STATE OF CALIFORNIA
The Resources Agency

Department of Water Resources

in cooperation with
County of Sacramento

BULLETIN No. 118-3

EVALUATION OF GROUND WATER RESOURCES:

SACRAMENTO COUNTY

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JULY 1974

FOREWORD

The ground water basin underlying Sacramento County has played an important role in the domestic, agricultural, and urban water supply of the area since the mid-1800s. Since 1940, extractions have exceeded recharge and have caused a gradual lowering of ground water levels and a reduction of ground water in storage. This cooperative study of the water resources of Sacramento County was undertaken in 1968 to provide the Sacramento County Water Agency information needed to implement its water policy guidelines and to provide the State with information on the ground water resources needed for statewide planning.

This report provides detailed information on the geology and hydrology of the ground water system underlying Sacramento County in sufficient detail to permit management studies. Included is a detailed inventory of the water resources during the period 1961 to 1970.

The information contained in this report and the mathematical model of the ground water system developed and verified during this study is being used in this cooperative study, which is the development and evaluation of alternative ways to manage the water resources of Sacramento County. The results of the alternative plans will be published in 1974 in the Bulletin 104 Series (Planned Utilization of Water Resources).

John R. Teerink

John R. Teerink, Director
Department of Water Resources
The Resources Agency
State of California
May 29, 1974

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ACKNOWLEDGMENT

The Department of Water Resources acknowledges with thanks the information and advice provided by the Ground Water Advisory Committee during the preparation of this bulletin.

Ground Water Advisory Committee

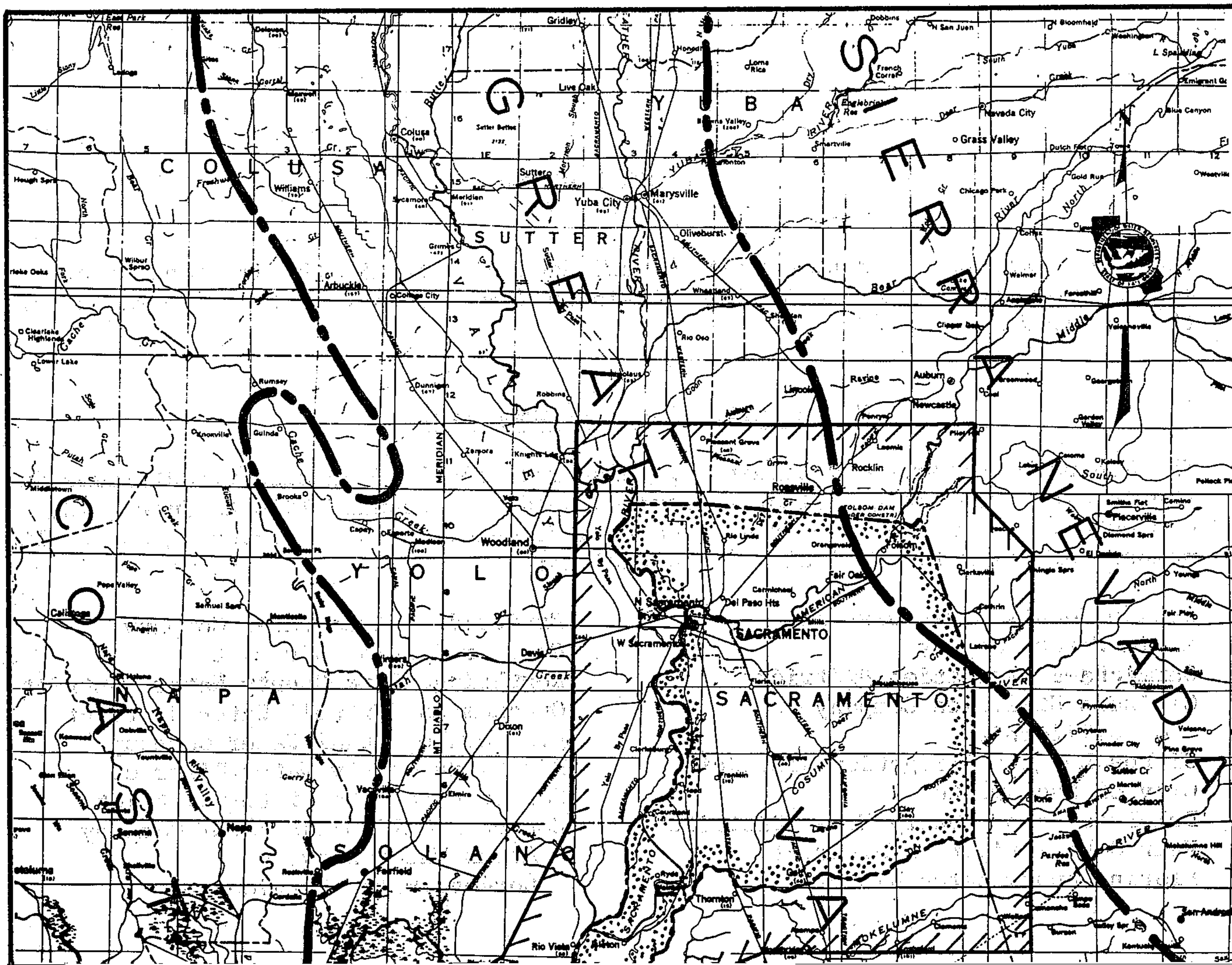
The Ground Water Advisory Committee, which was consulted on significant items in the investigation at a series of meetings held from January 1970 to June 1973, was established within the study area to give guidance to the investigators. Its members are from the following organizations:

Arcade County Water District
Arvin Water Company
Carmichael Irrigation District
Citizens Utilities Company
  of California
Citrus Heights Irrigation District
City of Sacramento
Del Paso Manor County Water District
Fair Oaks Irrigation District
Florin County Water District
Fruitridge Vista Water Company
Galt Irrigation District
Northridge Park County Water District
Omochumnes-Hartnell Water District
Orangevale Mutual Water Company
Rio Linda County Water District
San Juan Suburban Water District
Southern California Water Company
  Arden Water Service
  Cordova Water Service

ABSTRACT

Sacramento County is located in the lower portion of the Sacramento Valley and immediately north of the San Joaquin Valley. Since 1940, water demand has exceeded supply and ground water levels have declined. Concern over the continuing trend prompted local and state agencies to begin investigation of the water resources of the area as the first step in development of alternative plans for water resource management.

This bulletin contains the results of a cooperative study by the Department of Water Resources and the County of Sacramento of geologic and hydrologic conditions affecting the occurrence and movement of ground water and the relation between recharge to and withdrawals from the ground water system. The bulletin also contains a description of a mathematical model developed during the study to simulate the reactions of the ground water system to actions of man. The study is continuing and will evaluate alternate plans of water resource management.



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Knoxville
Rocklin
Sacramento
MERIDIAN
MT DIABLO
AMERICAN
COSUMNES
MOKELUMNE
FOLSOM DAM (UNDER CONSTR)

CHAPTER I. INTRODUCTION AND SUMMARY

Use of ground water in Sacramento County has increased steadily from the early domestic wells of the 1850's, through the expanding irrigated agriculture of the early 1900's, to the rapid increase in urbanization of the 1950's and 1960's. The present use of ground water represents 47 percent of the total water supply of Sacramento County.

From 1940 to 1968 the average ground water level in Sacramento County has been dropping more than one foot per year. By 1968 the average pumping lift was about 60 feet. The continuing steady decline of ground water levels throughout Sacramento County was a cause for concern to the Board of Supervisors. In 1968 the Board entered into an agreement with the Department of Water Resources to direct a cooperative investigation of the ground water resource. The conduct of the study has been on a cooperative basis, and accomplishes two goals. First, it develops the thorough understanding of the ground water resource needed by the County to implement water policy guidelines on management of the water resources of the County and needed by the Department to evaluate the possible roles of the ground water basin in the planning for adequate water supplies on a statewide basis. Second, the cooperative study insures that planning takes local conditions into account and that local agencies are completely involved in the planning effort.

Description of the Area

The area of investigation, shown on Figure 1, includes the Sacramento County portion of the Great Valley, as well as a perimeter zone about six miles wide extending into adjacent counties. Inclusion of the six-mile-wide zone around the County was necessary in order to properly arrive at ground water conditions at the county boundaries.

Sacramento County is but one portion of the Great Valley of California, a complex ground water basin which extends from Red Bluff on the north, south some 400 miles to Bakersfield; the valley averages 40 miles in width. Sacramento County is located in the north-central part of the Great Valley and in the southeastern part of the Sacramento Valley. It is bounded by Sutter and Placer Counties on the north, El Dorado and Amador Counties on the east, San Joaquin and Contra Costa Counties on the south, and Yolo County and the Sacramento River on the west. The approximate total area of the county is 644,000 acres. Of this, 528,000 acres are valley land (6 percent or less slope), 100,000 acres are hilly land (20 percent or less slope), and 16,000 acres are mountainous (greater than 20 percent slope).

Objective and Scope

The overall objective of this two-phase study is to evaluate the alternative ways that the ground water basin may be used in conjunction with surface, imported, and reclaimed waters to satisfy the future water needs of the area. To accomplish this objective it first is necessary to determine how the ground water basin accepts, stores, and transmits water and, in particular, how it reacts to use by man.

The study has been divided into two phases, viz: geohydrology and meeting water demands. The first phase included:

1. Data collection

2. Ground water geology

3. Hydrology and water quality

4. Development of a mathematical model of the basin

5. Verification of the model.

The results of the first phase are reported in this bulletin and are used as the starting point for the second phase, which will be considered subsequently and reported separately. The second phase will include:

1. Projection of land use patterns

2. Projection of water supply and demand

3. Review of future water supply sources

4. Development of future conjunctive operation plans

5. Evaluation of alternate plans.

History of Water Use

The history of Sacramento County is colorful, centering around Captain John Sutter's fort and the beginnings of the Gold Rush of 1849.

Captain Sutter first landed on the banks of the American River on August 12, 1839, near what is now 28th and "B" Streets in Sacramento. His dream was to build a colony named after his homeland, Switzerland. He called this settlement New Helvetia. Here he planted wheat and rice and established orchards using water from the Sacramento and American Rivers for limited irrigation.

The discovery of gold in 1848 in the Sierran foothills near what is now the town of Coloma ended Sutter's dream for New Helvetia and brought with it a great influx of people. The first water supply facilities to serve this increased population were constructed in 1849 and 1850 at what is now the foot of "I" Street in Sacramento. This facility consisted of pumps which lifted water from the Sacramento River to elevated storage tanks. Water was dispensed from these tanks into water wagons and sold by the gallon.

During this period several fires occurred which could not be successfully contained because of an inadequate water supply, and in 1852, a fire destroyed a large portion of Sacramento, causing the citizens to organize the first municipal water company on the west coast. This company began operation in April 1854, after acquisition of the 1850 water system. Its main physical works were located at Front and "I" Streets.

At the same time that water supplies were being developed for fire demands in Sacramento, water supplies also were being developed for hydraulic mining in the eastern section of the County. In 1854 the American Ditch Company was organized, and a diversion of American River water was made to supply water for mining along a 33-mile canal which terminated near Folsom. When the profitability of hydraulic mining declined, attempts were made to put this water to irrigation uses in the lands of the San Juan Grant. In the 1880's the cattle firm of Cox and Clarke acquired most of the lands of the San Juan Grant and the physical works of the American Ditch Company, which the firm reorganized into the North Fork Ditch Company. This private company was the sole supplier of surface waters to what is now the wholesale water service area of the San Juan Suburban Water District.

The demand for irrigation water increased in the latter part of the last century, as the large land grants were subdivided into 10- and 20-acre parcels for small farms. The first area to be developed in this manner was the Orangevale Colony in 1889. This was followed by Fair Oaks in 1898, Carmichael in 1909, and Citrus Heights in 1910. Dissatisfaction with the distribution system of the North Fork Ditch Company led to the formation of other water companies and irrigation districts. The first of these was Orangevale Mutual Water Company, organized in 1896, followed by Carmichael Irrigation District in 1916, Fair Oaks Irrigation District in 1917, and Citrus Heights Irrigation District in 1921. Water from the American River was supplied to these water purveyors by the North Fork Ditch Company until 1954, when the San Juan Suburban Water District was formed and purchased the North Fork Ditch Company.

Wells were used for domestic and stock watering supplies from the time of the earliest settlements, but owing to the lack of efficient pumps and power plants, wells were not used for irrigation purposes until 1879. In that year a well 18 inches in diameter and 24 feet in depth was drilled on the Blowers Ranch near Woodland. The success of this well encouraged further drilling.

During the period from 1890 to 1910, more advanced well drilling, well construction, and pumping techniques were developed. This, coupled with the increasing demand for irrigation waters on the small 10- and 20-acre farms beyond the reach of surface irrigation canals, resulted in increasing quantities of ground water being used.

In 1900, 7 wells ranging in depth from 114 feet to 190 feet, located in what is now the Oak Park area of the City of Sacramento, had a standing water surface of 12 feet below ground level. In 1914, after 14 years of use, these same wells had a standing water level of 25 feet below ground level.

In 1913 approximately 10,700 acres of land in Sacramento County were irrigated by ground water, and the continued use of ground water (probably in the south county) was resulting in a lowering of the water table at the rate of one foot per year. By 1928, 28 percent of the irrigated land was using ground water, and the water table was reported to be continuing to decline.

The Depression of the 1930's slowed the spread of farming until the war years of the early 1940's. However, shortly thereafter, the water needs of Carmichael, Citrus Heights, and Fair Oaks Irrigation Districts exceeded their surface supplies and they began utilizing ground water to meet peak demands. Carmichael Irrigation District canceled its contract with the North Fork Ditch Company in 1941 and began pumping directly from the American River as well as using ground water. In 1959 and 1960 the district constructed radial infiltration galleries along the river to be used as intake structures.

The City of Sacramento began utilizing ground water in the 1940's in order to irrigate parks and provide water to isolated areas in the system. It also acquired, by annexation, other areas served by ground water. At present, 20 percent of the City of Sacramento's peak demand is supplied from the ground water resource.

During the rapid urbanization following World War II, several small water districts were formed. Some have subsequently been taken over by larger districts, while others have merged. Most of the newer districts depend upon ground water for their supply. At present, 23 separate water districts, agencies, or companies supply water to Sacramento County residents.

The use of ground water in Sacramento County has increased steadily from the early domestic wells of the 1850's, through the expanding irrigated agriculture of the early 1900's, to the increased urbanization of the 1950's and 1960's, until at the present time ground water represents 47 percent of the total water supply of Sacramento County.

Previous Investigations

Ground water has been a major source of domestic, irrigation, and municipal water in the Central Valley for many years. Geology and hydrology as they relate to water supply have been the subject of a number of publications and technical papers. Those which bear a relationship to the current study are described below. The Bibliography in Appendix A lists those reports dealing with the ground water geology and hydrology of Sacramento County.

"Folsom-East Sacramento Ground Water Quality Investigation", State Department of Water Resources Bulletin 133, March 1966, is the most recent study in Sacramento County made by the Department. This investigation was undertaken in cooperation with other state and local agencies and industries to determine if waste water disposal from the rapidly increasing residential and industrial development east of the City of Sacramento had affected the ground water quality in the surrounding area. The quality levels as reported will serve as a base line against which to measure the effects of future development.

"Folsom North Unit - CVP - Reconnaissance Studies of Water Problems", U. S. Bureau of Reclamation, March 1956, is a report made in compliance with the enabling legislation for the construction of Folsom Dam and its subsequent distribution of surplus water. The report indicated that continuing the use of ground water would be more economical than either a surface water supply or a combined surface and ground water supply. However, this indication cannot be regarded as conclusive, since many factors were not or could not be fully evaluated until the desires of the local people are more fully known.

"American River Basin Investigation -- Report on Development Proposed for the California Water Plan", State Water Resources Board Bulletin 21, June 1955, reports on a development plan for the American River Basin. Proposed facilities to supply irrigation for valley floor service units of the American River include 22 reservoirs, 19 power plants, 300 miles of conduit, and 150 miles of main canal. The main storage units would include: (1) Auburn, Cedars, and Foresthill Divide Projects on the North Fork; (2) Middle Fork and Georgetown Projects on the Middle Fork; and (3) Silver Creek, Silver Fork, and Salmon Falls Projects on the South Fork. The estimated gross capacity of all units proposed for the Basin is 3,346,000 acre-feet. The plan for full development of the American River Basin includes in addition to water for irrigation and export, ground water replenishment, flood control, salinity control in the Delta, hydro-electric power, and recreation. Development of the Basin is an integral part of the California Water Plan. Total estimated cost of full development is $418,000,000.

Bulletin 21 reports on a conjunctive operation study to increase the yield of the projects. The basic postulate is that the water-bearing materials of the Great Valley could be used and operated as a conservation reservoir. The study estimated direct ground water replenishment by the American River to be 63,600 acre-feet per year. The estimated mean seasonal safe ground water yield, or replenishment of ground water storage, in the area of the ground water study is 964,800 acre-feet. The ground water study area includes portions of seven counties, viz: San Joaquin, Sacramento, Sutter, Placer, El Dorado, Amador, and Calaveras. The study area includes about 1800 square miles.

"Soil Survey, Sacramento Area, California", U. S. Department of Agriculture, August 1954, presents soil classification and soil maps of the Sacramento area. The bulletin was published for agriculturalists and others interested in soil management practices. For the various types of soil present, the suitability of different crops is projected considering the climatic requirements and probable yield.

"Report to Sacramento Regional Area Planning Commission on Preliminary Water and Waste Management Plan", Metcalf and Eddy, Engineers, November 1969, is a culmination of previous studies involving an inventory of water and waste management systems and the formulation of alternative plans. It covers the development of preliminary plans for water, sewerage, and drainage, and includes short range plans and programs over the next five to ten years.

"Geologic Features and Ground Water Storage Capacity of the Sacramento Valley, California", U. S. Geological Survey Water-Supply Paper 1497, 1961, was prepared in cooperation with the State Department of Water Resources and contains a dissertation on the reconnaissance geology of the water-bearing deposits with respect to their physical and hydrologic character, thickness, distribution, and structural features. Estimates were made of the total ground water storage capacity of the water-bearing deposits between a depth of 20 and 200 feet. The total ground water storage of the Sacramento Valley was estimated to be 33.5 million acre-feet. This paper provided the basis of the detailed surficial geologic survey made for this investigation.

"Water Investigation for Districts of Northern Sacramento County", Clendenan and Associates, February 1961, reports a comprehensive study of all of the public water service agencies in the northeastern portion of Sacramento County. The study investigated the water supply, physical plant, and organizational structures of the respective agencies. The report concluded that: (1) all districts except Del Paso Manor County Water District will have an increase in water requirements in the next 50 years; (2) safe yield of the ground water basin is 123,000 acre-feet per year; (3) ground water levels have and will continue to decline, but this is not cause for alarm; (4) ground water pumping is the most economical source of supplemental water for all districts except San Juan Suburban Water District; (5) the water table decline would average about 59 feet in the next 50 years under existing operating conditions, but by utilizing interties, the water table decline could be reduced to an average of only 45 feet over the next 50 years; (6) the average total cost of water would be $14.10 per acre-foot, which would be an increase of about 36 percent above the 1961 cost; and (7) ground water recharge is from both precipitation and from infiltration from the American River and tributary streams.

Current Investigation

The current study has been made in four phases, viz: data collection and organization, geology, hydrology and water quality, and modeling. A description of the work completed is contained in this section.

Data Collection and Organization

The first step in this study was the collection and organization of all readily available information on precipitation, water quality, pump efficiency tests, surface water flows, ground water pumpage and water levels, land use, water rights, population, municipal and industrial water use, and water well logs. The information was reviewed to determine what additional data were required. The data described below have become a data base for the County. Collection of additional data is continuing through the duration of the study and has become a continuing activity of the County. About 75 precipitation station records were gathered, duplicated, and filed. Continuous records are available for the City of Sacramento since 1849 in several locations.

Over 2,000 mineral analyses of ground water were gathered from previous investigations, hydrologic data files, and the files of the State Department of Public Health, Bureau of Sanitary Engineering. These data were encoded and punched onto machine computation cards, then the data were sorted and listed by an existing computer program.

Pump efficiency tests made by the Sacramento Municipal Utility District (SMUD) through 1971 were copied and recorded on microfilm.

There are 47 active and inactive stream gaging stations in the County. The longest term continuous record is American River at Fair Oaks, for which records are available since November 1904.

Municipal pumpage information was collected from the various water purveyors. Quantities of agricultural pumpage were estimated from power consumption records by the U. S. Geological Survey (USGS) for the years 1967, 1968, and 1969 as part of a cooperative program with the Department.

Water level measurements for all stations within the County and one township north, west, and south were keypunched on machine computation cards. The cards then were fed into a computer program which sorts and lists these data. About 18,000 measurements through 1970 were listed.

Land use surveys were available for Sacramento County for the years 1961 and 1968. The data were recorded on USGS quadrangle sheets and were duplicated for the study.

Water rights listings were prepared by the State Water Resources Control Board.

Historic and projected population figures were obtained from the Sacramento County Planning Department, Sacramento Regional Area Planning Commission, California Department of Finance, and U. S. Census reports.

Municipal and industrial water use figures were collected from all water purveyors in the County.

A file of water well logs was created by combining data from the Department and the County Department of Public Health. A master well file containing about 7,500 listings was created from the data contained in the well logs and includes the well location, purpose, owner's name, depth, diameter, county, and well driller.

Geologic Study

Surface exposure of geologic formations was investigated by compiling all available geologic mapping of the County and field checking critical areas. A map detailing all of these exposures was then developed.

Subsurface geologic features were determined with the aid of a computer by a technique utilizing a three-dimensional display of information from drillers' logs. The technique places the driller's call, or description of a subsurface material, into a standard group of materials. By assigning numeric values to these groups the results are printed out by the computer as an areal display of subsurface information for predetermined horizontal slices of the subsurface. The computer output was printed on transparent film and then stacked in their relative order of elevation for interpretation. The traces of the buried stream channels, areas of fine grained material, were identified and zones of hydraulic continuity between various levels were identified.

Hydrologic Study

The objective of the hydrologic element of the current study was to determine values for the parameters that control recharge, movement, and discharge of ground water. These values were used to determine annual amounts of ground water recharge, withdrawal, and change in storage over a period representative of normal climatic conditions. A base period of seven years, 1962 through 1968, was selected as the best representation of average climate and current development.

It was not possible to determine the surface outflow from the area of study because of tidal influences, therefore an accounting or balance of hydrologic items was made only by considering the changes to the mass of ground water. This type of computation is not independent of the amounts of water flowing in the streams, but does not use differences between surface inflow and outflow as a check on the hydrology.

Computation of the amounts of water available at the ground surface, the amount lost to evapotranspiration at the surface, the net amount available for recharge, the net change in the amount of water in storage, as well as the determination of pumpage were made.

Water Quality

Water quality was evaluated by review of the analyses of surface water and ground water for mineral quality. From the analyses, general characteristics of both ground water and surface water were derived. In addition, water quality hazard areas were identified by use of such quality parameters as sodium percentage, chloride ion, and elemental boron.

Preparation and Verification of a Model

After a satisfactory hydrologic balance had been attained over the seven-year base period, a mathematical model of the ground water system was designed. The design of the model entailed the division of the study area into a number of nodes, within each of which there were essentially like hydrologic characteristics. In this way Sacramento County and its adjacent area were subdivided into 102 nodes. The average nodal area thus derived comprised 8.89 square miles, or 5,693 acres. Quarter townships were selected as nodal areas because of the ease in preparing and tabulating data for the model. In addition there were no known geologic faults which transected the water-bearing materials. The western and southern boundaries of the ground water model lap into the adjacent counties. The southwestern portion of the County, that which extends into the Delta region, was excluded from the model because its principal water supply for irrigation purposes comes from rivers and sloughs. The ground water level for each node was derived by estimating the water level for the centroid of each node from annual ground water contour maps. Ground surface elevations were estimated in a similar manner.

In the model, connections between nodes are called branches, and the ability of water to move between nodes along the branches is expressed as transmissivity. Transmissivity values for each branch in the model were estimated from the relationship of specific yield values to transmissivity values. These values were computed for each 10-foot increment of elevation for the entire depth of water-bearing materials. For each branch, the transmissivity values were modified, depending on the angle between the branch and the axis of deposition of the subsurface materials. A ratio between flows in the direction of deposition and normal to that direction was also developed.

The mathematical model uses net recharge (recharge minus pumpage) values as input, together with initial water levels, storage coefficients, and transmissivity values. Program output is a change in storage represented by water levels. The mathematical model used was the latest version of a series of department ground water models programmed for processing on a digital computer. The computer simulates subsurface flow between the nodes and outputs the theoretical water levels over the study period. When the computer output was in agreement with the actual historical water levels, the model was considered verified and representative of the actual ground water basin.

Investigation Results

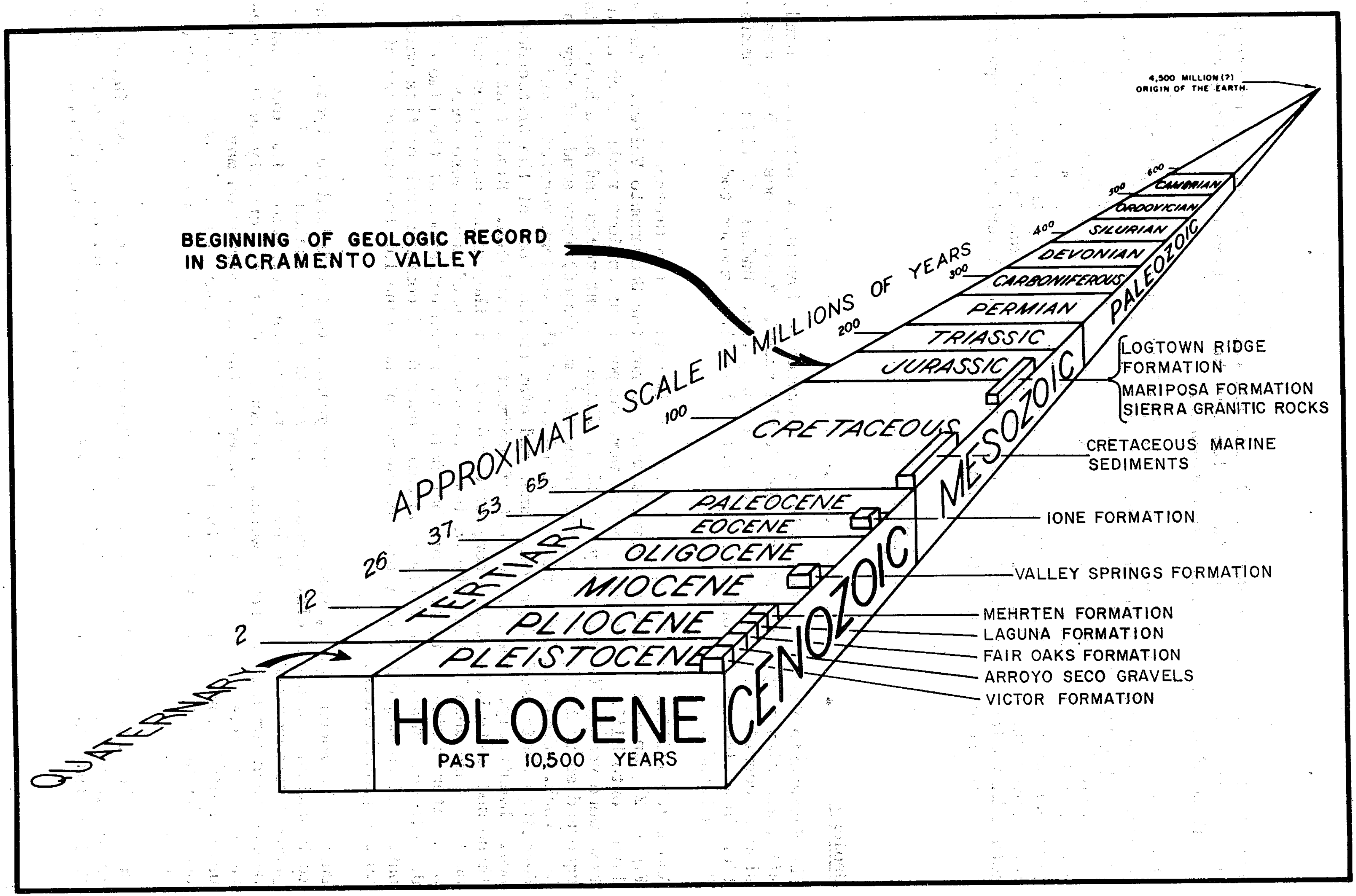
Geology

The Sacramento Valley is underlain by a sequence of layers, or strata, of sand, silt, and clay many thousands of feet in thickness. These deposits have been slowly accumulating over the last 100 million years. Underneath this accumulation is a floor of bedrock of a type not unlike that exposed today in the Sierra Nevada.

About 100 million years ago, during the early part of the Cretaceous Period (see Figure 2), an arm of the sea covered what is now the Sacramento Valley. This sea lapped onto hills to the east, which were composed of ancient rocks which at that time were nearly 100 million years old. These ancient rocks had been heated and squeezed so that they were reconstituted (metamorphosed) from sand and clay to hard rock. Sediment-laden rivers flowed out of the ancient mountains and deposited their load of gravel, sand, and clay on the floor of the Cretaceous sea. Eventually, over 15,000 feet of sediments accumulated. Since that time these sediments have become compacted and now form the marine sandstones and shales found deep beneath the valley. Because the sandstones were formed in a salt water environment, some of that salt water was entrapped at the time of deposition. Today, the Cretaceous sandstones still contain much of this salt water and consequently they are considered of no value for the production of usable ground water.

During the Eocene Epoch, some 50 million years ago, the inland sea became fresh to brackish. Sand and clay deposited on and near the beaches of this sea are now present as sandstone and shale belonging to the Ione Formation, the lowermost source rock for usable ground water. Although not as good quality as that contained in younger materials, ground water in the Ione Formation may be usable under certain conditions. For the next 30 million years the then-soft Ione sediments were sun-baked and eroded until a thickness of less than 500 feet was left.

During the early to middle parts of the Miocene Epoch, a great outpouring of rhyolitic volcanic debris took place in the ancestral Sierra Nevada to the east. Much of this debris was deposited as beds of ash, volcanic sand, silt, and clay



LOOKING BACK IN GEOLOGIC TIME

burying the surface made up of Ione sediments. This sequence of volcanic materials is now identified as the Valley Springs Formation.

Again there was a period of erosion, as the land stood above sea level. For about 10 million years the upper surface of the Valley Springs Formation was eroded until, during the late Miocene and early Pliocene, volcanic activity again broke out to the east. This time the volcanism was of the andesitic type which produced the "lavas" (tuff-breccia) and associated black sands of the Mehrten Formation common to many parts of the County.

By the close of the Mehrten volcanic period, about 8 million years ago, a broad volcanic plain laced by many streams stretched westward from the Sierran foothills to an inland sea. Another period of quiescence ensued for the next five million years. During this time the volcanic sediments were eroded into many lava-topped mesas, many of which became buried beneath younger sediments.

After this period of erosion deposition of continental sediments began anew. This time the materials were nonvolcanic, and have been named the Laguna and Fair Oaks Formations. These latter deposits date from the end of the Pliocene Epoch to the early part of the Pleistocene Epoch, about two million years ago. Deposition of these materials was accomplished by the American River and other streams, which by that time had become major streams entering the Sacramento Valley. Over the succeeding thousands of years the rivers meandered across the valley floor. Time and time again river courses shifted and river channel deposits became cut off and subsequently buried. It is these now buried stream channels which are of vast importance as conveyance channels and sources of ground water.

During the Pleistocene Epoch, when the great glaciers mantled the Sierra Nevada, floods on the American River swept boulders, gravel, and glacial debris onto the plain composed of Laguna and Fair Oaks sediments. These great outpourings of sediment-laden glacial meltwater created a river that was much larger than the American River of today. In places this riverbed was as much as 8,000 feet across. At one time this ancestral river flowed from the vicinity of Folsom southwesterly along a line somewhat parallel to Bradshaw Road to what is now the Cosumnes River. This ancestral channel, now buried under 20 to 30 feet of younger materials, comprises a major southward trending ground water conduit. Later in the Pleistocene Epoch the river changed its course and flowed southwesterly from near Mather Field toward Franklin. This middle channel also is an important ground water conduit. Once again the river changed course to the north, and flowed from Mather Field westerly toward South Land Park. It is this latter channel that provides the copious quantities of sand and gravel extracted near Brighton. Like the older channels, this latter channel also is a major supplier of ground water. Near the close of the Pleistocene Epoch, about 10,000 years ago, the American River, for a fourth time, changed its channel. It moved north again, this time to its present location.

Surface exposures of the geologic formations are shown on Plate 1. The locations and elevations of the buried stream channels and the relationship of aquifers to each other are discussed in detail and shown on maps and figures in Chapter II.

Surface Water

The average runoff from the American River, Cosumnes River, and Sacramento River watersheds was 1,473, 726, and 647 acre-feet per square mile, respectively. These figures show that the American River is twice as productive per square mile of drainage area as the Sacramento River or the Cosumnes River.

The effect of construction of Folsom Dam on the American River has enhanced fisheries and recreation downstream from Folsom Dam.

Ground Water

The average elevation of the ground water potentiometric surface from 1930 through 1940 remained steady at 30 feet. From 1941 to 1970 this level declined to about 5 feet below sea level. This represented a decline of about 35 feet in 30 years, or slightly over one foot per year.

The available fresh water in storage computed to the base of the Mehrten Formation, which is considered for this investigation to coincide with the base of fresh water, is 35,500,000 acre-feet in 1968. From 1930 to 1968 the ground water basin was depleted by 1,500,000 acre-feet. The average annual loss of water in storage during the study period 1962 to 1968 was 22,300 acre-feet.

For the period 1962-1969 for Sacramento County, ground water supplied 45 percent, or 250,100 acre-feet, of the agricultural water requirement; 48 percent, or 108,200 acre-feet, of the municipal and industrial water requirement; and 45 percent, or 358,300 acre-feet, of the total water requirement.

Water Requirement

The average annual total water requirement for Sacramento County during the period 1962-1969 was about 800,000 acre-feet.

Water Quality

Surface waters in the stream systems in the Sacramento County area are of excellent mineral quality and are suitable for all but the most exacting industrial uses. These waters are of bicarbonate type, with either calcium or magnesium being the predominant major cation.

Ground water in the water-bearing materials underlying most of Sacramento County is suitable for irrigation and most industrial purposes. Iron and manganese are a ground water quality problem in Sacramento County. It was found that ground water from many wells had amounts of iron and manganese which were not consistent over a period of time. In some cases a well might be sampled and the analysis would show that iron and manganese concentrations were below the USPHS limits. On resampling at a later date, one or both of these constituents would be in excess of the recommended limits. The presence of iron and manganese in ground water is attributed to leaching action from soils containing excessive amounts of these constituents.

Like the surface water, the ground water is of bicarbonate type, with calcium, magnesium, and sodium being the dominant cations. The ground water body ranges in depth from several hundred feet near the eastern portion of the County to an estimated 2,000 feet near the Sacramento River. Underlying this body of usable ground water is poor quality saline water which occurs mostly in the Valley Springs and older formations.

The Delta area contains a body of poor quality ground water, which ranges from sodium bicarbonate to sodium chloride in composition. In many areas this water is unusable for either domestic or irrigation purposes. The boundary between the poor quality water found in the Delta area and the good quality water is roughly along the boundary separating Townships 4 and 5 North. There are areas containing sodium chloride water occurring along the Sacramento River from the Delta north to Township 11 North and also along the Feather River in Township 11 North. This poor quality water is believed to be due to two causes. First, near surface saline water occurs along many buried stream channel deposits in the Delta. In the geologic past, some of this water may have migrated upstream during periods of low riverflow. Or, the areas of high salinity may be caused in a manner similar to the rising connate waters found in the central Delta area and also in southern Sutter County.

Ground water to the west of the Sacramento River has been derived from recharge along eastward flowing streams that drain the marine sediments to the west of the Great Valley. This water is predominantly a magnesium and magnesium-sodium bicarbonate water and is of poorer overall quality than that derived from the east.

Recharge Characteristics

Only a relatively small portion of the land area of Sacramento County is underlain by materials with sufficient infiltration capability to provide natural recharge to the ground water body. In the eastern foothill region, slopes are too steep and consequently precipitation in excess of evapotranspiration becomes runoff. The Victor plain and Delta area are underlain by soils containing hardpan or organic clays; the low permeability of these materials inhibits infiltration. It is only along active stream channels that sands and gravels occur of sufficient areal extent and depth that significant quantities of surface water may infiltrate to recharge the ground water body.

Most of the stream channel deposits in Sacramento County occur along the courses of the Cosumnes and American Rivers. Along the former, studies have shown that there is an annual recharge of 17,000 acre-feet along the river reach from Bridgehouse (east edge of the ground water basin) to McConnell. Downstream from McConnell, recharge is insignificant due to an abundance of clayey materials in the subsurface.

The gravel pits near Perkins and the broad expanse of tailings near Nimbus are composed of older stream channel deposits. In the case of the pits, where stream gravels have been exposed, precipitation may pond and infiltrate downward and laterally into presently buried deposits that are hydraulically contiguous. The tailings deposits have been churned up by gold dredgers, and they are now of lower permeability than the undisturbed stream channel materials. Even so, rainfall rapidly infiltrates and becomes ground water which moves down-gradient.

CHAPTER II. GEOLOGY

Sacramento County is situated in two geomorphic provinces, the Great Valley and the Sierra Nevada. By far the larger portion of the County is within the Great Valley province; only the eastern portion is within the Sierra Nevada province.

The portion of the County within the Great Valley province has been subdivided into four subunits: the Sacramento-San Joaquin Delta, the river floodplain, the alluvial plains, and the low foothills, as shown on Figure 1.

The Sacramento-San Joaquin Delta includes the southwestern portion of Sacramento County. Under historic conditions, the Delta was a tidal marsh traversed by meandering sloughs and waterways of the Sacramento, San Joaquin, and Mokelumne River systems. Reclamation of the Delta area has created many islands enclosed by levees. These islands are underlain by peat and related organic sediments. The islands are typically bowl-shaped, with the lowest elevations being near the center. The lowest land elevations in Sacramento County occur in the Delta area. Andrus and Brannan Islands each have elevations of seventeen feet below sea level (-17) at their centers, even though the water surface in the adjacent waterways fluctuates between minus three (-3) feet and plus five (+5) feet.

Although the maximum extent of the Delta area is not sharply defined in a geologic sense, for the geologic phase of this study it has been arbitrarily fixed at the zero-elevation contour, which roughly coincides with the contact between the organic and nonorganic soils.

Adjacent to the Delta area is an area identified as the river floodplains. Materials underlying this subunit consist principally of unconsolidated inorganic soils. Elevations range from near sea level adjacent to the Delta and 20 feet above sea level in the American Basin, in the northwest part of the County, to as much as 150 feet along the upper reaches of streams such as the American and Cosumnes Rivers.

To the east of the river floodplains is an extensive area of slightly disected alluvial plains. These areas slope gently upward from the Sacramento River and form a broad area which extends from Rio Linda south to Galt. This alluvial plain is a part of the larger "Victor Alluvial Plain" originally described by Piper and others [1939]. The alluvial plain is underlain by older soils which characteristically contain extensive layers of hardpan. The plain ranges in elevation from about 10 feet near Point Pleasant in the southwestern portion of the County to over 100 feet near Clay. It underlies much of the City of Sacramento, where it has an average surface elevation of about 20 feet.

Drainage across this plain exhibits many degrees of downcutting. Morrison Creek, as well as larger streams such as the American River, has areas where downcutting through layers of hardpan has produced near-vertical streambanks which range from 8 to 15 feet in height.

A low foothill area borders the alluvial plains to the east. Much of the area is presently undeveloped; however in the Sacramento area, the suburban communities of Carmichael, Fair Oaks, and Orangevale are situated on this subunit. This subunit is typified by rolling topography underlain by a variety of continental materials ranging from moderately consolidated silts, sands and clays, to the bouldery plains of the Arroyo Seco pediment.

Elevations in the low foothills range from 75 feet northeast of Elk Grove to over 300 feet south of Folsom. Drainage across this subunit is along well established watercourses, with streams confined to well defined valleys. Relief from streambed to hillcrest becomes bold, attaining as much as 170 feet at the bluffs near Nimbus Dam.

Only the northeastern part of Sacramento County is within the Sierra Nevada geomorphic province. This is an area underlain by hard, nonwater-bearing rock, and is characterized by steep sided hills and narrow, rocky stream channels. Elevations in this area are the highest in the County, attaining a maximum of 828 feet north of White Rock. Stream patterns in the area are well established and are controlled principally by bedrock features.

Geologic History

The earliest event of importance to the geologic history of Sacramento County was the formation of an ancestral Sierra Nevada range during the Nevadan Orogeny, which took place in late Jurassic and early Cretaceous periods (see Figure 2). This orogeny created the range by a process of folding, faulting, and igneous intrusion. Remnants of this range are present today as the steeply dipping metamorphic rocks found near the eastern side of the County. The ancient range was moderately high, as the intrusive rocks which formed deep within the core of the range were exposed by erosion at the close of the Cretaceous period. It is not known how far west this ancient range extended but it undoubtedly extended far to the west of the present foothill line. Seismic evidence suggests that the ancient Sierran block extends at depth at least as far as the western part of the Great Valley.

During the Cretaceous period enormous quantities of rock were eroded from the ancient range and were deposited as thick marine sediments in the adjacent Cretaceous Sea. While this erosion was going on, the sea slowly transgressed over the old eroded surface, and Cretaceous marine sediments were deposited on the granitic rocks emplaced during the Nevadan Orogeny. This eastward marine transgression was accompanied by a gradual subsidence of the eroded ancestral Sierra Nevada.

Marine deposition continued during the Paleocene and into the Eocene epoch. The shoreline at that time was relatively stable along a north-south line running through the eastern part of Sacramento County. A warm and humid climate developed during this time and a lush cover of broad-leaved vegetation formed on the hills east of the Eocene Sea. Lignite seams and severely weathered lateritic sediments attest to this tropical environment.

Commencing in the latter part of the Eocene epoch and continuing into the Miocene epoch, volcanic eruptions formed a variety of rocks along the present crest of the Sierra. Much of this volcanic ejecta was eroded and redeposited subaqueously farther to the west.

By middle Miocene time, the sea apparently had withdrawn from the Sacramento Valley area and, after a period of relative quiescence, volcanic activity began anew along the Sierran crest. These eruptions were andesitic in nature and sent a flood of mudflow breccias down the slopes to blanket the adjacent valley areas. Streams continually reworked these easily erodable deposits and deposited them over broad areas to the west. Eventually all but the highest of the foothills were submerged in this flood of volcanic debris, and drainage repeatedly was disrupted as old stream canyons became filled and new, consequent drainage patterns developed.

During this period of volcanic activity, which lasted from Miocene time into the Pliocene, the Sierran block was slowly being uplifted and tilted toward the west. Also during this time the climate of the area became milder than at present. Annual precipitation was about the same, but paleontological evidence suggests that rainfall was much greater during the summer months.

By the middle to late part of the Pliocene epoch, volcanic activity ceased and the Sierra Nevada again underwent a period of erosion, the products of which were deposited in the Great Valley. The present drainage patterns were established during that time. During the early to middle part of the Pliocene epoch, the Sierra Nevada underwent a series of uplifts which elevated it to nearly its present elevation.

