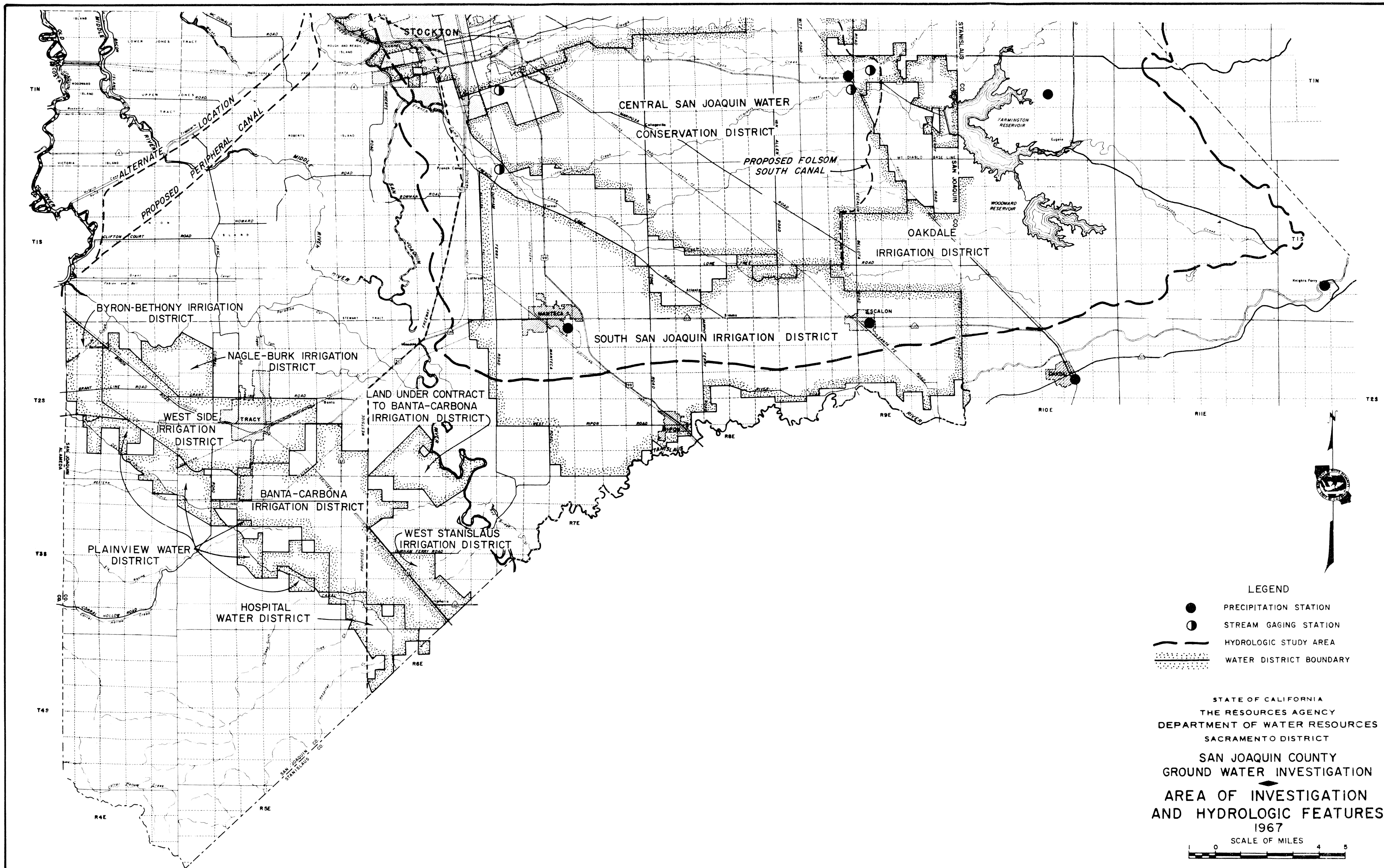
SAN JOAQUIN COUNTY GROUND WATER INVESTIGATION

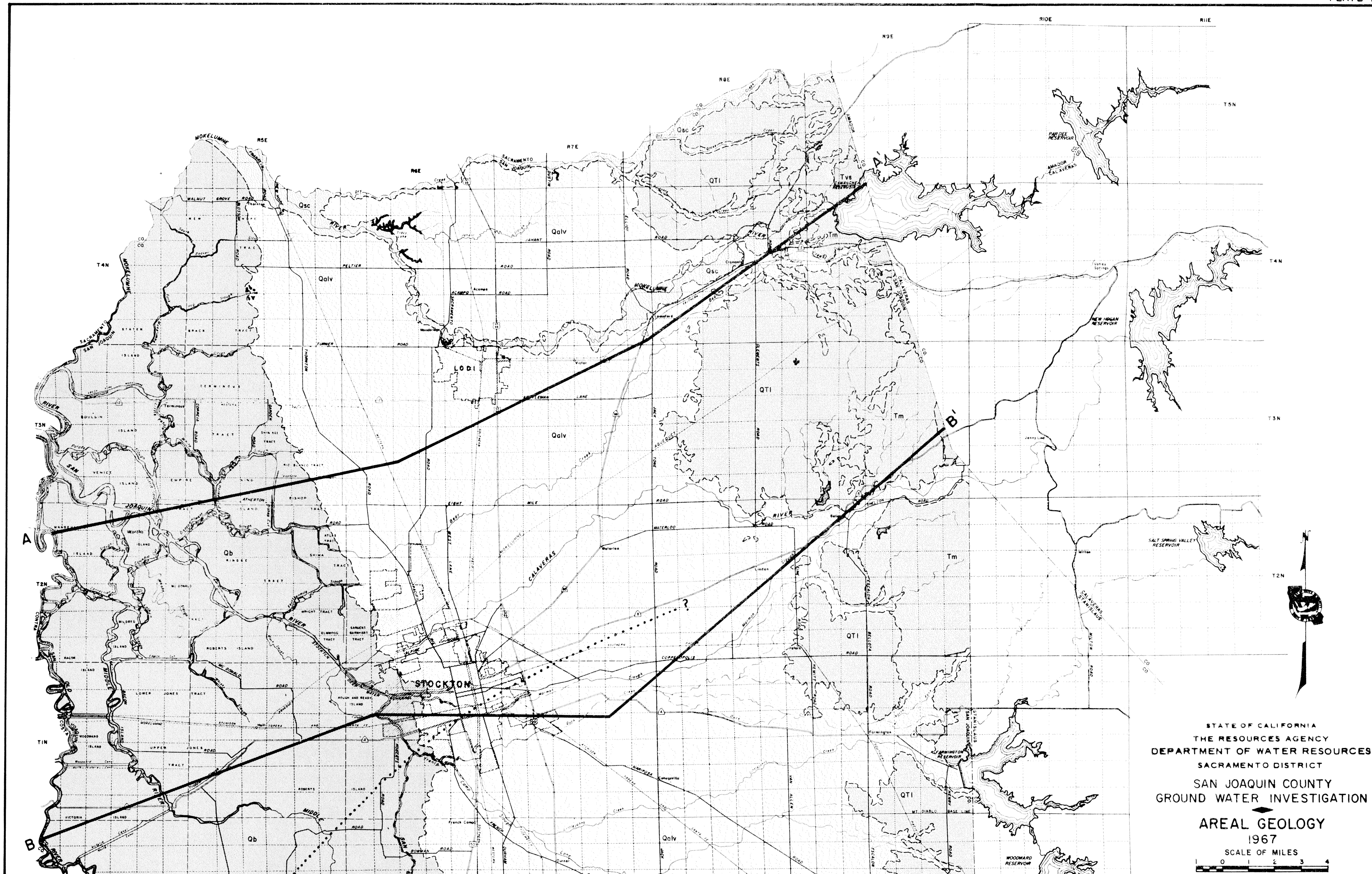
Land Use in Acres

Irrigated	1950-51	1951-52	1952-53	1953-54	1954-55	1955-56	1956-57	1957-58	1958-59	1959-60	1960-61	1961-62	1962-63	1963-64
Rice	8,000	10,000	15,000	17,000	10,000	9,000	5,000	6,170	7,000	7,000	6,000	5,000	7,000	6,000
Gen. Field	7,500	8,100	8,700	9,300	9,900	10,500	11,100	11,600	11,250	11,400	11,550	11,700	11,850	12,000
Sugar Beets	4,300	5,440	6,080	6,730	7,380	8,020	8,670	9,270	10,220	11,170	12,120	13,070	14,020	15,000
Alfalfa	17,000	16,880	16,760	16,640	16,520	16,400	16,280	16,160	17,130	18,100	19,070	20,040	21,010	22,000
Pasture	65,000	65,930	66,860	67,790	68,720	69,650	70,580	71,520	72,100	72,680	73,260	73,840	74,420	75,000
Misc. Truck	21,000	21,130	21,260	21,390	21,520	21,650	21,780	21,920	21,930	21,940	21,950	21,960	21,970	22,000
Tomatoes	21,000	21,400	21,800	22,200	22,600	23,000	23,400	23,810	23,010	22,210	21,410	20,610	19,810	19,000
Decid. Orch.	40,000	40,160	40,320	40,480	40,640	40,800	40,960	41,140	44,120	47,100	50,080	53,060	56,040	59,000
Vineyard	47,000	45,880	44,760	43,640	42,520	41,400	40,280	39,180	38,820	38,460	38,100	37,740	37,380	37,000
Subtropical	400	420	440	460	480	500	520	550	530	510	490	470	450	400
Subtotal	231,700	235,340	241,980	245,630	240,280	240,920	238,570	240,320	246,110	250,570	254,030	257,490	263,950	267,400
Dry-Farmed														
Hay and Grain Orchard Vineyard	49,000	47,900	46,800	45,700	44,600	43,500	42,400	41,320	41,430	41,540	41,650	41,760	41,870	42,000
Subtotal	49,000	47,900	46,800	45,700	44,600	43,500	42,400	41,320	41,430	41,540	41,650	41,760	41,870	42,000
Urban Res. Farms	18,000	18,910	19,820	20,730	21,640	22,550	23,460	24,360	25,300	26,240	27,180	28,120	29,060	30,000
Native Classes														
Water Surface	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000
Barr. and Rocky Dry Native	279,300	275,850	269,400	265,940	271,480	270,990	274,570	272,000	265,160	259,650	255,140	250,630	243,120	238,600
Subtotal	305,300	302,760	297,220	294,670	301,120	301,580	306,030	304,360	298,470	293,890	290,320	286,750	280,180	276,600