The high Sierra was repeatedly mantled by glaciers during the Pleistocene epoch, and there were also long interglacial periods when the snow and ice all but disappeared. Four glacial and three interglacial periods have been recognized during this epoch. All during these periods, westward flowing streams cut deep canyons into the underlying bedrock of the Sierra Nevada. The material removed from these canyons was deposited on the floor of the valley as an extensive gravel pediment.

Sea level fluctuated during these glacial and interglacial periods. When the glaciers were at their greatest areal extent, sea level was about 300 feet lower than at present. Drainage into and across the Great Valley was in a state of degradation. It was during these periods of lowered sea level that the deep gorges of Carquinez Strait and the Golden Gate were cut. During the interglacial periods, sea level stood about 100 feet higher than at present and streams were in a state of aggradation. It was during those latter periods that shorelines were at or near the central part of Sacramento County. Along these ancient shorelines, near the mouths of rivers and streams, extensive deposits of near-shore materials accumulated.

During the latter part of the Pleistocene epoch, regional upwarping with an associated change in base level brought about dissection of the gravel pediment and its underlying sediments. The sediments which were accumulating in the valley trough lapped eastward, burying some of the older landforms.

Under the present regimen, streams are eroding the low alluvial plains and dissected uplands and are aggrading the adjacent floodplains, flood basins, and stream channel areas.

Stratigraphy

The geologic formations of Sacramento County have been divided into two groups: nonwater-bearing and water-bearing. This division is based on the ability of the formation to yield significant quantities of water to wells. As used in this

TABLE 1

GEOLOGIC FORMATIONS IN SACRAMENTO COUNTY

Geologic Age			Formation	Thickness (feet)	Physical Characteristics	Water-Bearing Characteristics
CENOZOIC	QUATERNARY	HOLOCENE	Alluvium	0-100±	Unconsolidated gravel, sand, silt and clay deposited along stream channels, on terraces and floodplains, and in basins.	Gravels and sands act as important recharge areas and yield large amounts of water to wells. Silts and clays are of low permeability and yield little water.
CENOZOIC	QUATERNARY	PLEISTOCENE	Victor Formation	0-100+	Unconsolidated sand, silt, and clay. Hardpan present. Sand and gravel along old stream courses.	Generally yields little water. Yields larger amounts of water if old stream channels tapped.
CENOZOIC	QUATERNARY	PLEISTOCENE	Arroyo Seco Gravel	20-50	Sand and gravel in iron-cemented clay matrix.	Of relatively low permeability and thus would yield only small amounts of water to wells.
CENOZOIC	QUATERNARY / TERTIARY	PLIOCENE to PLEISTOCENE	Fair Oaks Formation	0-225+	Sand, silt, and clay. Hardpan present. Found principally north of American River. Cemented gravels south of the river.	Similar to the Victor Formation.
CENOZOIC	QUATERNARY / TERTIARY	PLIOCENE to PLEISTOCENE	Laguna Formation	125-200	Bedded silts, clays, and sands. Nonvolcanic.	Sand beds will yield moderate amounts of water to wells; clays yield little water.
CENOZOIC	TERTIARY	PLIOCENE	Mehrten Formation	200-1200	Beds of black volcanic sand, brown clay and sand; zones of volcanic tuff-breccia (lava). All of andestic origin.	Volcanic sands yield large quantities of water to wells. Brown sands yield lesser amounts; clays yield little water. Tuff-breccias yield no water.
CENOZOIC	TERTIARY	MIOCENE	Valley Springs Formation	75-125	Beds of light colored sand and ash, beds of greenish brown silty sand, few beds of gravel. All of rhyolitic origin.	Of low overall permeability. Yields only small amounts of water to wells.
CENOZOIC	TERTIARY	EOCENE	Ione Formation	100-400	Medium-grained quartz sandstone, thick beds of white to red clay, blue to gray clay with lignite.	Of low overall permeability. Yields only small amounts of fresh to brackish water to wells.
MESOZOIC		CRETACEOUS	Chico Formation	200-15,000±	Brown marine fossiliferous sandstone and shale. Occurs principally in the subsurface.	Usually nonwater-bearing; contains salt water. Local areas may be flushed and now contain usable ground water.
Pre-TERTIARY			Basement Complex	?	Slate and sandstone of the Mariposa Formation. Greenstone, schist, and assorted metavolcanics of the Logtown Ridge Formation. Granodiorite and other intrusive rocks of the Sierra Nevada.	Essentially nonwater-bearing. Where sufficiently decomposed and/or fractured may yield small quantities of water to wells.

Logtown Ridge Formation of Carboniferous age. Distinctive outcroppings of white quartz, for which the community of White Rock was named, occur as steeply dipping veins up to 10 feet in thickness. Occurring as discontinuous belts within the Logtown Ridge Formation are beds of slate and shale belonging to the Mariposa Formation of Jurassic age. All of the metamorphic rocks have been deformed into isoclinal folds and now dip nearly vertically. Their strike is roughly parallel to the axis of the Sierra Nevada.

Because of the relative resistance of most of the metamorphic rocks to weathering, they develop only a scant soil cover. Resistant masses such as amphibolite form steep-sided ridges, exhibiting prominent outcroppings of white quartz. Lower areas are underlain at shallow depth by the planed off beds of Mariposa slate and shale.

Because of the thin soil mantle, runoff from precipitation is large and little or no water infiltrates the ground. These rocks yield little if any water to wells except in a few areas such as fractured quartz veins. Wells which tap fracture systems probably yield only a few gallons per hour. The quality of this ground water is expected to be acceptable for most domestic purposes.

Granitic Rocks

Significant outcrops of granitic rocks occur only north of the American River, in the northeastern portion of Sacramento County. Minor exposures of this rock type also occur to the south near the Cosumnes River and along Scott Road.

The granitic rocks are a portion of the Sierran batholith which was emplaced during late Jurrassic and early Cretaceous time. These rocks range in composition from granite to gabbro, with granodiorite and quartz being the most common. The granitics north of the American River are part of a pluton which extends to beyond Auburn Ravine, and 20 miles to the north. The upper surface of this pluton has been named the Roseville Surface by Schlemon [1967b] and has been undergoing weathering and erosion since before the Pleistocene epoch. This weathering has produced, in many areas, up to five feet of decomposed granite and associated residual soil. The decomposed material is characteristically pale colored and is composed of a coarse sandy clay, with the sand fraction being essentially quartzose and the clay fraction made up of decomposed feldspar. South of the American River, the scattered exposures are relatively fresh and unweathered. Rock types here are similar to those north of the American River with the addition of a small area of hard, resistant hornblende gabbro along Scott Road.

Yields of wells drilled into the granitic rocks are generally meager. Wells tapping the fracture systems may yield as little as one gallon per minute. Shallow wells drilled into areas of decomposed granite may expect only a few gallons per minute as an average yield. The quality of water derived from the fractures systems and from the decomposed granite generally is good to excellent.

Marine Sediments

There are only two areas of outcrop of marine sediments in Sacramento County. One is to the northwest of Folsom, in the vicinity of the intersection of Greenback Lane and Auburn-Folsom Road. The other is along Scott Road, north of Carson Creek.

At the Folsom location, the marine sediments are composed of fairly soft brown sandstone containing abundant mollusks and pelecypods, which indicate a Cretaceous age. The sediments here appear to have a stratigraphic thickness of about 50 feet and rest on an eroded surface of granitic rocks. They are overlain by volcanic sediments of Miocene age, indicating that this exposure is but an erosional remnant of a much thicker section of sediments at this location. The sediments along Scott Road are of similar lithology and also contain abundant fossils. They unconformably overlie the metamorphic rocks and are in turn overlain by Eocene sediments.

These marine sediments represent portions of the eastern edge of a Cretaceous wedge of sediments. To the west these sediments dip beneath the floor of the Great Valley and thicken appreciably. They attain thicknesses of upwards of 12,000 feet where they are exposed to the west in the Coast Ranges.

Although the Cretaceous sediments are somewhat permeable, wells tapping them would be expected to yield saline water. Exceptions may occur in areas of outcrop where flushing has removed the saline water and replaced it with fresh water derived from precipitation and runoff. In such limited areas these sediments may be expected to yield small quantities of fair to good quality ground water, suitable for most domestic purposes.

Water-Bearing Rocks

The formations comprising the water-bearing sequence range in age from Eocene to Holocene, and in lithology from sandstone to clay and conglomerate. The mode of origin is as varied as the lithology, as the sequence includes sediments of subaqueous and subaerial deposition as well as those of volcanic origin. Most, if not all of these water-bearing units yield moderate to copious quantities of water of good to excellent quality. Exceptions are certain beds which yield brackish water or water locally degraded by deleterious minerals. Also an exception are the massive volcanic beds which more closely resemble a nonwater-bearing rock due to their extremely low permeability.

Ione Formation

Location and Age. The Ione Formation, of middle Eocene age, is exposed in eastern Sacramento County from Carbondale Road north to Folsom. In this area the formation is present as low rounded hills, presenting a subdued topography. It unconformably overlies the older metamorphic and marine sedimentary rocks to the east. To the west it is unconformably overlain by younger sediments. In some areas of younger sediments, it occurs as erosional windows along the bottoms of ravines. Similarly, toward the east bedrock areas are commonly exposed along stream bottoms in areas where the Ione is relatively thin. Near the eastern limit of the Ione, it also may occur as isolated outliers, capping hills composed of the older rocks. The Ione Formation is considered to be of Eocene age and to have been deposited contemporaneously with the auriferous gravels of the Sierra Nevada (Allen, 1929).

Lithology. The Ione Formation is divisible into three distinct members, only the upper two of which are exposed in Sacramento County. The uppermost member of the formation is composed principally of a uniformly graded, medium to coarse-grained quartz sandstone. This sandstone, which ranges from soft to very hard, diagnostically contains abundant flakes of white anauxite, a micaceous clay product derived from the weathering of Sierran granodiorite. Included with the sandstone, which is not everywhere present, are discontinuous lentils of white milky quartz. Stratigraphically, below the sandstone is a thick bed of white clay of ceramic quality. Like the sandstone, anauxite is abundant, indicating deposition in quiet water. In some areas this clay has been stained red to yellow. Where the staining is intense, the clay has become iron cemented and is present as ocher. The staining is derived from the precipitation of limonite from ground water moving from areas of deeply weathered bedrock. The deeply weathered areas were probably once extensive swamps and bogs which existed in a subtropical climate.

Although not exposed on the surface in Sacramento County, the Ione Formation also contains a thick lower member composed of blue to gray clay and occasional seams of brown coal and lignite. At the base of the formation is reported to be a zone of gravel composed of quartz and metamorphic fragments.

Structure. In outcrop, the Ione Formation appears to have a stratigraphic thickness of about 400 feet. As the exposed surface is one of erosion, it can be assumed that the original thickness of the formation was much greater. The Ione has a monoclinal dip of about 5 degrees to the west. In the subsurface it persists at least as far as the Sacramento River, when it apparently merges with contemporaneous marine sediments of the Domengine and other formations.

To the east the Ione is apparently contemporaneous with the Auriferous Gravels of the Sierra Nevada. In certain areas outside of Sacramento County, deposits of the Ione merge eastward with these gravels. Thus the mode of origin of the Ione appears to be of a deltaic and littoral, or near-shore nature.

Water-bearing Properties. In many areas of California the Ione Formation is considered to be nonwater-bearing. That is true because much of the formation was deposited in a marine environment. Deep wells entering the marine portions of this formation yield water having chloride concentrations of as much as 775 mg/l and total dissolved solids content of up to 1,800 mg/l.

In the eastern part of Sacramento County, where the Ione deposits are of a near-shore or on-shore nature, the formation yields fresh to brackish water to wells. In these areas yields are low because of the low permeability of the Ione sediments. Well 9N/7E-36N1 has half of its perforated interval in the Ione Formation. On test the well yielded about 500 gpm and had a specific capacity of 8 gpm per foot of drawdown. In some areas north of Sacramento County wells drawing entirely from the Ione yielded only 50 gpm and had specific capacities of less than 3 gpm per foot of drawdown.

That the Ione Formation can provide water from great depths is demonstrated by Well 4N/7E-12A1, which intercepted fresh water-bearing Ione sands at depths of 1,341 feet and 1,540 feet.

Valley Springs Formation

Location and Age. The Valley Springs Formation is exposed along the eastern side of Sacramento County from the southeastern corner, along Dry Creek, northward to the headwaters of Carson Creek. The formation generally is exposed over an area of from one to two miles in width. Its widest exposure is along Arkansas Creek, where it is exposed for four and one-half miles from east of Ione Road west to the Cosumnes River.

The Valley Springs Formation is generally believed to be of middle Miocene age. Work by Piper and others [1939] suggested that portions of the formation may be as old as late Eocene or early Oligocene. Recent work by Schlemon [1967b] indicates that age dating by radiometric methods on samples of biotite and sanidine from this formation show a range of ages from 19.9 to 21.9 million years, which would place the age as late Oligocene to early Miocene. These dates are for the formation of the particles themselves and it is reasonable to assume that the age of deposition of these particles is somewhat later, making a middle Miocene age valid.

Lithology. The Valley Springs Formation typically exhibits a somewhat greenish cast to the clayey members. This, in addition to the presence of acidic volcanic ejecta, serves to distinguish it from the underlying nonvolcanic Ione Formation and the overlying basic volcanic units. The formation typically contains varying amounts of rhyolite ash, vitreous tuff, quartz sand containing abundant glass shards, and pale colored beds of ashy clay. Frequently sediments of the formation contain fragments of pumice, some of which may be as much as one-quarter inch in diameter.

The following table presents a measured section of the Valley Springs Formation as reported by Piper and others [1939]. The section is near Stone House School Road in the southwest quarter of the southeast quarter, Section 33, Township 8 North, Range 8 East, and represents the entire thickness of the formation at this locality.

Description		Thickness (in feet)
Mehrten Formation, fine andestic sandstone		46
Valley Springs Formation:		
Silt and clay, siliceous, greenish gray, thin discontinuous bed of conglomerate at top	26	
Conglomerate, pebbles of metamorphics and shards of pumice in matrix of silt	6	
Silt and clay, greenish gray, little pumice	11½	
Gravel and coarse sand, chiefly greenstone and quartz; pumice common; bed not present to south	8½	
Silt and clay, siliceous, greenish gray, little pumice	2	
Concealed	13	
Sand with thin beds of clay, greenish gray	8	
Total thickness of Valley Springs sediments		75
Ione Formation, gray anauxitic sand		25

In the above section the elevation of the top of the Valley Springs is about 230 feet. The base of the measured section is about 25 feet above the bed of a creek.

Structure. The Valley Springs Formation lies unconformably over the older Ione Formation and metamorphic rocks. It dips west at a generally uniform rate of 1½ to 2 degrees. In the area of outcrop it has a stratigraphic thickness of at least 75 feet and in other areas it attains a thickness of about 125 feet. In the subsurface, certain wells have indicated a total thickness of about 200 feet of greenish gray sandy clay. The preserved thickness of the formation may not be the entire thickness deposited during Valley Springs time. As the materials are fairly easily erodable, a large part of the upper portion of the formation may have been stripped off prior to the deposition of the overlying Mehrten Formation. This may account for the absence of this formation both in outcrop and in the subsurface in the northern part of Sacramento County.

Water-bearing Properties. In and near its areas of outcrop the Valley Springs Formation is considered to be a producer of good quality ground water. Yields are generally low due to the presence of clay and pumiceous materials which tend to lower the overall permeability. In the subsurface, much of the Valley Springs lies below the present depth of water wells. However, data developed by the U. S. Geological Survey shows that portions of the Valley Springs Formation lying below an elevation of -1,500 feet contain highly mineralized water not generally suitable for use. The source of this mineralized ground water is not presently known.

Mehrten Formation

Location and Age. The Mehrten Formation is exposed discontinuously along a broad belt in eastern Sacramento County. The belt extends from the south county boundary at Dry Creek, where it is four miles wide, to the north county boundary west of Folsom Lake, where it is less than a mile wide. In the subsurface, the Mehrten Formation extends westward from the area of outcrop at least as far as the Sacramento River. The formation is a major water producer in Sacramento County and is the source of much municipal water in the North Area. To the south, deeper irrigation wells draw in part from the Mehrten.

Based on radiometric dating of volcanic fragments in the Mehrten Formation, an age of middle Miocene to middle Pliocene has been estimated. As the lower portion of the formation is principally sedimentary in nature and thus composed of erosion products of prior volcanic activity, it would be reasonable to assume that much of the Mehrten Formation in Sacramento County is of early Pliocene age.

Lithology. The Mehrten Formation is divisible into two strikingly different units. One is a sedimentary unit composed of gray to black andesitic sands reported by well drillers as "black sand" and interbedded blue to brown clay. The other is a hard, gray tuff-breccia reported by well drillers as "lava".

The black sands generally are fairly soft and are well sorted. They were formed as fluvial deposits having been derived from andesitic detritus washed down the slopes of the mountains. Frequently laminated, the beds of black sand are commonly about five feet thick, although beds up to twenty feet or more have been reported. Where exposed in road cuts, these beds exhibit cross-bedding and foreset bedding, indicating a beach or deltaic mode of origin. Pebbles and cobbles of hard andesite are common along certain horizons. These fragments are well rounded and are locally spoken of as "fossilized goose eggs".

Associated with the black sands are lenticular beds of stream gravel containing andesitic cobbles and boulders up to several feet in diameter. Also associated with the sands are beds of brown to blue clay and silt.

Near the base of the Mehrten Formation is a fairly thick bed, or series of beds, of hard gray sandstone. This sandstone is not over 25 feet thick and is even grained, being composed of quartz and dark minerals. The gray cast is given by grain coatings of authigenic montmorillonoid, a translucent fibrous clay. The clay coating has precipitated from solutions permeating the sandstone and probably was derived from the solution of andesitic rock fragments contained in parts of the sedimentary mass. Associated with the gray sandstone are thin, irregular beds of subaqueous laminated tuff which was deposited in bodies of quiet water. Some of the tuffaceous material was probably derived by reworking of the underlying Valley Springs tuffs.

The second major unit of the Mehrten Formation is the tuff-breccia. This rock is very dense and hard. It is composed of angular pieces and blocks of black, gray, and red fine-grained to porphyritic andesite which range from less than an inch to over several feet in diameter. The fragments are contained in a highly cemented ground mass composed of andesite lapilli and tan to gray ash.

The tuff-breccia was derived from andesitic eruptions to the east in the Sierra Nevada. During these eruptions, great quantities of highly mobile ash flowed down the then existing stream channels. In moving westward the ash picked up blocks of andesite debris which was incorporated into the mass. Moving into the valley, the mass spread out over the westward sloping plains and solidified as a pavement of hard, concrete-like rock which ranged from only a few feet to over 30 feet in thickness.

Flow patterns are readily evident where the upper surface of the tuff-breccia is now exposed. On this surface soil cover is scant or nonexistent, with the blocks of andesite usually standing out in bold relief giving the appearance of a boulder-strewn field. Because of the nature of the rocky surface, runoff from precipitation is nearly 100 percent. The only infiltration is along thin vertical fractures which developed normal to the direction of flow.

The presence of the flat-lying beds of tuff-breccia gives rise to the many "haystack" hills or mesas commonly found in the eastern part of the County. The table lands, which have only a thin soil cover supporting annual grasses, have relatively steep sides composed of the underlying softer sediments. Intervening swale areas frequently contain a pavement of tuff-breccia representing an earlier episode of volcanism.

The following measured section of Mehrten sediments has been described by Piper and others [1939]. The section is located south of Stone House School Road in the Southwest Quarter of the Southeast Quarter, Section 33, Township 8 North, Range 8 East.

Description :	Thickness (in feet)
Sandstone, dark gray, fine-grained, andesitic	7
Silt or clay, white, laminated	5
Sandstone and silt, dark gray, massive	24
Sandstone, very fine, laminated in beds 1/8-inch to 10 inches thick	10
Total thickness	46
Underlain by sediments of Valley Springs Formation	- -

Structure. In the area of outcrop the Mehrten Formation is about 200 feet thick. It dips westward at from one to two degrees. It also thickens to the west so that along the axis of the Great Valley, where it is essentially horizontal, it attains a thickness of from 400 to 500 feet. It may attain even greater thicknesses under the Sacramento-San Joaquin Delta area at MacDonald Island, where logs of gas wells indicate a thickness of about 1,300 feet of andesitic material.

The Mehrten Formation truncates all of the older formations and although being essentially conformable, overlaps them and progressively overlies older rocks to the east. In some areas a slight angular discordance has been reported but as it was less than one degree, it was hardly distinguishable.

After deposition of the entire Mehrten sequence, a long period of erosion ensued, resulting in a fairly rugged topography extending west to about the middle of Sacramento County. Younger sediments generally are deposited unconformably over this buried topography; but in certain areas, principally where Mehrten black sands exhibit cross-bedding and other aspects of stream deposition, younger materials interfinger and are deposited in a more conformable nature, indicating that axes of deposition during Mehrten time persisted into the later Laguna epoch.

Water-Bearing Properties. The Mehrten Formation provides copious quantities of ground water to many wells in Sacramento County. The water yielded by these sediments is generally of good to excellent quality.

It has been found that many wells derive their supply from the "black sands" reported on the drillers' logs. The tuff-breccias, or "lavas", conversely yield little water. Many wells bottom when the lava is reached. Wells that pass through the tuff-breccias reportedly have entered highly permeable materials and obtained large yields from the underlying sediments.

Because of the impermeable nature of the tuff-breccia and the low permeability of many of the clay beds, much of the water in the volcanic sands is in a state of semiconfinement. It has been reported that some of the deeper strata yield water of poor quality. Wells drilled by the Sacramento Natural Gas Company in 1892 and 1909 just south of Sacramento intercepted mineralized water below a depth of 1,500 feet, presumably in volcanic sediments of the Mehrten. It also was reported that the water was quite "gassy", possibly indicating the presence of methane.

Citrus Heights Irrigation District Well No. 2 (State Well 10N/6E-13N1) produces entirely from Mehrten sediments. It is reported that the well produces 1,000 gpm with a drawdown of 10 feet; the specific capacity is 100 gpm per foot of drawdown. Fair Oaks Irrigation District Well No. 2 (State Well 9N/7E-7H1) also produces from Mehrten volcanic sands. It yields 1,440 gpm with a drawdown of 31 feet; its specific capacity is 46 gpm per foot of drawdown. Citrus Heights Well No. 2 is an unusually good producer; however, Fair Oaks Well No. 2 is more nearly typical of wells producing from the Mehrten Formation.

Good production wells are not always obtained in the Mehrten Formation. Where most of the materials intercepted are sediments, production should be good, but where much of the strata is made up of tuff-breccia, yields are substantially less. This is illustrated by noting Well 9N/7E-12P2, located in the outcrop area of the Mehrten Formation south of Folsom. On test this well produced 20 gpm with a drawdown of 40 feet; the specific capacity was 0.5 gpm per foot of drawdown. Examination of the log of this well indicated that over half of the producing interval was tuff-breccia, and the remainder was reported as cemented volcanic sand and gravel.

Laguna Formation

Location and Age. The Laguna Formation is exposed in the eastern part of Sacramento County where it comprises much of the low, rolling foothills. In outcrop it extends northward from Dry Creek, where its area of exposure is about six miles wide, to its northernmost exposure, a road cut along Prairie City Road about one mile south of Highway 50. The Laguna Formation has not been identified north of the American River.

The Laguna Formation was deposited as a westward thickening wedge by consequent distributaries draining the Sierra Nevada. It rests conformably over the older Mehrten Formation, although irregularities in the eroded Mehrten surface may produce areas of local unconformities.

The age of the Laguna Formation ranges from late Pliocene to early Pleistocene. A portion of the formation has been identified as Pliocene based on the identification of an early Pliocene horse tooth obtained from a depth of 58 feet from Well 5N/7E-18H (Piper and others, 1939).

Lithology. The Laguna Formation is strikingly different from the underlying Mehrten Formation. Whereas the Mehrten Formation is andesitic in character and generally dark colored, the Laguna Formation is nonvolcanic and generally is a tan to brown in color. It is composed of a heterogeneous assemblage of beds of silt, clay, and sand with lenticles of gravel deposited on westward sloping floodplains by meandering, sluggish streams. Some of the sands are clean and well sorted; conversely, some of the gravels are extremely silty and poorly sorted.

The mineralogy of the particles in the Laguna Formation is decidedly granitic. Flakes of mica are locally abundant and serve as a distinguishing characteristic of much of the formation. The gravels are mostly from granitic and metamorphic rocks; little or no volcanics are present.

The nature of the sediments of the Laguna is locally variable. For example, in one area the formation consists of compact silt, clay, and lenses of poorly sorted gravel, sand, and silt. In other areas the Laguna contains sand with only a few interbeds of clay and silt.

The type locality of the Laguna Formation is on a southward facing bluff along Hadselville Creek, 3/4-mile northeast of Clay, in southern Sacramento County. Schlemon [1967b] presented the following measured section of the formation from its type locality in the northeast quarter of the northeast quarter, Section 25, Township 6 North, Range 7 East.

Description	Thickness (in feet)
Sand, medium grained, reddish-brown, granitic	39.9
Sand, medium grained, reddish-brown, abundant biotite, interbedded lenses of metamorphic pebbles	2.0
Sand, very coarse grained, red to reddish-brown, lenses laterally into granitic siltstone	6.5
Conglomerate, subrounded, quartzitic; coarse grained, granitic sand matrix; numerous scour and fill channels	5.2
Clay, reddish-brown, blocky	3.3
Siltstone, reddish-brown, slightly micaceous, weathers chalky gray	6.1
Sandstone, fine grained, gray, poorly sorted, slightly micaceous	5.5
Siltstone, granular, gray-brown	1.8
Total	70.3

The lower portion of the Laguna Formation is in gradational contact with the underlying Mehrten Formation. This gradational zone has been named the Laguna-Mehrten Transitional Zone by Schlemon [1967b]. In this zone beds of nonvolcanic, micaceous Laguna sediments are interbedded with volcanic Mehrten sediments. The type section of this transitional zone is along a cut on Dillard Road near the Cosumnes River Bridge in the southwest quarter of Section 1, Township 7 North, Range 7 East. The following measured section was presented by Schlemon from that location.

Description	Thickness (in feet)
Laguna Formation	
Sandstone, medium to coarse grained, gray-brown, granitic, slight cross-bedding	13.8
Siltstone, grayish-white	6.1
Laguna-Mehrten Transitional Zone	
Sand, coarse grained, black, poorly indurated, andesitic	1.7
Sandstone, very fine grained, grayish-white	0.2
Sand, fine grained, gray, massive, granitic, moderately indurated	5.1
Sand, fine grained, reddish-brown, granitic	1.8
Sand, fine grained, gray, massive, granitic, contains lenses of medium grained, micaceous sand	17.8
Sandstone, very fine grained, gray, granitic	0.8
Mehrten Formation	
Sand, very coarse grained, dark blue to black andesitic, strongly cross-bedded	12.3
Conglomerate, pebbles 2 inches in diameter, sand matrix coarse grained, granitic. Grades into gray very coarse grained andesitic sand	2.7
Silt, gray compact	2.8
Total	65.1

Structure. The Laguna Formation laps eastward onto the Mehrten Formation. At only a very few localities does it directly overlie the older Valley Springs or Ione Formations. In its area of outcrop, the Laguna Formation is estimated to be not over 200 feet thick. It dips westward toward the trough of the Sacramento Valley at an average gradient of about 90 feet per mile, a slope of slightly less than one degree. In the subsurface the Laguna thickens to not over 400 feet. It apparently interfingers with the Tehama Formation near the axis of the valley.

Water-Bearing Characteristics. Where fine grained, the Laguna Formation will yield only moderate quantities of water to wells. In areas where soft, well sorted granitic sands predominate yields will be high.

Olmstead and Davis [1961] reported the yield of Well 6N/6E-2D1, which was 455 feet deep, as 1,840 gpm with a drawdown of 37 feet. The well produced nearly entirely from the Laguna and had a specific capacity of 50 gpm per foot of drawdown. The overall yield factor[1] of the well was 12. However, much of the saturated thickness was clay and the adjusted yield factor for the sand portion only was 67. From the yield factor, the permeability of the sand can be estimated to be in the range of from 1,000 to 1,350 gallons per day per square foot of material.

Recharge to the Laguna Formation is afforded both by streams crossing the outcrop area and by direct precipitation. Much of the Laguna is fairly fine grained, resulting in low recharge rates. In certain areas the coarse grained granitic sands outcrop and here recharge rates are expected to be fairly high.

Fair Oaks Formation

Location and Age. The Fair Oaks Formation is exposed in outcrop only to the north of the American River. Here it forms a broad area of rolling topography extending from the American River north to beyond the north county line and from Orangevale west to beyond the Southern Pacific Railroad. The formation was named by Schlemon from a type locality described along the bluffs near the old Fair Oaks Bridge.

Schlemon [1967b] states that the Fair Oaks is coeval with the upper part of the Laguna Formation and that it does not occur south of the American River except for some low gravel deposits described by him as "Upper Fair Oaks". Based on well log data collected during this investigation it would appear that the Fair Oaks Formation extends in the subsurface to the west at least as far as the Sacramento River and to the southwest as far as Florin Road and Stockton Boulevard.

[1]Yield factor: Specific capacity per unit thickness of saturated material times 100 (Thomasson and others, 1960).

The Fair Oaks apparently is early Pleistocene in age, although some of the lower portions may be as old as very late Pliocene.

Lithology. The Fair Oaks Formation is composed of poorly bedded silts, clays, and sands with occasional lenses of gravel. The sediments bear a strong resemblance to those of the Laguna Formation. A diagnostic feature of the Fair Oaks appears to be numerous beds of white to gray-white tuff and tuffaceous silts. These beds are up to one foot thick and are exposed in road cuts throughout the area of outcrop. No beds of a similar nature have been noted in the exposures of the Laguna Formation. Beds of this type appear to be a distinguishing feature of the Fair Oaks Formation.

In naming the Fair Oaks Formation, Schlemon [1967b] described the type section as found along the bluffs between the old Fair Oaks Bridge and the Sunrise Avenue Bridge in Section 13, Township 9 North, Range 6 East. The description of the type section is given below.

Description	Thickness (in feet)
Obscured, probably silt and sand	20.0
Buried soil horizon, sandy loam to clay loam, yellow-brown to dark brown	3.3
Siltstone, micaceous, yellow-brown	6.3
Sandstone, medium to coarse grained, gray-brown	5.9
Siltstone, light gray	1.8
Buried soil horizon, sandy loam to clay loam, yellow-brown to dark reddish brown	4.6
Siltstone, micaceous, subangular quartz grains, light gray	9.7
Sandstone, medium grained, granitic, micaceous, pale brown	2.4
Siltstone, some medium grained sand, micaceous, yellow-brown to light gray	5.9
Siltstone, micaceous, light gray, blocky	2.2
Siltstone, micaceous, light gray, weathered	9.2
Sandstone, silty, fine grained, light gray, cross-bedded	±25
Sandstone, fine grained, granitic, light gray	±25
Sandstone, fine grained, subangular quartz biotite, yellow brown	7.9
Clay, silty, light gray, ferruginous	17.5
Total	±146

Tracing of the Fair Oaks Formation in the subsurface has been accomplished mainly by correlating the numerous thin beds of white material. These are reported on logs of water wells as "white clay". Similar materials, reported on some logs as "dun clay" or "tan clay", may be the same beds. Well logs from the area of outcrop show quite a few horizons of the white clay, as do wells south of the American River from the vicinity of Mercy Hospital south to Florin Road.

Structure. The Fair Oaks Formation appears to have a generally westward dip of about 15 feet per mile. Local undulations in the bedding produce dips as great as one degree. With material this flat-lying, it is nearly impossible to get reliable attitudes and thus the tracing of beds from one outcrop to another is not always possible.

It appears that the Fair Oaks Formation is about 225 feet thick in its outcrop area. It apparently wedges westward and in the subsurface may be as much as 400 feet thick. It probably interfingers with the uppermost part of the Tehama Formation and/or the lowermost portion of the Red Bluff Formation near the central part of the valley.

Water-Bearing Characteristics. The water-bearing characteristics of the Fair Oaks Formation are similar to that of the Laguna Formation. Wells tapping only the Fair Oaks Formation yield up to 3,500 gpm with drawdowns on the order of 30 feet; specific capacities of such wells range from 80 to 120 gpm per foot of drawdown. Many wells in excess of 300 feet in depth also tap the underlying Mehrten Formation. Yields from these latter wells generally are in the same range as those which tap only the Fair Oaks Formation.

Arroyo Seco Gravels

Location and Age. The Arroyo Seco Gravels, which for this investigation include both the Arroyo Seco Gravels and the Gravels of Uncertain Age described by Piper and others [1939], occur as a thin veneer capping hills in the east-central part of Sacramento County. The gravels overlie sediments of the Laguna Formation and rise from an elevation of [illegible]

Lithology. The Arroyo Seco Gravels are composed of discontinuous beds and lentils of stream laid detritus. This material was deposited as a pediment, or constructional plain, by many rivers and streams of great competence which drained the Sierra Nevada during the middle and latter parts of the Pleistocene epoch.

The Arroyo Seco is easily distinguished from the underlying materials by the coarseness of the particles and the red color of the iron oxide cement. The Arroyo Seco is made up of well rounded pebbles and cobbles of dark colored metamorphic rocks (about 40 percent of total), weathered Mehrten andesite (about 30 percent of total) with lesser amounts of white quartz, dark chert, and other rocks. Occasional fragments of granitic rocks weathered to grus also occur. All of these rock fragments are contained in a matrix of iron-cemented granitic sand and clay.

Piper and others [1939] described a measured section of Arroyo Seco gravels from the west wall of a gravel pit near the Elk Grove Cemetery in the southeast quarter, Section 31, Township 7 North, Range 6 East.

Description	Thickness (in feet)
Sand, unsorted, fine to medium, with unsorted gravel	5
Sand, unsorted, fine to medium, iron-stained	5
Gravel, less than 1 inch, some cobbles to 4 inches in matrix of unsorted silty sand that is iron-stained	9
Total	19

Schlemon [1967b] measured a section of the Arroyo Seco Gravels on the north side of Jackson Road, 3/4-mile west of Sloughhouse in the southwest quarter of Section 34, Township 8 North, Range 7 East.

From the following it would appear that there were two episodes of pediment construction, separated by a period of normal sedimentation. Apparently to the east the upper and lower conglomerate members merge into one thicker unit. To the west the conglomerate members may separate and thus account for some of the varied "red sandy gravels" reported in well drillers' logs west of the area of outcrop of the gravels.

Description	Thickness (in feet)
Conglomerate, dark metamorphic, quartzite and chert; sand, coarse grained, red granitic	11.8
Siltstone, white blocky	5.5
Sand, medium grained, red, granitic, micaceous, slightly cross-bedded	10.9
Sand, medium to coarse grained, red, granitic, micaceous, noncalcareous cemented crust	2.9
Siltstone, reddish-brown, andesitic near base, weathers to variegated red and gray	0.8
Silt, gray, weathers blocky, grading to white clay near base	1.7
Sand, very fine grained, grayish-white, granitic	0.3
Sand, very fine grained, reddish-brown, granitic	4.5
Sand, fine to medium grained, thin stringers of quartzite and dark metamorphic conglomerate	8.0
Conglomerate, dark metamorphic and chert, angular, pebbles less than one inch diameter, coarse grained, reddish-brown granitic sand matrix	6.1
Total	52.5

Structure. The Arroyo Seco Gravels slope about 20 feet per mile in a direction that is about S60°W. They are slightly unconformable over the underlying materials, there being a discordance of about 80 feet per mile. The gravels range in thickness from about 50 feet as measured along Jackson Road, to 19 feet at the Elk Grove Outlier. It is reported that Well 7N/6E-8P1 went through 33 feet of hard gravel in a red sandy matrix.

Water-Bearing Characteristics. The Arroyo Seco Gravels are relatively unimportant as a source of ground water. This is because they are relatively thin and usually are located above the zone of saturation. In those portions of the valley where the gravels are within the zone of saturation, they would be expected to yield little water to wells because of their impermeable nature caused by their iron oxide cementation.

It is believed that the gravels have a low recharge potential because where exposed they exhibit soils having a high percentage of hardpan and thus would have low infiltration rates.

Gravels of Uncertain Age

Small areas of Gravels of Uncertain Age occur capping hilltops east of Folsom and at other localities in the eastern part of Sacramento County. These gravels are similar to the Arroyo Seco gravels, and in fact may be related to them. As no diagnostic evidence has been developed that definitely links them to any other gravel deposit in Sacramento County, they are termed as being of uncertain age.

Because these gravels are perched above the surrounding lowlands, they are considered as being nearly devoid of ground water. Thus, as they have no hydraulic connection with any water-bearing unit, they are of little importance to ground water in Sacramento County.

South Fork Gravels

Location and Age. A discontinuous belt of partially cemented channel gravels extends southwesterly from Mormon Island Dam nearly to Elk Grove. These deposits, herein named the South Fork Gravels, occur as a sinuous deposit which is about one mile in width. The gravels have previously been mapped by Schlemon [1967b] as three separate units, viz: South Fork American River Gravels, which occur in the area from Mormon Island Dam to Folsom; Arroyo Seco Gravels, which occur in the area north of the American River; and Upper Fair Oaks Formation, which occurs in the area from Mather Field southwest to Gerber Road. The deposits are herein concluded to have been deposited contemporaneously by the same river system due to the similarity of materials and the nearly even gradient from Mormon Island Dam to Elk Grove.

The age of the South Fork Gravels has not been definitely established. Based on correlation with adjacent materials, the gravels appear to be younger than the Arroyo Seco Gravels and older than the Victor Formation. This would place the South Fork Gravels as probably mid-Pleistocene in age.

Lithology. The South Fork Gravels are composed of deposits of rounded pebbles and cobbles in a medium to coarse grained granitic sand matrix. Surface soils on this unit are mostly in the Corning series which is identified by a dark reddish-brown color and an absence of a hardpan layer. Some sandy micaceous clays are present as a binder to the larger fragments.

Structure. The South Fork gravels have an upper surface that slopes from 5 to over 20 feet per mile. In the vicinity of Mormon Island Dam, the gravels trend southerly, being situated in a dry valley formed in pre-Cretaceous rocks. Here the slope is about 5 feet per mile, which can be assumed to be about the original gradient of the river which once occupied the valley. About a mile south of Mormon Island Dam, the channel of this river turns to the west and the gradient increases to about 20 feet per mile. This steeper gradient undoubtedly has been produced by subsequent westward tilting of the Sierran block. South of the American River, where the channel gravels again trend toward the south, the gradient decreases to a uniform 7 to 10 feet per mile.

Water-Bearing Characteristics. Areas of South Fork gravels north of the American River and in the vicinity of Folsom are relatively unimportant as sources of ground water. This is due to their relative thinness, the presence of clay and iron cement which reduces their overall permeability, and the lack of any appreciable areas for recharge. Local supplies of ground water may be produced from the South Fork gravels in areas along Blue Ravine Road. Here the gravels appear to be about 50 feet thick and in some areas may produce sufficient water for domestic uses.

South of the American River the South Fork gravels are recharged from the tailings deposits found near Nimbus. Downstream from this point some ground water flows through the gravels. Although not very thick, the gravels are of sufficient thickness and permeability to produce domestic supplies of ground water to shallow wells.

Victor Formation

Location and Age. The Victor Formation underlies a broad alluvial plain, termed the Victor Plain, which occupies the central portion of Sacramento County from Dry Creek north to the northern county line. In the vicinity of Elk Grove, the Victor Plain is about 10 miles wide from west to east. To the east it laps onto older materials composed of the Laguna Formation and the Arroyo Seco Gravels. To the west it is in turn overlain by younger alluvial materials. North of the American River the Victor Plain is only about 5 miles wide. Here it laps eastward onto sediments of the Fair Oaks Formation. To the west it dips beneath the American Basin and surfaces near the Sacramento [illegible]

River as a low ridge having a maximum elevation of 26 feet.

The City of Sacramento is situated on the Victor Plain and in this locality the sediments of the Victor Formation extend westward to the Sacramento River.

The Victor Formation was deposited on a plain of aggradation that has across the plain have cut trenches into it in which sediments of Holocene age have been deposited.

The upper surface of the Victor Formation is characterized by a gently undulating surface. Local variations in relief are as much as 15 feet, such as along Poverty Ridge and at Whisky Hill in Sacramento.

The age of the Victor Formation ranges from middle to late Pleistocene. It is probably correlative to the Donner Lake advance of Sierran glaciation. Three fossils have been reported from the Victor Formation. Piper and others [1939] reported the finding of the left shoulder blade (scapola) of a Pleistocene horse (Equus?) at a depth of 17½ feet in a gravel pit 1½ miles north of Elk Grove in the northeast quarter of the southwest quarter, Section 30, Township 7 North, Range 6 East. Schlemon [1967b] reports the finding of Pleistocene horse teeth (Equus) and a femur from a Pleistocene camel (Camelops) from a gravel pit north of Jackson Road in the north half of the southwest quarter, Section 13, Township 8 North, Range 5 East.

Lithology. The Victor Formation is composed of interbedded granitic sand, silt, and clay with lenses of metamorphic channel gravels. The lithology bears a striking similarity to that in the Laguna and Fair Oaks Formations, making it nearly impossible to differentiate the formations on the basis of well log data. The lithology of the Victor is heterogeneous and laterally and vertically discontinuous, indicating a fluviatile environment. The apparent extreme variability of grain size also is the result of many intricately braided stream channels. For this reason it is usually not possible to correlate from well to well, even though well spacing may be as close as 1,000 feet.

Well log data indicate that the grain size in the Victor Formation tends to decrease toward the west. The percentage of reduced clay also increases toward the west, suggesting a mode of deposition in a shallow body of water.

The surface soils of the Victor Formation diagnostically contain a layer of hardpan. The occasional stringers of gravel contain an average of 80 percent dark metamorphic gravels and less than 5 percent each of quartzite, light metamorphics, dark igneous, and chert.

Structure. The Victor Formation has a homoclinal dip of about 5 feet per mile toward the west along its uppermost surface. This surface is assumed to represent the top of the formation. The base of the formation dips westward at about 11 feet per mile, indicating a gradual wedging to the west. Throughout most of Sacramento County the Victor Formation is up to 90 feet thick. To the west, where it dips beneath a cover of younger materials, it probably attains thicknesses of about 150 feet.

Water-Bearing Properties. The Victor Formation has a moderate overall permeability. Most of the domestic and shallow irrigation wells located on the Victor Plain draw from this formation. The Victor frequently has a higher permeability than the underlying Laguna sediments.

Alluvial Sequence

The alluvial sequence, of Holocene age, is divisible into six separate units. The various units occur along present stream channels and also underlie the islands of the Sacramento-San Joaquin Delta. Certain alluvial units also occur in other areas of recent sedimentation such as the American Basin. Each of these units is briefly described below.

Floodplain Deposits. Unconsolidated deposits of clay, sand, and silt occur as floodplain deposits adjacent to the Sacramento River. The deposits were formed from winter overwash of the river and are part of the natural sedimentation taking place in the Sacramento Valley. These deposits overlie sediments of the Victor Formation and are at most about 50 feet thick.

Basin Deposits. Basin deposits, consisting of unconsolidated beds of clay, occur under the American Basin and at other localities in the western part of Sacramento County. The deposits were formed in local sink areas and represent the finest grained materials deposited from winter overwash. The deposits interfinger with the floodplain deposits; they overlie the Victor Formation.

Muck and Peat. Deposits of muck, peat, and related organic clay occur in nearly all of the islands of the Sacramento-San Joaquin Delta. Although containing a moisture content upwards of 200 percent, the deposits are of very low permeability. They were formed in backwater areas at or near sea level and represent an accumulation of tules, reeds, and other vegetative matter. The deposits commonly overlie the Victor Formation. Near the central part of the Delta they may overlie river deposits or other alluvial materials of varying permeability.

Sand Deposits. Isolated deposits of aeolian sand occur throughout the Delta area. These deposits are composed of wind-blown river sand that is heaped into small dunes. The deposits are usually underlain by alluvial or organic sediments. They are highly permeable and provide infiltration areas for precipitation.

Stream Channel Deposits. Deposits of unconsolidated sand and gravel occur as streambed deposits and point bar deposits. The deposits overlie those of the Victor Formation, as well as other alluvial materials.

Being generally very permeable, the deposits afford large areas for infiltration of surface water to the ground water body.

Valley Alluvium. Stringers of valley alluvium extend along the many westward draining stream courses. These materials, such as found along the Cosumnes River and along Dry Creek, consist of unconsolidated deposits of sand, silt, clay, and occasional lenses of water-worn gravel. Permeabilities vary from fairly high to low, and in certain areas the valley alluvium acts as an important recharge area for percolating surface water to enter the ground water body.

Gravel Pits

Gravel pits are located throughout Sacramento County. The greatest concentration is in the area of Perkins, where Teichert Aggregates and other operators maintain gravel extraction plants. The opening of a gravel pit entails the stripping off of a cover of Victor Formation materials, usually about 10 to 15 feet thick. Beneath this cover is a deposit of river gravels that at places is up to 75 feet thick. The gravels are composed of well rounded particles of acid intrusive, basic intrusive, and volcanic rocks which grade from sand size to over 6 inches in diameter. The deposits were formed in the various channels of the American and other rivers as they meandered over the Victor floodplain.

Gravel pits are important as possible artificial recharge areas. Because of their high natural infiltration capacity, they should be ideal for the recharge of water to the ground water body. Although gravel pits tend to silt up on the bottom, high infiltration rates through the sides of the pits are maintained long after the recharge rate through the bottom of the pit has been reduced.

Tailings

Deposits of tailings occur south of the American River near Nimbus and at other scattered localities in the central and eastern portions of Sacramento County. The largest single expanse of tailings extends from near Folsom southwesterly nearly to Mather Air Force Base, a distance of about 12 miles; it has a width which ranges from 1 to 4 miles and covers an estimated 12,000 acres. These tailings are the result of gold dredge operations and consist of windrows of gravel, cobbles, boulders, sand, and silt. Tailings are considered to be quite pervious and, as such, should make an excellent recharge area. Also, being permeable, they are good sources of ground water in spite of the fact that it may be extremely difficult to construct a well thereon due to the presence of numerous cobbles and boulders.

Geologic Structure

Sacramento County is situated on the eastern side of the structural trough which makes up the Great Valley. To the east is the Sierra Nevada, a block mountain range which has been tilted upward on the east and dips westward beneath the Great Valley. To the west of the Great Valley are the Coast Ranges, a complexly folded and faulted mountain range oriented nearly parallel to the axis of the Great Valley.

The Great Valley is a large structural basin which has become filled with sedimentary rocks ranging from early Cretaceous to Holocene. The older rocks have become uplifted and deformed to the west of the valley and now form the eastern part of the Coast Ranges. The valley trough is asymmetrical; the deepest part of the basin is near the western edge, west of the present axis. The valley deposits thin eastward and overlap the crystalline basement complex rocks of the Sierra Nevada block.

Throughout Cretaceous time and during most of the Tertiary, the axis of thickest marine sedimentation was to the west of the present axis of the valley. A westward projection of the slope of the Sierra Nevada basement complex suggests that the marine sediments may be more than 20,000 feet thick along the southwestern margin of the valley. Here the Cretaceous sediments are estimated to be at least 10,000 feet thick. Post-Cretaceous marine rocks, mostly Eocene in age, are about 3,000 feet thick, although exposures some 7,000 feet thick occur in the Coast Ranges to the west. Post-Eocene sediments in the valley are mostly nonmarine. They are about 3,000 feet thick, but in places may attain thicknesses of about 4,000 feet.

All of the sediments of the Sacramento County portion of the Great Valley have a uniform westerly dip. Dips range from as much as 300 feet per mile to as little as 5 feet per mile. The sediments in this area are essentially devoid of either folds or faults. The only feature that can be attributed to folding is a somewhat indistinct monoclinal feature having a northwesterly orientation located to the east of Roseville. This feature, which is identifiable only on the basis of examining the gradients of the ancestral channels of the American River, appears to have a southwesterly dip which changes from 60 feet per mile to 100 feet per mile across the inferred monoclinal axis. Whether this is truly a monoclinal feature or is an apparent change in fall of the river cannot be determined at this time. There apparently are no major faults transecting Sacramento County.

Subsurface Geology

The identification of horizontal and vertical boundaries of aquifers is extremely difficult in most alluvial-filled valleys of California. In the past this identification has been accomplished only on a gross scale and has been derived through the construction of geologic sections using drillers' logs of water wells as well as electric logs of oil and gas wells. Using this method, generalized formational boundaries and member boundaries can usually be determined.

This method of analysis does not provide the degree of detail that is required for operational studies of ground water basins, particularly those in which older buried stream channels provide the media through which the major portion of ground water moves. Consequently a new approach utilizing computer methods was developed to determine the continuity of the various aquifer systems present in Sacramento County. In the construction of a depositional feature such as the Sacramento Valley, the contributing streams have meandered back and forth across the surface of the valley, depositing stream-borne materials which range in size from coarse gravel and boulders down to clay. During periods of normal runoff, a stream course is established which contains the coarsest grained materials. These materials grade from large gravels and boulders near the foothills to sand and silt near the axis of the valley. Adjacent to the stream channel are clays and silts which grade outward to even finer grained materials. Periodically, during periods of storm runoff, a stream will abandon its course and seek a new route. It also may meander over short distances of less than a thousand feet, thus forming braided channel deposits. In time, as deposition continues, the abandoned stream channels become covered with younger materials. These materials usually are fine grained, thus isolating the old stream channel and converting it into a tabular aquifer. In a few cases younger stream channels may form along or across older channels, thus creating areas of hydraulic continuity between different channel deposits. In a few cases the older, buried channels may subsequently become warped or cut off due to regional tilting or faulting.

In Sacramento County a special program was developed to utilize information on the subsurface materials derived principally from logs of water wells. In analyzing these logs it was found that the "calls" used by various drillers differed for the same material. It also was found that drillers' calls may be grouped, and thus a statistical analysis may be made based on these calls. This same approach was used by the U. S. Geological Survey, which grouped the drillers' calls by specific yield values in its study of the San Joaquin Valley. This grouping of calls, modified for the Sacramento County area, is presented on Table 2. The steps in the geologic analysis which utilized this grouping are briefly described below.

1. The deepest well per quarter-quarter section (a one-quarter mile spacing) in the study area was identified and the values of the equivalent specific yield (ESY) tabulated for each material reported on the log. Equivalent specific yield is defined as being equal to the specific yield of a given material under unconfined conditions. The ESY of a material is a pure number and remains the same whether the material contains ground water under confined or unconfined conditions, as it relates to the relative grain size and not to the quantity of ground water which could be derived from it.

2. The ESY values were averaged for 10-foot increments of elevation for each well used.

3. The averaged ESY values were then converted to symbolic form for utilization in graphic presentation. Four symbols were used which represent the main types of depositional material:

Symbol	Range of ESY Values	Typical Material
.	1 to 7	Clay and Silt
-	8 to 12	Clay with Fine Sand
+	13 to 17	Sand with Clay Streaks
0	18 to 25	Gravel and Coarse Sand

TABLE 2

SPECIFIC YIELD VALUES
FOR DRILLERS CALLS

General Material Type and Specific Type	Drillers Calls		
Crystalline Bedrock Specific Yield = 00 Percent	Granite Lava	Hard Rock Rock	
Clay and Shale Specific Yield = 03 Percent	Adobe Boulders in Clay Cemented Clay Clay Clayey Loam Decomposed Shale	Granite Clay Hard Clay Hard Pan Hard Sandy Shale Hard Shell Muck Mud	Shale Shaley Clay Shell Rock Silty Clay Loam Soapstone Smearey Clay Sticky Clay
Clayey Sand and Silt Specific Yield = 05 Percent	Chalk Rock Clay and Gravel Clayey Sand Clayey Silt Conglomerate Decomposed Granite Gravelly Clay Lava Clay Loam	Peat Peat and Sand Pumice Stone Rotten Conglomerate Rotten Granite Sand and Clay Sand and Silt Sand Rock Sandstone	Sandy Clay Sandy Silt Sediment Shaley Gravel Silt Silty Clay Silty Loam Silty Sand Soil
Cemented or Tight Sand or Gravel Specific Yield = 10 Percent	Arcade Sand Black Blue Sand Caliche Cemented Boulders Cemented Gravel	Cemented Sand Cemented Sand and Gravel Dead Gravel Dead Sand Dirty Pack Sand Hard Gravel	Hard Sand Heavy Rocks Lava Sand Soft Sandstone Tight Boulders Tight Coarse Gravel Tight Sand
Gravel and Boulders Specific Yield = 15 Percent	Cobbles and Gravel Coarse Gravel Boulders Broken Rocks	Gravel and Boulders Heaving Gravel Heavy Gravel Large Gravel	Rocks Sand & Gravel, Silty Tight Fine Gravel Tight Medium Gravel Muddy Sand
Fine Sand Specific Yield = 15 Percent	Fine Sand	Quicksand	Sand, Gravel, and Boulders
Sand and Gravel Specific Yield = 20 Percent	Dry Gravel Loose Gravel	Gravelly Gravelly Sand Medium Gravel	Sand and Gravel Sand Water Gravel
Coarse Sand and Fine Gravel Specific Yield = 25 Percent	Coarse Sand	Fine Gravel	Medium Sand Sand and Pea Gravel

Based on Geological Survey Water Supply Paper 1469, "Ground Water Conditions and Storage Capacity in the San Joaquin Valley, California", 1959.

4. The symbolic ESY values then were plotted on maps having a horizontal scale of 1 inch equals 4,000 feet for each 10-foot elevation increment from the interval +150 to +140 feet down to -280 to -290 feet. Values were plotted for each 20-foot increment of elevation from the interval -290 to -310 feet down to -450 to -470 feet. Using 20-foot increments for the deeper intervals was necessitated by a lack of well data. Each of these incremental maps then was printed on transparent media and prepared for viewing and analysis.

5. Geologic interpretation of the several maps was then made by stacking them in ascending order of elevation. By viewing the maps from above, the traces of the buried stream channels could be seen meandering down through the various levels. Also, areas of fine grained material could be identified as well as zones of hydraulic continuity between various levels.

The water-bearing sequence beneath Sacramento County is divisible into two main sections. The superjacent, or upper series, is composed of the Fair Oaks, Laguna, and Victor Formations, as well as the overlying Holocene deposits. The subjacent, or lower series, is composed of the Mehrten Formation and those water-bearing materials underlying it (Valley Springs and Ione Formations). Separating the two series is a buried erosion surface of moderate to strong relief representing a hiatus which took place between deposition of the Mehrten and the Laguna and Fair Oaks Formations. This time interval of the hiatus is estimated to be on the order of from 3 to 5 million years.

Superjacent Series

The superjacent series includes the Laguna, Fair Oaks, and Victor Formations, as well as all Holocene deposits. These materials constitute a water-bearing sequence that is hydraulically isolated from the deeper aquifers. Contained in the superjacent series are a number of now-buried stream channel deposits. These deposits, which are composed of permeable sand and gravel, are enclosed by less permeable silt and clay. This has resulted in a network of meandering tabular aquifers. Figure 3 shows the areal distribution of many of these buried stream channels. The geologic cross-sections shown on Figure 4 depict the channel deposits as they are distributed vertically.

Throughout all of post-Mehrten time the Sacramento Valley has been undergoing aggradation which has resulted in a thick sequence of materials deposited by meandering, braided stream channels separated by intervals of fine grained, relatively impervious materials. These channels, which have high transmissivities, are composed of sand, gravel, cobbles, and occasionally boulders. They were formed by streams draining the Sierra Nevada during both glacial and interstadial periods. During glacial times streams were vigorously aggrading and created channel deposits which were up to 5,000 feet across and several hundred feet deep. In periods such as this, coarse detritus was the rule for streams draining the mountains. Deposits of gravel extended into the valley, and thick sand deposits interbedded with fine glacial flour extended even farther. During interstadial times rivers were of smaller consequence and had less bed load. The various river systems identified during the study are shown on Figure 3. Each is briefly discussed below.

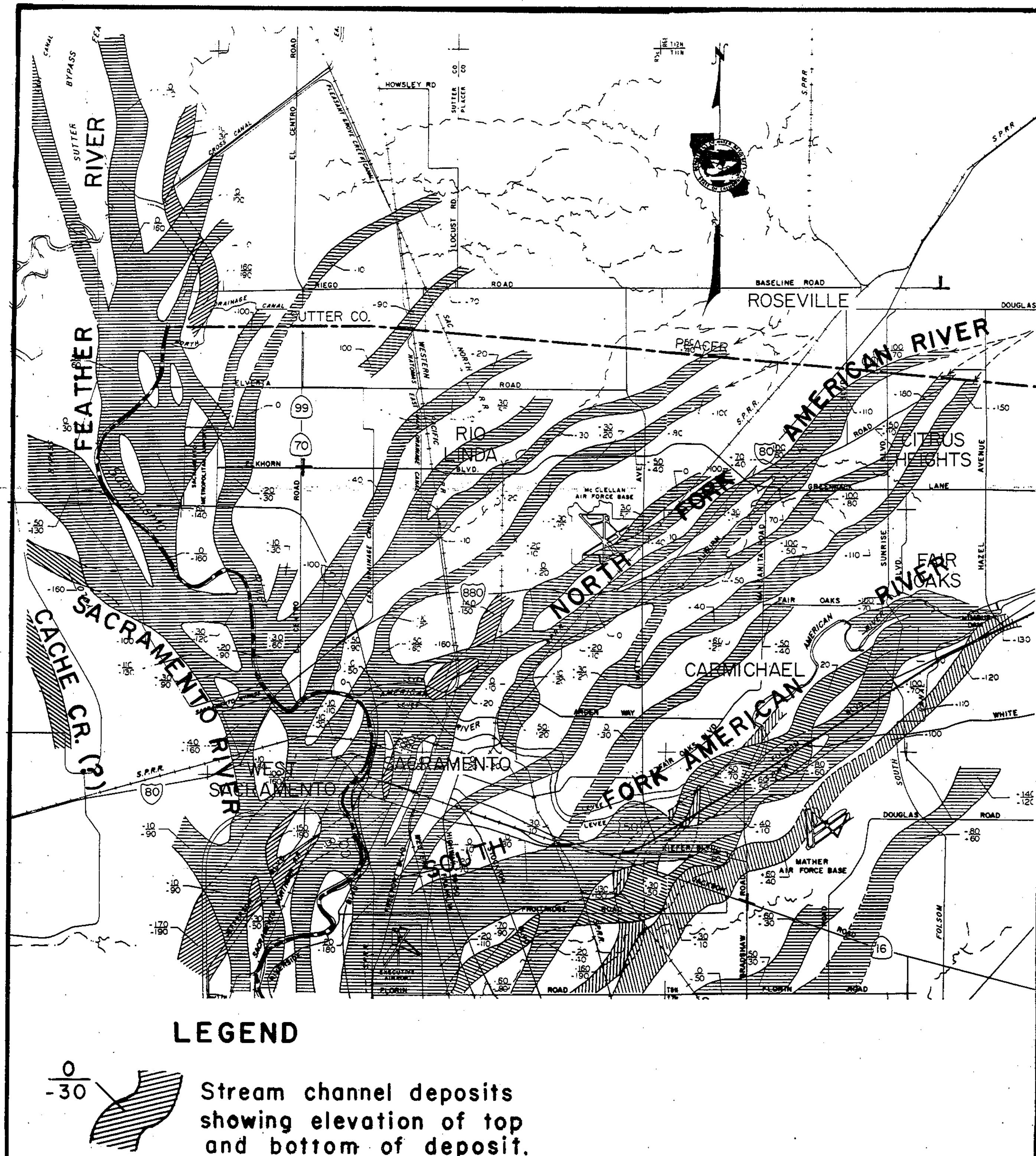


Figure 3, SUPERJACENT STREAM CHANNEL DEPOSITS
Sheet 1 of 2

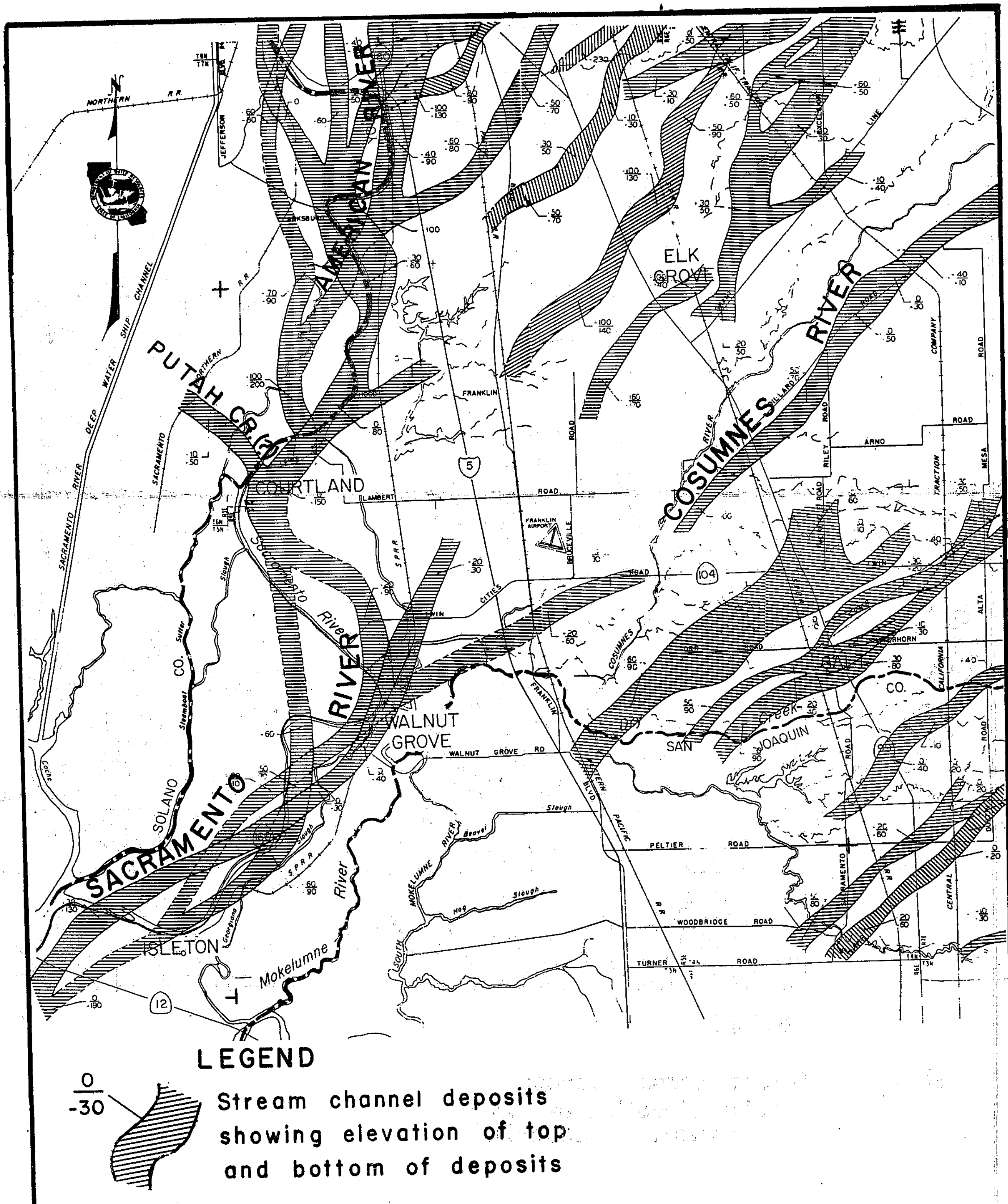
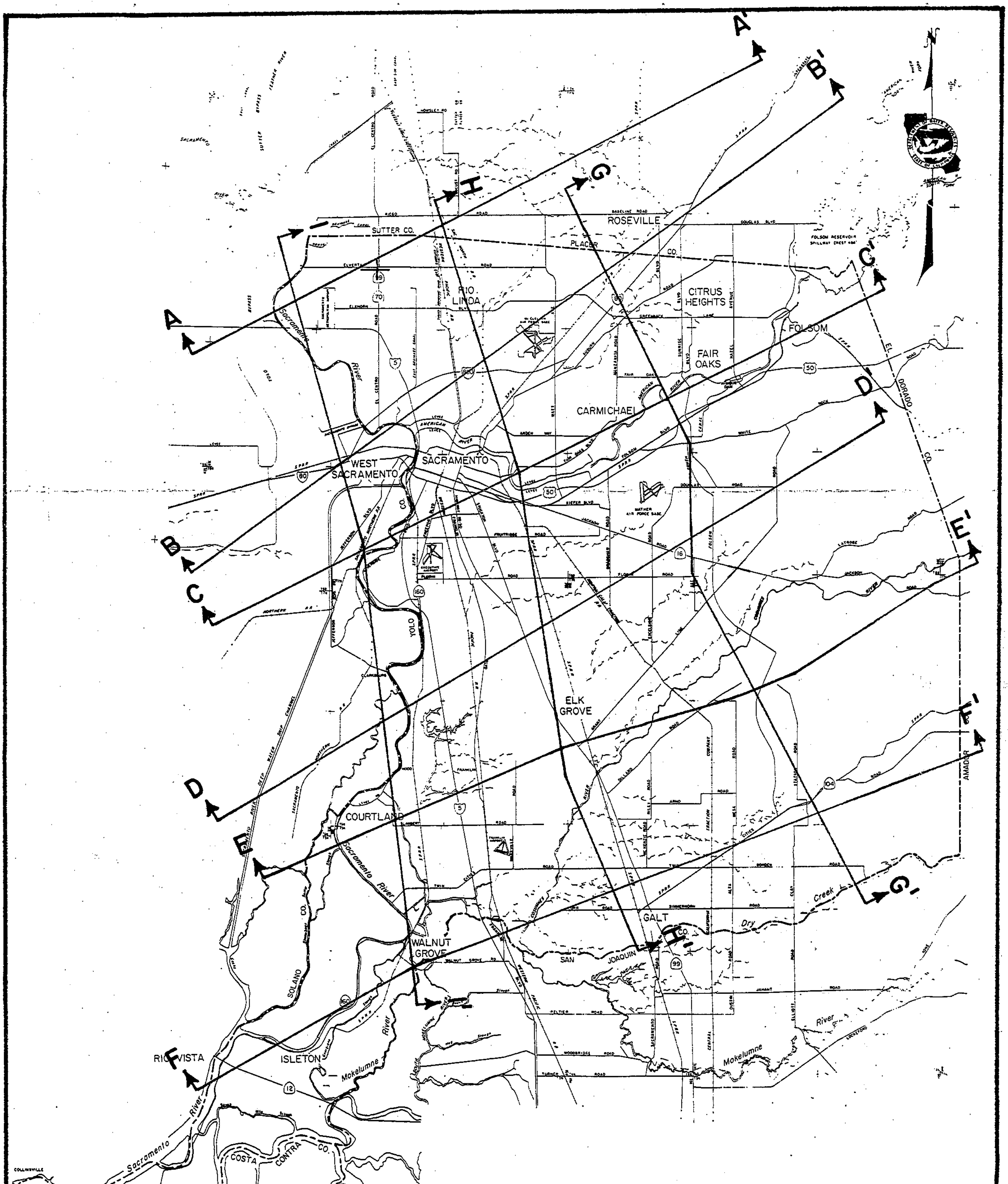
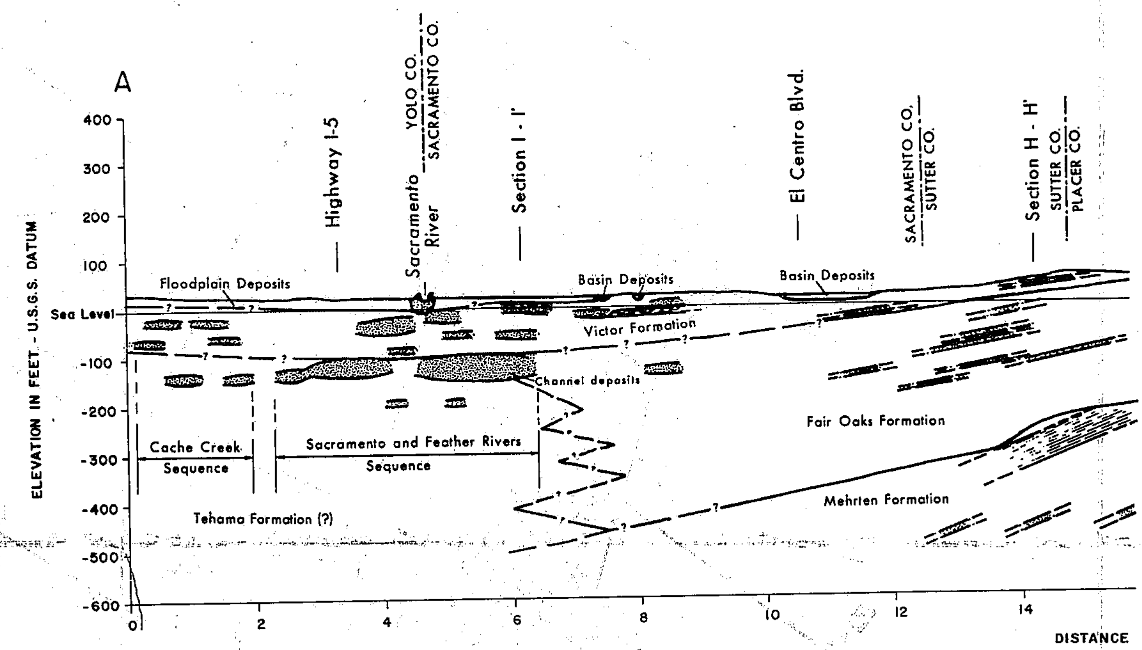
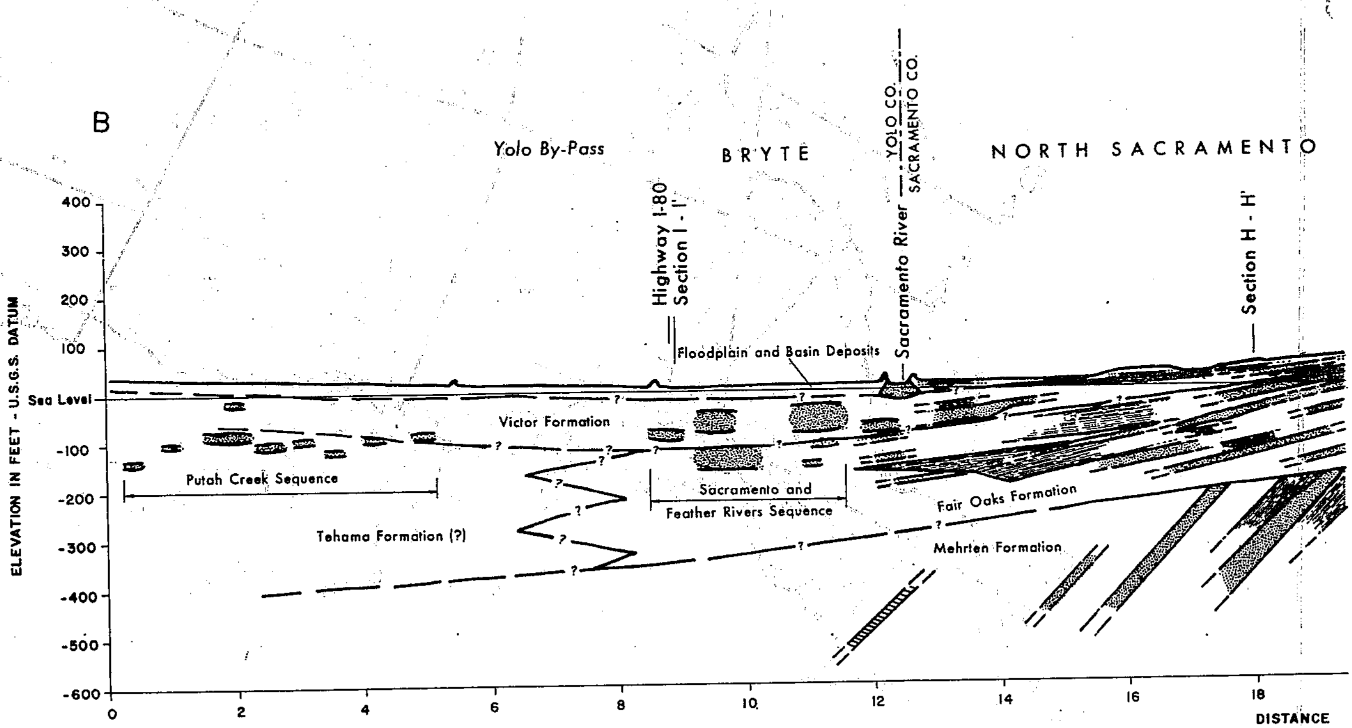


Figure 3, SUPERJACENT STREAM CHANNEL DEPOSITS
Sheet 2 of 2



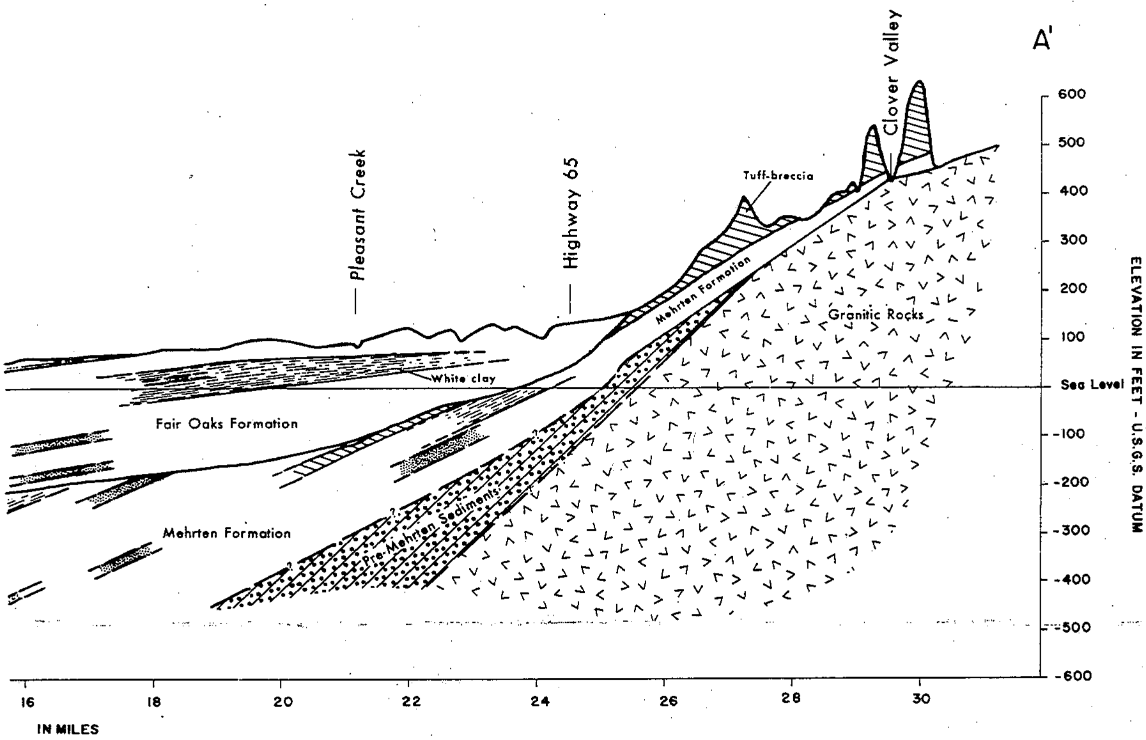
GEOLOGIC SECTIONS SACRAMENTO COUNTY

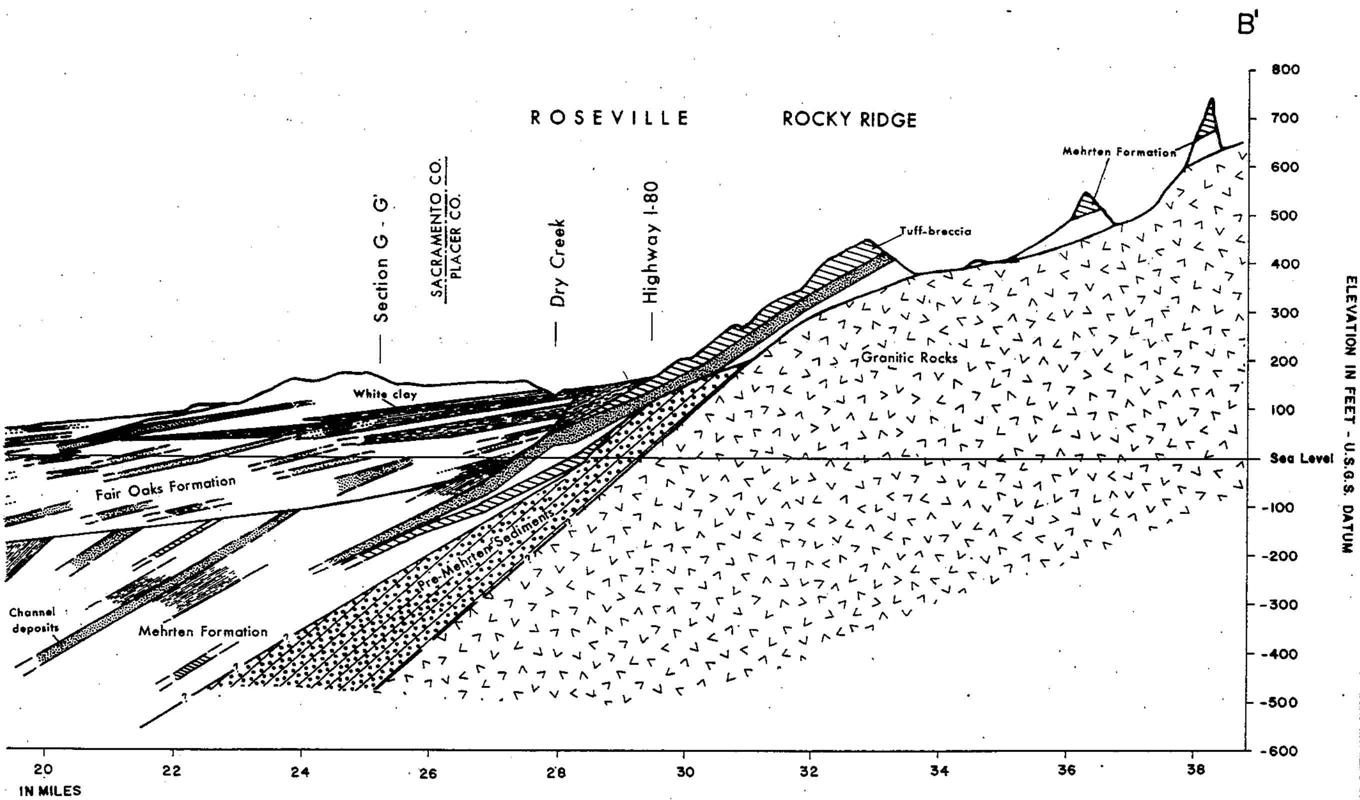




GEOLOGIC SECTIONS

See Plate I for locations of sections.





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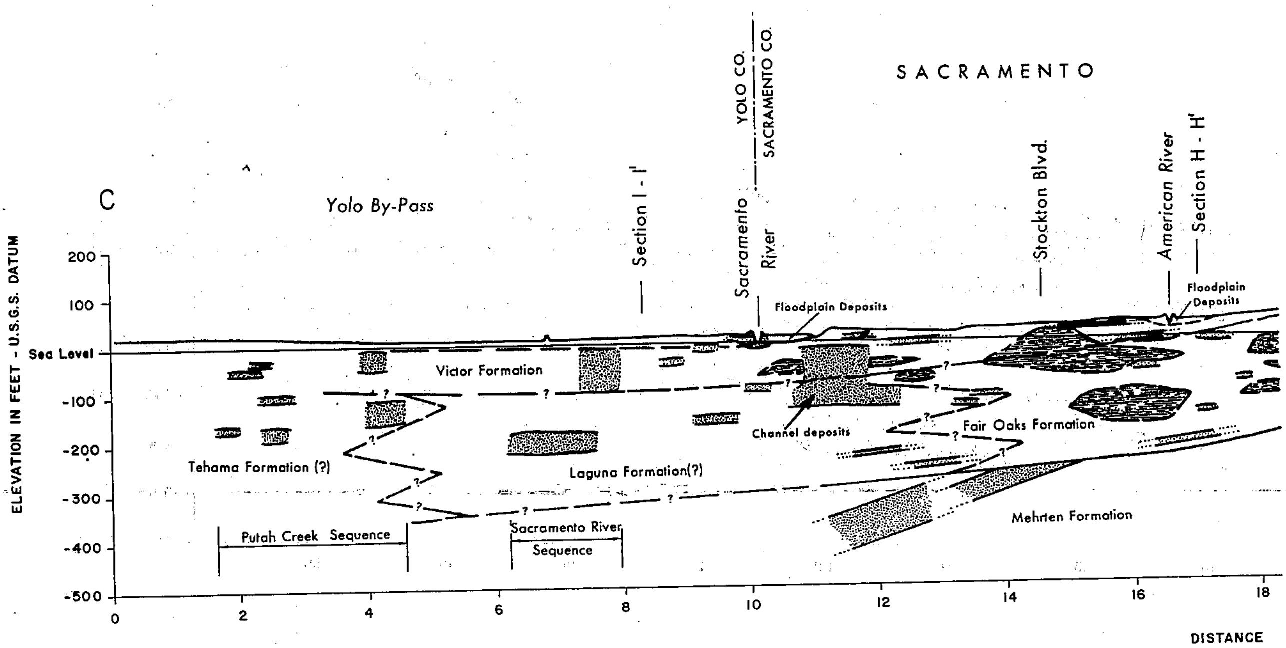
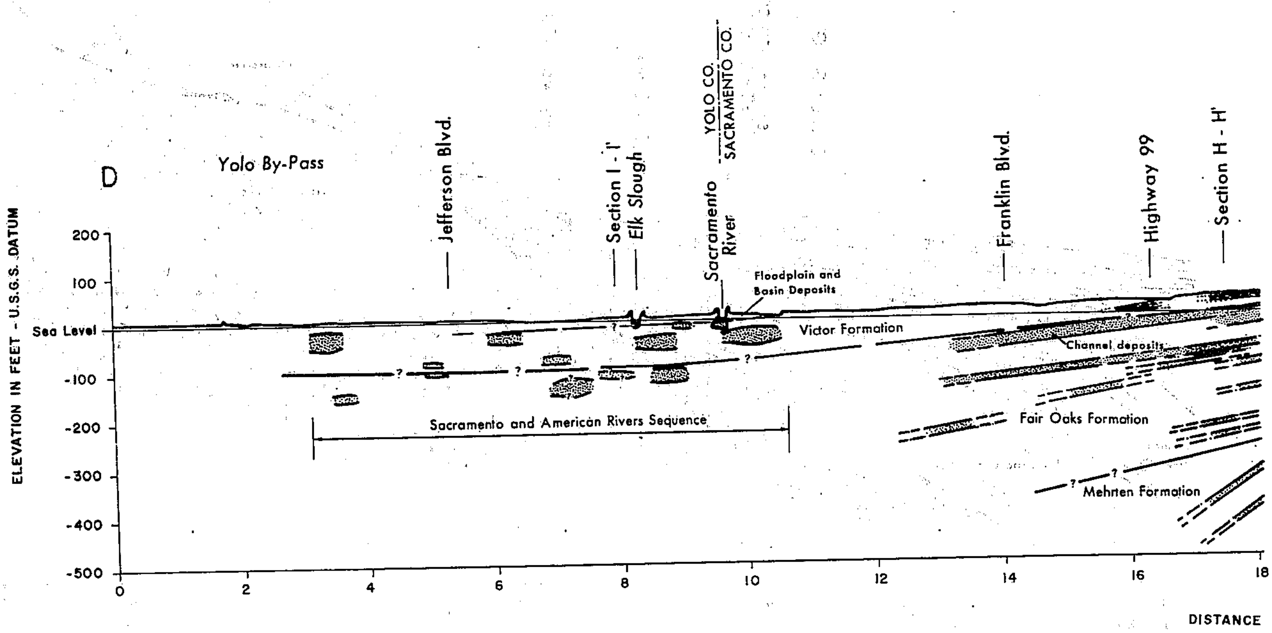
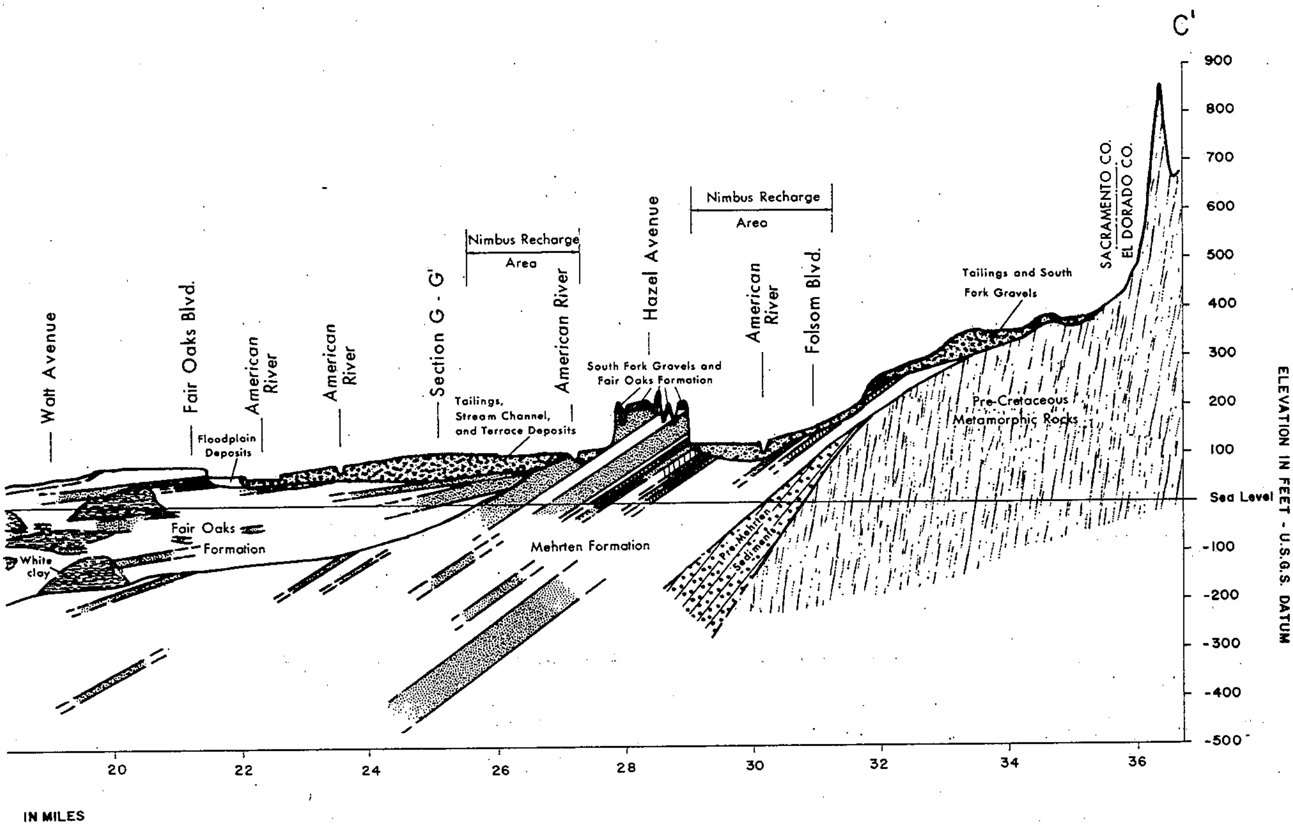
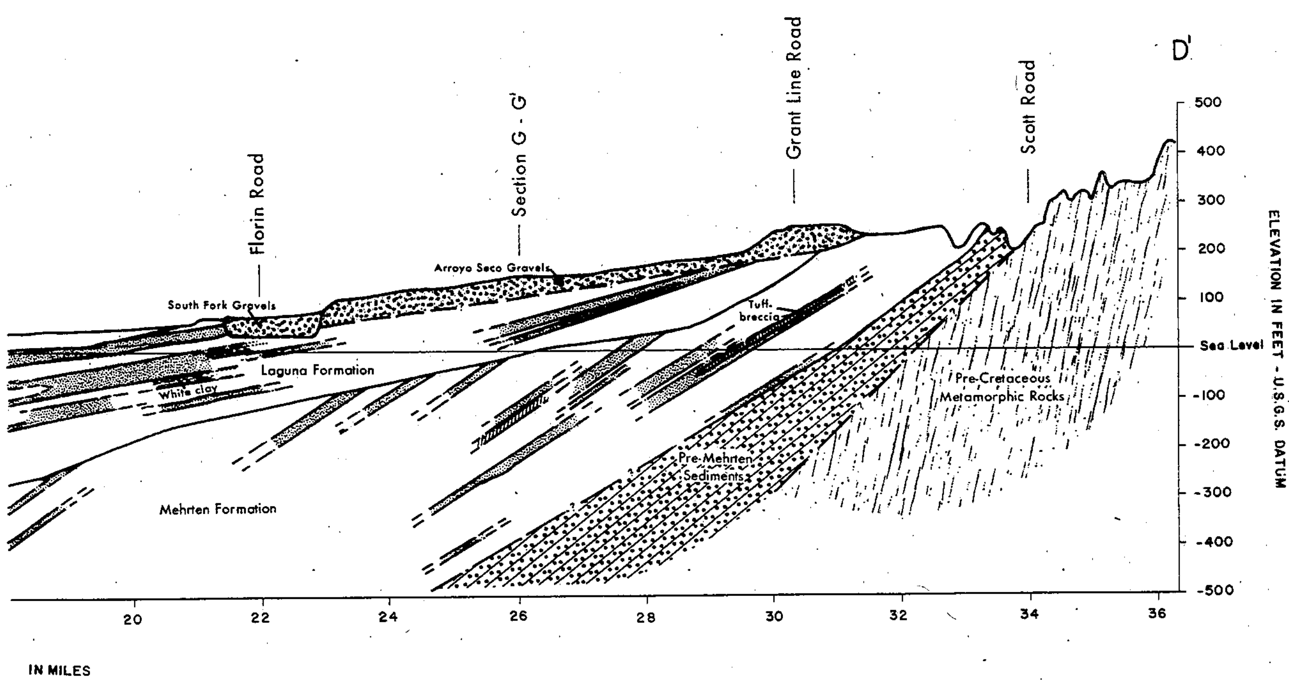




GEOLOGIC SECTIONS

See Plate I for locations of sections.