Total	586,000	586,000	586,000	586,000	586,000	586,000	586,000	586,000	586,000	586,000	586,000	586,000	586,000	586,000

Notes:
(1) 1958 values from DWR survey
(2) Urban areas distributed by census population with 1958 as base
(3) Land use calculated as percentage of annual values reported in Agricultural Commissioner's Reports
(4) Rice values are County totals


STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SACRAMENTO DISTRICT
SAN JOAQUIN COUNTY
GROUND WATER INVESTIGATION
AREA OF INVESTIGATION
AND HYDROLOGIC FEATURES
1967
SCALE OF MILES
LEGEND
PRECIPITATION STATION
STREAM GAGING STATION
HYDROLOGIC STUDY AREA
WATER DISTRICT BOUNDARY
WOODBRIDGE WATER USERS
NORTH
SAN JOAQUIN WATER
CONSERVATION DISTRICT
AND
IRRIGATION DISTRICT
STOCKTON AND EAST
SAN JOAQUIN WATER
CONSERVATION DISTRICT
CENTRAL SAN JOAQUIN WATER
CONSERVATION DISTRICT
STOCKTON
LODI
PROPOSED PERIPHERAL CANAL
ALTERNATE LOCATION
PROPOSED FOLSOM SOUTH CANAL
CAMANCHE RESERVOIR
PARDEE RESERVOIR
NEW HOGAN RESERVOIR
SALT SPRING VALLEY RESERVOIR
FARMINGTON RESERVOIR
WOODWARD RESERVOIR
R5E
R6E
R7E
R8E
R9E
R10E
R11E
T5N
T4N
T3N
T2N
T1N


STOCKTON
CENTRAL SAN JOAQUIN WATER CONSERVATION DISTRICT
PROPOSED FOLSOM SOUTH CANAL
ALTERNATE LOCATION
PROPOSED PERIPHERAL CANAL
OAKDALE IRRIGATION DISTRICT
FARMINGTON RESERVOIR
WOODWARD RESERVOIR
MANTECA
ESCALON
SOUTH SAN JOAQUIN IRRIGATION DISTRICT
BYRON-BETHONY IRRIGATION DISTRICT
NAGLE-BURK IRRIGATION DISTRICT
LAND UNDER CONTRACT TO BANTA-CARBONA IRRIGATION DISTRICT
WEST SIDE IRRIGATION DISTRICT
TRACY
BANTA-CARBONA IRRIGATION DISTRICT
WEST STANISLAUS IRRIGATION DISTRICT
PLAINVIEW WATER DISTRICT
HOSPITAL WATER DISTRICT
SAN JOAQUIN RIVER
STANISLAUS RIVER
T1N
T1S
T2S
T3S
T4S
R4E
R5E
R6E
R7E
R8E
R9E
R10E
R11E
LEGEND
PRECIPITATION STATION
STREAM GAGING STATION
HYDROLOGIC STUDY AREA
WATER DISTRICT BOUNDARY
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SACRAMENTO DISTRICT
SAN JOAQUIN COUNTY
GROUND WATER INVESTIGATION
AREA OF INVESTIGATION
AND HYDROLOGIC FEATURES
1967
SCALE OF MILES
1 0 4 5



STATE OF CALIFORNIA
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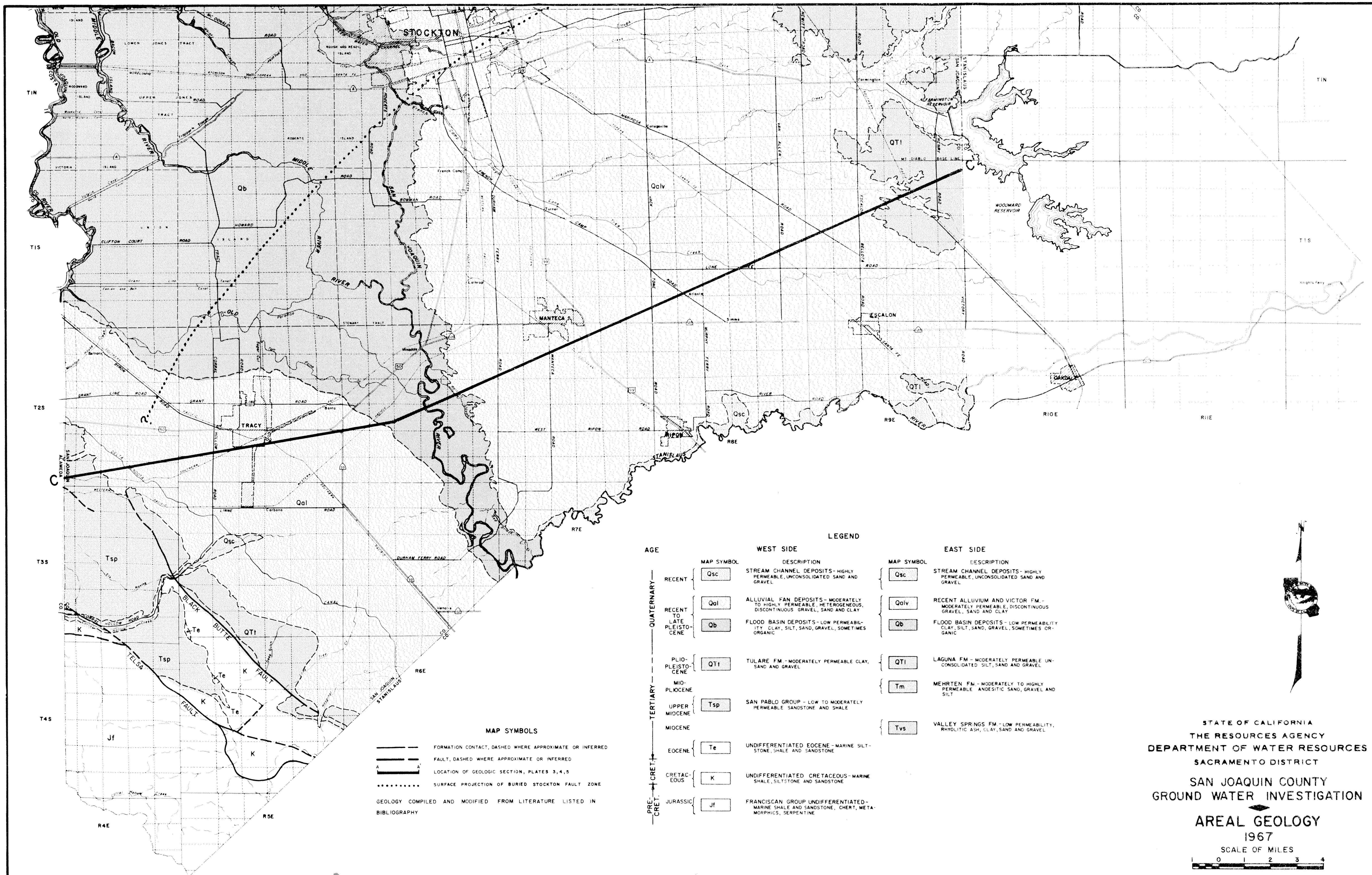
SACRAMENTO DISTRICT

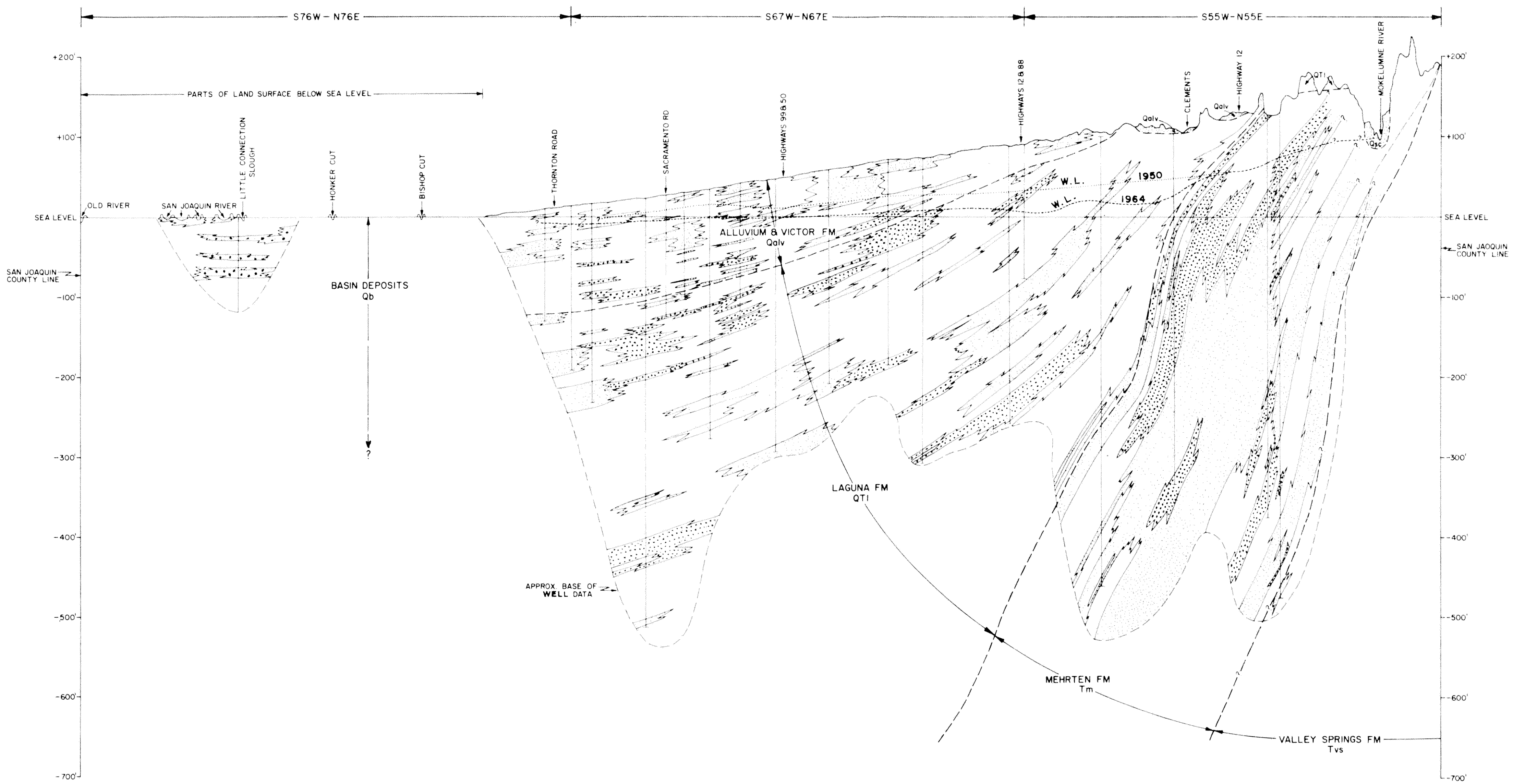
SAN JOAQUIN COUNTY
GROUND WATER INVESTIGATION

AREAL GEOLOGY
1967

SCALE OF MILES
1 0 1 2 3 4


STOCKTON
MANTECA
TRACY
ESCALON
RIPON
OAKDALE
FARMINGTON RESERVOIR
WOODWARD RESERVOIR
SAN JOAQUIN RIVER
STANISLAUS RIVER
OLD RIVER
MIDDLE RIVER
BLACK BUTTE FAULT
TELSA FAULT
T1N
T1S
T2S
T3S
T4S
R4E
R5E
R6E
R7E
R8E
R9E
R10E
R11E
Qb
Qal
Qalv
Qsc
QTt
QTl
Tsp
Te
K
Jf
C
LEGEND
AGE
WEST SIDE
MAP SYMBOL
DESCRIPTION
EAST SIDE
MAP SYMBOL
DESCRIPTION
QUATERNARY
RECENT
Qsc
STREAM CHANNEL DEPOSITS - HIGHLY PERMEABLE, UNCONSOLIDATED SAND AND GRAVEL
Qsc
STREAM CHANNEL DEPOSITS - HIGHLY PERMEABLE, UNCONSOLIDATED SAND AND GRAVEL
RECENT TO LATE PLEISTOCENE
Qal
ALLUVIAL FAN DEPOSITS - MODERATELY TO HIGHLY PERMEABLE, HETEROGENEOUS, DISCONTINUOUS GRAVEL, SAND AND CLAY
Qalv
RECENT ALLUVIUM AND VICTOR FM. - MODERATELY PERMEABLE, DISCONTINUOUS GRAVEL, SAND AND CLAY
Qb
FLOOD BASIN DEPOSITS - LOW PERMEABILITY CLAY, SILT, SAND, GRAVEL, SOMETIMES ORGANIC
Qb
FLOOD BASIN DEPOSITS - LOW PERMEABILITY CLAY, SILT, SAND, GRAVEL, SOMETIMES ORGANIC
PLIO-PLEISTOCENE
QTt
TULARE FM. - MODERATELY PERMEABLE CLAY, SAND AND GRAVEL
QTl
LAGUNA FM - MODERATELY PERMEABLE UNCONSOLIDATED SILT, SAND AND GRAVEL
TERTIARY
MIO-PLIOCENE
Tm
MEHRTEN FM. - MODERATELY TO HIGHLY PERMEABLE ANDESITIC SAND, GRAVEL AND SILT
UPPER MIOCENE
Tsp
SAN PABLO GROUP - LOW TO MODERATELY PERMEABLE SANDSTONE AND SHALE
MIOCENE
Tvs
VALLEY SPRINGS FM. - LOW PERMEABILITY, RHYOLITIC ASH, CLAY, SAND AND GRAVEL
EOCENE
Te
UNDIFFERENTIATED EOCENE - MARINE SILTSTONE, SHALE AND SANDSTONE
CRET.
CRETACEOUS
K
UNDIFFERENTIATED CRETACEOUS - MARINE SHALE, SILTSTONE AND SANDSTONE
PRE-CRET.
JURASSIC
Jf
FRANCISCAN GROUP UNDIFFERENTIATED - MARINE SHALE AND SANDSTONE, CHERT, METAMORPHICS, SERPENTINE
MAP SYMBOLS
FORMATION CONTACT, DASHED WHERE APPROXIMATE OR INFERRED
FAULT, DASHED WHERE APPROXIMATE OR INFERRED
A A'
LOCATION OF GEOLOGIC SECTION, PLATES 3, 4, 5
SURFACE PROJECTION OF BURIED STOCKTON FAULT ZONE
GEOLOGY COMPILED AND MODIFIED FROM LITERATURE LISTED IN BIBLIOGRAPHY
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SACRAMENTO DISTRICT
SAN JOAQUIN COUNTY
GROUND WATER INVESTIGATION
AREAL GEOLOGY
1967
SCALE OF MILES
1 0 1 2 3 4