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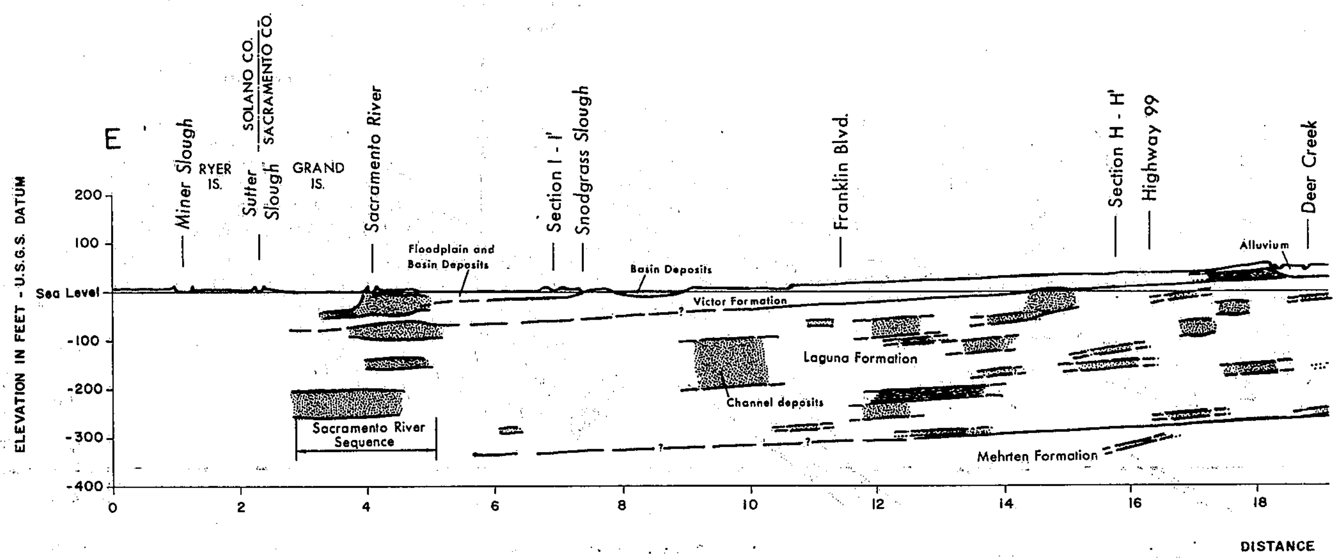
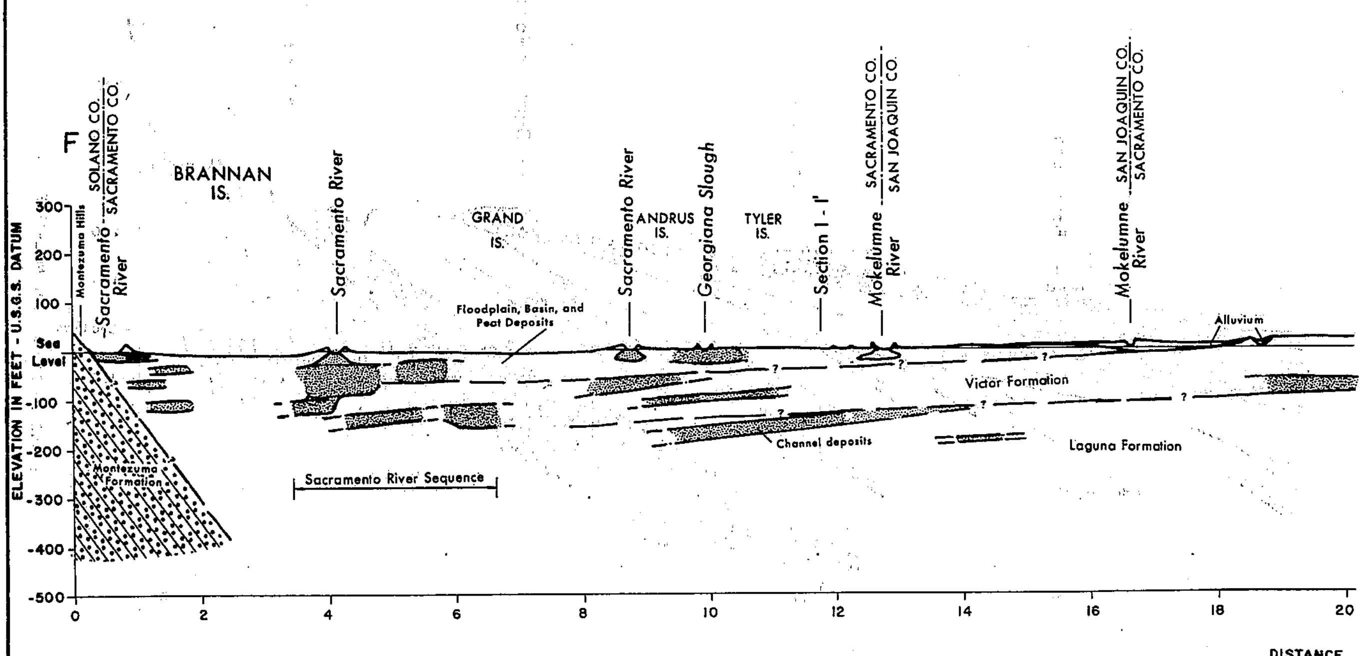
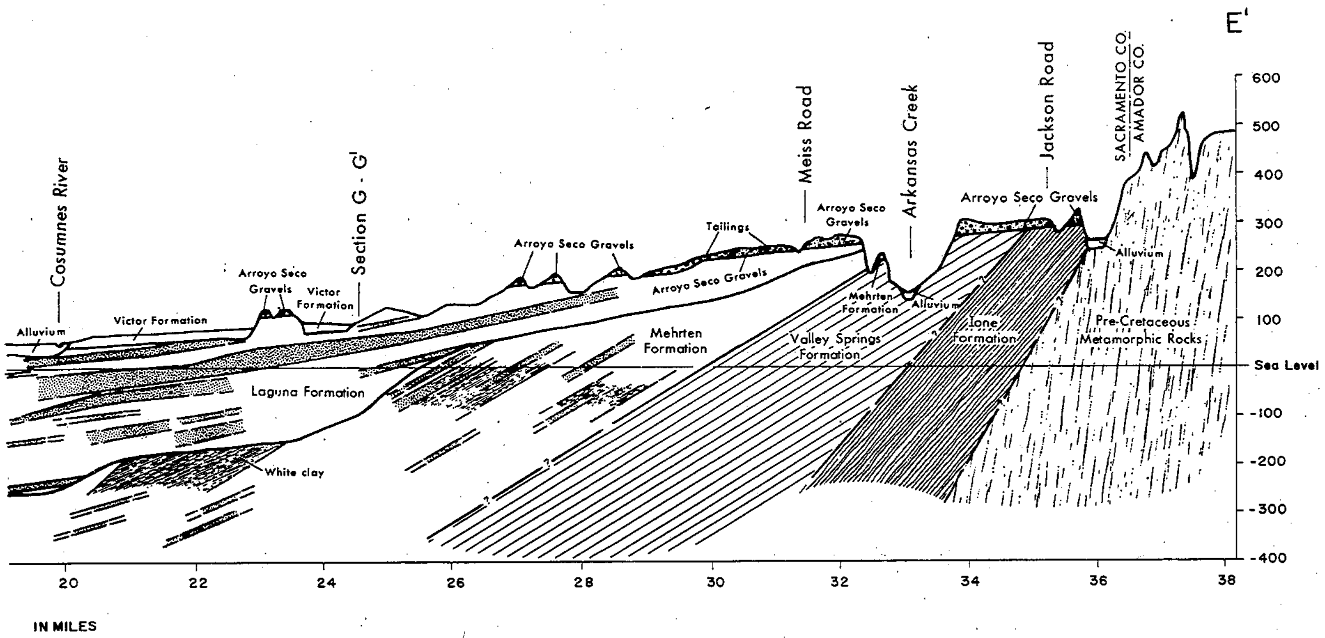
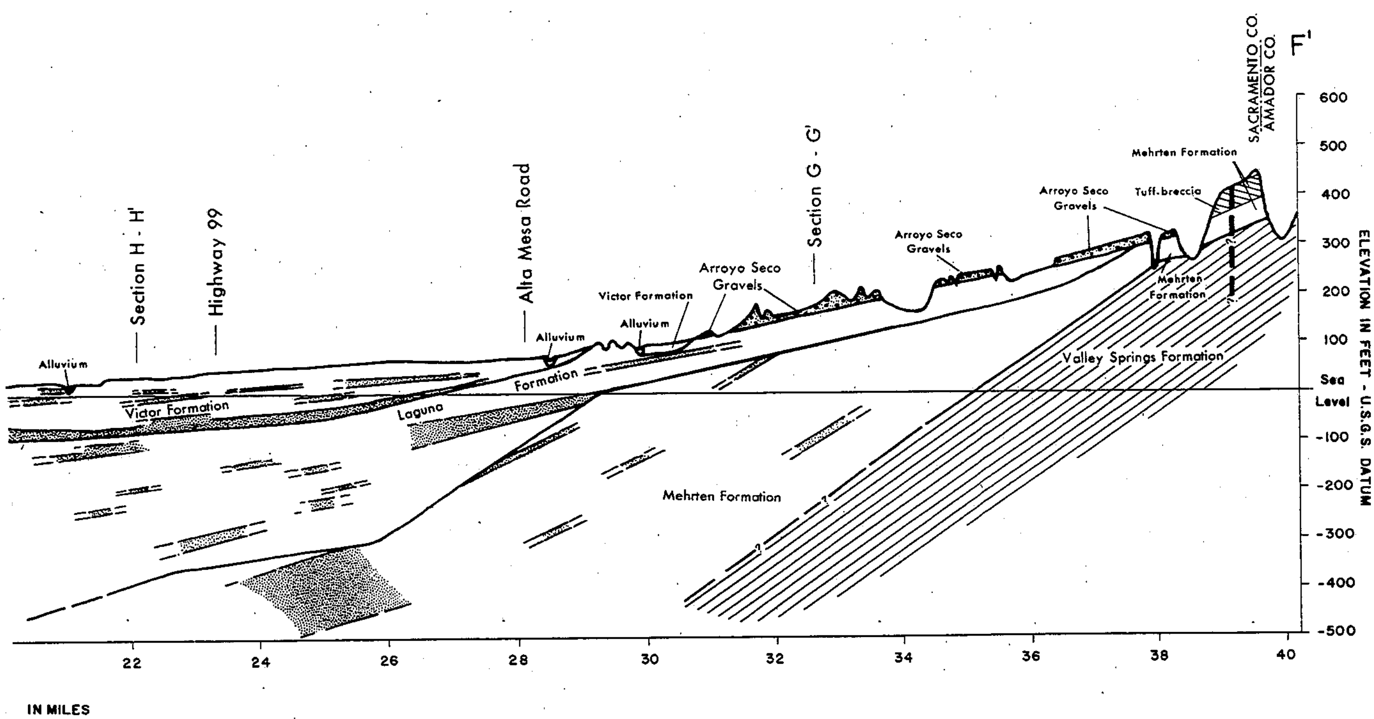




GEOLOGIC SECTIONS

See Plate I for locations of sections.





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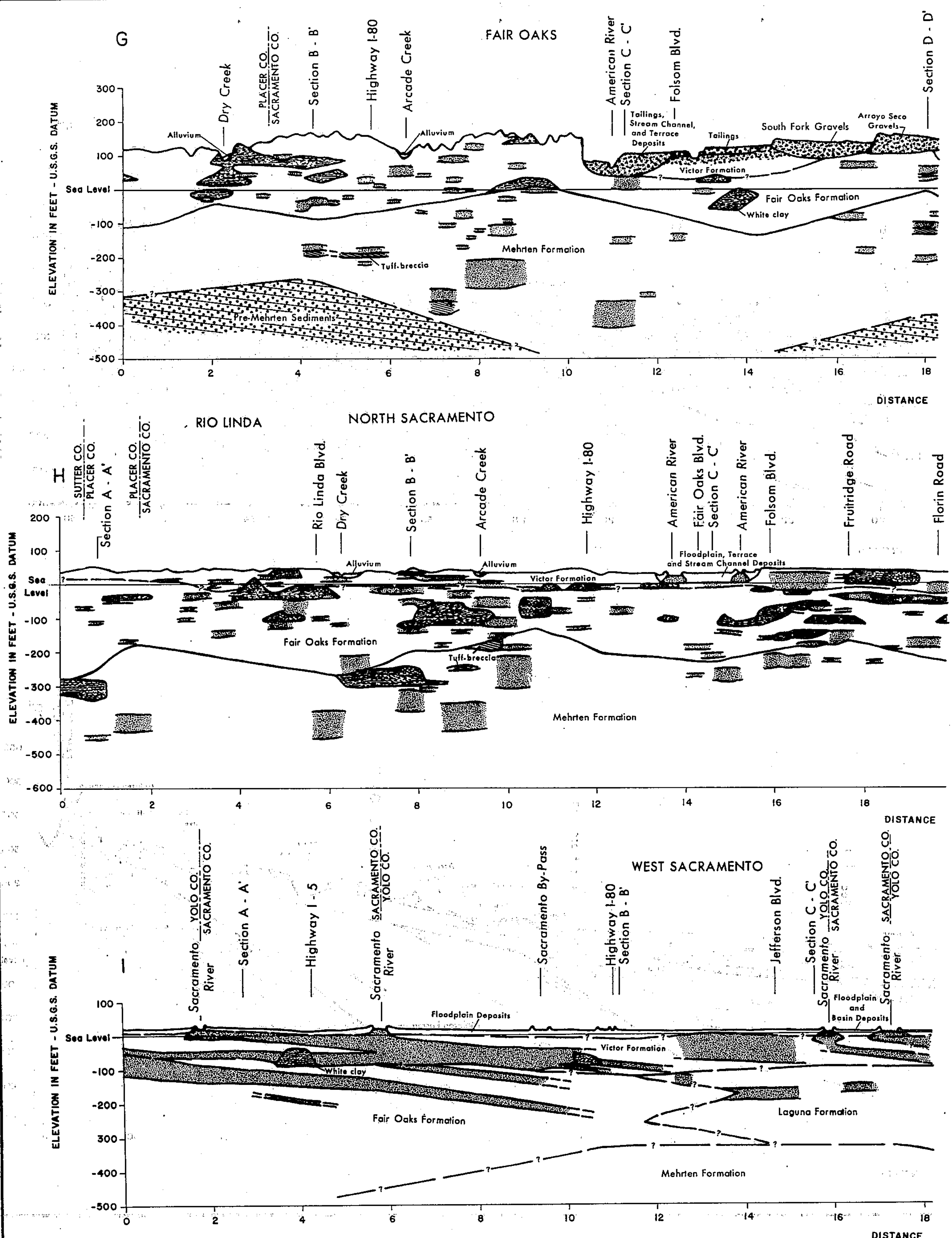
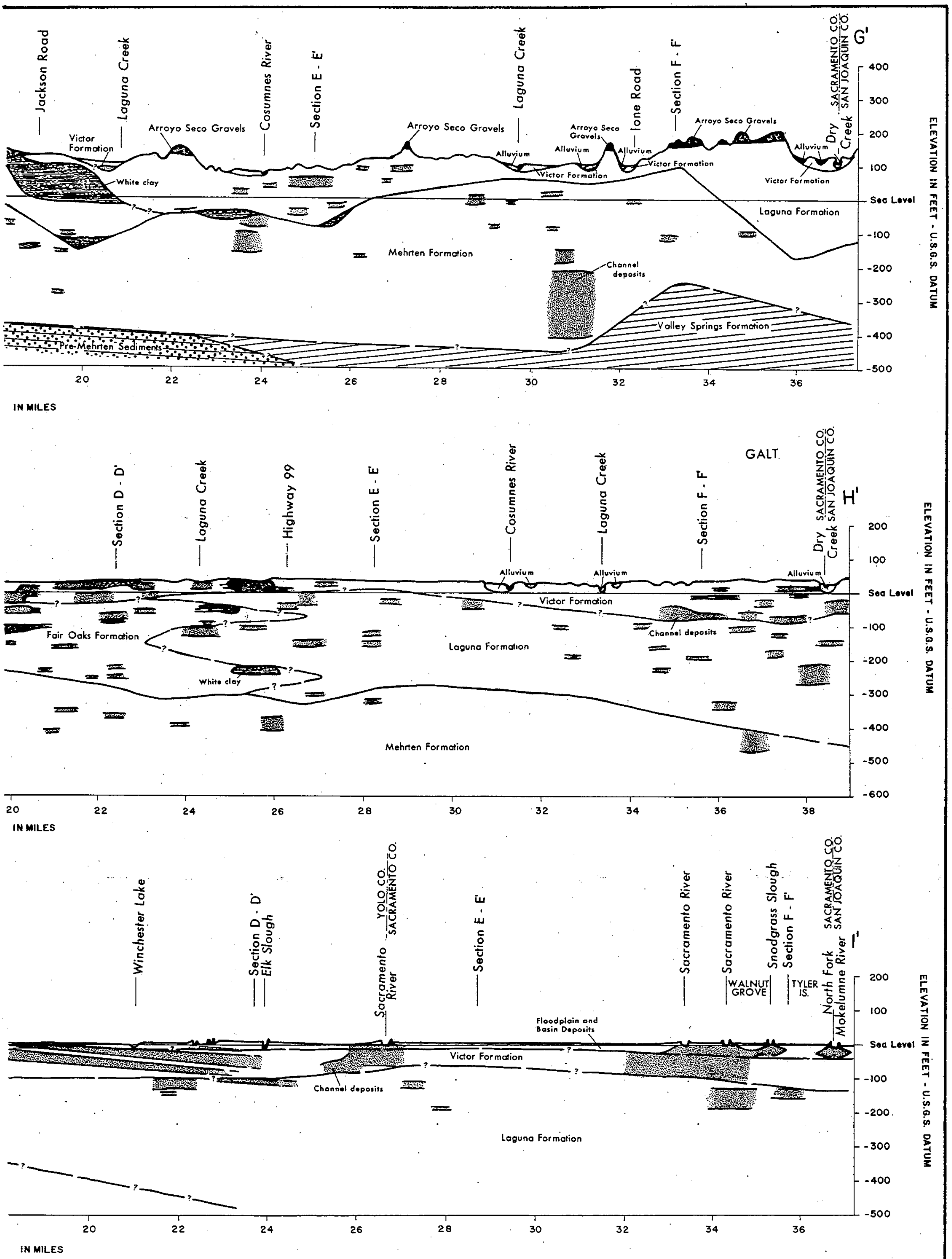


GEOLOGIC SECTIONS

See Plate I for locations of sections.



SACRAMENTO COUNTY

American River

The American River has coursed its way across what is now Sacramento County since the time of deposition of the Mehrten Formation in the Pliocene epoch. During the post-Mehrten period the river has been present most of the time as two distinct forks. One was a North Fork American River, which entered the Great Valley near what is now the intersection of Douglas Boulevard and Sierra College Boulevard. This fork then flowed southwesterly along a trio of channels and joined the Sacramento River west of the present Executive Airport.

The South Fork American River apparently was a more consequent stream than was the North Fork. The South Fork flowed south and west past the Folsom area and continued southwesterly through the area now occupied by Mather Air Force Base. The fork entered the Sacramento River in the area of Clarksburg. At a later time, probably through the medium of stream capture, the course of the North Fork was altered so that it joined the South Fork northeast of Folsom. Three distinct deposits of channel material stemming from this combined river trend southwesterly from Folsom. The oldest channel heads near Hazel Avenue at elevation +40 and meanders southwest to enter the Sacramento River near Clarksburg at elevation -100. A younger channel also heads near Hazel Avenue and flowed southwest toward Hood, where it entered the Sacramento River at elevation -50. Both of these channel deposits are about 2,000 feet wide and represent a river of about the same size as the present American River. The youngest American River deposit, which has been described by Schlemon [1967b] as being late Pleistocene in age, also begins near Hazel Avenue, at an elevation of +100 feet. These deposits then widen and meander southwesterly to the vicinity of Land Park, where the river joined the Sacramento River. At this point American River deposits are from 8,000 to 10,000 feet wide, indicating a river of great competancy. With all probability the American was the greater of the two rivers, as the Sacramento River deposits appear to be only about 6,000 feet wide.

Cosumnes River

Two channels of the Cosumnes River have been identified. The earliest, a Laguna-age channel, flows roughly from the vicinity of Dillard and Alta Mesa Roads at an elevation of +30 feet, southwest toward the confluence of the present-day river with the Mokelumne River, where the Laguna-age channel has an elevation of about -100 feet. A second, younger channel exists between the present-day channel and Twin Cities Road, where it is present at elevation 0, and the Walnut Grove area, where it is present below elevation -20. This channel apparently was formed by a Holocene channel of the Cosumnes River prior to its capture by the Mokelumne River.

Feather River

A major, braided channel of the Feather River trends southerly from north of Sacramento County south to West Sacramento. In the past the Feather River has flowed into the Sacramento River at numerous locations, from the vicinity of Bryte Bend south as far as Broderick. Elevations of the channel deposits at the various confluences range from elevation -30 to -50 feet. Throughout much of its course, the Feather River appears to have been a stream of major consequence. Its channel deposits range in width from 2,000 feet to as much as 6,000 feet.

Sacramento River

The course of the Sacramento River appears to have been essentially in the same location throughout much of the time from the late Pliocene to the present. Entering the Sacramento County area, the river flowed southeasterly toward a confluence with the Feather River near Bryte Bend. The course of the river then turned southerly, and it picked up the various channels of the American River from there to Walnut Grove. In this interval meandering channels of low gradient were the rule, with channels being on the order of 2,000 feet across. South of Walnut Grove the river made a swing to the west. In this latter area the channel deposits are about 1,500 to 2,500 feet across and range in depth up to 200 feet.

Subjacent Series

The subjacent series includes the Mehrten Formation and a portion of the underlying Valley Springs and Ione Formations. This series is the principal water producer to deep wells in the North Area, as well as along the eastern portion of the County. The series is composed of numerous channels of sands and gravels derived from the erosion of volcanic material. The channels located during the study are shown on Figure 5. Overlying some of the channel deposits, or occurring separately within the series, are sinuous beds of tuff-breccia which flowed down preexisting watercourses during periods of volcanic eruption to the east.

During Mehrten time, major river systems entered the Great Valley at different locations than at present as shown on Figure 5. Three separate forks of the American River have been identified by Lindgren [1911] and others working in this part of California. The northernmost of these is the North Fork American River which is identifiable on the surface, due to topographic inversion, as a sinuous ridge capped by tuff-breccia that begins near Newcastle, where it has a base elevation of about 800 feet. From this point the channel trends southwesterly to just north of Roseville where it passes beneath the ground surface. The channel apparently continues in a southwesterly direction across the southwestern portion of Placer County. All identifiable components of this channel are to the north of the area covered by Figure 5.

The trace of the Mehrten Middle Fork American River enters the Great Valley east of Roseville. Forming the full extent of Rocky Ridge, the channel plunges beneath the ground surface at Douglas Boulevard, where its upper surface has an elevation of 175 feet. During Mehrten time this river flowed in a 3,000-foot-wide meandering course across a terrain composed of low granitic hills. Channel deposits formed by this river consist of cobbles and boulders of volcanics and granitics all encased in a matrix of partly cemented sand. Near Douglas Boulevard a layer of tuff-breccia occurs within the gravels, indicating a brief episode of volcanism when fluid agglomerate flowed down the river channel only to become buried by younger stream gravels. Capping the channel deposits is a bed of highly resistant tuff-breccia that is about 20 feet thick. Apparently when this flow moved down the riverbed it displaced the stream, as no overlying gravels have been noted.

Southwest of Douglas Boulevard, the channel deposits of the Middle Fork American River continue for several miles. Gravel deposits directly related to this channel are present in the subsurface as far as North Highlands, where they are present at elevation -430 feet. The tuff-breccia forming the upper surface of Rocky Ridge appears also to plunge southwestward and spread out so that it forms a broad apron in the subsurface, southwest of Douglas Boulevard.

A sinuous ridge of tuff-breccia marks a large portion of the channel of the Mehrten South Fork American River. This feature can be traced from Mooney Ridge near Folsom Lake, at elevation 550 feet, southwest to near Sailor Bar. At Mooney Ridge the channel apparently was about 1,000 feet wide; here, gravels are about 50 feet deep. At Sailor Bar the channel deposits plunge beneath the ground surface. At this locality the elevation of the upper surface is 125 feet.

In the subsurface a number of channels of the South Fork American River are identifiable. One such channel apparently trends southwestward from the vicinity of Greenback and Hazel Avenues, where it is present at elevation 80 feet. Southwest of this location the channel apparently divides into a number of distributaries. One passes beneath Manzanita Avenue north of Fair Oaks Boulevard at elevation -290 feet, another passes beneath Watt Avenue north of Arden Way at elevation -210 feet, while a third passes beneath Arden Way and Interstate 80 also at elevation -210 feet.

Well log data indicate that in addition to the above described river channels, many other channels of the American River existed during Mehrten time. These other channels occur either stacked above or below those described above or occur as separate meanders at one side or the other and at somewhat differing elevations than those previously described.

In addition to all of the above described American River channels, many channels of other streams and rivers occur throughout the Mehrten Formation. Many of these are of major importance, being up to 50 feet thick, but because they cannot be traced over any great distance, they cannot be accurately defined nor identified. In addition, because deposition of the Mehrten Formation occurred over a long period of time, many episodes of erosion and deposition took place. This produced a thick sequence of strata separated by many local disconformities and unconformities. Easily erodable sediments, coupled with meandering stream channels, created many instances where previously deposited channel materials were cut out. Also, periods of high runoff caused massive flooding of the aggrading alluvial fans and caused many previously established river channels to be abandoned and new channels to be formed. Hence, it is seldom possible to trace a particular channel any great distance.

Two thick sand deposits occur within the Mehrten Formation in the southern part of the County: one northwest of Clay; the other east of Galt, south of the area shown on Figure 5. These sand deposits range from 250 to 300 feet in thickness and consist of black volcanic sand. The one near Clay occurs between elevations

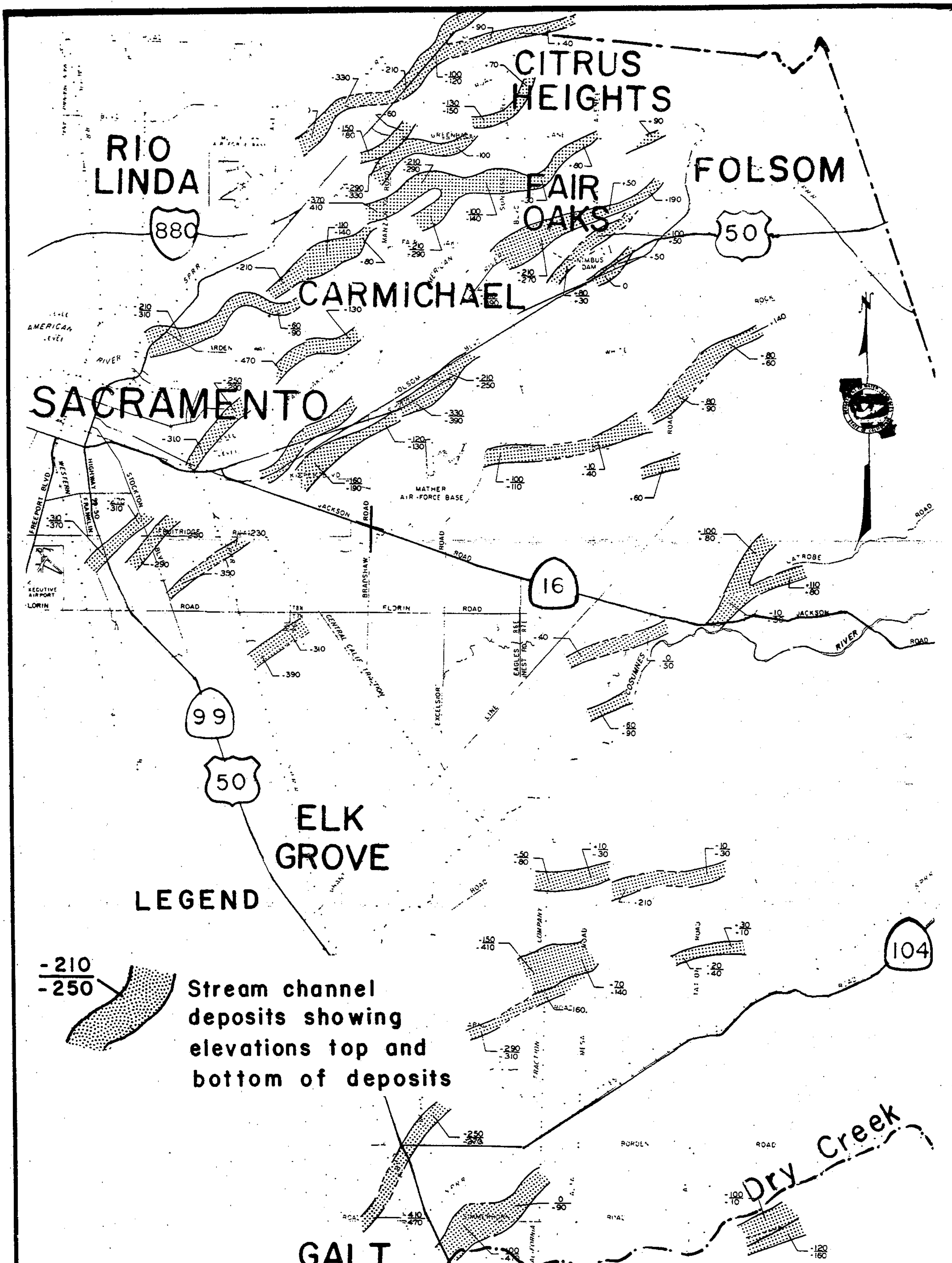


Figure 5, SUBJACENT STREAM CHANNEL DEPOSITS

-150 to -410 feet; the Galt sand occurs between elevations 0 to -330 feet. Origin of the sand deposits is not definitely known. However, deposits of this nature could have been formed under beach or strand conditions when the Miocene sea occupied the region to the west.

Influence of West Side Streams

During the time of deposition of the subjacent and superjacent series, the Sacramento River apparently was to the west of the present course. Streams flowed in a generally southwesterly direction across a plain of aggradation, and all flow direction in the area of Sacramento County was in a direction toward the Sacramento River, that is, to the southwest. Streams draining the ancestral Coast Ranges, which at that time probably existed merely as a group of low hills, entered the Sacramento River far to the west.

During post-Mehrten time, as the Coast Ranges increased in height, streams draining them increased in competancy. This caused the Sacramento River to migrate eastward so that today its course is parallel to and somewhat east of its original position. During this period the Cache Creek and Putah Creek drainages were established. These two streams debouched onto the plain at about the same location as they do today. An ancestral channel of Cache Creek has been identified as entering the Sacramento River near Bryte Bend at elevation -160 feet (see Figure 3, Sheet 1). A second probable channel of Cache Creek enters the Sacramento River at elevation -10 feet southeast of West Sacramento. Data are lacking to identify the ancestral channels of Putah Creek. However, a southeast trending channel that may be associated with Putah Creek enters the Sacramento River channel at elevation -10 feet near Courtland (see Figure 3, Sheet 2).

Because of the general southwesterly direction of flow of the ancestral streams in the Sacramento County area, it is doubtful if any westside stream systems had any effect on deposition in the Sacramento County area.

Discontinuous Confining Beds: The White Clay

The northern half of Sacramento County is underlain by a series of discontinuous confining beds identified by well drillers as "white clay, dun clay, or white ash". These clay-like materials occur in individual flat-lying beds which range in thickness from a few feet to 30 to 50 feet. In aggregate thickness the beds range up to 200 feet. The white clay beds are relatively dense and act as confining beds to ground water occurring below in permeable sands and gravels. They also inhibit any downward percolation of water available for recharge.

There is much speculation as to the composition and origin of the white clays. Some of the white clay beds occur below zones of tuff-breccia and black sands, placing them positively within the Mehrten Formation. These Mehrten white clay beds have dips of from one to two feet per mile, similar to those of other Mehrten beds. Origin of the Mehrten white clay is probably volcanic, being either primary, that is deposited as the result of ash falls during Mehrten time, or secondary, being an erosion product of then-soft Valley Springs tuffaceous material. In the eastern part of Sacramento County, at Rancho

Murietta, deposits of light-colored tuff interbedded with hard gray Mehrten sands were observed. The tuff appeared to have been deposited in a subaqueous environment. It was located about 30 feet stratigraphically above Valley Springs material.

Beds of white clay also occur in the superjacent series. These have a nearly uniform valleyward dip of 5 to 50 feet per mile, typical of beds of the Fair Oaks, Laguna, and Victor Formations. These beds also are probably of tuffaceous

CHAPTER III. EVALUATION OF HISTORIC WATER SUPPLY AND USE

To understand how the ground water system underlying Sacramento County works, estimates of its ability to receive, transmit, and store water must be made and verified.

The ability of a ground water basin to store and transmit water is investigated by first determining transmissivity, ground water storage capacity and yield factors for the ground water system and then determining the reaction of that system to development by superimposing historic water development and use on natural hydrologic events, such as precipitation, recharge, and consumptive use.

A schematic representation of the entire hydrologic system in Sacramento County is shown in Figure 6. That portion of the hydrologic system below the land surface is considered to constitute the ground water basin.

An analysis of a ground water system is made over a historic period by taking inventory of recharge to and withdrawals from the ground water body. The result is an estimate of the change in amount of ground water in storage. The accuracy of the analysis, which is performed by a computer, can be gaged by how close the simulated response of the basin, in the form of water level fluctuations, compares with the historic record. The relationship of recharge and withdrawals to change in water levels is shown by the equation:

$$R - W = \Delta S \qquad (1)$$

where

R = recharge to the ground water body by precipitation, streamflow, artificial recharge, and delivered water;

W = withdrawals of ground water by pumpage, consumptive use, springs and flowing wells, and water from nonreversible compaction of clays; and

ΔS = reversible change of the potentiometric surface of ground water in storage.

Some of the items in the inventory can be measured directly, some are calculated indirectly, and some can be measured only for a part of the study period and are calculated for the remainder of the period.

Study Period

The major rivers in Sacramento County are controlled by man and have continuous sustained flow. Smaller streams respond to seasonal precipitation. Therefore, the amount of precipitation on the County and its adjacent region serves as an index to the water supply available to the study area. By analysis of long-term precipitation records, a relatively short, recent study period can be selected which represents the long-time average water supply. Such a period is needed for study purposes because long-term records are not available for all of the data items required to make a hydrologic inventory.

Hydrologic conditions during a study period should reasonably represent long-term conditions and include normal, wet, and dry years. The study period should be within the period of available records and should include recent years so that the effects of development on the basin can be included. The climatic and basin conditions preceding the beginning and ending year of a study period should be similar so that the amount of water in transit between the bottom of the root zone and the water table prior to each of these two years will be of about the same magnitude. Large differences in depths to water at the beginning and end of the period also should be avoided in order to reduce differences in amounts of water in transit.

The chosen study period was water years 1962 through 1968 on the basis of the criteria presented earlier. It begins and ends on a dry year, includes recent man-made works, and the study period mean corresponds closely with the long-term mean. The 1962-68 study period also is best suited to the available data. The availability of data is:

Agricultural Pumpage	1967, 1968, 1969
Municipal Pumpage	1961-1969
Detailed Land Use	1960-61, 1968-69
Water Levels	Prior to 1960 to date
Stream Diversions	Prior to 1960 to 1969

Precipitation

The Galt, Represa, and Sacramento Weather Bureau City precipitation stations shown on Figure 7 were selected to represent the rainfall situation for Sacramento County because they are strategically located so as to provide an excellent mean annual rainfall value for Sacramento County and also have long continuous records. The Sacramento Weather Bureau City records date back to 1849; Galt to 1878; and Represa to 1892.

The Sacramento station required adjustment because Weather Bureau records indicate that the Sacramento Weather Bureau City gage had been located at nine different locations since the record began. In addition, an analysis of an accumulated precipitation graph indicated that a significant change occurred in the rainfall catchment between approximately 1908 and 1935. The adjustment to the record was made by multiplying the annual precipitation by 1.32 for years 1910 through 1938 and by 1.06 for years 1939 through 1970. Since the precipitation stations at Galt, Represa, and Sacramento Weather Bureau City were selected to represent the rainfall situation for the County, the longest concurrent period was required for precipitation analyses. The period used was 1890 to 1970. As the Represa gage started at 1892, two years of record were needed to fulfill the period desired. The record was extended by using the normal ratio method with the other two gages; annual precipitations for Represa for the years 1891 and 1892 were estimated to be 21.00 inches and 29.57 inches, respectively.

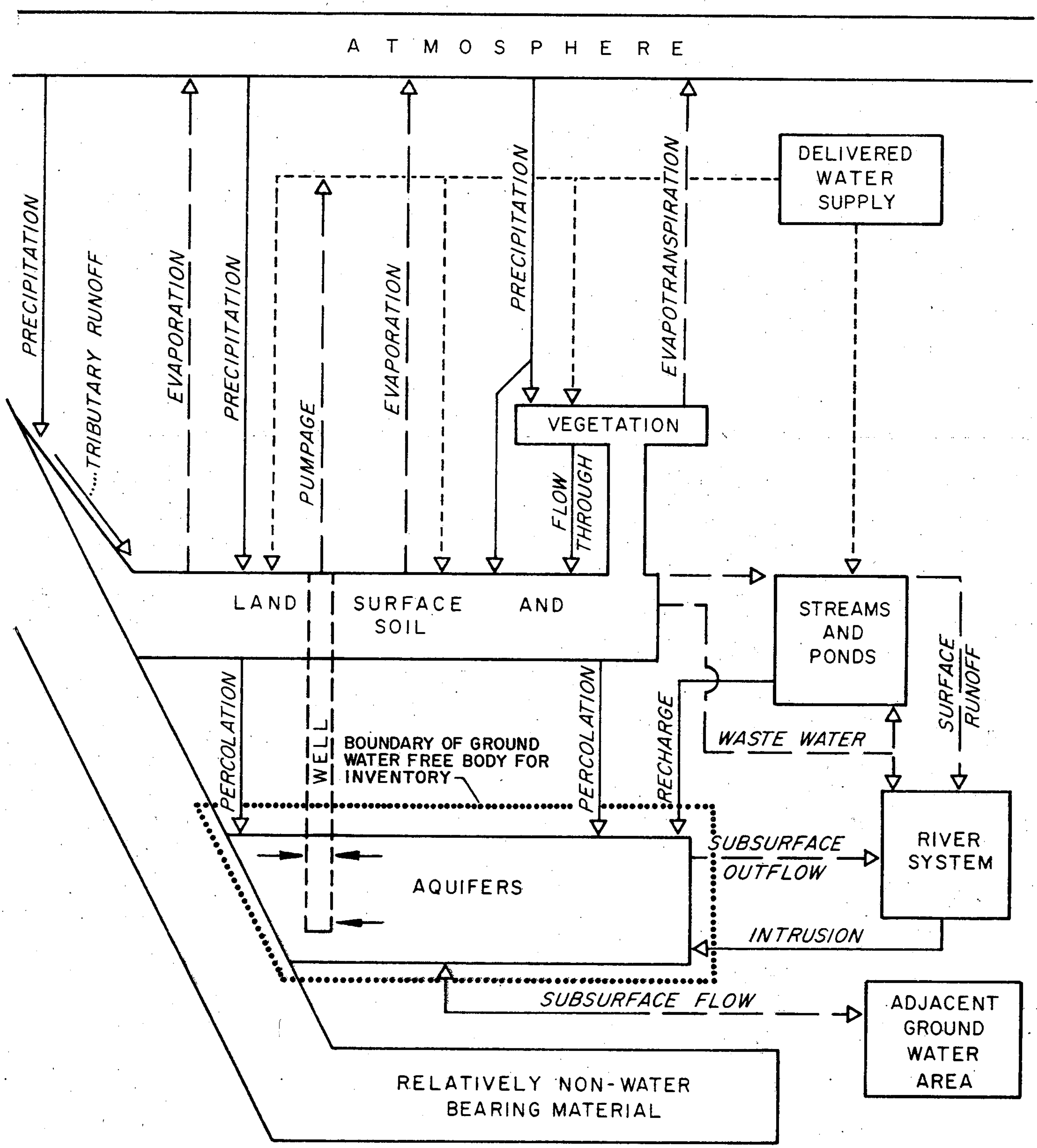
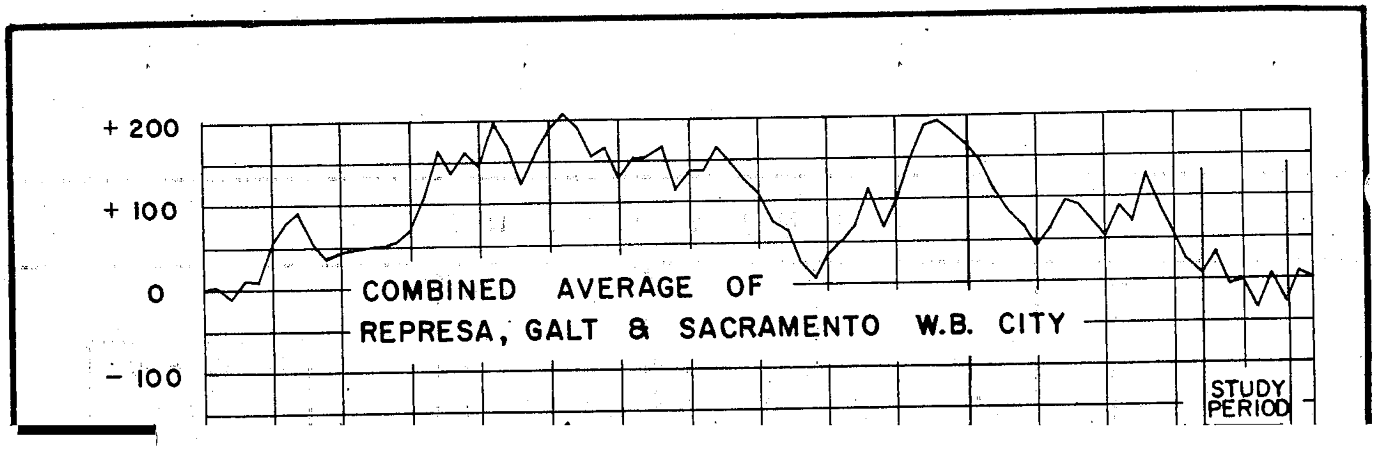


Figure 6. HYDROLOGIC SYSTEM (SCHEMATIC)



+ 200
+ 100
0
- 100
COMBINED AVERAGE OF
REPRESA, GALT & SACRAMENTO W.B. CITY
STUDY PERIOD

Figure 7 depicts the accumulated deviation from the mean graphs of precipitation at each of the Sacramento Weather Bureau City, Galt, and Represa gages, and for their combination. Each of these graphs shows three pairs of wet and dry trends, covering progressively the periods 1890-91 through 1935-36, 1936-37 through 1960-61. The period 1961-62 through 1969-70 is rather indeterminate as to whether it is a dry or wet trend of the future. The combined mean annual rainfall of the three gages for this period is 4 percent lower than for the long-term mean.

The average precipitation of combined annual precipitation for Represa, Galt, and Sacramento Weather Bureau City gages and index of wetness for this 80-year period are shown on Table 3. The 80-year long-term average precipitation is 19.91 inches with a standard deviation of 4.86 inches. During this period the maximum precipitation occurred in 1957-58, with 31.06 inches and an index of wetness of 156 percent; the minimum precipitation occurred in 1923-24, with 10.35 inches and an index of wetness of 52 percent. For the study period 1962-1968, the average precipitation is 18.48 inches and a standard deviation of 5.76 inches. Variations in average annual and monthly amounts of precipitation are shown on Figure 8.

The mean precipitation for the 26 precipitation gages active in Sacramento County during the study period (1961-62 to 1967-68) are listed in Table 4. Their locations are shown on Figure 9. For the study period, these 26 stations are considered adequate coverage for the study area. The mean precipitation for these 26 stations is 19.49 inches per year, with a standard deviation of 3.13 inches. The normal precipitation for the Sacramento Weather Bureau City station for the period 1931 through 1960 is 18.02 inches.

The prevailing track for the storms during the rainy season from December through April is from the northwesterly direction. Storms that bring rain to the area are frontal type storms -- usually a cold front colliding with a warm front. Figure 10 shows that the amount of precipitation increases generally from west to east. This can be explained by stating that because the land surface increases in elevation from west to east, an air mass passing eastward is lifted and thus becomes unstable, causing precipitation. This lifting of air masses over mountain barriers is called orographic lifting -- hence most of the rainfall in the area is termed orographic precipitation. In addition to this type of precipitation, Sacramento County also receives rainfall from thunder storms, which are convective type storms.

Variations in precipitation are important because recharge to the ground water body is mainly a function of precipitation and secondarily of rooting depth of crop, moisture retention of the soil within the rooting depth, evapotranspiration of the crop, and the relative amount of impervious cover in the area.

Streamflow

There are 47 active and inactive stream gaging stations in Sacramento County. Only two active stations, Arcade Creek near Del Paso Heights and Morrison Creek near Sacramento, measure flows originating entirely within the County. The American River is the main stream traversing from the east to the west through the north central portion of the County. Flow measurements have been available at American River at Fair Oaks since November 1904, and correlated flows since

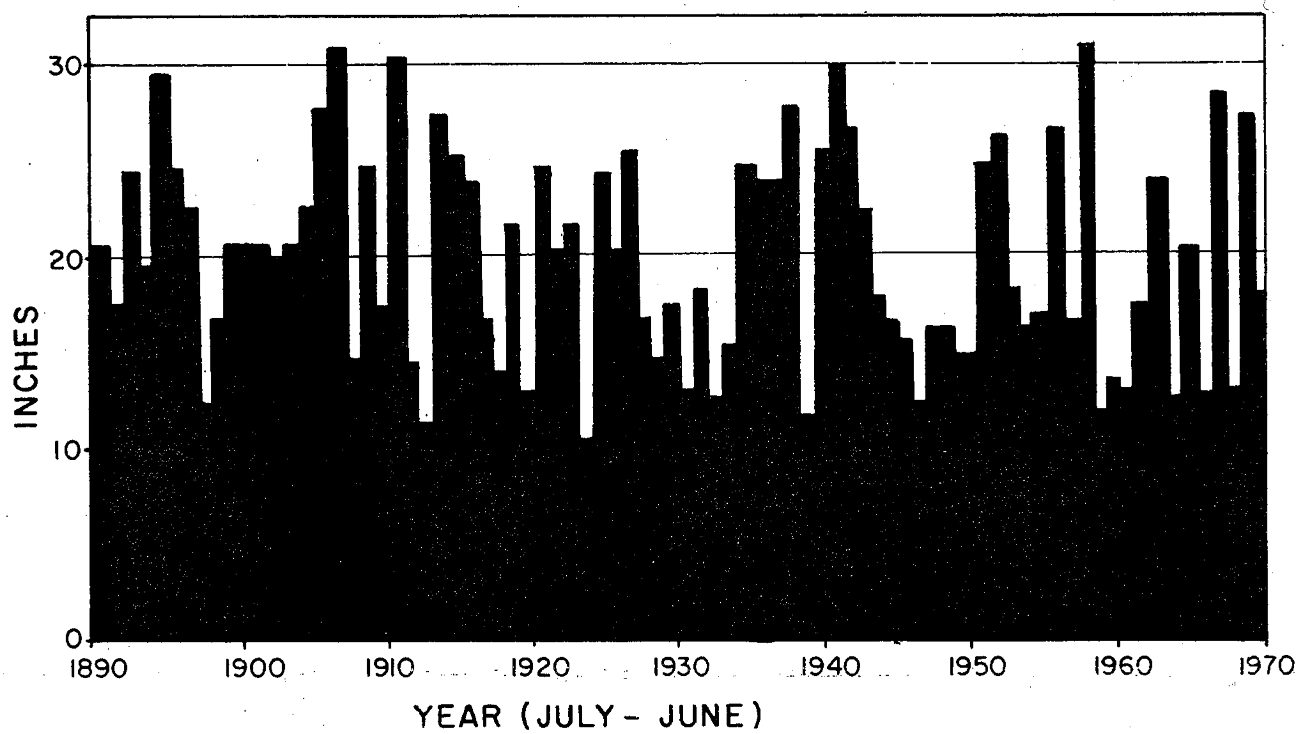
TABLE 3

Annual Precipitation[a] and
Index of Wetness
1891-1970

Fiscal Year[b]	Inches	Index of Wetness[c]	Fiscal Year	Inches	Index of Wetness	Fiscal Year	Inches	Index of Wetness
1890-91	20.51	103	1920-21	24.41	123	1945-46	15.59	78
91-92	17.04	86	21-22	20.03	101	46-47	12.07	61
92-93	24.35	122	22-23	21.90	110	47-48	16.05	81
93-94	19.31	97	23-24	10.35	52	48-49	16.05	81
94-95	29.67	149	24-25	24.01	121	49-50	14.99	75
1895-96	24.41	123	1925-26	20.17	101	1950-51	24.95	125
96-97	22.36	112	26-27	25.35	127	51-52	26.34	132
97-98	12.20	61	27-28	16.78	84	52-53	18.04	91
98-99	16.92	85	28-29	14.45	73	53-54	16.05	81
99-00	20.71	104	29-30	17.44	88	54-55	16.95	85
1900-01	20.63	104	1930-31	12.94	65	1955-56	26.74	134
01-02	20.63	104	31-32	18.12	91	56-57	16.45	83
02-03	19.91	100	32-33	12.46	63	57-58	31.06	156
03-04	20.83	105	33-34	15.39	77	58-59	11.87	60
04-05	22.76	114	34-35	24.81	125	59-60	13.74	69
1905-06	27.73	139	1935-36	23.75	119	1960-61	13.00	65
06-07	30.98	156	36-37	23.89	120	61-62	17.38	87
07-08	14.53	73	37-38	27.99	141	62-63	24.15	121
08-09	24.61	124	38-39	11.47	58	63-64	12.74	64
09-10	17.12	86	39-40	25.54	128	64-65	20.71	104
1910-11	30.26	152	1940-41	29.98	151	1965-66	12.94	65
11-12	14.20	71	41-42	26.48	133	66-67	28.47	143
12-13	11.01	55	42-43	22.16	111	67-68	13.00	65
13-14	27.28	137	43-44	17.78	89	68-69	27.54	138
14-15	25.15	126	44-45	16.84	85	69-70	18.32	92
1915-16	23.81	120						
16-17	16.45	83						
17-18	13.54	68						
18-19	21.56	108						
19-20	12.60	63						

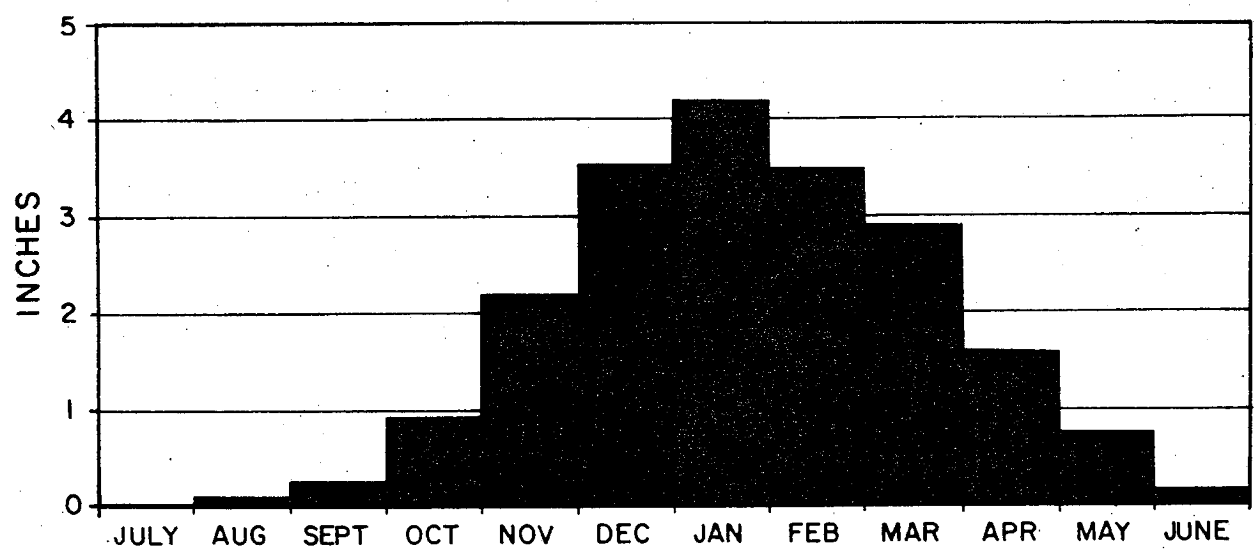
Averages			Inches	Index of Wetness
Averages	80 years,	1891-1970	19.91	100.0
	Standard deviation =		4.86	
	7 years,	1962-1968	18.48	92.8
	Standard deviation =		5.76	

a/ Average of combined annual precipitation for Represa, Galt, and Sacramento WB City gages.
b/ July thru June.
c/ Index of wetness is the percent of 80-year average.



AVERAGE ANNUAL PRECIPITATION
1890-91 to 1969-70

(Average of combined annual precipitation for Repressa, Galt, and Sacramento WB City gages.)



AVERAGE MONTHLY PRECIPITATION

Figure 8. AVERAGE ANNUAL AND MONTHLY PRECIPITATION

TABLE 4

PRECIPITATION STATIONS IN SACRAMENTO COUNTY
MEAN PRECIPITATION DURING STUDY PERIOD 1962-68
IN INCHES

	Station Name	Station Number	Mean Precipitation During Base Period 1962-1968 in Inches
1.	Aerojet F.S.	A0-0039-34	24.04
2.	Arden & Mission	A0-0255	17.95
3.	Arden Park Bailey	A0-0256	21.73
4.	Brannan Island State Park	B9-1043	15.17
5.	Central Valley Hatchery	B0-1635-01	19.04
6.	Citrus Heights	A0-1773	23.53
7.	Clay 1 N.W.	B0-1785	17.05
8.	Country Club Center	A0-2073-34	19.39
9.	Del Paso Park	A0-2367	19.35
10.	Dewey & Winding	A0-2414	23.20
11.	Elkhorn Ferry	A0-2744	18.06
12.	Folsom Dam	A7-3113	25.77
13.	Fruitridge & Hedge	A0-3266-11	17.43
14.	Galt	B0-3301	18.11
15.	Grand Island RD3	B9-3541	18.30
16.	Herald F.S.	B0-3919	15.20
17.	Mather AFB	A0-5403	20.84
18.	McClellan	A0-5447	18.75
19.	North Sacramento	A0-6271	18.02
20.	Orangevale Beach	A0-6481	23.21
21.	Rancho Cordova F.S.	A0-7247-01	18.19
22.	Represa	A7-7370	22.14
23.	Sacramento WB AP	A0-7630	18.36
24.	Sacramento City W.B.	A0-7633	18.96
25.	Town & Country, Mitchell	A0-8984-34	20.54
26.	Walnut Grove	B9-9428	14.50
		Mean	= 19.49
		Standard Deviation	= 3.13

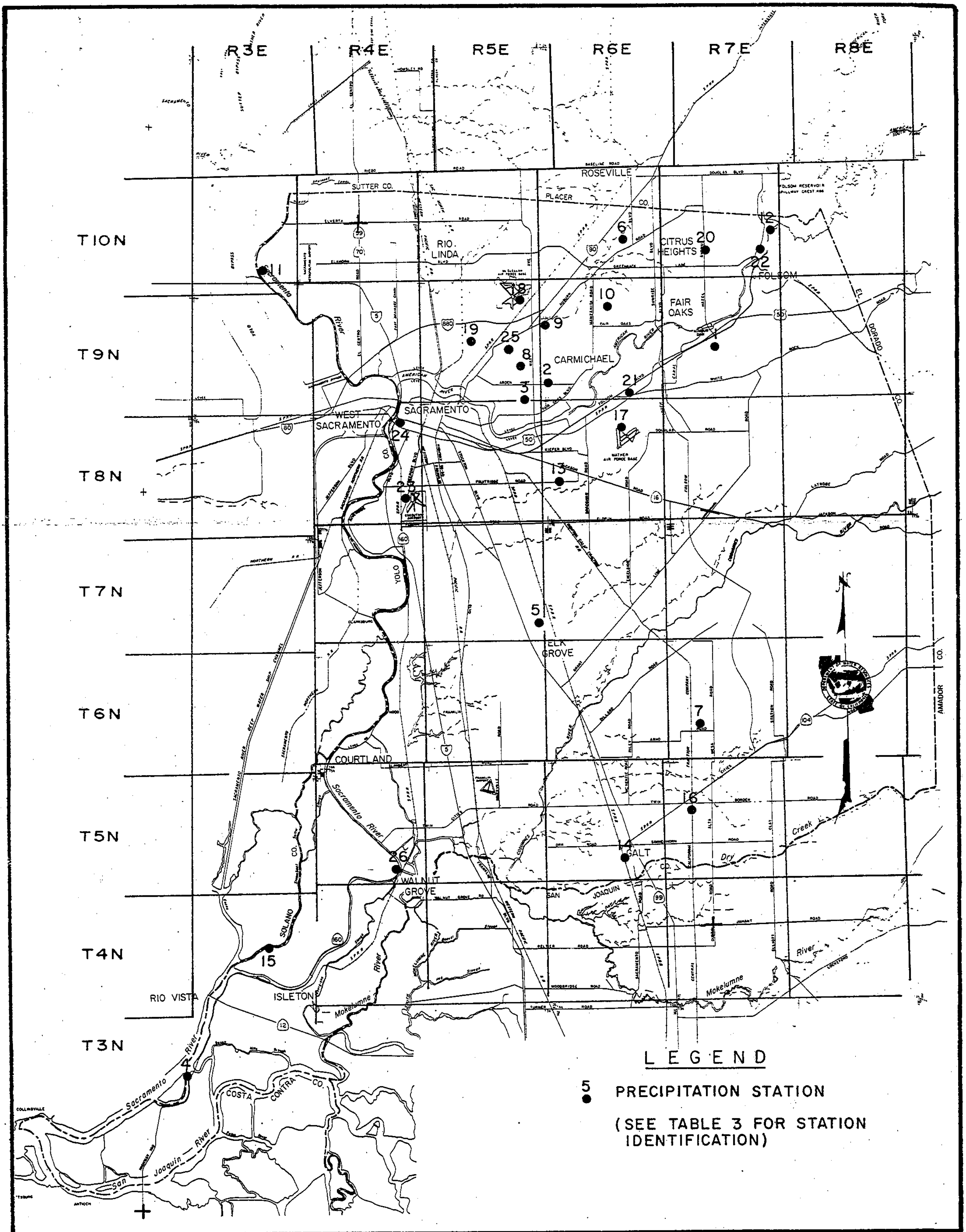


Figure 9. LOCATION OF PRECIPITATION STATIONS

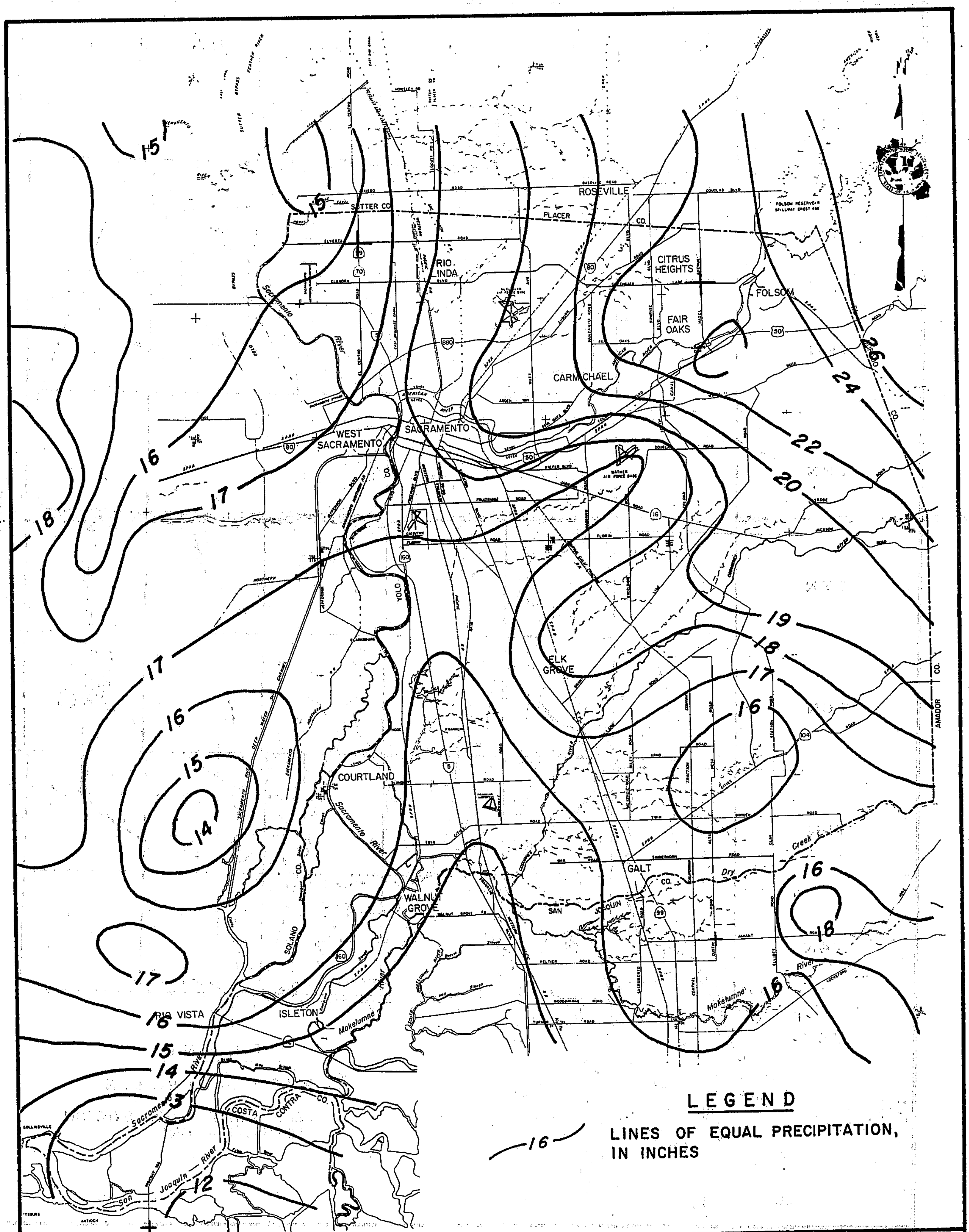


Figure 10. 50 YEAR AVERAGE ISOHYETAL MAP
1910-11 TO 1959-60

October 1900. The drainage area at this site tributary to the American River is 1,889 square miles. The mean annual unimpaired flow for this station is 2,782,800 acre-feet for the period 1900-01 through 1969-70. Cosumnes River flows through the southeastern corner of the County and has been gaged at Michigan Bar since October 1907. The drainage area at this site is 537 square miles. The average unimparied flow from the Cosumnes River at Michigan Bar from 1907-08 through 1969-70 is 347,380 acre-feet. The Sacramento River, which forms the western county boundary, has been gaged at the Sacramento "I" Street Bridge on an intermittent basis since May 1924, and on a continuous basis since January 1939. The drainage area above this gage is 23,508 square miles. The average annual gaged water year flow for the period 1940 through 1970 is 17,059,000 acre-feet. Based on the above information, the average runoff from the American River, Cosumnes River, and Sacramento River watersheds was 1,473, 726, and 647 acre-feet per square mile, respectively. These figures show that the American River drainage basin is twice as productive in runoff as are the drainage basins of the Sacramento River or the Cosumnes River.

The effect of construction of Folsom Dam on the monthly flows of the American River is depicted on Figure 11 by two graphs. The upper chart shows the unregulated gaging station at Fair Oaks (prior to Folsom Dam) and the lower chart shows the regulated American River at Fair Oaks (after Folsom Dam). Unregulated flows varied from 0.6 percent in September to a maximum of 19.7 percent in May. Regulated minimum flows still occur in September, but have increased threefold to 1.9 percent of the annual flow. The regulated maximum flow occurs in May, and is 14.8 percent. The decrease in the maximum percentage month of some 5 percentage points, or about 25 percent, provides flood protection. Increased flows during low-flow months provide enhancement of fisheries and recreation. The October flow was increased about fivefold (from 1.1 percent to 6.0 percent) to enhance salmon spawning downstream from Folsom Dam and mitigate the lack of spawning upstream of the dam. Due to regulation there now are two peak flows in the river: one in January due to releases from the reservoir to gain more flood reservation to control the peak snowmelt runoff, and one in the peak snowmelt runoff month, which occurs in May.

Figure 12 depicts monthly flows as percent of average annual flows for the Sacramento River at Sacramento and the Cosumnes River at Michigan Bar. The bar chart for the Sacramento River is more typical of a predominantly rainfall watershed than a snowpack watershed. Although perennial snowpacks do occur around Mount Shasta and Mount Lassen, many unregulated streams contribute to the Sacramento River downstream from Battle Creek (the main tributary originating from Mount Lassen), and the unregulated stream runoff due to rainfall overshadows the snowmelt runoff. Because of the large watershed, the percent flow dropoff from February to May is gradual rather than steep.

The monthly variation of the Cosumnes River indicates a combination of a rainfall and a snowmelt watershed. The sharp increase and decline of the flows indicate a small watershed and small baseflow.

Monthly streamflow data are contained in Supporting Data Reports on file in the offices of the County and the Department.

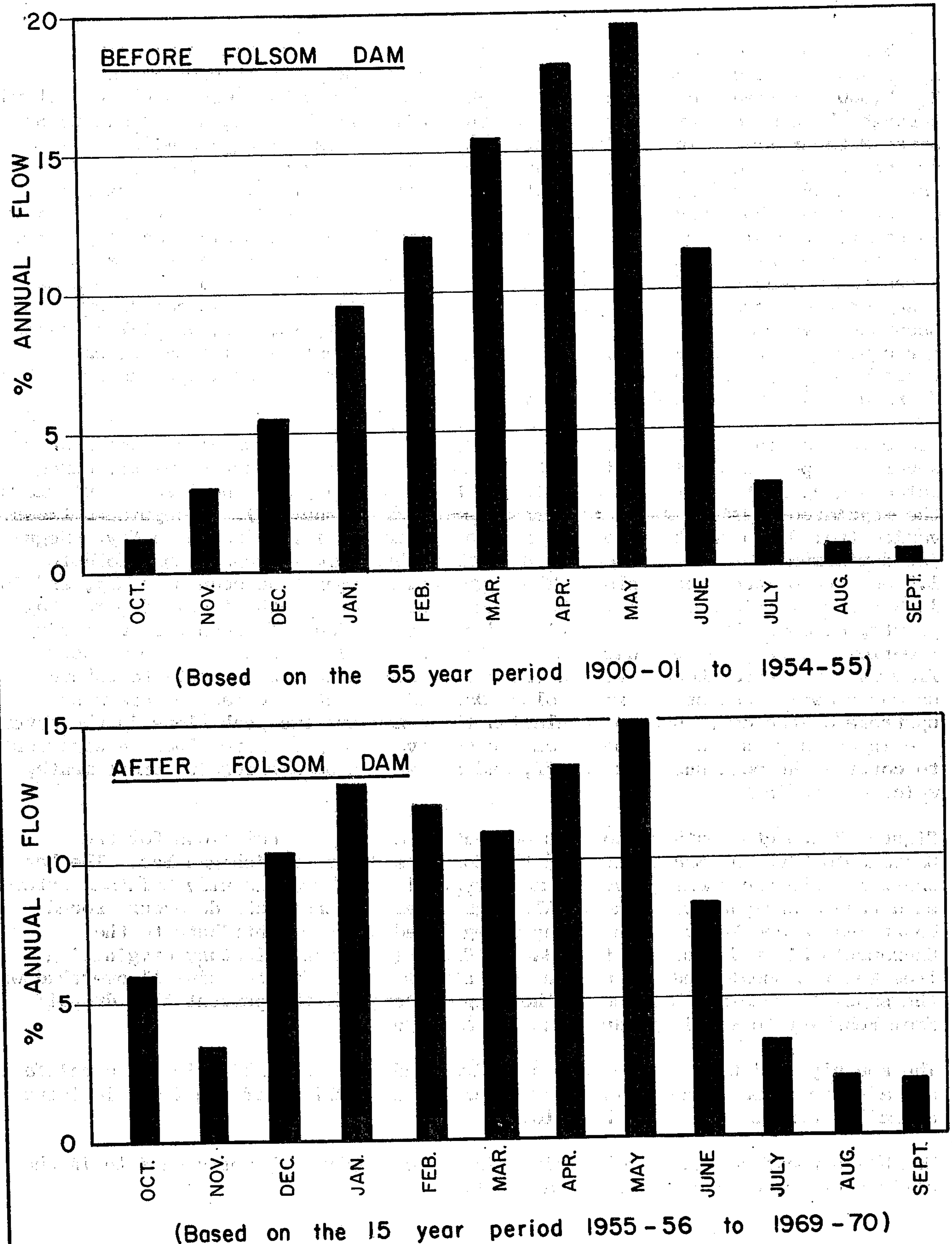


Figure 11. PERCENT AVERAGE ANNUAL FLOW AMERICAN RIVER AT FAIR OAKS

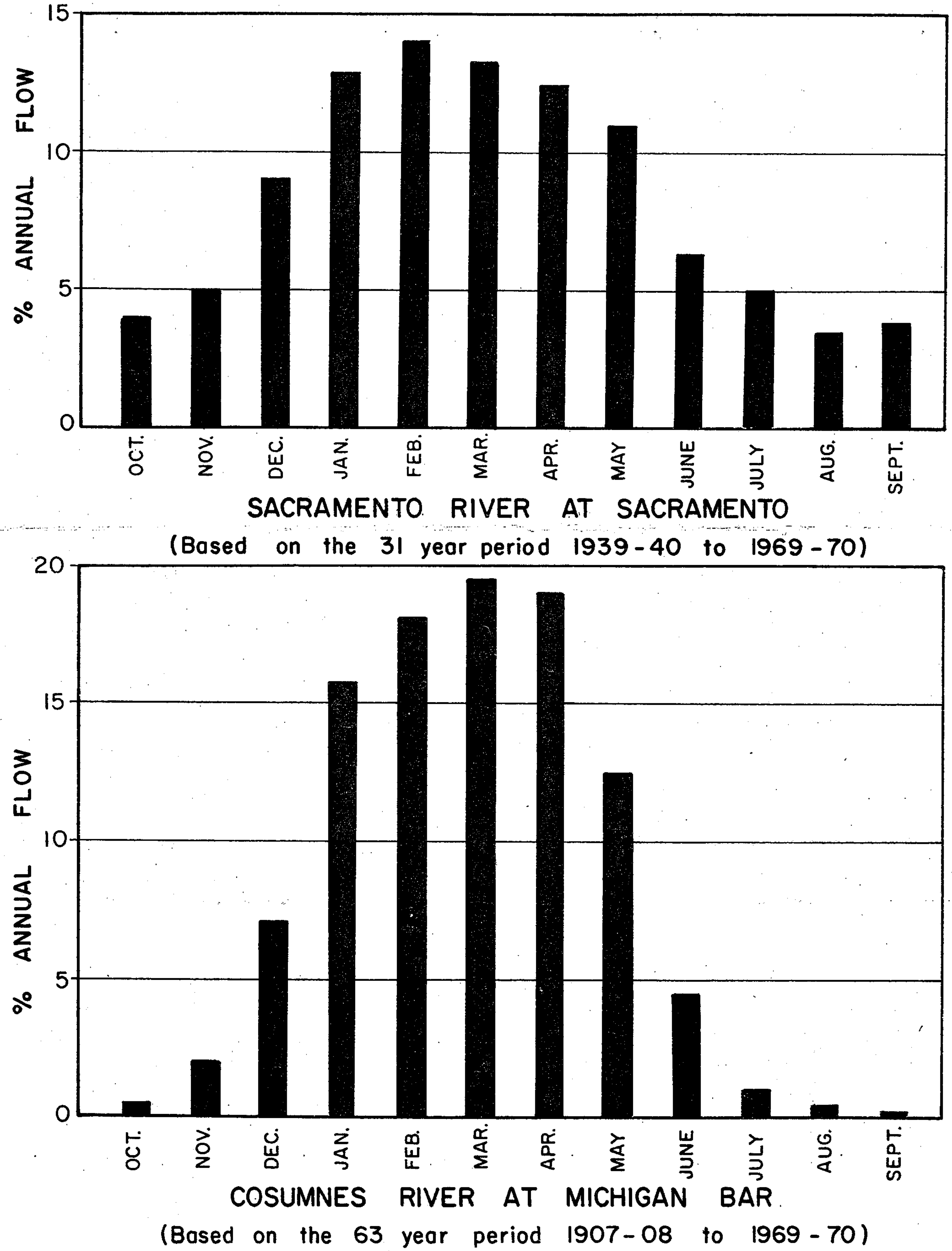


Figure 12. PERCENT AVERAGE ANNUAL FLOW
SACRAMENTO AND COSUMNES RIVERS

Surface Water Quality

Analyses of surface water of the American River, Cosumnes River, and Sacramento River indicate that they are of a bicarbonate type of excellent mineral quality with either calcium or magnesium as the predominant major cation. Representative analyses are shown in Table 5. The total hardness varies from soft (16 mg/l) to moderately hard (72 mg/l). For irrigation use, the water is classified as Class 1. For municipal and industrial uses, the water meets all drinking water requirements for mineral content and is suitable for all but the most exacting industrial uses.

Water quality at Nimbus Dam station of the American River is very similar to the quality at those stations located upstream on the Middle Fork and South Fork. On the Cosumnes River, only very minor increases in conductivity were noted between Michigan Bar and McConnell station, indicating no significant sources of degradation. On the Sacramento River, the mineral concentration at Sacramento is lower than at Knights Landing due to the influence of inflow from the American and Feather Rivers.

Ground Water

Ground water is defined as subsurface water occurring in the zone of saturation (below the water table) and moving under control of the water table slope or gradient. Below the ground surface there are two zones: an unsaturated zone and a saturated zone. The unsaturated zone is that zone between the land surface and the water table and includes the capillary fringe. Perched water bodies may exist within the unsaturated zone. The saturated zone is that part of the water-bearing material in which all voids, large and small, are filled with water.

Precipitation, applied water, and streamflow enter the unsaturated zone from the surface and flow by gravity toward the saturated zone. The rate at which this water reaches the saturated zone depends on factors which include: the amount of precipitation or applied water available; the type of soil (sandy or hardpan) and moisture content of the soil belt; and vertical permeability of the unsaturated zone. If only a small amount of water is applied or is available through precipitation, it may be consumed by evapotranspiration of the vegetative growth in the soil zone. Water that passes through the soil zone moves downward through the unsaturated zone. Water that reaches the saturated zone is considered as deep percolation and is treated as an increment to the ground water supply.

The time of travel through the unsaturated zone is unknown due to the variation of soil type and varying distance to the water table. Actual field measurements have been made at several localities in the San Joaquin Valley. In the Mendota area, Poland [1958] found that water traveled 128 feet in 6 months and 150 feet in 15 months, through a deep and dry unsaturated zone. Near Woodville, Tulare County, the U. S. Department of Agriculture found that ground water could be sensed at 35 feet below ground surface 5 days after application began.

In the Natomas area the response of the water table to precipitation or irrigation should be several days. However, in the southern part of the County it would be considerably longer. For this study it is assumed that recharge water takes less than a year to travel to the water table.

Pumpage

Ground water pumpage consists of agricultural, municipal, and industrial pumpage. Only a few individual ground water users keep records on their pumpage. Agricultural pumpage was estimated for the Department by the USGS in a cooperative study for the years 1967, 1968, and 1969, from electric power consumption records obtained from Sacramento Municipal Utility District (SMUD) for the Sacramento County area and Pacific Gas and Electric Company (PG&E) for the Yolo County area. Power records were not available to estimate pumpage for prior years in the Sacramento County area. Agricultural pumpage for years prior to 1967 were estimated from land use and water use data discussed later in this chapter. Municipal pumpage records were available for a number of districts. Unrecorded municipal pumpage was estimated using population and water use data. Estimates of water pumped by individual industries was estimated from records of water use, production or sales. The annual amounts of pumpage by use are listed in Table 6. The average annual pumpage for the study period is 358,000 acre-feet, with agriculture accounting for two-thirds of the total.

Ground Water Quality

Ground water contained in the water-bearing materials underlying most of Sacramento County is of excellent quality for irrigation and domestic use. Its character is principally calcium, magnesium, and calcium-sodium bicarbonate and reflects its origin, having been derived by recharge from streams draining the crystalline and metamorphic rock areas to the east. The main ground water body in Sacramento County ranges in thickness from several hundred feet near the eastern portion of the County to an estimated 2,000 feet near the Sacramento River. Underlying this body of ground water is one of poorer quality sodium sulfate water which occurs mostly in the Valley Springs and Ione formations; this deeper ground water is tapped by a few wells in the eastern foothill areas. According to studies by the U. S. Geological Survey [1973], the base of fresh water is defined as that zone of water having an electrical conductivity of 3,000 micromhos. The USGS found that the base of fresh water in Sacramento County slopes from elevation -800, near Sloughhouse, to -2,000 feet along the Sacramento River.

The Delta area contains a separate body of poor quality ground water, which ranges from sodium bicarbonate to sodium chloride in composition and in many areas is unusable for either domestic or irrigation purposes. The boundary between this Delta water and the good quality water is roughly along the common boundary separating Townships 4 and 5 North. There are areas containing sodium chloride ground water along the Sacramento River from the Delta as far north as Township 11 North and also along the Feather River in Township 11 North. The presence of this poor quality water is believed to be due to two causes. First, near surface saline water occurs along many buried channel deposits in the Delta area. This water may be present due to upstream saline migration during periods of low riverflow in the geologic past. The high salinity also may be attributed to rising connate water found generally throughout the central Delta area and in the southern part of Sutter County.

Ground water to the west of the Sacramento River has been derived from recharge along eastward flowing streams that drain the marine sediments west of the Great Valley. This water is predominantly magnesium and magnesium-sodium bicarbonate, and is of poorer quality than that derived from the east. Most of this water type occurs in Yolo County. Figure 13 shows the water characteristic types in and adjacent to the study area. On the figure it may be noted that the magnesium bicarbonate water occurs west of the Sacramento River and calcium bicarbonate water occurs to the east of the river. Because the Yolo Bypass appears to be a ground water mixing area, this feature may serve as a ground water subbasin boundary.

In February 1973, a 1,550-foot well was drilled in Yolo County (8N/4E-9L). Water samples were taken at the 1,000-foot level, 1,350-foot level, and 1,550-foot level. The water characteristics were sodium-calcium chloride, magnesium-sodium bicarbonate, and sodium chloride, respectively, corresponding to the 1,000-foot, 1,350-foot, and 1,550-foot levels. The 1,350-foot aquifer is distinctly eastside water, while the other two are mostly sodium chloride. This is probably due to upstream migration of saline water in geologic past.

Table 7 lists the analyses of the foregoing samples, an analysis of a sample taken at 1,700 feet by Brown and Caldwell Laboratory from the same well, and an analysis of a sample taken from a 1,400-foot deep well (8N/2E-21Q) at the University of California at Davis. The well at UCD was gravel packed at selected intervals. The water at UCD is sodium bicarbonate type, which is distinctly different from that at the Yolo County well. Based on the water quality analysis at 8N/4E-9L, the well is in the ground water mixing area, where stream deposits from the eastside stream and valley trough are inter-fingered together. There is no evidence of the westside stream channel, based on the UCD water characteristics.

Each mineral constituent that is present in the ground water of Sacramento County in undesirable quantities is summarized below.

Iron and Manganese

The only water quality problem in Sacramento County study area is one of excessive amounts of iron and manganese in ground water. The 1962 Drinking Water Standards of the U. S. Public Health Service included a recommended limit of 0.3 mg/l for iron and 0.05 mg/l for manganese. These limits are for esthetic and taste considerations because iron and manganese tend to precipitate as insoluble hydroxides and stain laundry and porcelain fixtures. Large concentrations of these minerals could discolor the water. However, the concentrations of iron and manganese found in ground water in the study area do not constitute a public health hazard.