SECTION A-A' (SOUTH LODI)



LEGEND

FORMATIONAL CONTACT – DASHED WHERE APPROXIMATE

FAULT – DASHED WHERE APPROXIMATE

APPROXIMATE BASE WELL DATA

SAND, GRAVEL — INFERRED DISTRIBUTION BASED ON DRILLERS LOGS. INTERVENING BLANK AREAS CONSIST OF CLAY AND/OR SILT AND MIXTURES OF THESE WITH SAND AND/OR GRAVEL

W.L. 1950 — LOCATION OF FALL 1950 ELEVATION OF WATER

W.L. 1964 — LOCATION OF FALL 1964 ELEVATION OF WATER

WATER WELL

S50W – N80E — AZIMUTH OF GEOLOGIC SECTION

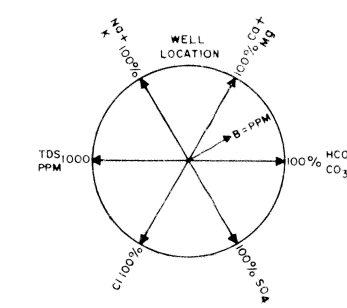
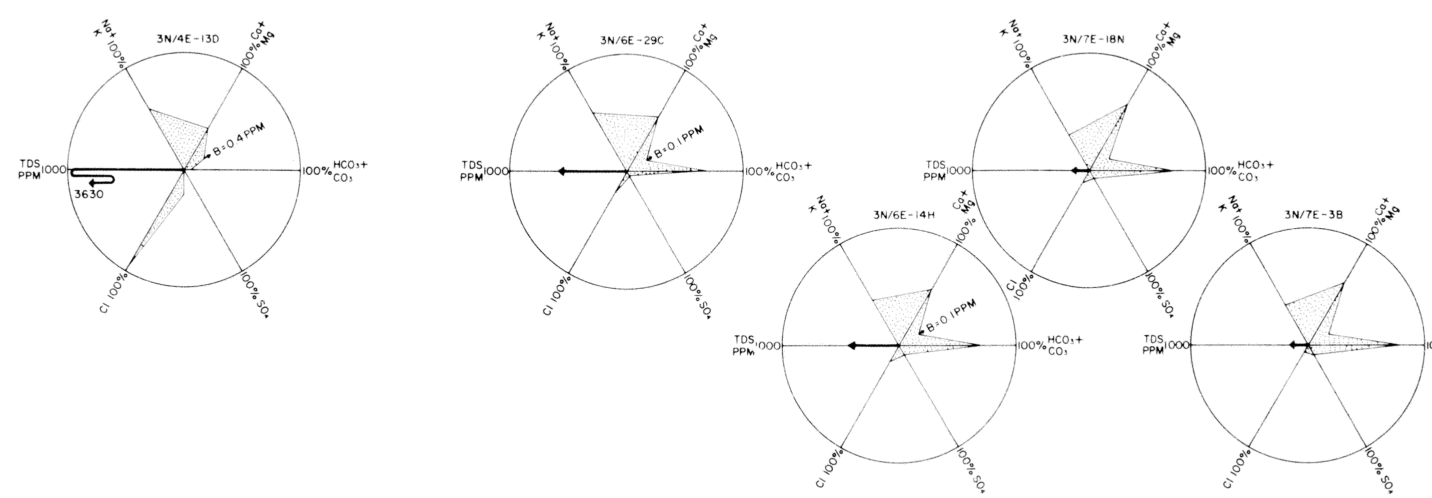


DIAGRAM OF PERCENT REACTING VALUES (MILLIEQUIVALENTS/LITER) OF WATER IN WELLS ALONG LINES OF CROSS SECTIONS

VERTICAL EXAGGERATION APPROX. 100:1

SEE PLATE 2A FOR LOCATION OF SECTION

QUALITY OF WATER IN WELLS ALONG SECTION A-A'



NOTE: THESE QUALITY DIAGRAMS ARE CENTERED AT THEIR APPROXIMATE PROJECTED POSITION IN THE LINE OF GEOLOGIC SECTION.

STATE OF CALIFORNIA
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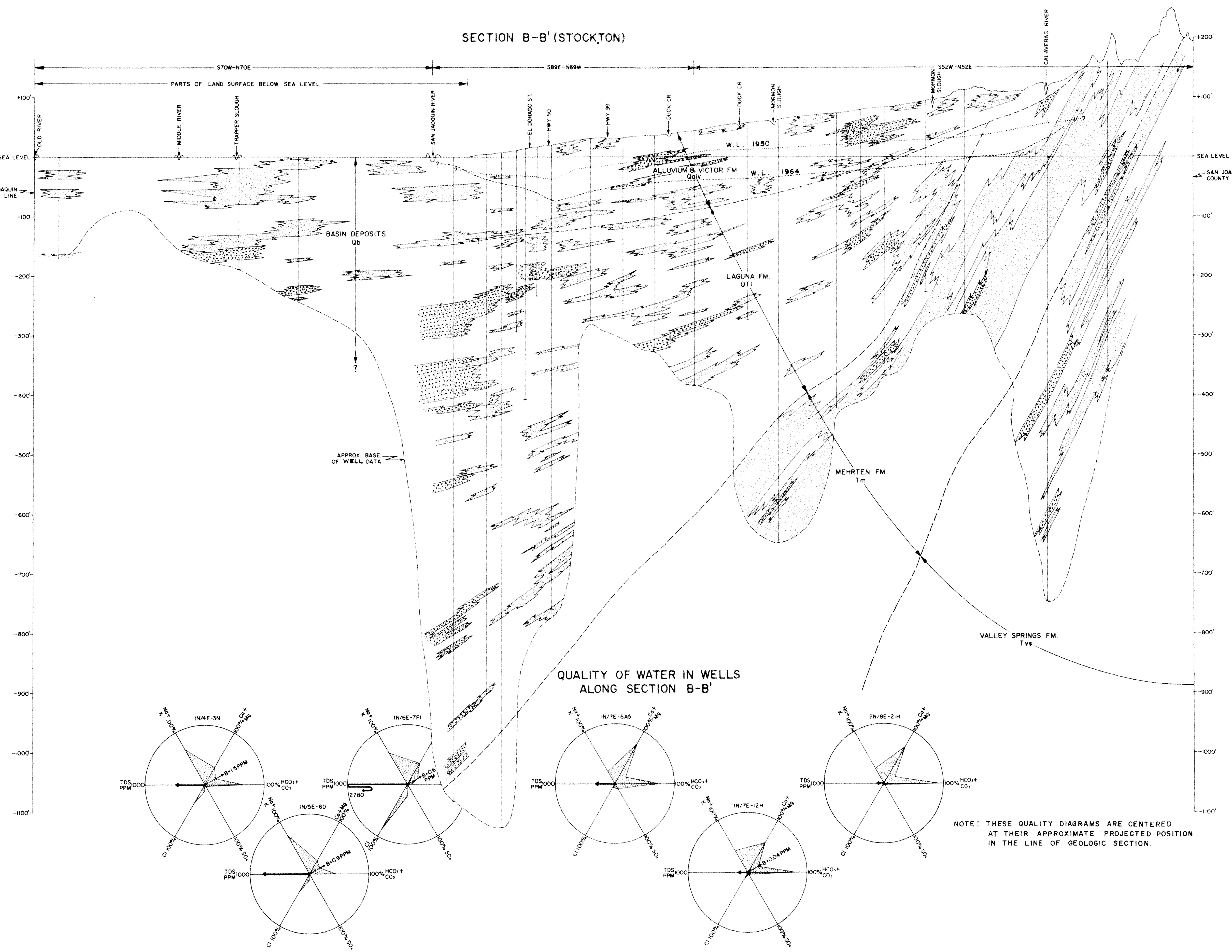
SACRAMENTO DISTRICT