Of 304 wells sampled for iron and manganese, a total of 216 showed an iron concentration in excess of 0.3 mg/l and/or a manganese concentration in excess of 0.05 mg/l. Many wells sampled over a period of time showed a wide range in concentration of these constituents. For example, Well 9N/4E-27K1 was sampled on April 30, 1958; the mineral analysis of the ground water showed a concentration of 0.29 mg/l of iron and 0.96 mg/l of manganese. The well was sampled again on September 16, 1959; the mineral analysis of this later sample indicated 0.94 mg/l of iron and 0.00 mg/l of manganese. Not all wells in Sacramento County have been

TABLE 5

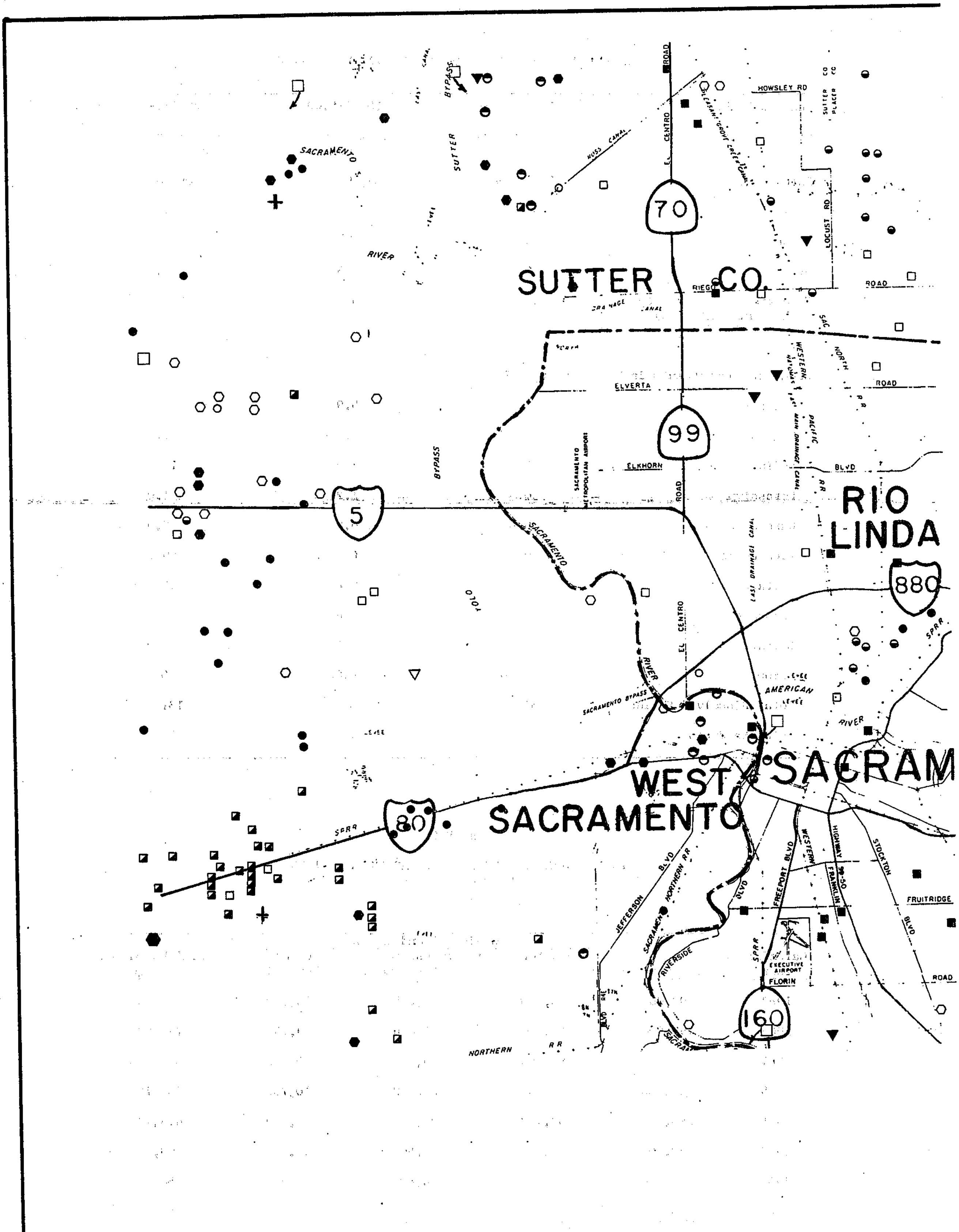
SURFACE WATER QUALITY FROM REPRESENTATIVE STATIONS

Station Number	A0 7175.00	B0 1125.00	B9 1849.80
Station Name	American River at Fair Oaks	Cosumnes River at McConnell	Sacramento River at Freeport
Date	10-27-69	04-29-70	06-08-66
Time	0730	0730	1445
Temperature	58°F	51°F	69°F
pH	6.8	7.3	7.7
Electrical Conductivity (Micromhos at 25°C)	40	75	208
Turbidity	5E	3E	--
Chemical Constituents in Milligrams per Liter:			
Calcium	4.7	5.9	17
Magnesium	1.1	3.6	7.2
Sodium	1.6	3.9	15
Potassium	0.8	1.2	1.0
Carbonate	0.0	0.0	2.0
Bicarbonate	20	40	89
Sulfate	0.0	9.4	15
Chloride	1.4	0.4	10
Nitrate	0.1	0.0	1.9
Boron	0.00	0.00	0.00
Total Dissolved Solids	36	66	131
Total Hardness	16	29	72

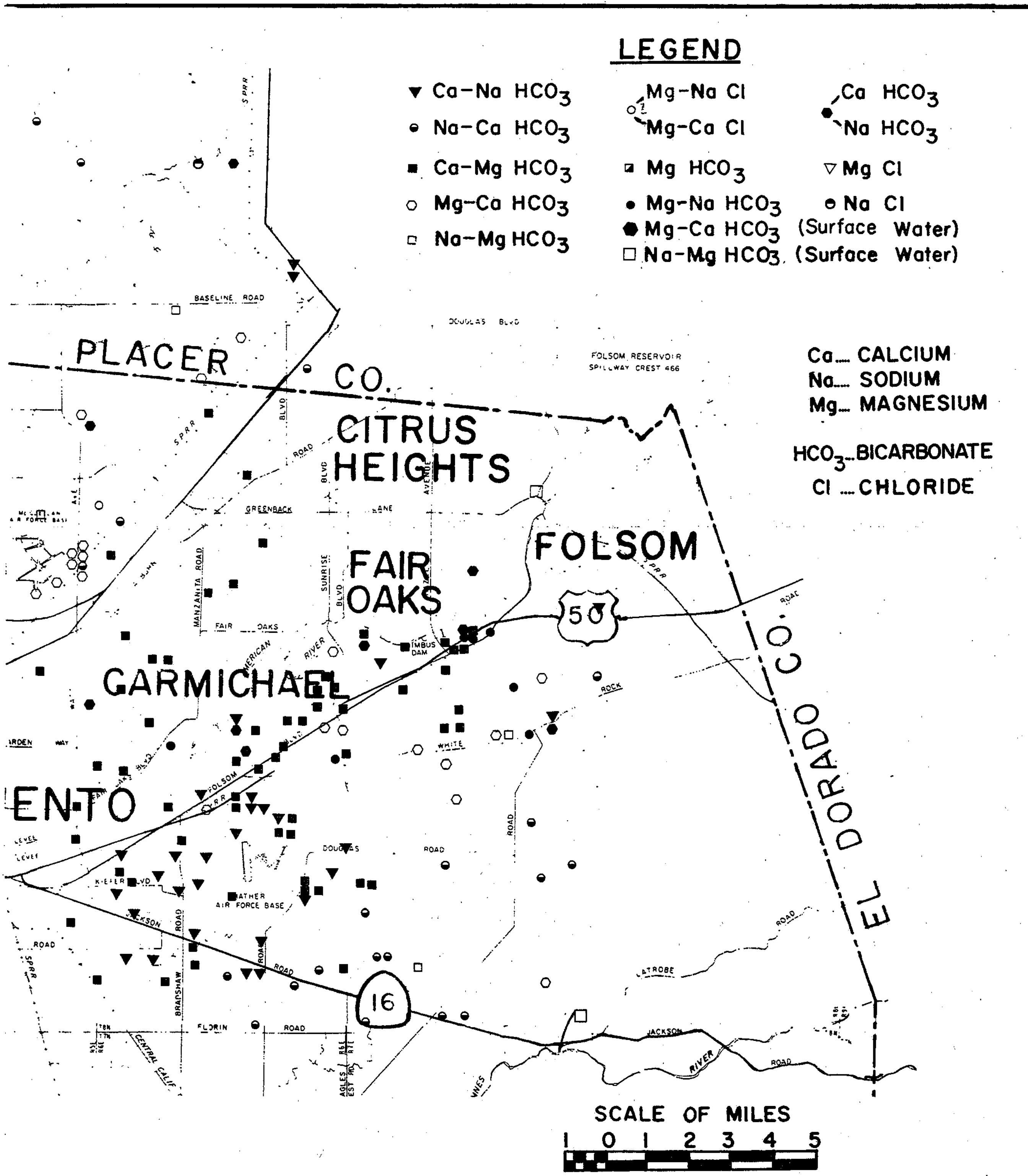
TABLE 6

TOTAL ESTIMATED PUMPAGE FOR SACRAMENTO COUNTY
1962 THROUGH 1969
(in Acre-Feet)

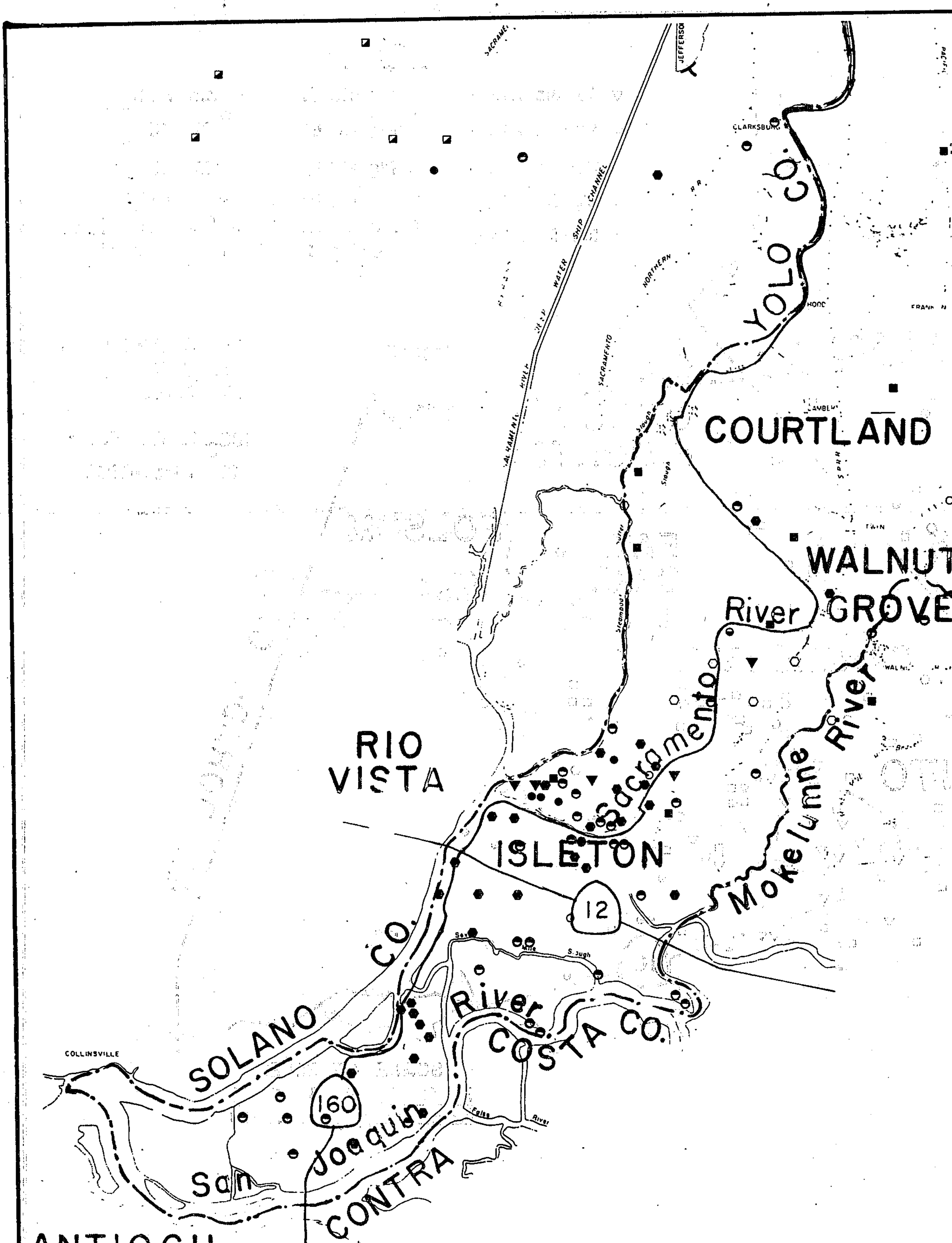
Calendar Year	Agricultural	Municipal and Industrial: Water Purveyors	Municipal and Industrial: Industrial Self-Produced	Municipal and Industrial: Rural Domestic	Total Estimated Pumpage
1962	293,000	73,400	19,200	10,800	396,400
1963	199,000	63,100	17,400	9,100	288,600
1964	297,000	67,300	19,800	10,500	394,600
1965	249,800	69,900	20,700	10,700	351,100
1966	296,000	82,400	23,400	12,300	414,100
1967	189,200	77,200	21,500	11,200	299,100
1968	232,100	85,200	24,800	12,600	354,700
1969	244,800	87,200	23,400	12,500	369,900
Average	250,100	75,700	21,300	11,200	358,300
% of Total	69.8	21.1	6.0	3.1	100.0



WATER QUALITY
(NORTH


LEGEND
▼ Ca–Na HCO3
Na–Ca HCO3
Ca–Mg HCO3
Mg–Ca HCO3
Na–Mg HCO3
Mg–Na Cl
Mg–Ca Cl
Mg HCO3
Mg–Na HCO3
Mg–Ca HCO3 (Surface Water)
Na–Mg HCO3 (Surface Water)
Ca HCO3
Na HCO3
Mg Cl
Na Cl
Ca... CALCIUM
Na... SODIUM
Mg... MAGNESIUM
HCO3...BICARBONATE
Cl ...CHLORIDE
PLACER CO.
CITRUS HEIGHTS
FAIR OAKS
FOLSOM
CARMICHAEL
ENTO
EL DORADO CO.
BASELINE ROAD
FOLSOM RESERVOIR
SPILLWAY CREST 466
GREENBACK LANE
MANZANITA ROAD
SUNRISE BLVD
FAIR OAKS
AMERICAN RIVER
50
16
BRADSHAW ROAD
FLORIN ROAD
JACKSON ROAD
LATROBE
RIVER
MATHER AIR FORCE BASE
SCALE OF MILES
1 0 1 2 3 4 5

TYPES
SHEET)



WATER QUALITY

(SOUTH

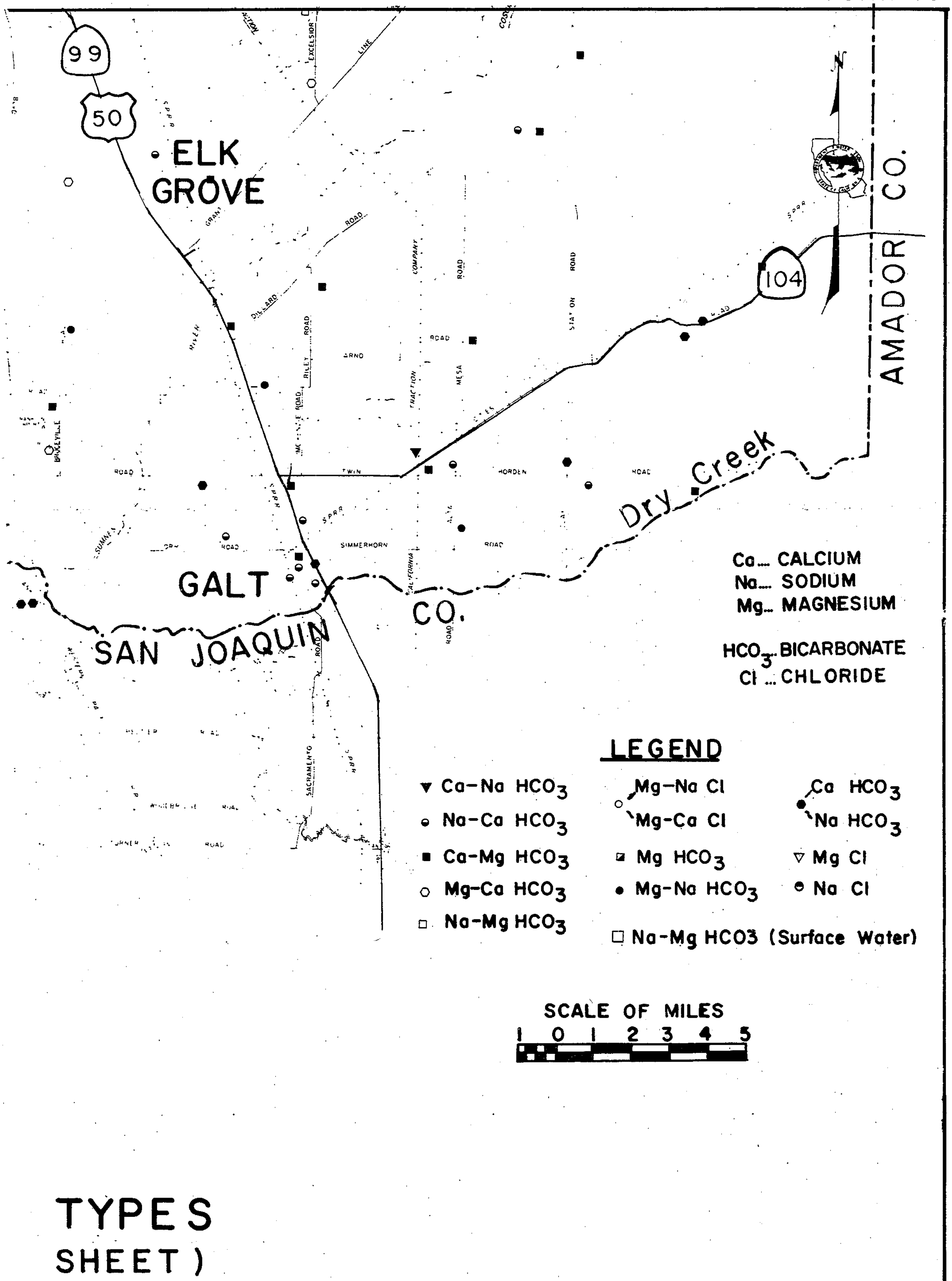

99
50
ELK GROVE
GALT
SAN JOAQUIN CO.
Dry Creek
104
AMADOR CO.
Ca... CALCIUM
Na... SODIUM
Mg... MAGNESIUM
HCO3... BICARBONATE
Cl ... CHLORIDE
LEGEND
Ca-Na HCO3
Na-Ca HCO3
Ca-Mg HCO3
Mg-Ca HCO3
Na-Mg HCO3
Mg-Na Cl
Mg-Ca Cl
Mg HCO3
Mg-Na HCO3
Na-Mg HCO3 (Surface Water)
Ca HCO3
Na HCO3
Mg Cl
Na Cl
SCALE OF MILES
1 0 1 2 3 4 5
TYPES
SHEET)

TABLE 7

GROUND WATER QUALITY ANALYSES

Chemical Constituents in ppm	8N/4E-9L Sample at 1000 ft	1350 ft	1550 ft	1770 ft*	8N/2E-21Q 1400 ft
Hardness as CACO3	368	299	101	88	96
Calcium	89	41	27		16
Magnesium	36	48	8.3		14
Sodium	142	50	229		79
Potassium	9	1.6	5.8		1.9
Bicarbonate	148	284	232		256
pH	7.7	7.3	7.8	8.0	8.1
Sulfate	2.8	82	0.8		34
Chloride	403	69	308	349	19
Nitrate	0.1	0.0	0.2		0.9
Boron	0.6	1.0	2.0		0.8
Total Dissolved Solids	1000	464	761		319
Specific Conductance (Micromhos at 25°C)	1500	801	1360	1780	510
Arsenic	0.00	0.00	0.00		0.0
Cadmium	0.00	0.00	0.00		0.0
Copper	0.00	0.00	0.00		0.0
Iron	0.16	0.01	0.01	2.35	0.01
Lead	0.01	0.01	0.01		0.01
Manganese	0.93	0.90	0.90	0.06	0.02
Zinc	0.29	0.32	0.32		0.02

*Brown & Caldwell Laboratory

sampled for iron and manganese. This is partly due to sampling techniques which require stabilizing these two constituents by acidizing the water sample immediately after obtaining it.

The statistic of 216 samples out of 304 samples, or about 71 percent, exceeding the USPHS standards for iron and manganese is not as significant as it indicates. This is due to bias that the water was suspected to contain a high iron and manganese concentration before the analysis was ordered. If all water samples were analyzed for iron and manganese, the percentage would have been a lot lower.

Because of wide variations of concentrations of iron and manganese at sampled wells, it is not possible to delineate areas of Sacramento County which consistently produce ground water exceeding U. S. Public Health standards for these two constituents. Examples of this wide variation over a period of time are presented on Table 8.

TABLE 8

VARIATIONS OF IRON AND MANGANESE CONCENTRATIONS WITH TIME

	Date Sampled	Iron (mg/1)	Manganese (mg/1)
Well 08N/04E-36R	12/28/53	4.30	1.50
	06/28/57	0.28	0.00
	08/20/58	0.01	0.00
	06/17/59	0.07	0.00
	08/14/60	0.00	0.00
	07/27/60	0.04	0.00
	01/11/61	0.07	0.00
	07/18/61	0.00	0.00
	08/27/62	0.02	0.00
	08/29/62	0.02	0.00
	00/00/68	0.00	0.10
	08/06/69	0.06	0.51
	08/14/69	0.06	0.51
	07/06/71	0.01	0.06
Well 08N/05E-15M01	06/03/61	0.04	0.06
	05/15/61	0.63	0.15
	05/15/61	0.50	0.28
	09/17/62	0.04	0.00
Well 09/05E-35Q	04/09/58	0.40	0.05
	04/15/58	0.40	0.05
	09/19/58	0.20	0.50
	10/30/58	0.26	0.70
	01/25/60	0.10	0.80
	01/09/68	0.06	0.05

Large concentrations of iron and manganese are not normally found in surface water. Iron and manganese usually precipitate as chlorides, nitrates, and hydroxides because they are only sparingly soluble. For this reason, manganese ions seldom are present in surface waters in concentrations above 1.0 mg/l. In ground water subject to reducing conditions, manganese can be leached from the soil and may occur in high concentrations. Iron frequently accompanies manganese in such ground waters.

The solution of iron- and manganese-bearing minerals is attributed to the action of carbon dioxide in ground waters. Carbon dioxide is generated by bacterial decomposition of organic matter leached from soil and swamp areas. These minerals enter into solution under anaerobic conditions and in the presence of certain reducing agents change from the higher oxide state (ferric and manganic ion) to the lower state (ferrous and manganous ions). (From American Water Works Association Water Quality and Treatment, 1971.)

Well logs are available from four of the locations of iron concentrations exceeding the USPHS drinking water standards recommended limit of 0.3 mg/l. These logs are from Wells 9N/5E-13P, 9N/5E-16Q3, 9N/5E-19F, and 9N/5E-25C. It was noted that the perforations were at or just below a clay layer -- white, yellow, and dun clay. It is suspected that during the leaching process, water percolating into the ground water basin carried ferrous and manganous ions along with it. Since the ferrous and manganous ions are relatively heavy, they tend to settle in the ground water body until they are concentrated on top of a clay lens. In the process of well design and construction where perforations are to be placed in the well casing, probably to insure good production, most wells are over-perforated into the clay layers. If this postulation is correct -- and there is no inexpensive method to verify it -- presumably the concentrations of iron and manganese should diminish with time.

Sodium

Sodium is a very active metal which does not occur in its native state in nature. Sodium compounds constitute 2.83 percent of the crust of the earth. Most sodium salts are extremely soluble in water, therefore, any sodium that is leached from soil or discharged to streams will remain in solution. Sodium ion in ground water is derived from the decomposition of sodic feldspar by water containing carbon dioxide. One of the products of this decomposition is sodium bicarbonate, which is present in water in its dissociated state, that is, in the ionic form (Na^+ and HCO_3^-). Large amounts of sodium also are derived from the intrusion of sea water and from migration of formation waters from marine sediments. Both of these types of water are sodium chloride in character.

For many years the percent sodium has commonly been reported in analyses of irrigation water because the presence of sodium ion was known to adversely affect the tilth and permeability of certain soils. The opposite is true for calcium and magnesium ions, which in proper proportions will maintain soil in good condition of tilth and structure. When a soil containing exchangeable calcium and magnesium ions is irrigated with a water containing large amounts of sodium ion, a decrease in tilth and permeability results due to base exchange. This is because sodium ion has been adsorbed by the soil minerals, replacing the calcium and magnesium ions.

In the Delta region the average sodium ion concentration in ground water was found to be 208 mg/l, from 261 samples; the range of values was from 9 mg/l to 587 mg/l. For Townships 5, 6, and 7 North, the average concentration was only 26 mg/l from 168 samples; the range of concentration was from 6 to 277 mg/l. For Townships 8, 9, and 10 North, the average sodium ion concentration was 22 mg/l from 745 samples; the concentration ranged from 1 mg/l to 1,480 mg/l.

Figure 14 depicts percent sodium contours that are more or less parallel with the Sacramento, American, and Cosumnes Rivers. The percent sodium increases with distance away from the recharge sources, which appear to be the rivers. Qualitatively, the rivers are recharging the ground water basin, but it cannot be quantified. This verifies that the rivers are losing streams, thereby recharging the ground water basin. From the standpoint of the percent sodium, the Delta portion of the County is distinctly different from the rest of the County.

The U. S. Salinity Laboratory [1954] revised the concept of sodium percentage and adopted the Sodium Adsorption Ratio, or SAR. The SAR values are used to describe the sodium (alkali) hazard of irrigation water. This ratio expresses the relative activity of sodium ion in the exchange reactions with soil. Hem [1959] has defined the SAR value as follows:

$$SAR = \frac{Na^{+}}{\sqrt{\frac{1}{2}\,(Ca^{++} + Mg^{++})}}$$

where Na^{+}, Ca^{++}, and Mg^{++} are concentrations of the respective ions in equivalents per liter of water.

The SAR value for a water is related to the adsorption of sodium by a soil to which water is added. As a means of estimating the possible results of using water for irrigation, the SAR value is more directly significant than the percent sodium value.

Figure 15 is modified from the chart derived by the U. S. Salinity Laboratory [1954]. Based on an SAR scale from 0 to 30 and conductivity values of 100 to 5,000 micromhos per cm at 25°C, this diagram classifies irrigation waters with respect to sodium and salinity hazards.

On Figure 16, sodium hazard areas for Sacramento County have been delineated. All of the County, with the exception of the Delta area, lies within the zone of low sodium hazard. In the Delta area the sodium hazard ranges from medium, near Isleton, to very high on Sherman Island.

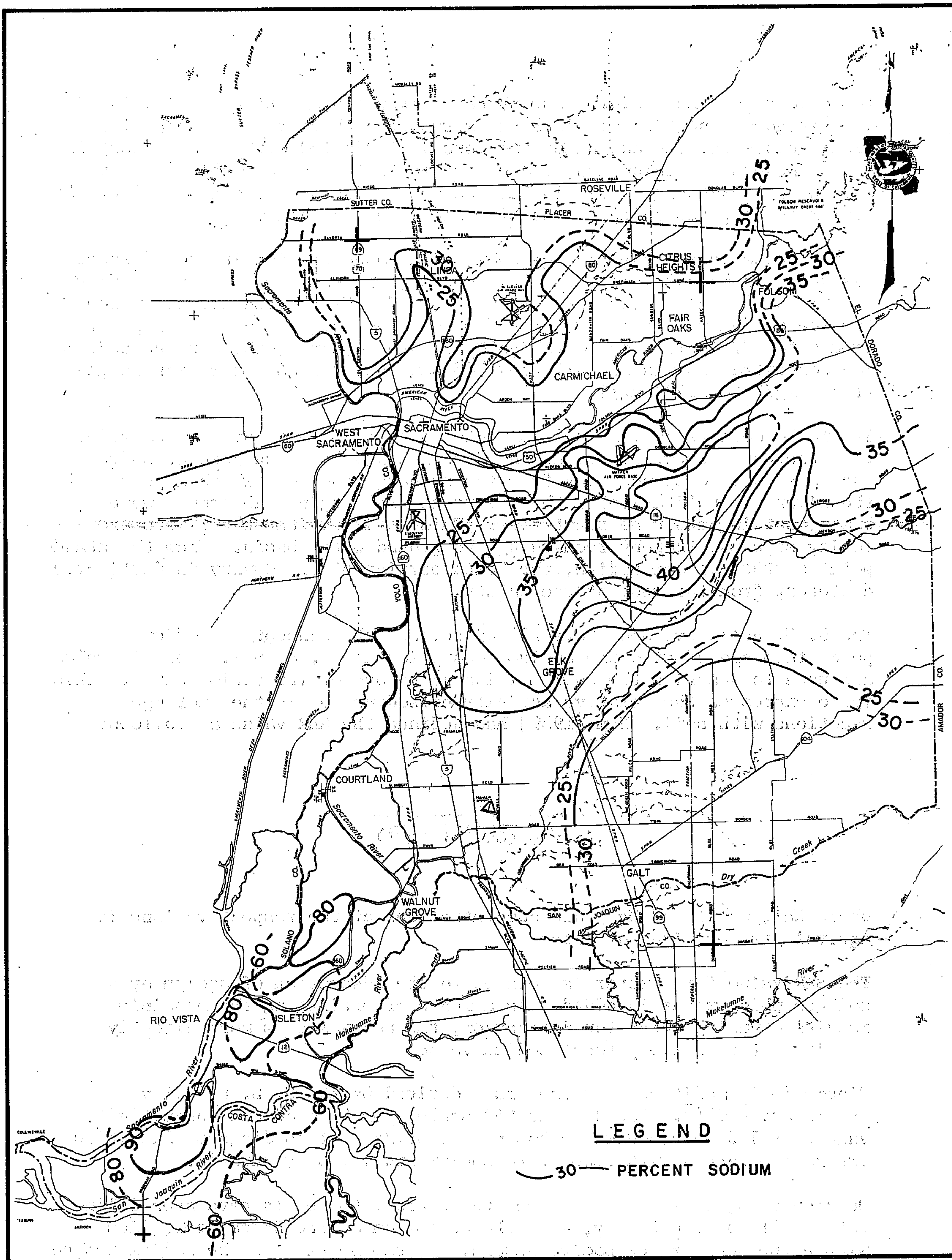


Figure 14. CONTOURS OF EQUAL SODIUM PERCENTAGE

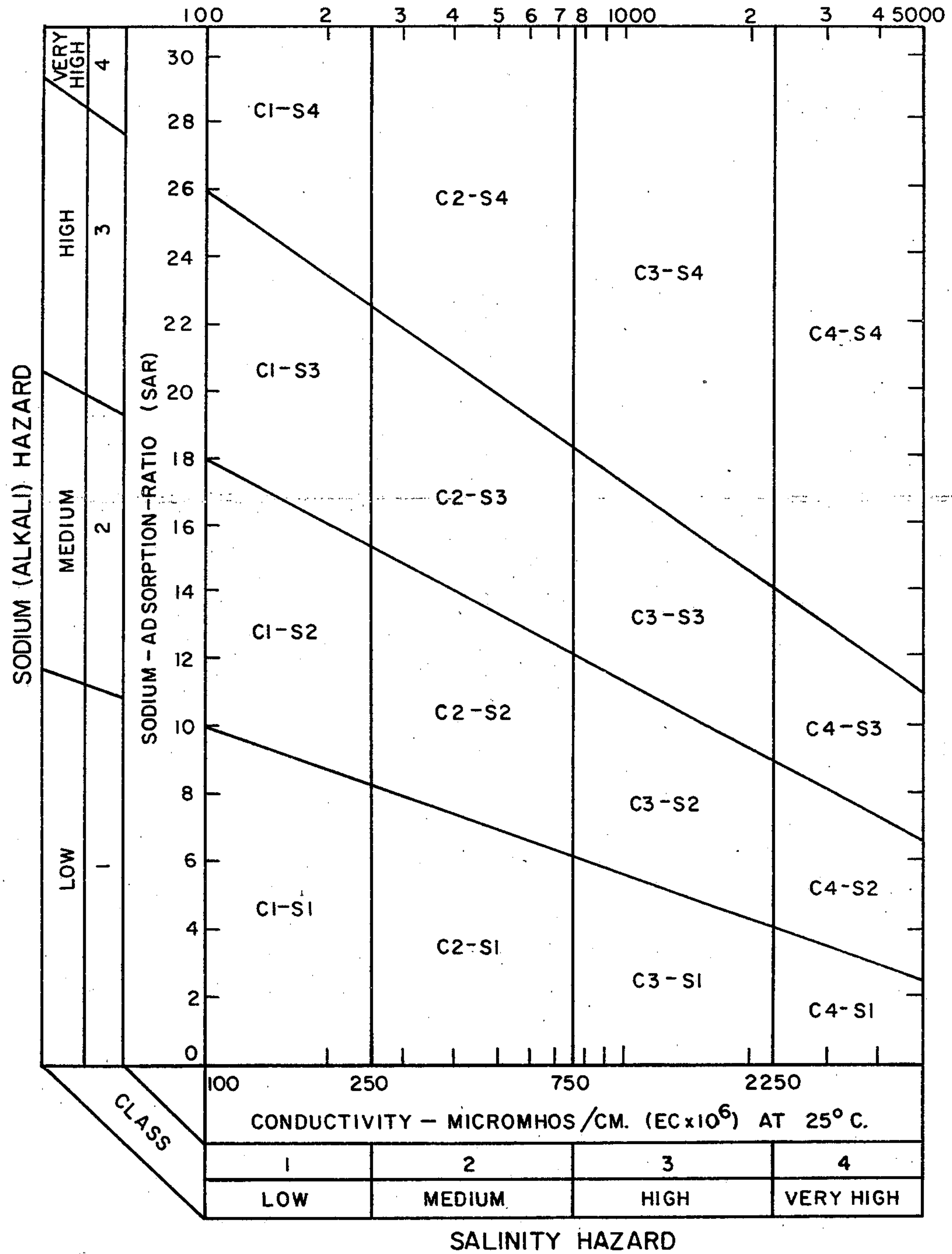
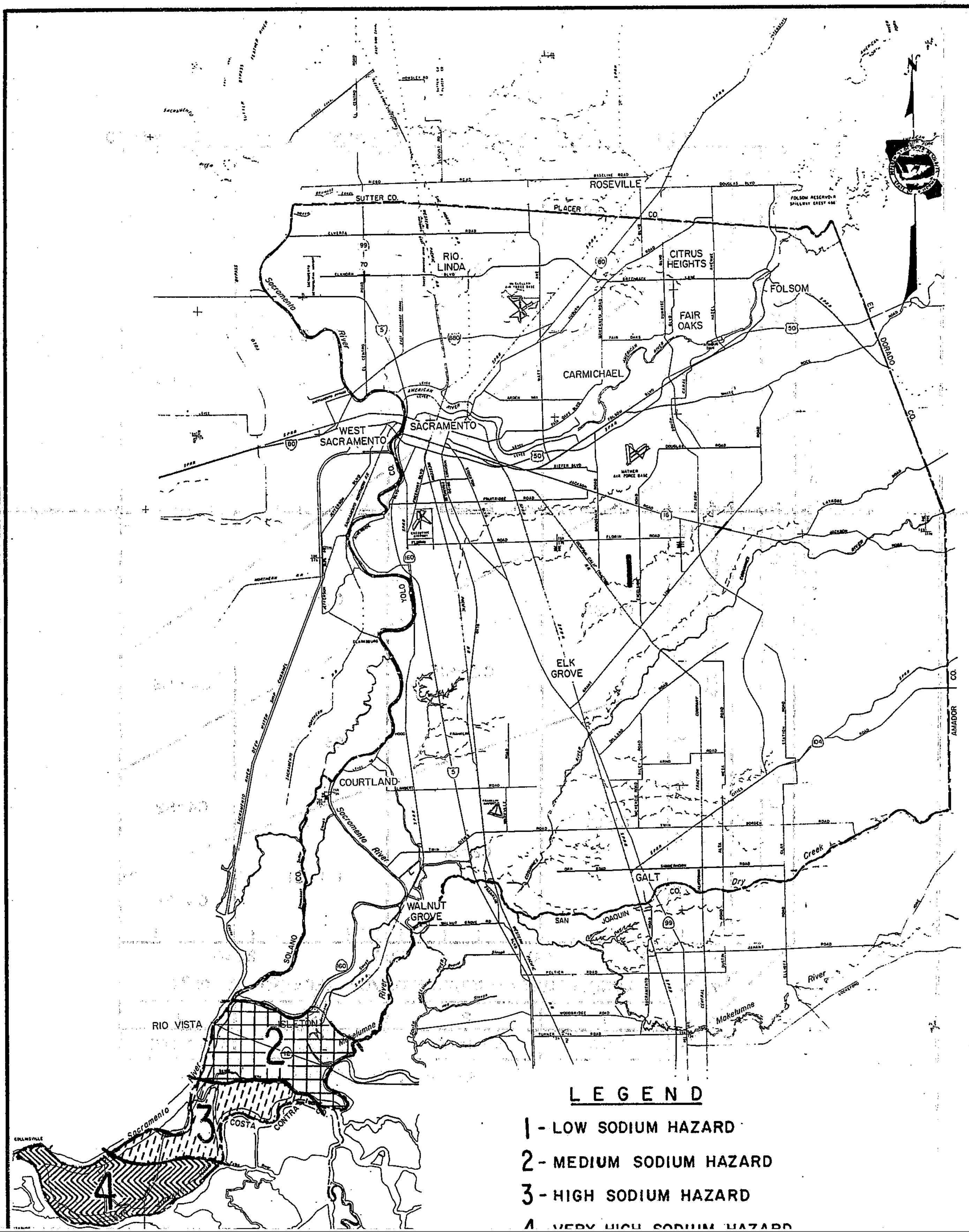


Figure 15. CLASSIFICATION OF IRRIGATION WATERS


ROSEVILLE
SUTTER CO.
PLACER CO.
RIO LINDA
CITRUS HEIGHTS
FOLSOM
FAIR OAKS
CARMICHAEL
EL DORADO CO.
SACRAMENTO
WEST SACRAMENTO
Sacramento River
ELK GROVE
COURTLAND
Sacramento River
WALNUT GROVE
GALT
Dry Creek
SAN JOAQUIN CO.
AMADOR CO.
SOLANO CO.
YOLO CO.
Mokelumne River
RIO VISTA
ISLETON
COSTA CONTRA CO.
1
2
3
4
LEGEND
1 - LOW SODIUM HAZARD
2 - MEDIUM SODIUM HAZARD
3 - HIGH SODIUM HAZARD

Chloride

Chlorine is a member of the halogen group of elements, and it is the most important and widely distributed member of this group. It is highly soluble in water where it occurs as chloride ion (Cl^-). Chloride ion is present in oceanic waters in great abundance where it is the principal anion. Chloride ion also is present in large quantities in marine connate waters.

Ground water with high chloride concentration occurs only in the Delta area. Here the average chloride ion concentration is 132 mg/l, with the range of concentration being from 6 to 904 mg/l for 261 samples. This relatively high chloride concentration also affects the electrical conductivity and total dissolved solids (TDS) of the ground water. The average conductivity was found to be 872 micromhos, with the range being from 114 to 3,250 micromhos for the 151 samples tested. The average TDS value was found to be 509 mg/l, with the range being from 100 to 1,740 for 103 samples.

Boron

Boron is essential in trace quantities to plant nutrition, but it becomes toxic to certain plants when present in amounts in excess of 0.5 mg/l in irrigation water. Certain other plants are more tolerant, being able to survive boron concentrations of up to 2.0 mg/l.

Excessive boron in ground water usually is derived from the intrusion of sea water and from rising marine connate waters. In Sacramento County most of the boron problem occurs in the Delta area. Here the average concentration of elemental boron is 0.8 mg/l; the concentration in 82 samples was found to range from 0.0 mg/l to 3.1 mg/l. Excessive concentrations of boron usually are associated with high concentrations of chloride ion.

Water Levels

In 1970, the Department listed in Bulletin 130-70 the water level measurements for 336 wells in Sacramento County. Of these wells, 17 were measured monthly. Five different agencies are responsible for these measurements. They are: (1) Sacramento County, (2) Arcade County Water District, (3) Sacramento Municipal Utility District, (4) U. S. Bureau of Reclamation, and (5) California Department of Water Resources.

These measurements are of sufficient coverage to draw annual ground water contours for the model period, 1962 through 1968, in the areas of greatest concern. Because there were only a few wells in the eastern foothills areas, ground water contours were not as accurate as for the remainder of the County. However, in the eastern foothills, where the depth of alluvium is fairly small, the amount of pumpage is also small and therefore large errors in the assumed ground water level did not affect the overall ground water storage.

From inspection of driller's logs it was noted that pressure conditions exist locally throughout the County, indicating a certain degree of confinement caused by lenses of clay. The largest rise in pressure levels was for Well 9N/6E-20N2, where water was first encountered at 92 feet; after development of the well, the standing water level was 66 feet, indicating a potentiometric rise of 26 feet. Throughout the County the average rise in water levels amounts to less than 10 feet. Ground water contour maps were drawn for each year of the study period, using 398 wells located within the study area. Water level contours for spring 1968 are shown on Figure 17, and the net change in water levels from spring 1962 to spring 1968 are shown on Figure 18. Because of the complex subsurface geology of Sacramento County, these water level measurements represent combinations of unconfined, semiconfined, and confined conditions within each well, with the actual degree of confinement in each well remaining unknown.

Recognizing the fact that each geologic formation should have its own potentiometric surface, an attempt was made to group the water level measurements by formation and thus contour the potentiometric surface for each formation. However, it was found that in most cases the potentiometric surfaces of the various formations coincided, and thus a separation of the ground water body on the basis of water level measurements could not be made. For this reason it was decided that the ground water system could be considered as a single layer of water-bearing materials.

Four hydrographs of water level fluctuations are shown on Figure 19. The top graph represents an average for the entire county area. From 1930 through 1940, ground water levels have remained fairly steady, therefore during this period ground water pumpage was fairly constant. From 1940 to date, the decline in the water table is fairly uniform, being about one foot per year. The average ground water surface elevation decreased from 30 feet (mean sea level) in 1940 to about minus 5 feet in 1970, or a decrease of about 35 feet in 30 years.

The second graph, Well 6N/5E-10G1, of unknown depth, is located just north of Franklin, in the pumping depression in southwestern Sacramento County. The ground water surface elevation for this well has declined from minus 20 feet in 1950 to minus 70 feet in 1970. The rate of decline was in excess of 2½ feet per year from 1950 to 1970 and then appeared to asymptotically approach an equilibrium level. This suggests that the lowering of the ground water level increased the slope or gradient from the Sacramento River, thereby increasing infiltration from the river.

The third graph, Well 6N/7E-28E1, of unknown depth, is located in the southeastern part of the County. The ground water level has steadily declined at this well from an elevation of 31 feet in 1951 to minus 10 feet elevation in 1970, an average decline of over a foot and a half per year. The rate of decline appears to be unchanged in 1970.

The last graph on Figure 19 shows Well 9N/5E-21M1, of 94 feet depth, located in the northern portion of the County. The water levels at this well have declined steadily from an elevation of 9 feet in 1950 to minus 10 elevation in 1970. This decline of about one foot per year appears to be continuing.

The first two wells are located in agricultural areas, while the third well is located in an urban area. The ratio of agricultural pumpage to municipal and industrial pumpage is approximately two to one in the County.