SAN JOAQUIN COUNTY GROUND WATER INVESTIGATION

GEOLOGIC SECTION A-A' (SOUTH LODI)

1967

SCALE OF MILES 1 0 4 5



LEGEND

FORMATIONAL CONTACT - DASHED WHERE APPROXIMATE

FAULT - DASHED WHERE APPROXIMATE

APPROXIMATE BASE WELL DATA

SAND, GRAVEL — INFERRED DISTRIBUTION BASED ON DRILLERS LOGS. INTERVENING BLANK AREAS CONSIST OF CLAY AND/OR SILT AND MIXTURES OF THESE WITH SAND AND/OR GRAVEL

W.L. 1950 — LOCATION OF FALL 1950 ELEVATION OF WATER

W.L. 1964 — LOCATION OF FALL 1964 ELEVATION OF WATER

WATER WELL

S50W-N50E — AZIMUTH OF GEOLOGIC SECTION

DIAGRAM OF PERCENT REACTING VALUES (MILLIEQUIVALENTS/LITER) OF WATER IN WELLS ALONG LINES OF CROSS SECTIONS

VERTICAL EXAGGERATION APPROX. 100:1

SEE PLATE 2A FOR LOCATION OF SECTION

STATE OF CALIFORNIA
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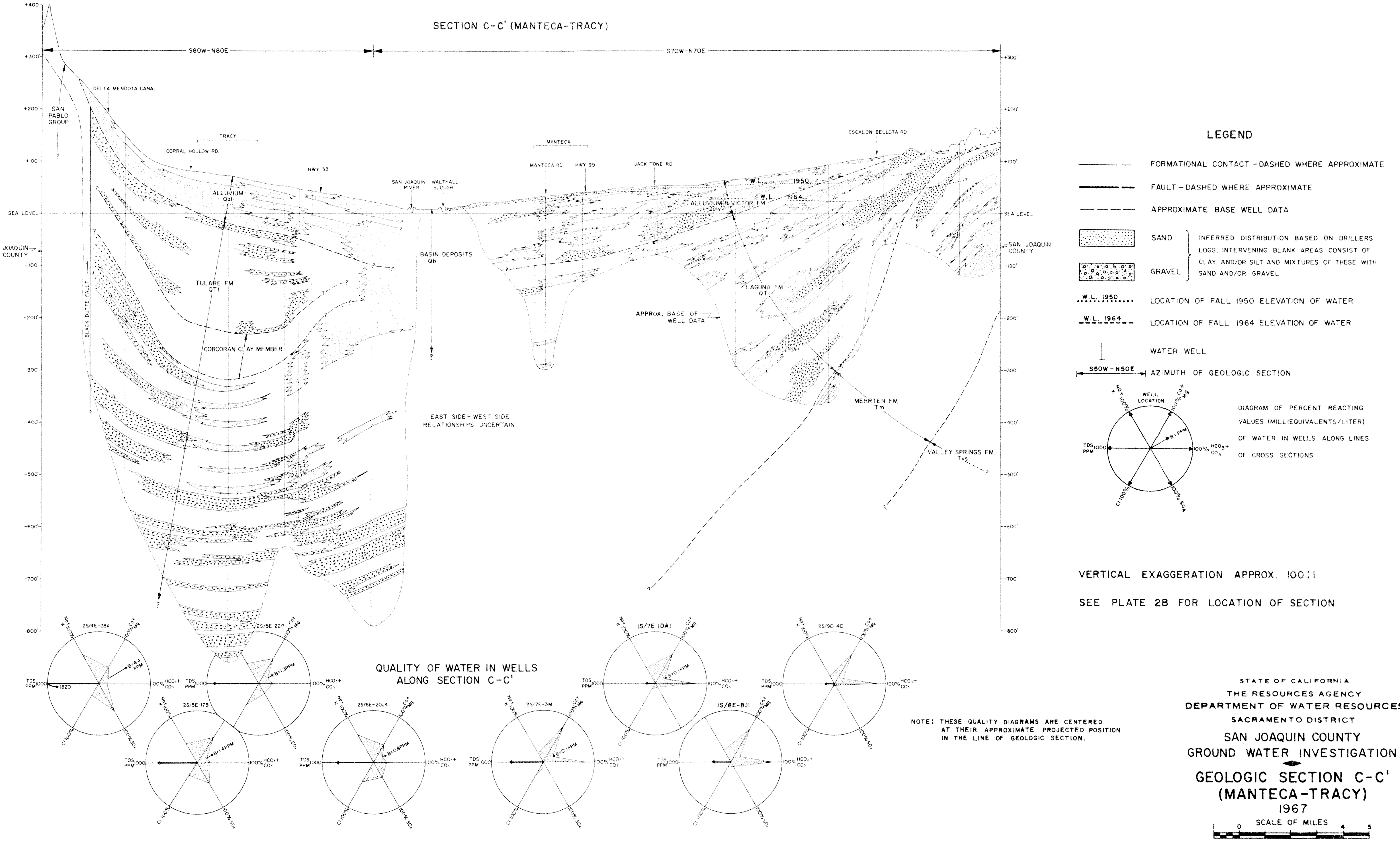
SACRAMENTO DISTRICT

SAN JOAQUIN COUNTY
GROUND WATER INVESTIGATION

GEOLOGIC SECTION B-B' (STOCKTON)

1967

SCALE OF MILES



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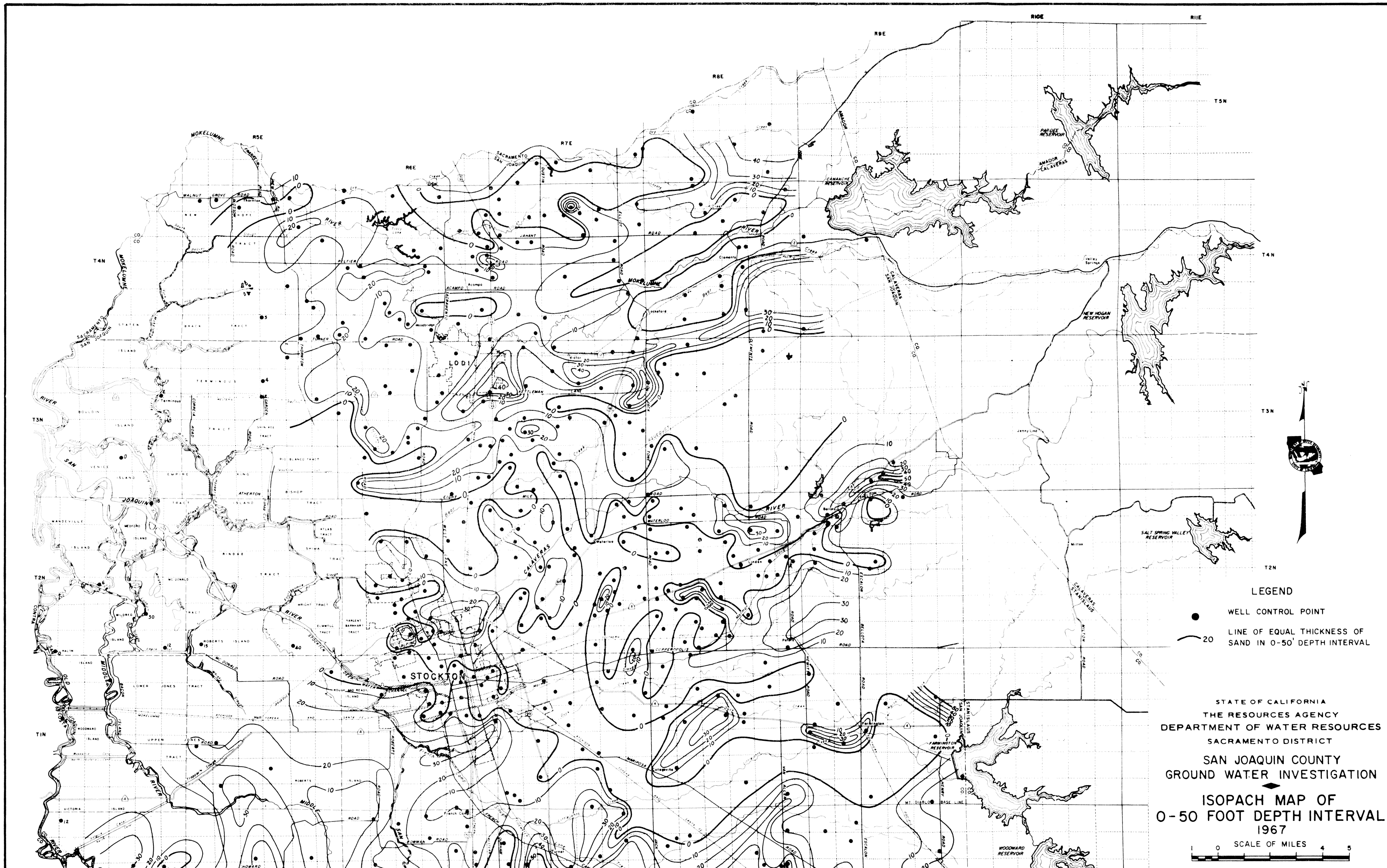
SACRAMENTO DISTRICT

SAN JOAQUIN COUNTY
GROUND WATER INVESTIGATION

GEOLOGIC SECTION C-C' (MANTECA-TRACY)

1967

SCALE OF MILES



LEGEND

● WELL CONTROL POINT

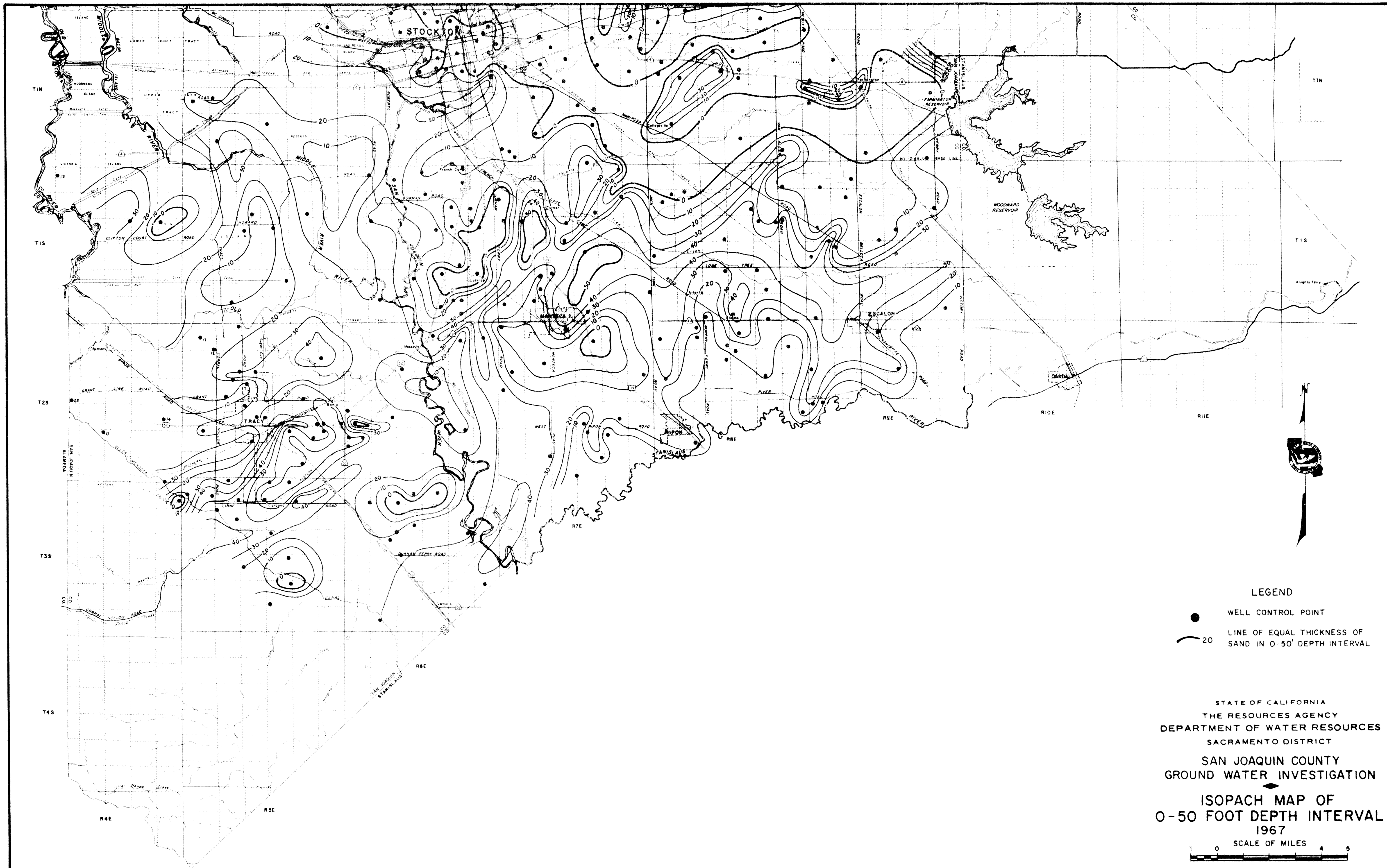
—20 LINE OF EQUAL THICKNESS OF SAND IN 0-50' DEPTH INTERVAL

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

SAN JOAQUIN COUNTY
GROUND WATER INVESTIGATION

ISOPACH MAP OF 0-50 FOOT DEPTH INTERVAL
1967

SCALE OF MILES
1 0 1 2 3 4 5



LEGEND

● WELL CONTROL POINT

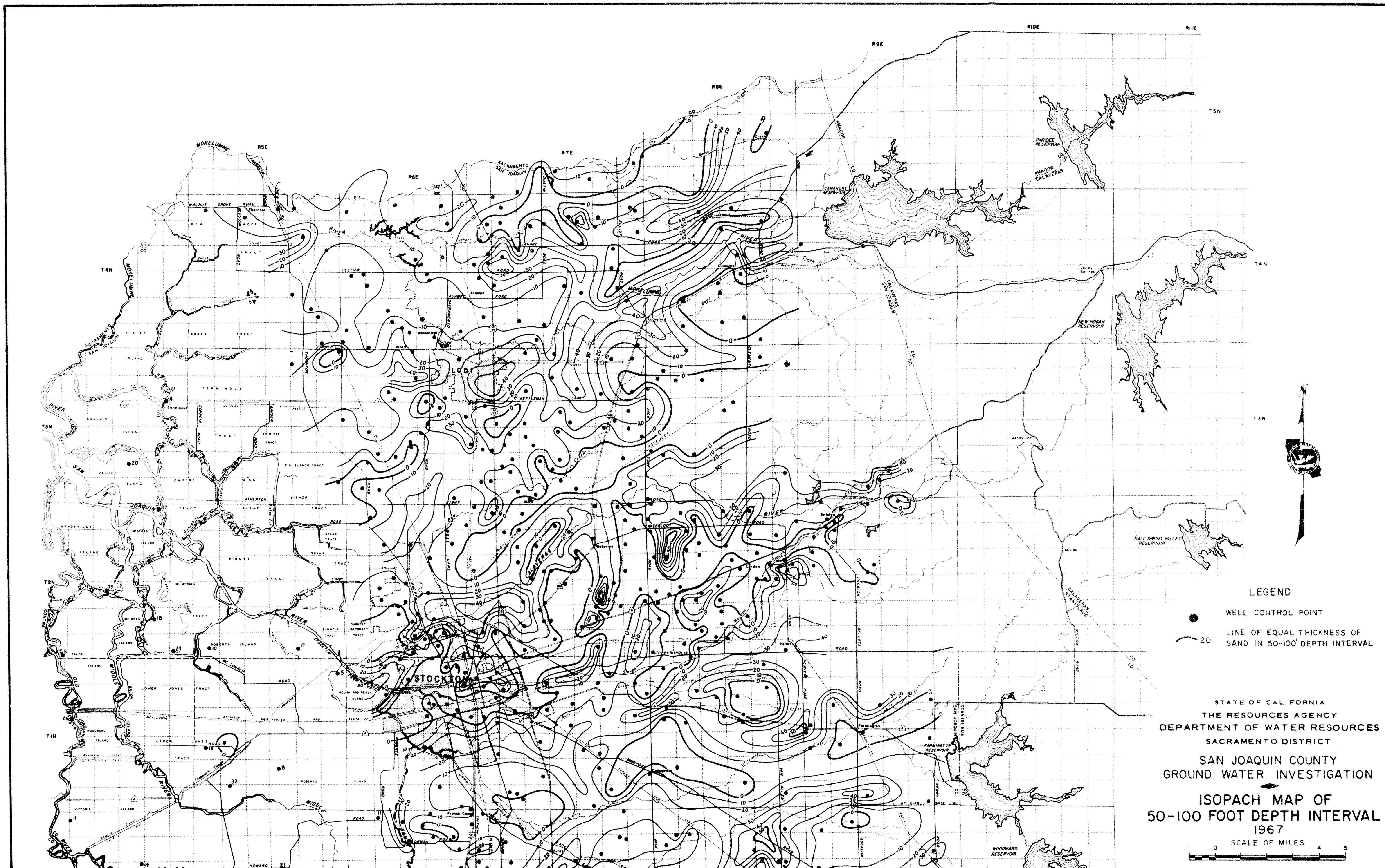
⌒ 20 LINE OF EQUAL THICKNESS OF SAND IN 0-50' DEPTH INTERVAL

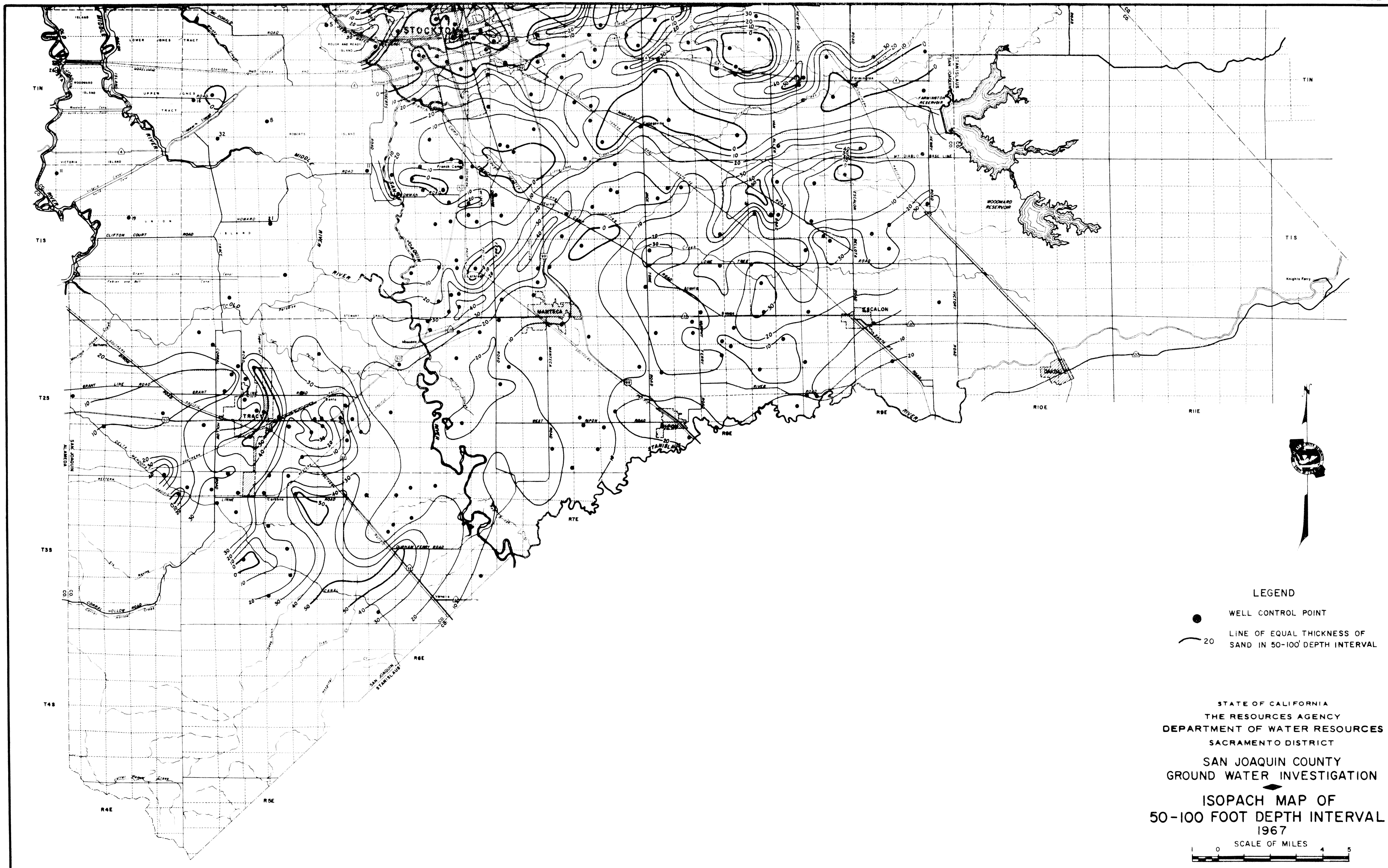
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SACRAMENTO DISTRICT

SAN JOAQUIN COUNTY
GROUND WATER INVESTIGATION

ISOPACH MAP OF
0-50 FOOT DEPTH INTERVAL
1967

SCALE OF MILES
1 0 4 5


LEGEND
WELL CONTROL POINT
LINE OF EQUAL THICKNESS OF SAND IN 50-100' DEPTH INTERVAL
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SACRAMENTO DISTRICT
SAN JOAQUIN COUNTY
GROUND WATER INVESTIGATION
ISOPACH MAP OF
50-100 FOOT DEPTH INTERVAL
1967
SCALE OF MILES
STOCKTON
LODI
R5E
R6E
R7E
R8E
R9E
R10E
R11E
T5N
T4N
T3N
T2N
T1N
PARDEE RESERVOIR
CAMANCHE RESERVOIR
NEW HOGAN RESERVOIR
SALT SPRING VALLEY RESERVOIR
FARMINGTON RESERVOIR
WOODWARD RESERVOIR