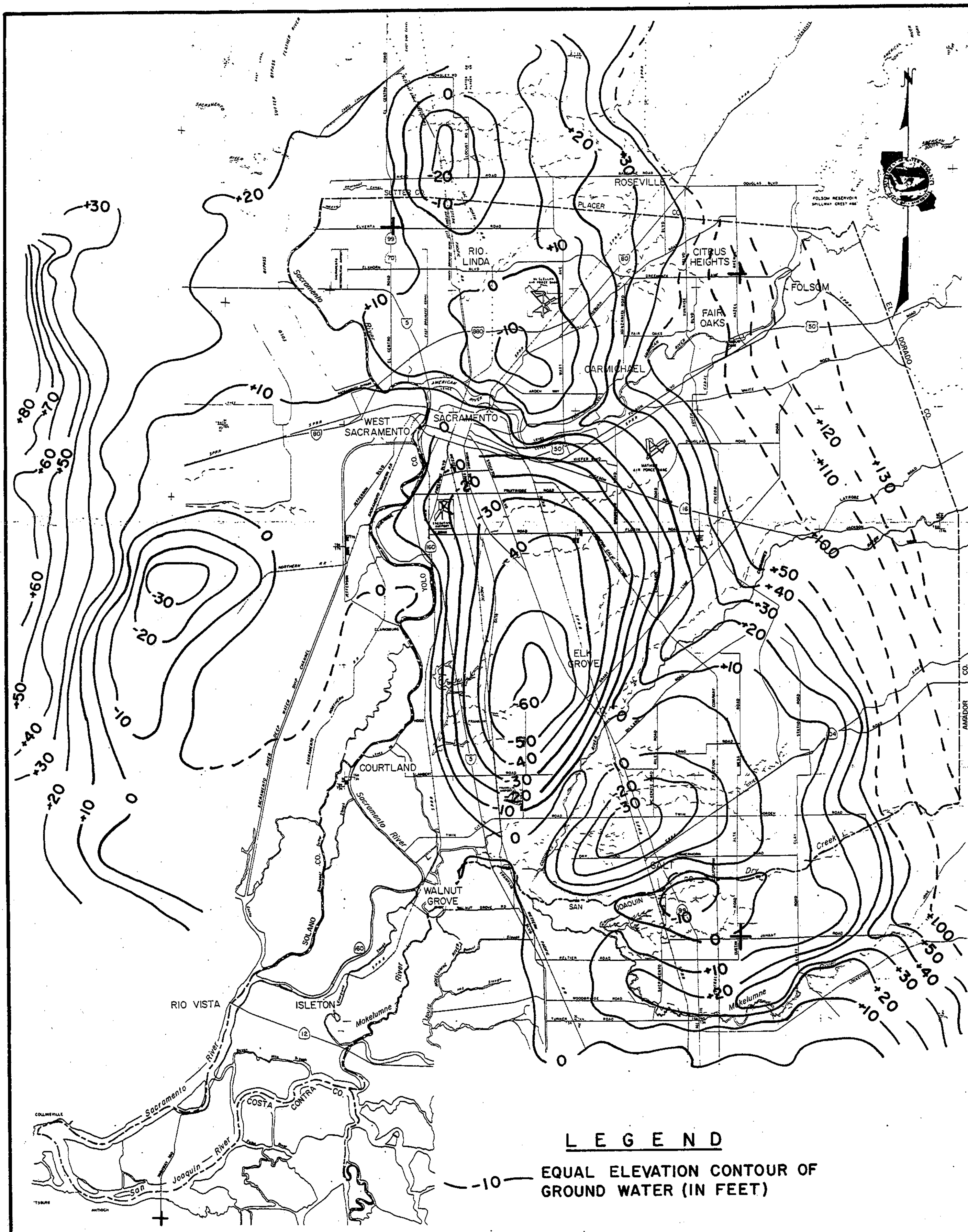


Figure 17. CONTOURS OF EQUAL ELEVATION OF GROUND WATER, SPRING 1968

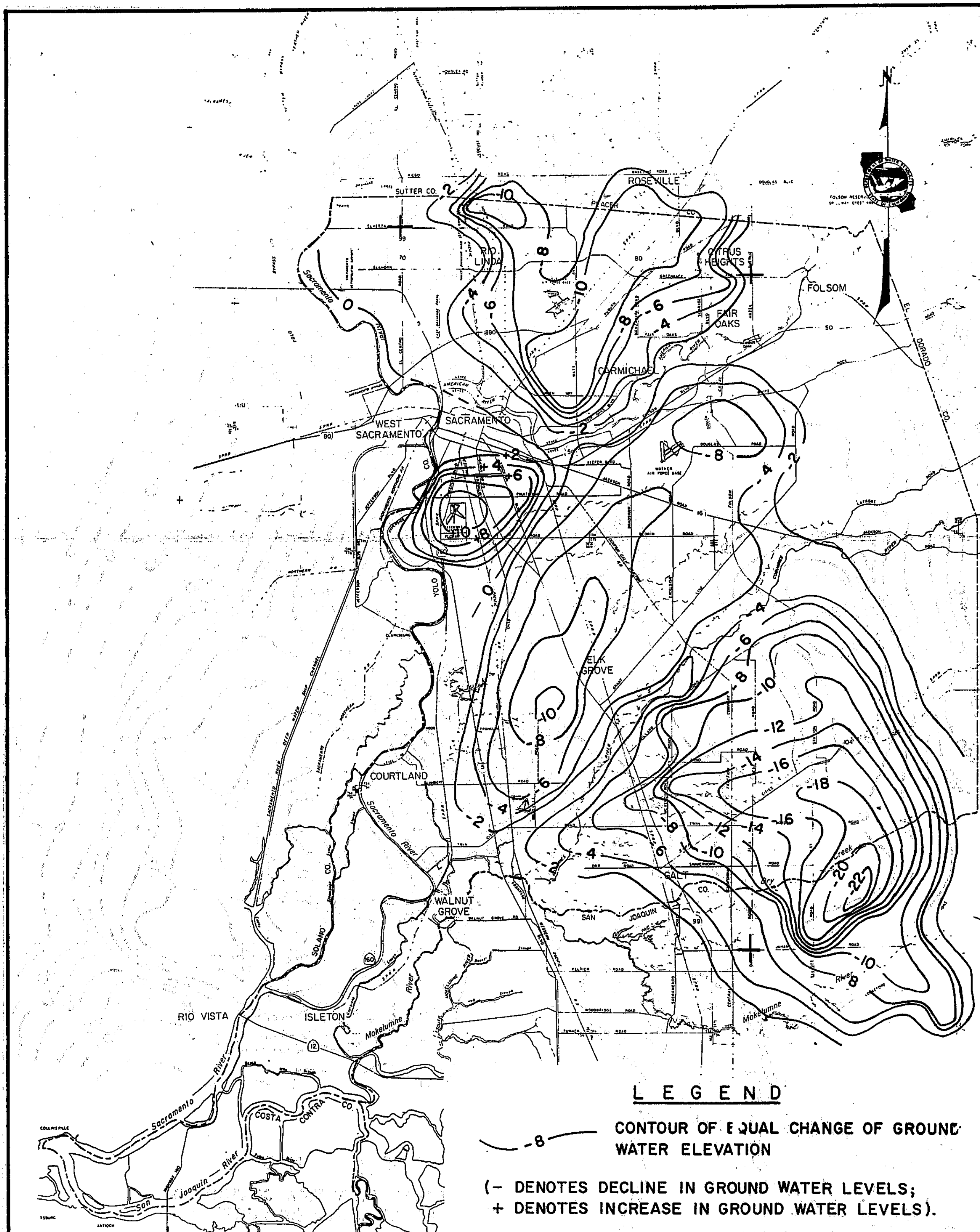


Figure 18. CONTOURS OF EQUAL CHANGE IN GROUND WATER LEVELS - SPRING 1962 TO SPRING 1968

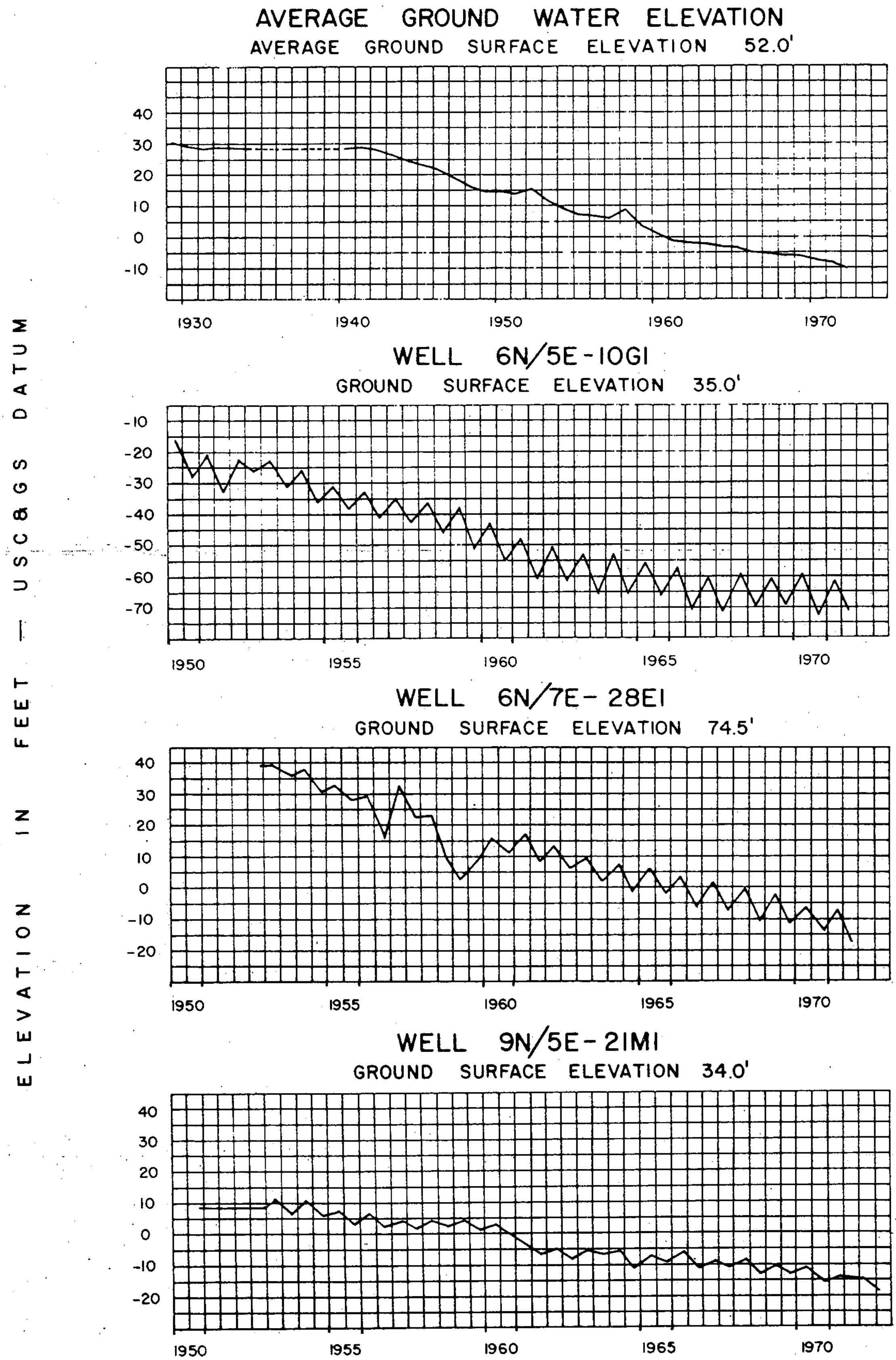


Figure 19. FLUCTUATION OF WATER LEVEL IN WELLS

Land Use

In the late 1940's, the Department initiated a survey activity designed to identify the nature, location, and extent of present land use and lands suitable for various kinds of water-using development. After completing these surveys for most of the State and meeting the then-current data needs, the Department initiated a continuing survey program to monitor land use changes on a cycle of 5 to 10 years.

The Department makes two kinds of surveys: (1) land use surveys to record the nature and extent of present water-related land development; and (2) land classification surveys to determine the location and extent of lands with physical characteristics suited to specific kinds of uses. The nature of land characteristics identified is such that the data are useful in determining alternative uses for the land.

The land use surveys are accomplished through interpretation of current aerial photography supplemented by field inspections. The acreage of each specific category of land use is presented on Table 9 for 1968.

The land classification surveys involve field examination of soil characteristics such as depth, texture, salinity, etc., and land features such as slope, microrelief, physiographic position, etc. Table 10 lists acreage in each category of land class. The type of land use and classification information recorded during surveys is shown by the land use and land classification legends presented on Figures 20 and 22. Examples of completed land use and land classification maps are shown on Figures 21 and 23. These are reductions of the original maps, which were on 22 X 27-inch U. S. Geological Survey 7½-minute quadrangles at a scale of 1:24,000. The areal extent of irrigated agricultural lands and urban lands for 1968 is shown on Figure 24.

Population

Population data are needed for analysis of historic water use and are available from the U. S. Census, taken every decade, and also from the California Department of Finance. Population is available both for small areas and for the County as a whole. Estimates made by the California State Department of Finance on July 1 of the following years for Sacramento County are given below:

Year	Population	Year	Population
1961	533,300	1966	606,500
1962	554,400	1967	612,600
1963	574,600	1968	614,800
1964	587,300	1969	622,000
1965	598,300	1970	634,800

TABLE 9

1968 LAND USE SUMMARY FOR SACRAMENTO COUNTY
(In Acres)

Land Use Symbol*	Irrigated Lands	Nonirrigated Lands
G	2,735	
R	11,904	
F	2,053	339
F1	50	
F2	9,701	
F5	3,809	
F6	27,231	
F7	15,794	
P	87	
P1	14,725	
P2	231	
P3	62,237	
P4	5	1,814
P5	36	
T	257	8
T2	2,230	
T3	295	
T6	92	
T9	25	
T10	45	
T11	134	
T13	224	
T15	12,295	
T16	156	
T18	498	
T20	12	
D	7,406	405

Land Use Symbol*	Irrigated Lands	Nonirrigated Lands
D6	2,482	
V	330	12
S	7	
S1	85	
S2	131	
S4	10	
S4 (P)	296	
S5	8	4
E (M)		9,310
NV		343,999
NV (P)		945
NR		6
NR1		27
NR2		33
NW		738
U		80,770
U (P)		147
UR		29
UR01		4
UI		1,465
UI2		34
UV		9,199
UV1		10,529
Total	177,616	459,817
GRAND TOTAL	637,433	

*See Figure 20

TABLE 10

LAND CLASSIFICATION SUMMARY FOR SACRAMENTO COUNTY

Land Class Symbol*	Acres
V	67,756
VB	54,646
V2	5,853
V4	1,728
VW	241
VWB	406
VH	19,192
VH2	490
VH4	64
VL	225
VL2	81
VP	110,992
VPB	4,553
VP2	71,302
VP4	18,866
VP6	302
VR	258
VPR	8
VPR2	203
Total V	357,166

Land Class Symbol*	Acres
H	427
HL	42
HP	99,808
HPL	19
HPR	380
Total H	100,676
M	78
MP	14,772
MPH	97
MPL	150
MPR	781
MPM	11
MPRH	37
MPRL	50
MPRM	291
Total M	16,267
UD	90,668
Total UD	90,668

Land Class Symbol*	Acres
RR1	25
RC	67
Total R	92
PP	914
Total PP	914
VM	4,071
VM2	13
Total VM	4,084
N	67,058
NW	6,746
Total N	73,804
COUNTY TOTAL	643,671

*See Figure 22

AGRICULTURE

Each parcel of agricultural land use is labeled with a notation consisting basically of three symbols. The first of these is a lower case "i" or "n" indicating whether the parcel is irrigated or nonirrigated. This is followed by a capital letter and number which denote the use group and specific use as shown below.

C SUBTROPICAL FRUITS
1 Grapefruit
2 Lemons
3 Oranges
4 Dates
5 Avocados
6 Olives
7 Miscellaneous subtropical fruits

D DECIDUOUS FRUITS AND NUTS
1 Apples
2 Apricots
3 Cherries
5 Peaches and Nectarines
6 Pears
7 Plums
8 Prunes
9 Figs
10 Miscellaneous or mixed deciduous
12 Almonds
13 Walnuts

G GRAIN AND HAY CROPS
1 Barley
2 Wheat
3 Oats
6 Miscellaneous and mixed hay and grain

F FIELD CROPS
1 Cotton
2 Safflower
3 Flax
4 Hops
5 Sugar beets
6 Corn (field or sweet)
7 Grain sorghums
8 Sudan
9 Castor beans
10 Beans (dry)
11 Miscellaneous field

T TRUCK AND BERRY CROPS
1 Artichokes
2 Asparagus
3 Beans (green)
4 Cole crops
6 Carrots
7 Celery
8 Lettuce (all types)
9 Melons, squash, and cucumbers (all kinds)
10 Onions and garlic
11 Peas
12 Potatoes
13 Sweet potatoes
14 Spinach
15 Tomatoes
16 Flowers and nursery
18 Miscellaneous truck
19 Bushberries
20 Strawberries
21 Peppers (all types)

P PASTURE
1 Alfalfa and alfalfa mixtures
2 Clover
3 Mixed pasture
4 Native pasture

V VINEYARDS

R RICE

I IDLE
1 Land cropped within the past three years but not tilled at time of survey
2 New lands being prepared for crop production

S SEMIAGRICULTURAL AND INCIDENTAL TO AGRICULTURE
1 Farmsteads
2 Feed lots (livestock and poultry)
3 Dairies
4 Lawn areas

Special conditions are indicated by the following additional symbols and combinations of symbols.

A ABANDONED ORCHARDS AND VINEYARDS
F FALLOW (tilled but not cropped at time of survey)
S SEED CROPS
Y YOUNG ORCHARDS AND VINEYARDS
X PARTIALLY IRRIGATED CROPS

INTERCROPPING (or interplanting) is indicated as follows: $i\,\frac{D13\text{-}y}{T9}$ = a melon crop planted between rows of young walnut trees

URBAN

UC - URBAN COMMERCIAL

UC 1 Miscellaneous establishments (offices and retailers)
UC 2 Hotels
UC 3 Motels
UC 4 Apartments, barracks (three family units and larger)
UC 5 Institutions (hospitals, prisons, reformatories, asylums, etc., having a reasonably stable 24-resident population)
UC 6 Schools (yards mapped separately if large enough)
UC 7 Municipal auditoriums, theaters, churches, buildings, and stands associated with race tracks, football stadiums, baseball parks, rodeo arenas, etc.
UC 8 Miscellaneous high water use (indicates a high water use not covered above)

UI - URBAN INDUSTRIAL

UI 1 Manufacturing, assembling, and general processing.
UI 2 Extractive industries (oil fields, rock quarries, gravel pits, public dumps, rock and gravel processing plants, etc.)
UI 3 Storage and distribution (warehouses, substations, railroad marshalling yards, tank farms, etc.)
UI 6 Saw mills
UI 7 Oil refineries
UI 8 Paper mills
UI 9 Meat packing plants
UI 10 Steel and aluminum mills
UI 11 Fruit and vegetable canneries and general food processing
UI 12 Miscellaneous high water use (indicates a high water use not covered above)

UV - URBAN VACANT

UV 1 Miscellaneous unpaved areas
UV 4 Miscellaneous paved areas

UR - URBAN RESIDENTIAL

One and two family units, including trailer courts

RECREATION

RR RESIDENTIAL
Permanent and summer home tracts within a primarily recreational area. (The estimated number of houses per acre is indicated by a number in the symbol.)

RC COMMERCIAL
Commercial areas within a primarily recreational area (includes motels, resorts, hotels, stores, etc.)

RT CAMP AND TRAILER SITES
Camp and trailer sites in a primarily recreational area

P PARKS

NATIVE

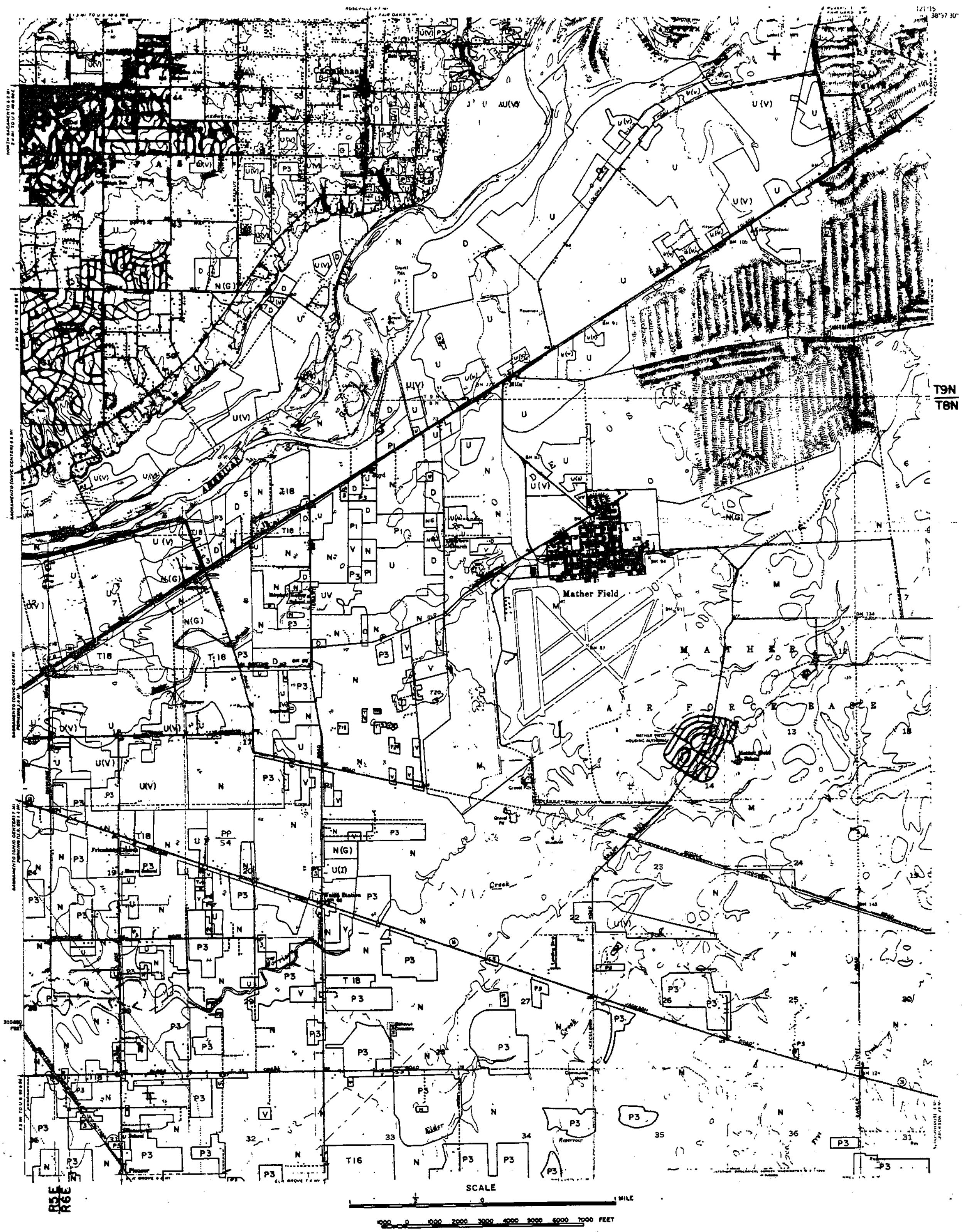
NV NATIVE VEGETATION

NR RIPARIAN VEGETATION
NR 1 Swamps and marshes
NR 2 Meadowland

NW WATER SURFACE

NC NATIVE CLASSES UNSEGREGATED

Figure 20. LAND USE LEGEND



CARMICHAEL QUADRANGLE 1969

Figure 21. TYPICAL LAND USE QUADRANGLE

URBAN AND RECREATIONAL LANDS

RR Existing and potential permanent and summer home tracts within a primarily recreational area. The estimated number of houses, under conditions of full development, is indicated by a number in the symbol, i.e., RR-3 is suitable for three houses per acre.

RT Existing and potential picnic, camp and trailer sites within a primarily recreational area.

RC Existing and potential commercial areas which occur within a primarily recreational area and which include motels, resorts, hotels, stores, etc.

PP Existing race tracks, fairgrounds, and private, city, county, state, and federal parks.

UD The total area of cities, towns and small communities presently used for residential commercial, recreational, and industrial purposes.

IRRIGABLE LANDS

Irrigable lands are identified by notations which begin with a letter "V", "H", or "M". These symbols indicate the general slope conditions, and may appear along or followed by (other) modifying symbols. The slope conditions indicated by these letters are:

V These lands are level or slightly sloping and vary from smooth to hummocky or gently undulating relief. The maximum slope is 6 percent for smooth, reasonably large bodies lying in the same plane.

H These are lands with greater slope and/or relief than those of the "V" class. They vary from smooth to moderately rolling or undulating relief. The maximum slope is 20 percent for smooth, reasonably large bodies lying in the same plane.

M These are lands with greater slope and/or relief than those of the "H" class. They vary from smooth to steeply rolling or undulating relief. The maximum slope is 30 percent for smooth, reasonably large bodies lying in the same plane.

The description below applies to all "V", "H", and "M" lands on which these slope symbols appear by themselves:

Have soils of medium or deep effective root zones; are permeable throughout; are relatively free of salinity, alkalinity, rock, or other conditions which would limit crop adaptability; are suitable for all climatically adapted crops, being limited only by topographic conditions.

The symbols below, appended to "V", "H", or "M", indicate the described modifying conditions.

S Indicates the presence of an excess of soluble salts or exchangeable sodium in slight amounts.

SS Indicates the presence of an excess of soluble salts or exchangeable sodium in moderate amounts.

SA Indicates the presence of an excess of soluble salts or exchangeable sodium in large amounts.

P Indicates shallow depth of the effective root zone.

W Indicates the presence of a high water table.

L Indicates fairly coarse textures and low moisture-holding capacities.

H Indicates very fine textures.

R Indicates enough rock on the surface or within the plow zone to limit use of the land for cultivated crops.

-B Indicates low-lying basin and seep areas.

-2, -4, -6, or -8 Number indicates, in feet, the average difference between highs and lows due to microrelief.

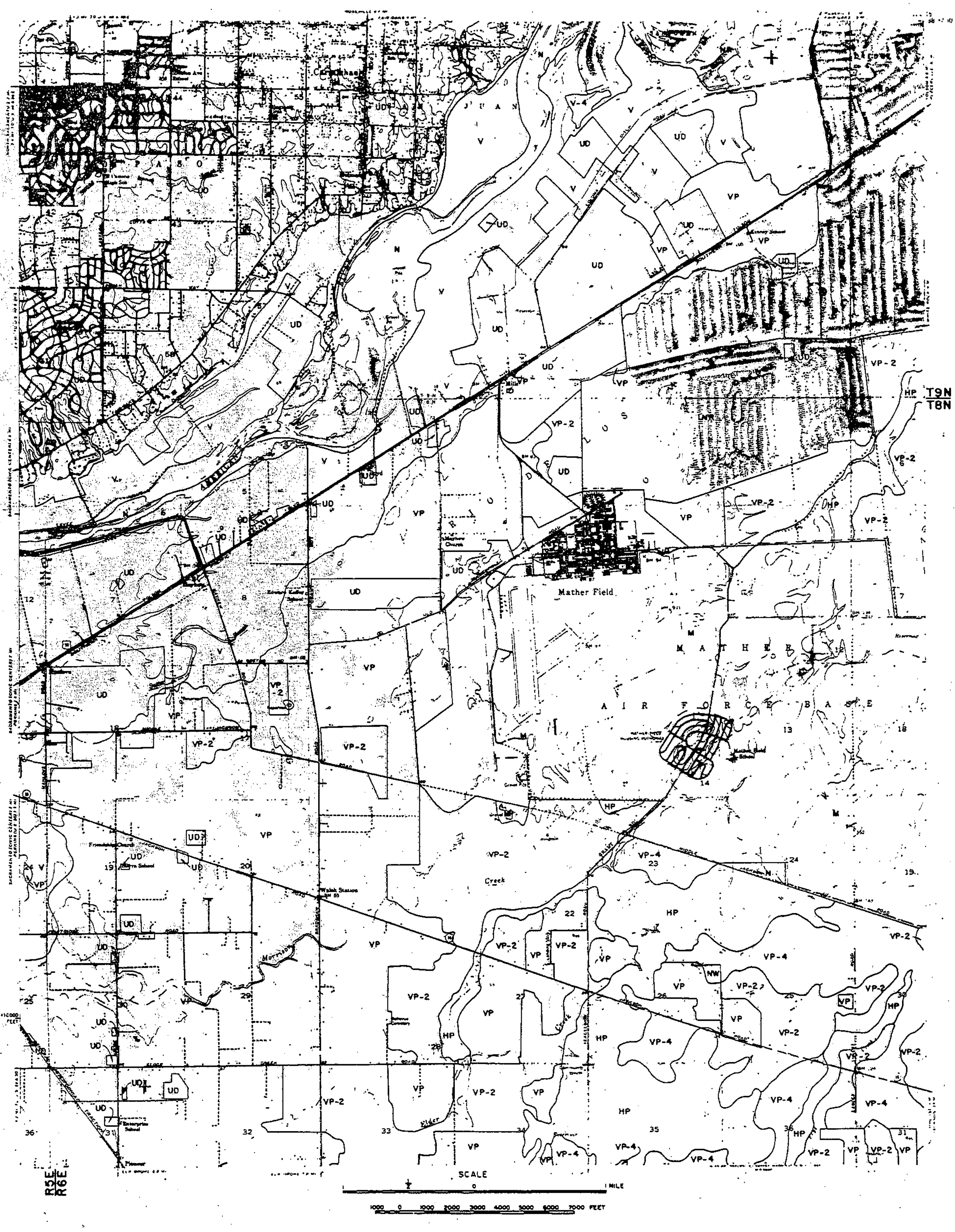
MISCELLANEOUS LANDS

F Presently forested lands, or lands subject to forest management, which meet the requirements for irrigable land but which, because of climatic conditions and physiographic position, are better suited for timber production or some type of forest management program rather than for irrigated agriculture.

VM Swamp and marsh lands which usually support a heavy growth of phreatophytes and are covered by water most of the time.

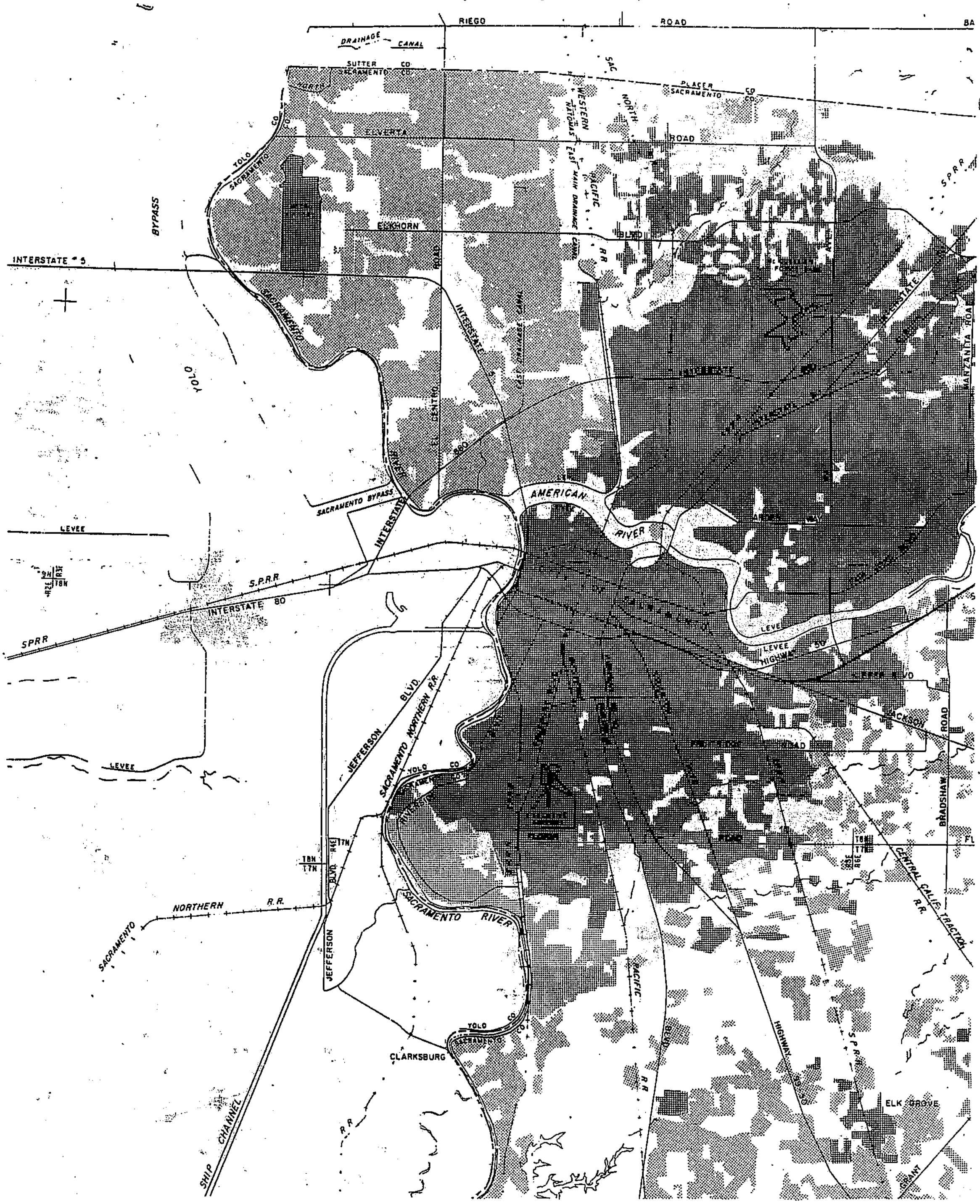
N Includes all lands which fail to meet the requirements of any of the foregoing classes.

Figure 22 LAND CLASSIFICATION LEGEND

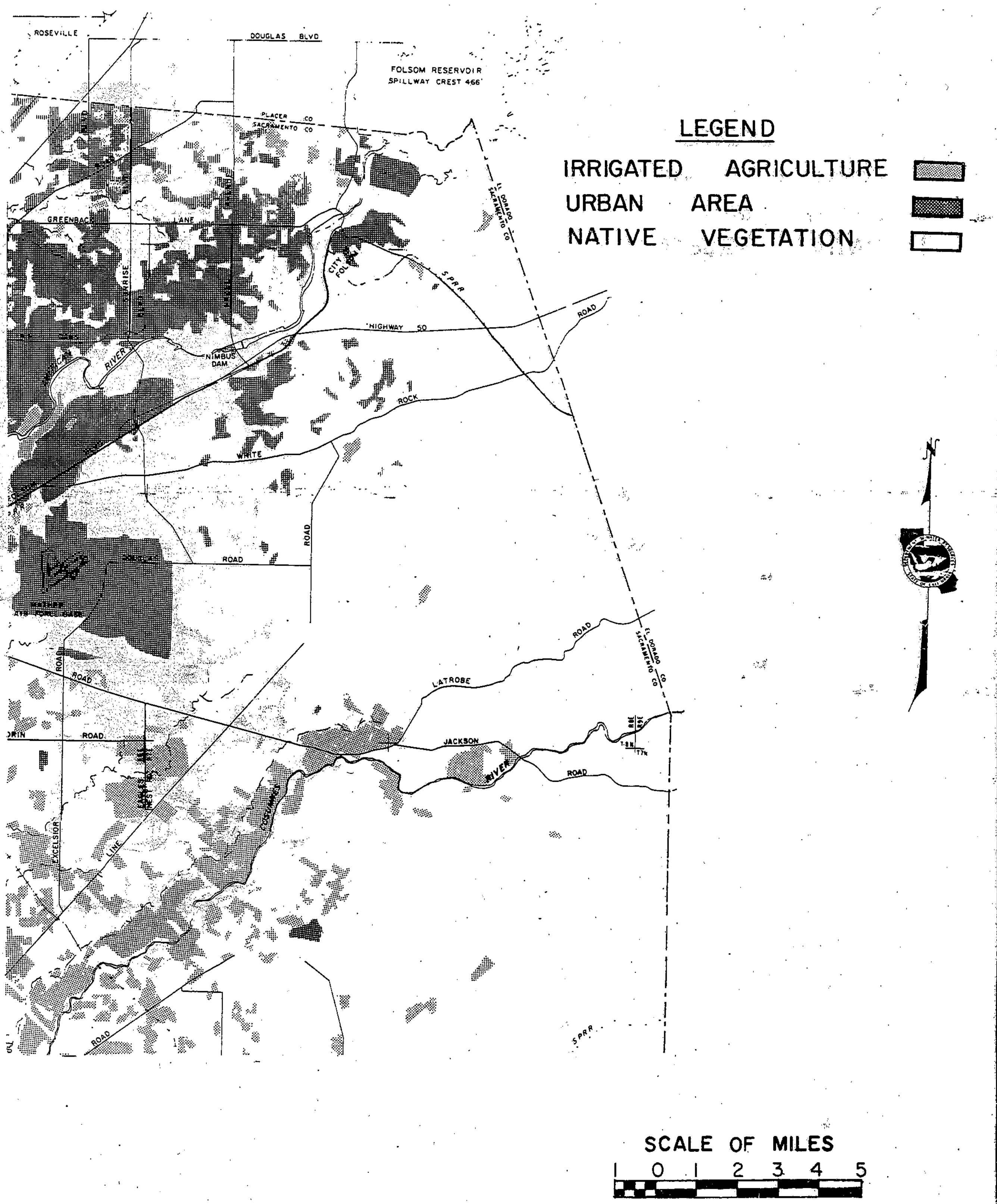


CARMICHAEL QUADRANGLE 1963

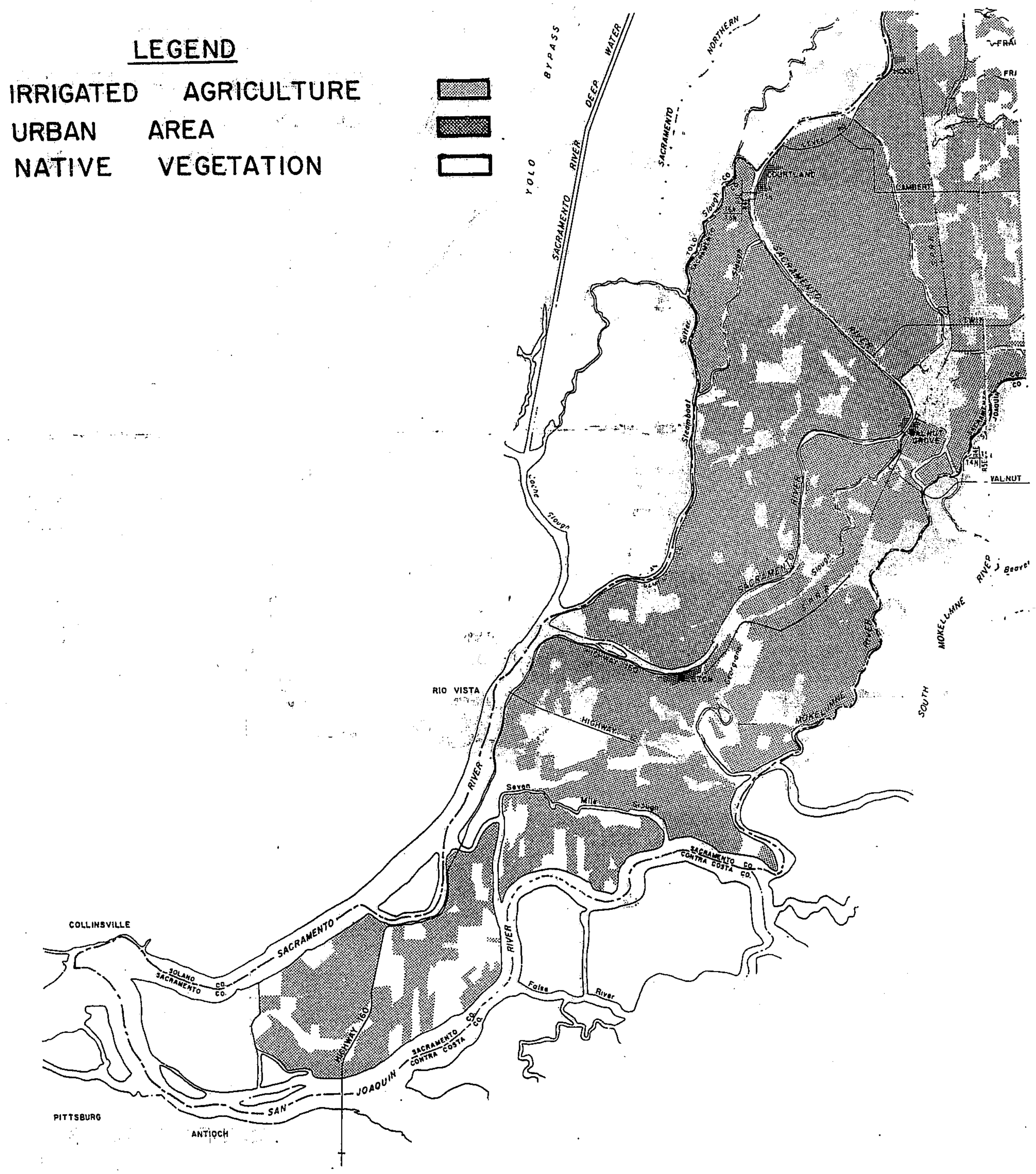
Figure 23. TYPICAL LAND CLASSIFICATION QUADRANGLE



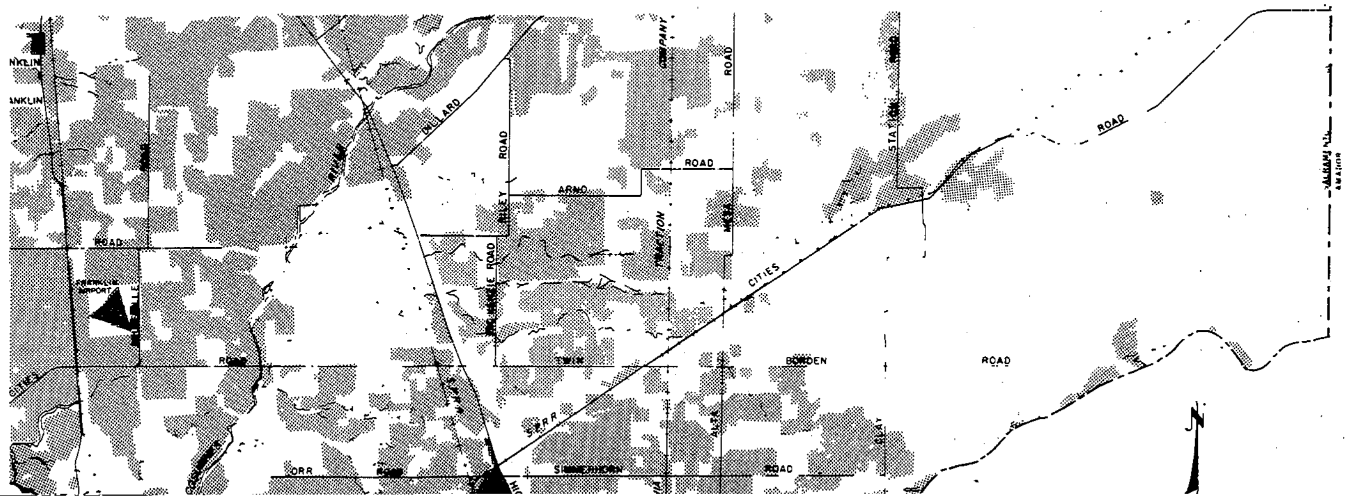
IRRIGATED AGRICULTURE


ROSEVILLE
DOUGLAS BLVD
FOLSOM RESERVOIR
SPILLWAY CREST 466'
PLACER CO
SACRAMENTO CO
LEGEND
IRRIGATED AGRICULTURE
URBAN AREA
NATIVE VEGETATION
GREENBACK
LANE
SUNRISE
BLVD
CITY FOLSOM
EL DORADO CO
SACRAMENTO CO
SPRR
HIGHWAY 50
ROAD
NIMBUS DAM
RIVER
ROCK
WHITE
ROAD
ROAD
LATROBE
JACKSON
RIVER
ROAD
ROAD
EXCELSIOR
LINE
ROAD
SPRR
SCALE OF MILES
1 0 1 2 3 4 5

& URBAN AREAS



IRRIGATED AGRICULTURE


DILLARD
ROAD
RILEY
ARNO
ROAD
COMPANY
ROAD
TRACTION
CITIES
TWIN
BORDEN
ROAD
ROAD
ORR
ROAD
SIMMERHORN
ROAD
STATION
N

Water Use

The following is a list of all water purveyors in Sacramento County. Those distributing only surface water or a mixture of surface water and ground water are noted; all others distribute ground water.