LEGEND

WELL CONTROL POINT

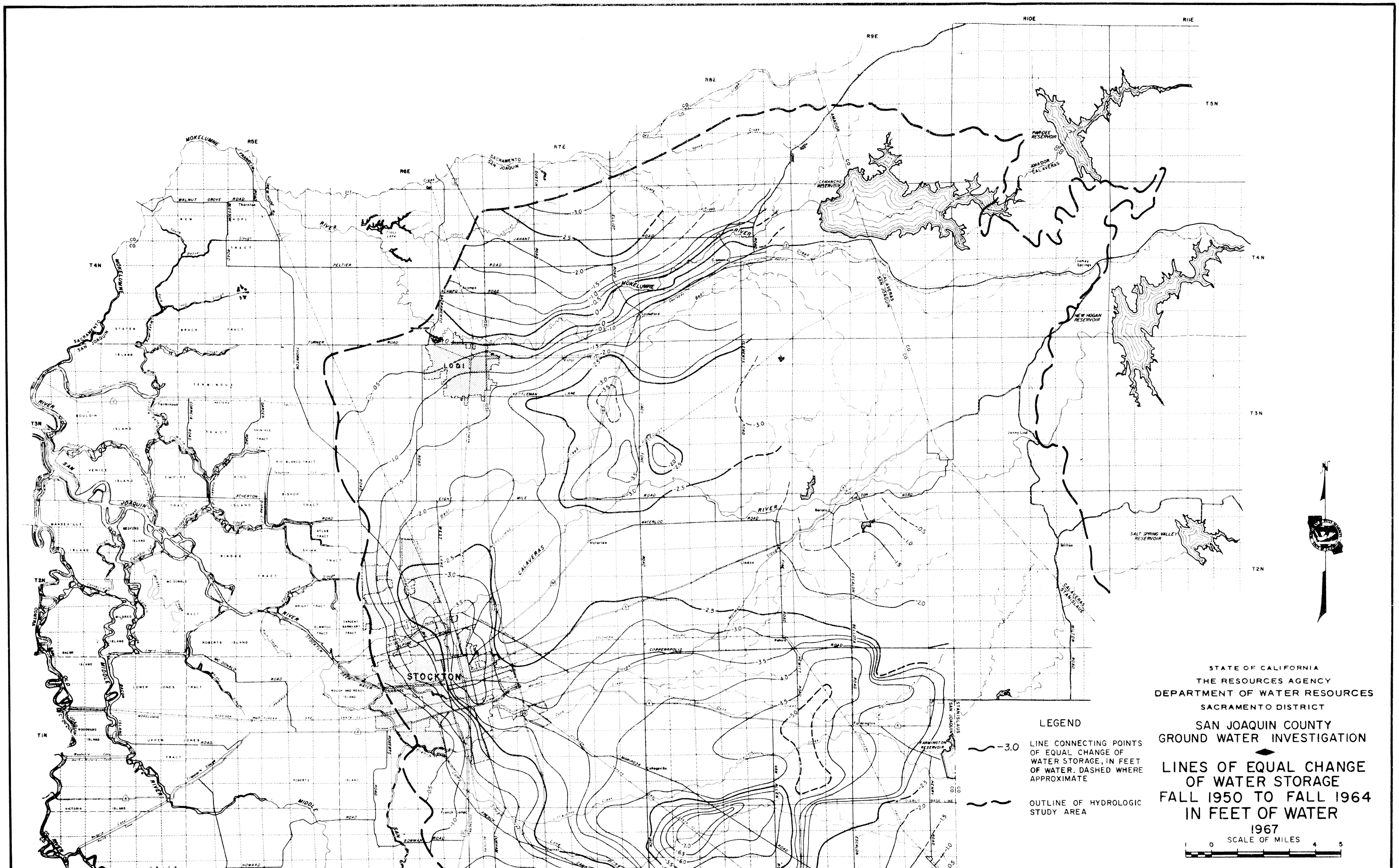
LINE OF EQUAL THICKNESS OF SAND IN 50-100' DEPTH INTERVAL

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

SAN JOAQUIN COUNTY
GROUND WATER INVESTIGATION

ISOPACH MAP OF 50-100 FOOT DEPTH INTERVAL
1967

SCALE OF MILES


STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SACRAMENTO DISTRICT
SAN JOAQUIN COUNTY
GROUND WATER INVESTIGATION
LINES OF EQUAL CHANGE
OF WATER STORAGE
FALL 1950 TO FALL 1964
IN FEET OF WATER
1967
SCALE OF MILES
LEGEND
-3.0 LINE CONNECTING POINTS OF EQUAL CHANGE OF WATER STORAGE, IN FEET OF WATER. DASHED WHERE APPROXIMATE
OUTLINE OF HYDROLOGIC STUDY AREA
STOCKTON
LODI
MOKELUMNE
CALAVERAS
PARDEE RESERVOIR
CAMANCHE RESERVOIR
NEW HOGAN RESERVOIR
SALT SPRING VALLEY RESERVOIR
FARMINGTON RESERVOIR
R5E
R6E
R7E
R8E
R9E
R10E
R11E
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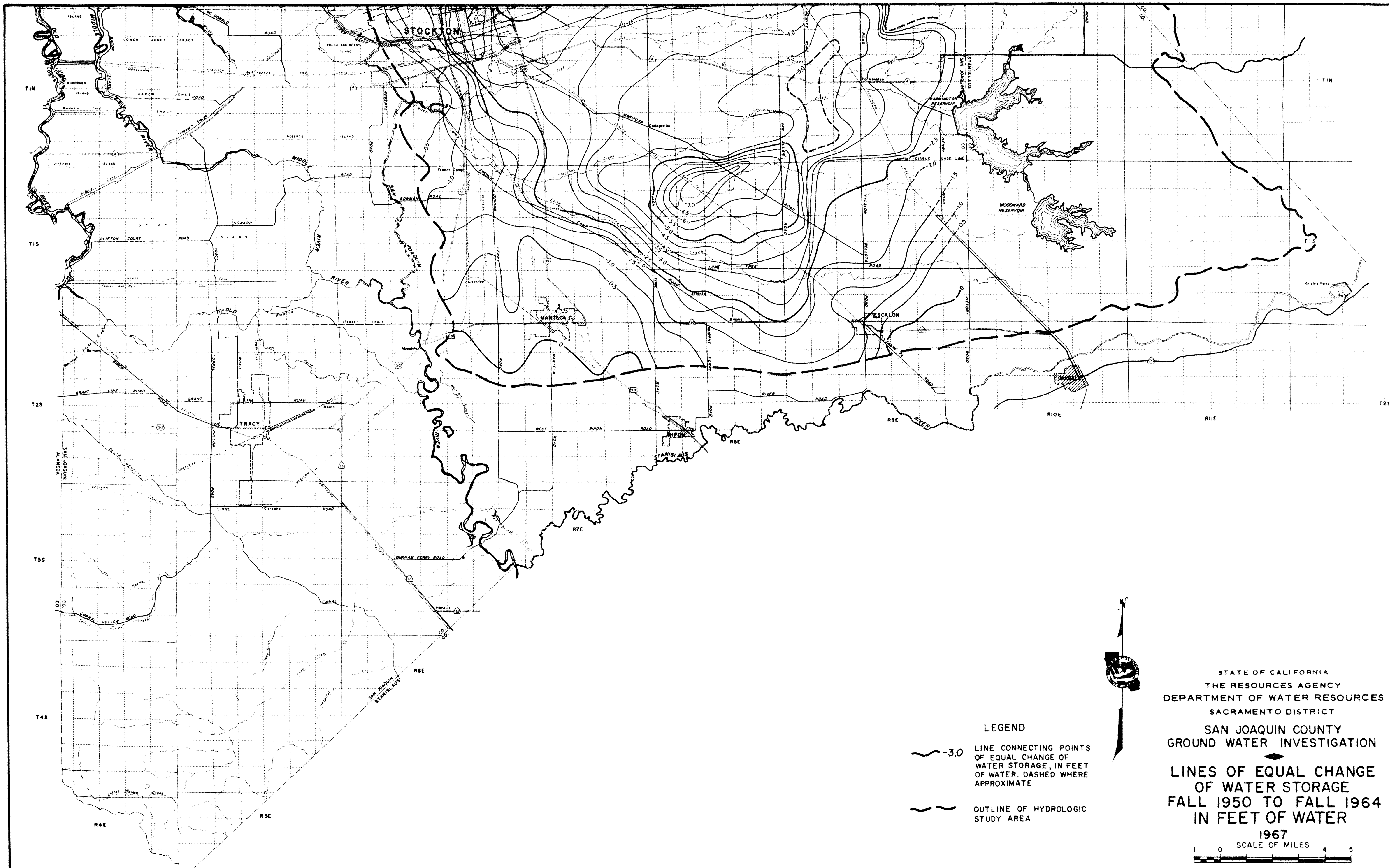
T3N
T2N
T1N



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SACRAMENTO DISTRICT

SAN JOAQUIN COUNTY
GROUND WATER INVESTIGATION

LINES OF EQUAL CHANGE OF WATER STORAGE FALL 1950 TO FALL 1964 IN FEET OF WATER

1967