Publicly Operated:

- Arcade County Water District1/
- Carmichael Irrigation District1/
- Citrus Heights Irrigation District1/
- City of Sacramento1/
- City of Galt
- City of Folsom1/
- Clay Water District
- County Maintenance Districts
    - Arcade Oaks Terrace Water M.D.
    - Arden Park Bluffs M.D.1/
    - Arden Park Vista Water M.D.
    - Southwest Tract Water M.D.1/
    - Valley Hi Greens Water M.D.
- Del Paso Manor County Water District
- Elk Grove Water Works
- Fair Oaks Irrigation District1/
- Florin County Water District
- Galt County Water District
- Galt Irrigation District
- Northridge Park County Water District
- Omochumnes-Hartnell Water District1/
- Rio Linda County Water District
- San Juan Suburban Water District2/

Privately and Mutually Operated:

- Alex Brown Water Company
- Arvin Water Company
- Citizens Utilities Company of California
    - Citizens Arden Company
    - Citizens Suburban Company
    - Isleton Water Company
    - Lincoln Oaks Water Company
    - Parkway Water Company
    - Royal Oaks Water Company
- El Ranchito Mutual Water Company
- Fruitridge Vista Water Company
- Hood Improvement Water Company
- Locke Mutual Water Company
- Natomas Mutual Water Company2/
- Orangevale Mutual Water Company2/
- Southern California Water Company
    - Arden Water Service
    - Cordova Water Service
- Tokay Park Water Company
- Walnut Grove Estate Water Company

Unit Water Use

Unit water use figures were developed for the five basic land use groupings at the beginning of the study. These groupings are on the basis of rooting depth of crops and were made for the ease of handling and computing the land use data for the nodal areas. These basic groups of crops and their average unit applied water are listed in Table 11.

The applied water figures are representative of irrigation practices in the Sacramento area and measured headgate deliveries of 2 million acre-feet of water to nearly 9,700 land parcels comprising 820,000 acres. The data cover a span of four or more years, with the latest year 1969.

Future municipal and industrial water requirements are usually based on unit per capita water use and population projections. There are many possible sources to obtain this information. The Department has determined unit per capita water use for many areas of the State, including Sacramento County. With information gathered by this investigation, unit per capita water use figures were calculated for years 1961 through 1969. Table 12 lists these unit use figures, which range in value from 293 gallons per capita per day (gpcpd) to 377 gpcpd, with an average of 343 gpcpd. For estimating future water requirements, 340 gpcpd was used in this study.

The per capita water use figures included water used for many purposes other than domestic or industrial use. Some of these are flushing of sewers and hydrants, hydrant tapping for use of water on construction jobs, leakage in the system, and fire fighting. The foregoing may amount to 10 to 15 percent of the per capita use. Since these things which have occurred in the past most probably will occur again in the future, they should be included in the per capita water use figure.

TABLE 11

LAND USE GROUPS AND UNIT APPLIED WATER

LAND USE GROUP	CROPS	AVERAGE UNIT APPLIED WATER (Feet)
A	Beans, field, orchard, tomatoes	2.5
B	Corn, pasture, alfalfa, sugar beets	3.2
C	Truck, grain sorghum	1.8
D	Safflower and grain	0.5
E	Rice	7.8
F	Native vegetation	---
G	Urban	---

In DWR Bulletin 166-1, "Municipal and Industrial Water Use", August 1968, the reported per capita water use was 278 gpcpd in 1960. Using the average per capita water use of 343 gpcpd and the Bulletin 166-1 figure of 278 gpcpd, this increase is over 23 percent. Projecting this increase into the future by decades, the 1980 unit use will be over 400 gpcpd. This increase may be possible, but in the present period of environmental concern, it is difficult to justify. As noted previously, the unit use of water is expected to level off or slightly decrease with smaller subdivision lots and a greater concentration of apartment complexes. It is anticipated that programs of public education on the more efficient use and the value of water and even greater use of metering may be necessary to stop the increase in per capita use. Also, with the issuance of stricter waste discharge requirements, it may become an economic necessity for industry to reclaim and reuse water.

Surface Water Diversions

Surface water diversions for municipal purposes are listed in Table 13 by political subdivision. The City of Sacramento is the largest surface water purveyor, using about 50 percent of the municipal diversions. Estimates of diversions for agricultural purposes are discussed along with pumpage.

Pumpage

To augment the agricultural pumpage data for 1967-69, agricultural pumpage estimates were needed for years 1962 through 1966. These estimates were based on land use surveys. Straight line interpolations were made between the available land use surveys of 1961 and 1968 to estimate the crop pattern for each of the years. It was assumed that crops along the Sacramento River were being irrigated from surface water.

For the study, the various crops were placed into the seven crop groups based mainly on rooting depth of the crops (see Table 11). In 1961 and 1968 there were 180,623 acres and 186,759 acres, respectively, under irrigation in the Sacramento ground water basin model area, or about a 3 percent increase in irrigated agriculture. The dramatic increase was in urban land, from 63,097 acres in 1961 to 93,384 acres in 1968, or a 48 percent increase. Most of the new urban acreage came from land previously classified as native vegetation.

The computation of annual agricultural pumpage is shown in Table 14. An initial average water requirement is calculated as the product of the acreages for the various groupings and the appropriate unit water duty (Column 2, Table 14). The average ground water pumpage is calculated as the requirement not satisfied by surface water and is obtained by subtracting the sum of (1) average water requirement for the area assumed to be irrigated by Sacramento River water and (2) measured surface water diversions from the other streams in the County, from (3) the average water requirement. The final estimated ground water pumpages for

TABLE 12

ESTIMATED TOTAL AND PER CAPITA
MUNICIPAL AND INDUSTRIAL USE

Year	Surface Water Diversion Acre-Feet (1)	Municipal Pumpage Acre-Feet (2)	Surface Water[1/] Diversion and Pumpage Acre-Feet (3)	Self Produced[2/] Water by Private Companies (4)
1961	105,300	71,000	176,300	18,800
1962	106,600	73,400	180,000	19,200
1963	98,600	63,100	161,700	17,400
1964	116,400	67,300	183,700	19,800
1965	122,900	69,900	192,800	20,700
1966	134,900	82,400	217,300	23,400
1967	123,100	77,200	200,300	21,500
1968	136,600	85,200	221,800	24,800
1969	129,900	87,200	217,100	23,400

Year	Total Municipal and Industrial Water Use[3/] Acre-Feet (5)	Population Served by Public & Private Water Purveyors (6)	Per Capita Water Use (gpdcp) (7)
1961	195,100	508,000	342
1962	199,200	526,000	338
1963	179,100	547,000	293
1964	203,500	558,000	326
1965	213,500	570,000	334
1966	240,700	577,000	372
1967	221,800	583,000	339
1968	246,600	585,000	377
1969	240,500	593,000	363

Average gallons per capita per day = 340
1/ Summation of Columns 1 and 2
2/ 10.7% of Column 3
3/ Summation of Columns 3 and 4

be made; consequently the factor 6/5 or 1.2 is derived for a dry year. Conversely, during a wet year, one less application is made -- 4/5 or 0.8.

Municipal pumpages for years 1961 through 1969 are shown in Table 15. These pumpage figures include those supplied by the various districts on request and pumpages estimated by power consumption records. The figures with footnotes have been estimated through correlation, that is, relating the pumpage of one district with that of another district.

An example of this type of correlation is shown on Figure 25 for Arcade County Water District, Northridge Park County Water District, and Citizens Utilities Company. The Y-axis represents the annual pumpage of Arcade County Water District in thousands of acre-feet; the X-axis represents pumpage for Northridge Park County Water District and Citizens Utilities Company in thousands of acre-feet. After plotting the corresponding annual pumpages for the five years 1965 through 1969, the correlative lines of best fit were drawn. The correlative equations are:

Northridge P.C.W.D. = -2,190 + 0.376 Arcade C.W.D.

Citizens Utilities Co. = -6,360 + 0.832 Arcade C.W.D.

where Arcade, Northridge, and Citizens Utilities annual pumpage are in acre-feet. These equations were used to estimate annual pumpages for from 1961 through 1964 for Northridge P.C.W.D. and Citizens Utilities Co.

The estimated pumpages for Mather and McClellan Air Force Bases were estimated by using their mean values. Because no relationship could be established between other districts that have records for the years 1961 to 1969 and the military bases, the mean values were used for the missing years. In cases such as these where no correlative relationship could be established, the mean of the values

Figure 26 is a bar chart depicting the percentage of 1968 municipal and industrial pumpage by water purveyors in Sacramento County. Arcade County Water District is by far the biggest ground water user, with 23.9 percent, or almost one-quarter of total M&I ground water pumpage. The second largest user is Citizens Utilities, with 14.2 percent, followed closely by the City of Sacramento, with 13.8 percent. Mather and McClellan Air Force Bases had a combined pumpage of 11.0 percent. Northridge Park County Water District is fifth largest ground water user, with 7.4 percent, followed by Southern California Water Company (Cordova and Arden Water Service), with 7.0 percent.

TABLE 13

MUNICIPAL SURFACE WATER DIVERSIONS[1/]
SACRAMENTO COUNTY
(in Acre-Feet)

Year[2/]	City of Sacramento: Sacramento River	City of Sacramento: American River	Arcade Water District	Carmichael Irrigation District	City of Folsom	San Juan Suburban Water District	State of California	Total Municipal Surface Water Diversions
1961	41,940	--	--	8,129	23,647	31,546	--	105,300
1962	41,230	--	--	8,311	25,420	31,666	--	106,600
1963	44,424	--	--	6,653	20,189	27,300	--	98,600
1964	37,536	18,770	--	7,694	20,966	31,409	--	116,400
1965	30,075	31,489	--	9,276	20,722	31,293	--	122,900
1966	33,168	32,864	--	9,557	24,983	34,342	--	134,900
1967	31,177	30,375	1,435	8,014	20,403	31,709	--	123,100
1968	35,357	30,311	2,139	9,779	21,361	36,015	1,660	136,600
1969	34,590	30,380	2,280	8,345	18,790	35,430	1,674	129,900

1/ Data obtained from Bulletin 130, except for Arcade Water District, which were supplied by the District.
2/ Water year, October through September.

TABLE 14

ESTIMATED AGRICULTURAL PUMPAGE
SACRAMENTO COUNTY, 1962-69
(in Acre-Feet)

Calendar Year	Average Water Requirement	Average Surface Water Irrigation[a/]	Surface Water Diversion[b/]	Average Ground Water Pumpage	Weather Modifying Factors	Total Estimated Agricultural Pumpage
1962	565,800	304,800	17,000	244,000	1.2 (Dry)	293,000
1963	567,700	305,100	14,300	248,300	0.8 (Wet)	199,000
1964	569,600	305,300	17,000	247,300	1.2 (Dry)	297,000
1965	571,400	305,500	16,100	249,800	1.0 (Normal)	249,800
1966	573,300	305,800	20,900	246,600	1.2 (Dry)	296,000
1967	561,400	306,000	18,900	236,500	0.8 (Wet)	189,200[c/]
1968	527,000	306,300	27,300	193,400	1.2 (Dry)	232,100[c/]
1969	639,300	306,800	26,500	306,000	0.8 (Wet)	244,800[c/]

a/ Estimated amounts from Sacramento River.
b/ American River, Cosumnes River, Mokelumne River, and Snodgrass Slough.
c/ Estimated by USGS from power consumption.

TABLE 15

SACRAMENTO COUNTY
ESTIMATED MUNICIPAL PUMPAGE IN ACRE-FEET

	1961	1962	1963	1964	1965	1966	1967	1968	1969
Rio Linda County Water District	670[a]	630[a]	650[a]	651	885	815	944	962	939
Citizens Utilities Co.	7,200[b]	7,600[b]	7,030[b]	9,049	9,580	11,448	11,647	12,117	12,678
Citrus Heights Irrigation District	1,670[c]	2,037	1,880	1,970	1,229	1,649	1,268	1,762	1,557
Arcade Water District	16,277	16,766	16,108	18,878	18,848	22,101	19,269	20,346	20,557
Sacramento County Maintenance District	2,880[b]	3,020[b]	2,850[b]	3,540[b]	3,530[b]	4,350[b]	3,980[b]	4,300	4,440
Fruitridge Vista Water Company	2,780[d]	2,830[d]	2,800[d]	2,721	2,890	3,279	3,060	3,137	3,409
Del Paso Manor County Water District	1,465	1,520	1,480	1,430	1,680	1,850	1,670	1,840	1,920
Northridge Park County Water District	3,940[b]	4,120[b]	3,880[b]	4,910[b]	4,900	5,930	5,540	6,250	6,645
Elk Grove Water Works	650	608	629	773	752	896	841	911	975
Mather AFB	4,000[c]	4,000[c]	4,000[c]	4,000[c]	3,499	4,114	3,855	4,460	4,008
McClellan AFB	4,655[c]	4,655[c]	4,668	4,592	4,390	4,585	4,467	4,936	4,948
Carmichael Irrigation District	400[f]	400[f]	400[f]	400[f]	466	492	636	897	1,073
City of Sacramento South of American River	12,000	13,300	4,750	455	445	660	670	700	580
City of Sacramento North of American River	3,000[a]	2,000[a]	2,500[a]	4,000	5,820	7,850	7,970	9,360	10,000
City of Sacramento Northgate	690[d]	830[d]	720[d]	1,450	1,080	1,190	970	1,730	1,730
Fair Oaks Irrigation District	1,300[d]	1,320[d]	1,310[d]	1,290[d]	1,380[d]	1,400[d]	1,377	1,537	1,378
Arvin Water Company	1,790[d]	1,880[d]	1,820[d]	1,780[d]	2,020	2,310	2,250	2,470	2,660
Arden Water Service	490[d]	600[d]	520[d]	420[d]	910[d]	1,240[d]	889	1,310	1,299
Cordova Water Service	3,750[d]	3,900[d]	3,790[d]	3,660[d]	4,207	4,891	4,418	4,689	4,994
Miscellaneous[e]	1,400	1,400	1,400	1,400	1,400	1,400	1,400	1,400	1,400
Total[g]	71,000	73,400	63,100	67,300	69,900	82,400	77,200	85,200	87,200

a - Correlated with Elk Grove
b - Correlated with Arcade
c - Estimated using mean value
d - Correlated with Del Paso Manor
e - Estimated pumpage for Del Paso and Northridge Golf and Country Clubs and Tokay Park Water Company
f - Assumed values
g - Rounded to the nearest hundred

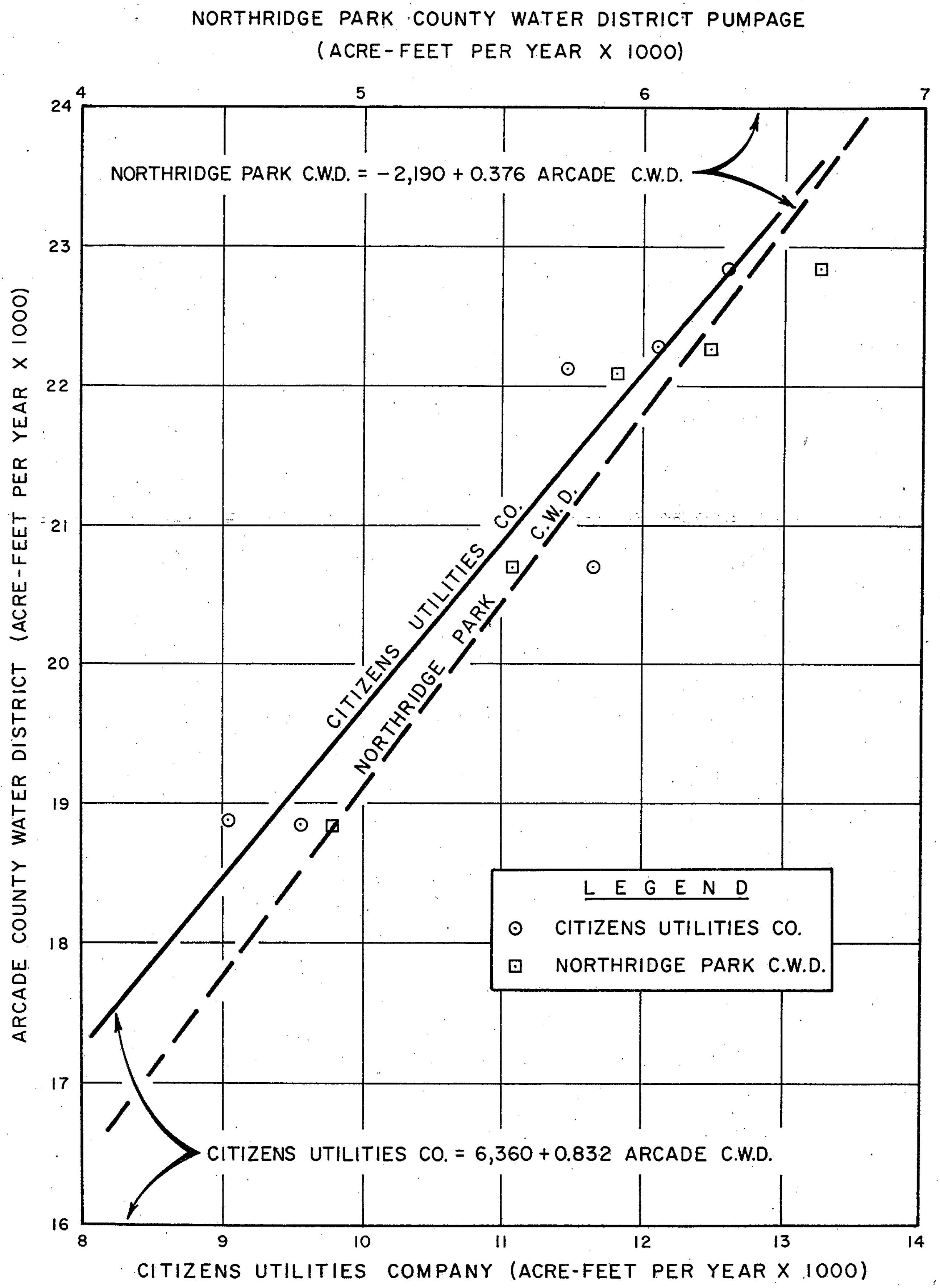


Figure 25. ANNUAL PUMPAGE CORRELATION

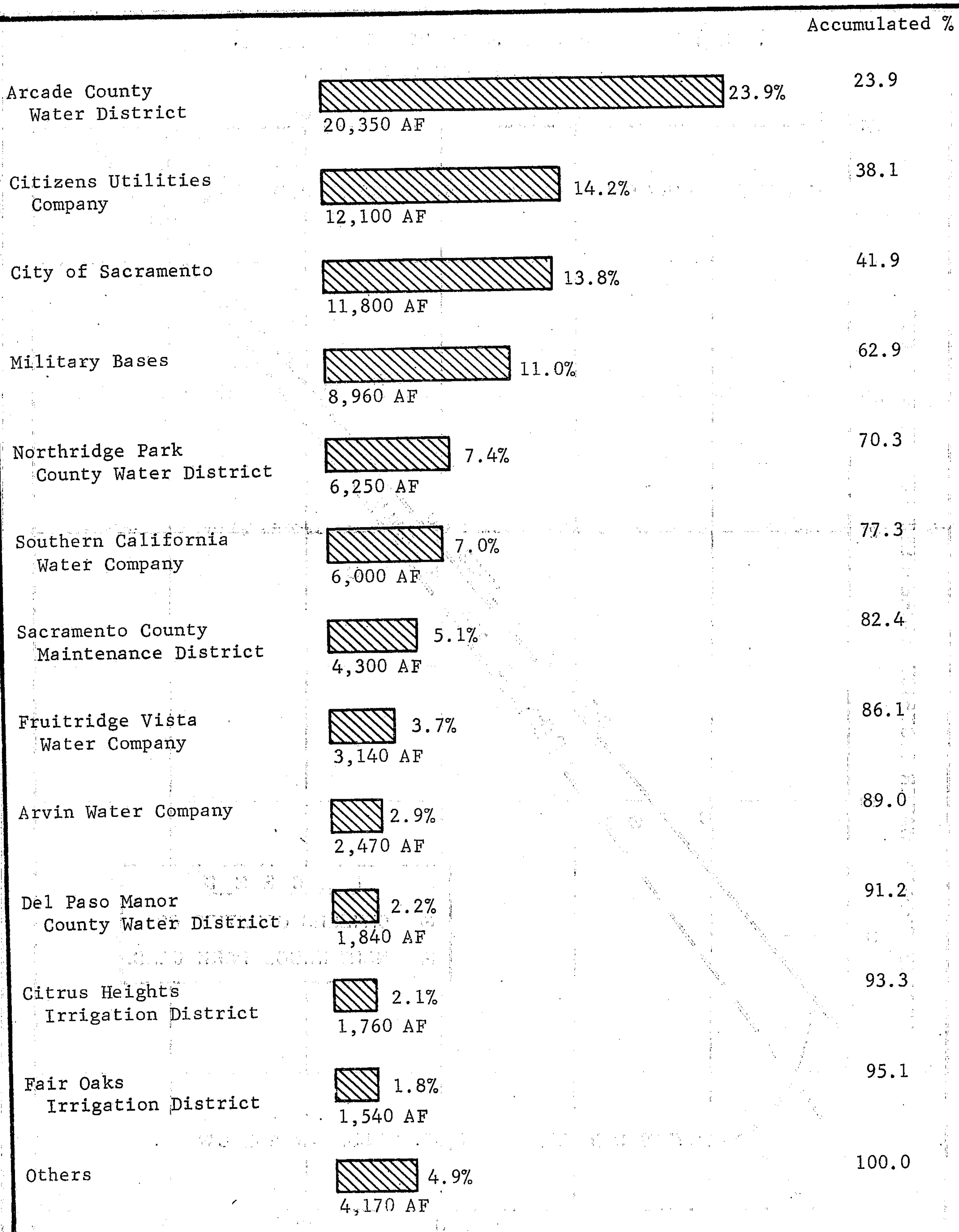


Figure 26. 1968 MUNICIPAL AND INDUSTRIAL PUMPAGE

average unit water use is about 3.1 acre-feet per year if the rice water requirement is included. If the above average rice water requirement is excluded, the unit water requirement is 2.8 acre-feet per year.

Municipal and industrial water use is about 258,100 acre-feet per year, with ground water supplying 53.5 percent of the M&I use, or 138,000 acre-feet.

Recharge

Recharge to the ground water basin is derived from three major components -- precipitation, applied water, and streamflow. Precipitation is the general term for all forms of moisture emanating from the clouds and falling to the ground. In Sacramento County precipitation usually occurs as rainfall. Once the rain hits the ground, it can evaporate, become streamflow, or infiltrate.

Applied water is a general term for all forms of water applied by man to the ground to irrigate crops. In general, about 65 percent of all irrigation water is consumptively used by plants for vegetative growth. Thus, about 35 percent of all irrigation water is available for percolation, evaporation, runoff, etc. Depending on the soil, about 10 to 25 percent of the irrigation water infiltrates the ground water basin.

Streamflow will usually recharge an underlying ground water basin. Since the ground water elevations throughout the County are lower than the stream water surface elevation, all the rivers and streams in the County should theoretically recharge the ground water body if no impervious surface impedes the downward flow path. Due to the tidal regimen of the lower portions of the main rivers, they cannot be gaged for outflow, and hence a direct measurement of total stream recharge within the study area is not possible.

Recharge from Rain and Applied Water

A soil moisture balance was used for computing unit deep percolation for each crop according to its potential evapotranspiration, rooting depth, and unit applied water. Applied water was adjusted for each year according to the index of wetness. Because this program calculated the unit deep percolation for individual crops, a subsequent breakdown of Land Use Group A and Group B was made. Land Use Group A was divided into field, deciduous (orchard), and tomatoes, and Land Use Group B was divided into pasture, sugar beets, and corn.

Data input required for the soil moisture balance program are: (1) potential evapotranspiration; (2) rainfall; (3) evaporation of rain on impervious soil; (4) evaporation of rain on pervious soil; (5) evaporation of irrigation water on pervious soil; (6) applied water; (7) rooting depth; (8) moisture per foot of soil; (9) irrigation efficiency; and (10) percent impervious area.

In the foregoing list, the first six items required monthly data from October through April; during the growing season it is taken care of as a whole. The potential evapotranspiration data was based on Department Bulletin 132-2, "Vegetative Water Use", dated August 1967, and applied water data was based on a Department Memorandum Report dated August 1970, "Irrigation Use and Practices in Central District".

Average precipitation varies from 15 inches to 26 inches in Sacramento County. In order to take the precipitation variation into account, the study area was divided into four sectors -- northwest, northeast, southwest, and southeast -- as shown in Figure 27. Elkhorn Ferry, Represa, Central Valley Fish Hatchery, and Sloughhouse rain gages represent the northwest, northeast, southwest, and southeast, respectively.

Different crops have different root depths and varying rooting depth is directly related to the ability of the plant to gather moisture from the soil profile. The computer program compares the available water from rainfall and irrigation against the water required for evapotranspiration and soil moisture deficiency. If there is any excess water on pervious land, it is considered to be deep percolation. Percolation was computed by month during the rainy season, October through April. The growing season, May through September, was considered as a single unit.

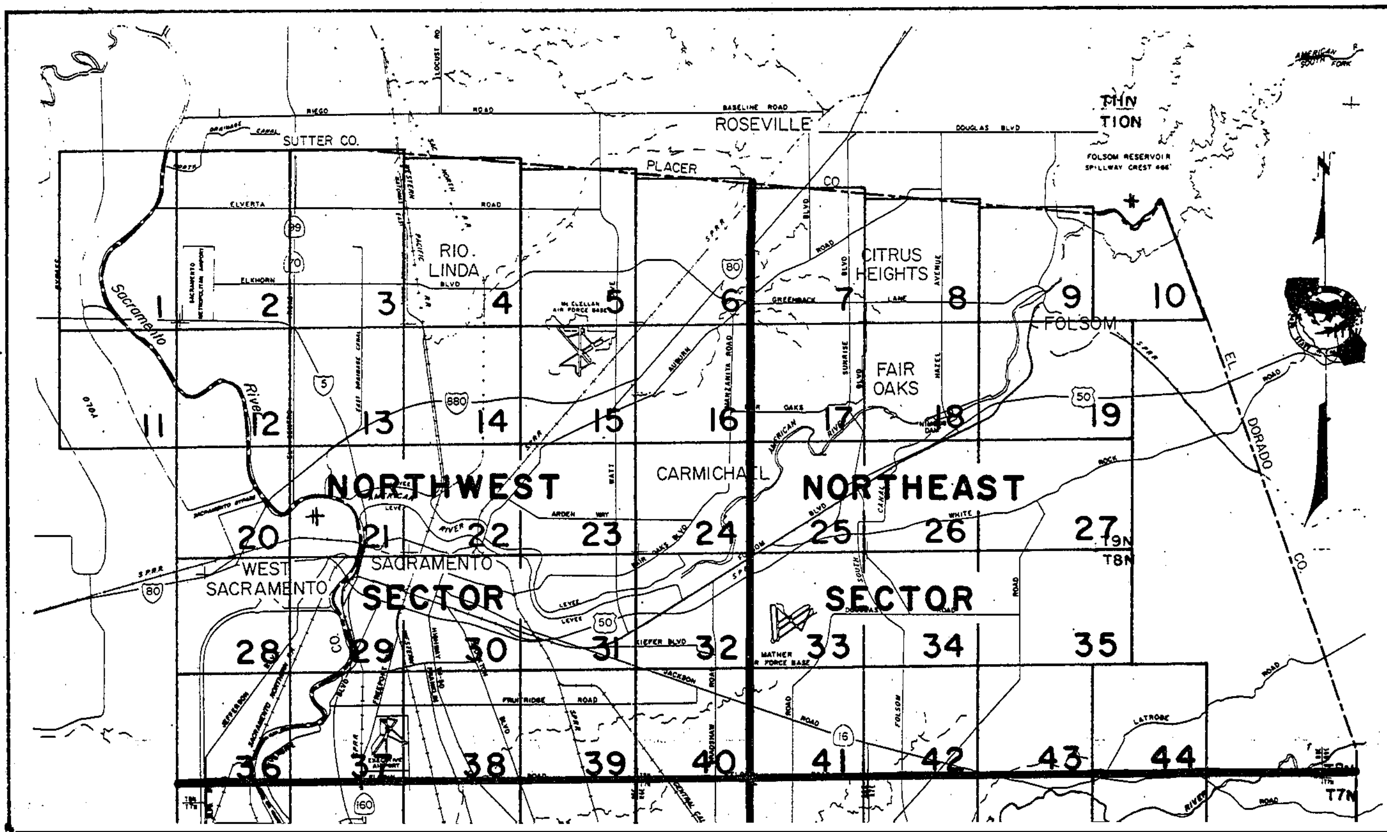
The unit values of deep percolation for various crops were checked and increased where necessary to include a minimum of 20 percent of the applied water. This was necessary to compensate for more of the irrigation water infiltrating at the beginning of the growing season due to shallow rooting depths of the new plants.

The rainfall on impervious areas remaining after evaporation was assumed to be runoff. Ten percent of the agricultural and native vegetation areas is estimated to be impervious and 50 percent of the urban area is impervious. In the urban area, 20 percent of the runoff from the impervious area ran onto adjacent pervious areas and was used by the plants, evaporated, or became deep percolation.

The annual unit values of deep percolation from the combination of rain and applied water for each of the five agricultural groups of land uses is listed in Table 16.

Recharge from Streamflow

The traditional method to calculate streamflow recharge is to subtract the upstream gage and local inflows from the downstream gage. For the County there are two such sets of stream gaging stations from which recharge could be calculated. These are on the American River and Cosumnes River. On the American River, flow measurements are made at the American River at Fair Oaks gage, which is downstream from Nimbus Dam. A continuous stage recorder is installed at H Street for flood forecasting. Supplemental measurements to determine flows at this station were discontinued in 1960. In order to obtain the flow at H Street, it was necessary to establish a relationship between gage readings (height of flow) and quantity of flow. Because the H Street recorder is affected by tidal backwater, a downstream gage is necessary to determine the hydraulic gradient downstream from the H Street gage. A stage recorder was installed on the American River at the Elvas Railroad Crossing to ascertain if backwater was affecting the flow at the H Street gage. If there were tidal effects at Elvas, it would reflect a small hydraulic gradient between H Street and Elvas, thereby decreasing the streamflow.



SUTTER CO.
PLACER
CO.
ROSEVILLE
RIO LINDA
CITRUS HEIGHTS
FOLSOM
FAIR OAKS
CARMICHAEL
NORTHWEST
SECTOR
NORTHEAST
SECTOR
WEST SACRAMENTO
SACRAMENTO
Sacramento River
EL DORADO CO.
FOLSOM RESERVOIR SPILLWAY CREST 466'
T9N
T8N
T7N
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TABLE 16

UNIT DEEP PERCOLATION

NORTHWEST SECTOR
In Feet

Land Use Symbol	LUA			LUB			LUC	LUD	LUE
	F	D	T15	P	F5	F6	T&F7	F2&G	R
1961	0.33	0.10	0.19	0.76	0.96	0.76	0.33	0.01	2.31
1962	0.61	0.58	0.40	0.86	1.28	0.86	0.61	0.36	2.39
1963	0.90	0.88	0.66	0.62	1.00	0.62	0.90	0.61	1.41
1964	0.09	0	0.17	0.49	1.12	0.49	0.09	0.22	2.13
1965	0.36	0	0.27	0.56	0.94	0.56	0.36	0.25	1.20
1966	0.12	0	0.18	0.52	1.10	0.52	0.12	0	2.13
1967	0.94	0.60	0.72	0.97	1.04	0.97	0.94	0.63	1.36
1968	0	0	0.19	0.45	0.73	0.45	0	0.04	1.88
1969	1.01	0.81	1.01	1.35	1.53	1.35	1.01	0.73	1.93
1970	0.58	0.58	0.69	1.03	1.21	1.03	0.58	0.38	1.68

NORTHEAST SECTOR
In Feet

Land Use Symbol	LUA			LUB			LUC	LUD	LUE
	F	D	T15	P	F5	F6	T&F7	F2&G	R
1961	0.40	0.09	0.40	0.62	0.62	0.62	0.40	0.18	2.13
1962	0.58	0.60	0.58	0.73	0.73	0.73	0.58	0.45	2.22
1963	0.51	0.73	0.51	0.40	0.51	0.51	0.51	0.37	0.96
1964	0.24	0.11	0.24	0.49	0.49	0.49	0.24	0.18	2.08
1965	0.48	0.63	0.48	0.59	0.59	0.59	0.48	0.54	1.19
1966	0.32	0.36	0.32	0.54	0.54	0.54	0.54	0.28	2.04
1967	0.72	0.97	0.72	0.76	0.76	0.72	0.76	0.90	1.16
1968	0	0	0	0.21	0	0	0	0.11	0.80
1969	0.91	0.85	0.91	1.16	1.16	1.16	0.91	1.25	1.68
1970	0.27	0.36	0.27	0.53	0.53	0.53	0.27	0.49	1.06

Table 16 (continued)

SOUTHEAST SECTOR
In Feet

Land Use Symbol	LUA			LUB			LUC	LUD	LUE
	F	D	T15	P	F5	F6	T&F7	F2&G	R
1961	0.64	0.27	0.64	0.84	1.35	1.35	0.64	0.18	2.40
1962	0.95	0.93	0.95	1.11	1.69	1.69	0.95	0.56	2.65
1963	0.75	0.85	0.75	0.63	0.99	0.99	0.75	0.36	1.29
1964	0.40	0.15	0.40	0.61	1.34	1.34	0.40	0.40	2.26
1965	1.09	1.17	1.09	1.19	1.80	1.80	1.09	0.86	1.95
1966	0.59	0.57	0.59	0.75	1.35	1.35	0.75	0.36	2.31
1967	1.36	1.47	1.36	1.35	1.35	1.35	1.26	1.26	1.95
1968	0.22	0	0.22	0.45	0.91	0.45	0.45	0.25	1.89
1969	1.62	1.53	1.62	1.79	2.30	1.79	1.79	1.56	2.43
1970	0.78	0.78	0.78	0.94	1.35	0.94	0.94	0.76	1.59

SOUTHWEST SECTOR
In Feet

Land Use Symbol	LUA			LUB			LUC	LUD	LUE
	F	D	T15	P	F5	F6	T&F7	F2&G	R
1961	0.44	0	0	0.44	0.73	0.44	0.33	0	2.02
1962	0.71	0.22	0.45	0.71	1.26	0.71	0.61	0.06	2.27
1963	0.45	0.58	0.45	0.45	0.67	0.45	0.90	0.38	1.05
1964	0.36	0	0	0.36	0.99	0.36	0.09	0.07	1.99
1965	0.54	0.31	0	0.54	1.03	0.54	0.36	0.35	1.27
1966	0.37	0.13	0	0.37	0.98	0.37	0.12	0	1.96
1967	0.67	0.63	0.22	0.67	0.71	0.67	0.94	0.34	1.10
1968	0.15	0	0	0.45	0.91	0.45	0	0.04	1.89
1969	1.02	0.37	0.49	1.02	1.44	1.02	1.01	0.51	1.68
1970	0.49	0.23	0.23	0.49	0.84	0.49	0.58	0.04	1.11

Under backwater effects, the flow discharge at the H Street gage is calculated with a ratio discharge curve developed by the U. S. Geological Survey in 1958. Using their methods and their rating curve, dated 1958, the flows of the American River at H Street were calculated for the period 1962 through 1969.

The incremental drainage area between the Fair Oaks gage and the H Street gage is some 30,000 acres. Local inflows, including local runoff and sewage outflow from the sewage treatment plants, and outflows, such as diversions out of the river by Carmichael Irrigation District, the City of Sacramento, and farmers for irrigation, must be accounted for. In addition, there are natural outflows in the riverbank area consisting of water consumed by over 600 acres of phreatophyte growth and evaporation from the water surface. Sewer outflows were obtained from the County. Diversion records from the river were obtained from DWR Bulletin 130. There were many unnamed tributary areas into the American River in this incremental area. Flows in these channels were computed using the rational method based on runoff factors developed from Arcade Creek at Del Paso Park gage.

By accounting for all of the inflows and outflows from the American River, the annual recharge for the years 1962 through 1969 were estimated; these are shown on Table 17.

TABLE 17

FIRST APPROXIMATION OF STREAM RECHARGE
AMERICAN AND COSUMNES RIVERS
(in acre-feet)

YEAR	AMERICAN RIVER	COSUMNES RIVER
1962	185,600	39,900
1963	370,800	80,000
1964	229,800	28,500
1965	409,500	106,800
1966	390,600	33,600
1967	449,100	132,700
1968	540,400	34,800
1969	689,400	123,300
Average	408,200	72,500

For the Cosumnes River the situation is similar to that of the American River. There is an upstream gage at Michigan Bar and a downstream gage at McConnell Station. The records at these two gages are considered accurate by the U. S. Geological Survey, except during the summer months. There are diversions for irrigation purposes between the two stations; the incremental drainage area is 188 square miles. Table 16 presents estimated stream recharge for the American and Cosumnes Rivers for the years 1962 through 1969.

Subsurface Flow

The 1968 ground water surface contours shown on Figure 17 indicate that there is no subsurface flow in or out of the County on its western and southern boundaries because the Sacramento River and Dry Creek both are losing streams. On the eastern boundary there is no subsurface inflow due to the presence of nonwater-bearing crystalline and metamorphic rocks. Along the eastern half of the north county boundary, ground water contours are more or less normal to the county line, indicating a no-flow boundary. There is a pumping depression along the western portion of the north county line. The center of the depression is in Sutter County, with the ground water gradient sloping northward from Sacramento County. This is the only subsurface outflow from the County.

Available Storage

The available storage capacity is computed from the ground surface to the bottom of the Mehrten Formation, which is considered to be the base of fresh water for this investigation. The bottom of the Mehrten Formation is defined in the eastern foothill through interpretation of well drillers logs; however, the western boundary could not be defined due to a lack of data. By projecting the angle of dip of the Mehrten Formation, the bottom of the formation could be estimated for the center of each quarter township. Figure 28 shows the contoured base of the Mehrten Formation as projected. The thickness of alluvium was calculated for each quarter section and an average thickness of 880 feet was calculated for the model area. There are 559,365 acres in Sacramento County. Using an average specific yield of 7.5 percent, the total ground water storage capacity of the County is about 37,000,000 acre-feet, exclusive of the Delta area. In the Delta, which encompasses 45,008 acres, the storage capacity is about 1,000,000 acre-feet, based on a depth of 300 feet to the base of fresh water and an average specific yield of 7.5 percent. The amounts of ground water in storage in the 1930 to 1968 interval are shown in Table 18.

TABLE 18

GROUND WATER IN STORAGE ABOVE BASE OF MEHRTEN FORMATION

YEAR	AVERAGE DEPTH TO WATER (feet)	GROUND WATER IN STORAGE (million acre-feet)
1930	22	37.0
1932-1942	24	36.9
1968	58	35.5

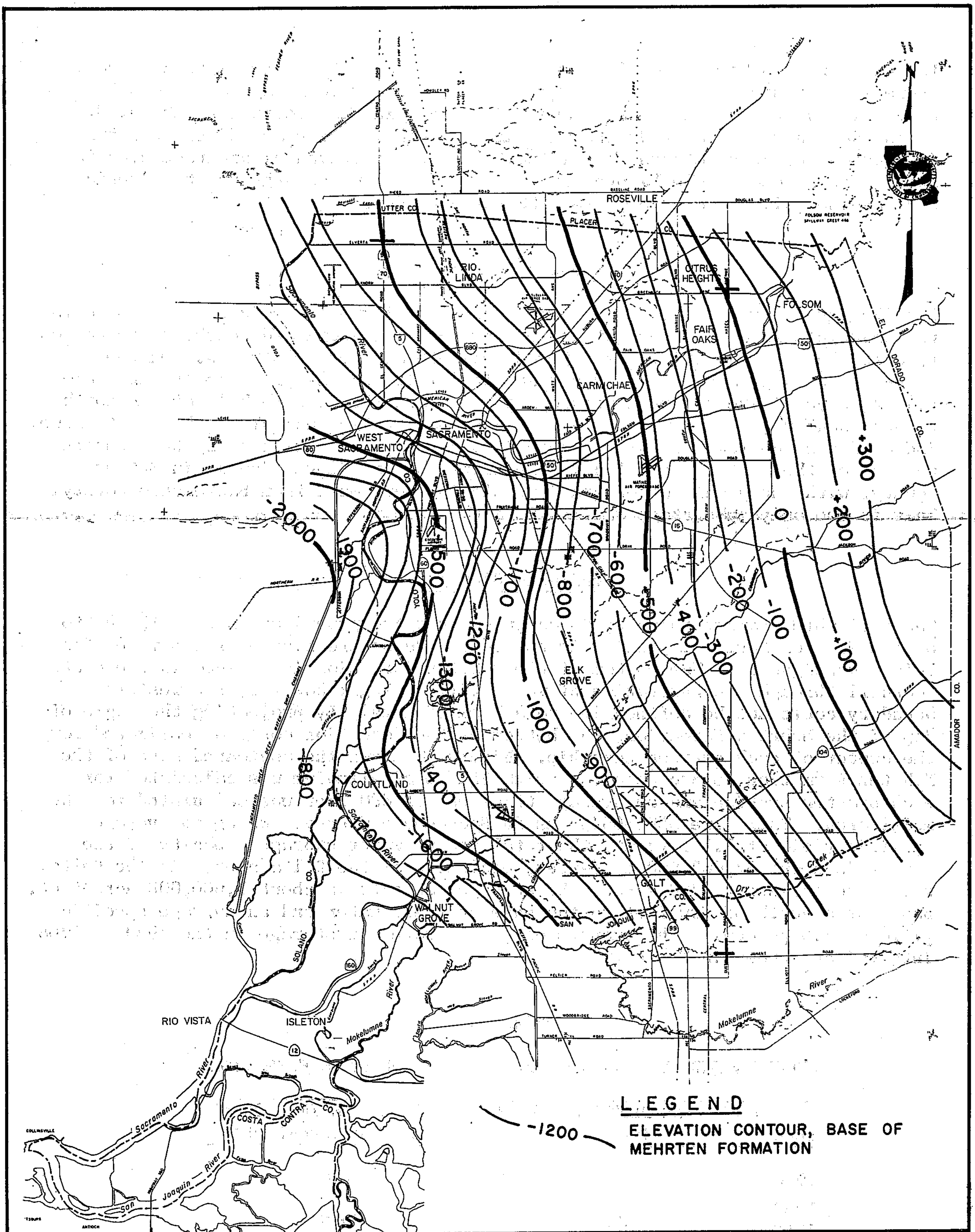


Figure 28. ELEVATION CONTOURS ON BASE OF MEHRTEN FORMATION

Change in Storage

Change in storage can be computed from the change in water levels. The method used in determining the change in storage was sum the products of the average specific yield value times the annual changes in water levels for quarter section. The average specific yield values were determined by a computer program for each nodal area. The change in water level elevations was determined from spring water level contour maps. Estimated annual changes in storage in acre-feet for the study period 1962 through 1968 are listed on Table 19. Using the average specific yield of 7.5 percent, the average decline in water level is about 0.5 foot per year.

Hydrologic Balance

Hydrology is an earth science concerned with the distribution and occurrence of water on and under the earth's surface, that is, with "what happens to the rain". A hydrologic balance is concerned with the supply and disposal of water within that system. In making a hydrologic balance, there are three different references or concepts which may be used. These three concepts, shown on Figure 29, are: (1) watershed, (2) ground water basin, and (3) ground water body. Each of these concepts has its particular advantages and uses. The watershed concept eliminates most of the need for streamflow data, but makes necessary, reliable estimates of consumptive use of native vegetation. The ground water basin concepts require streamflow data, but not pumpage information. The ground water concept eliminates all surface water items but requires deep percolation data.

TABLE 19

ANNUAL CHANGE IN STORAGE
FOR STUDY AREA

Water Year	Annual Change in Storage (acre-feet)
1962	- 19,650
1963	51,510
1964	-170,960
1965	29,560
1966	-196,200
1967	303,440
1968	-157,700
Summation	-160,000
Average Annual	- 22,860

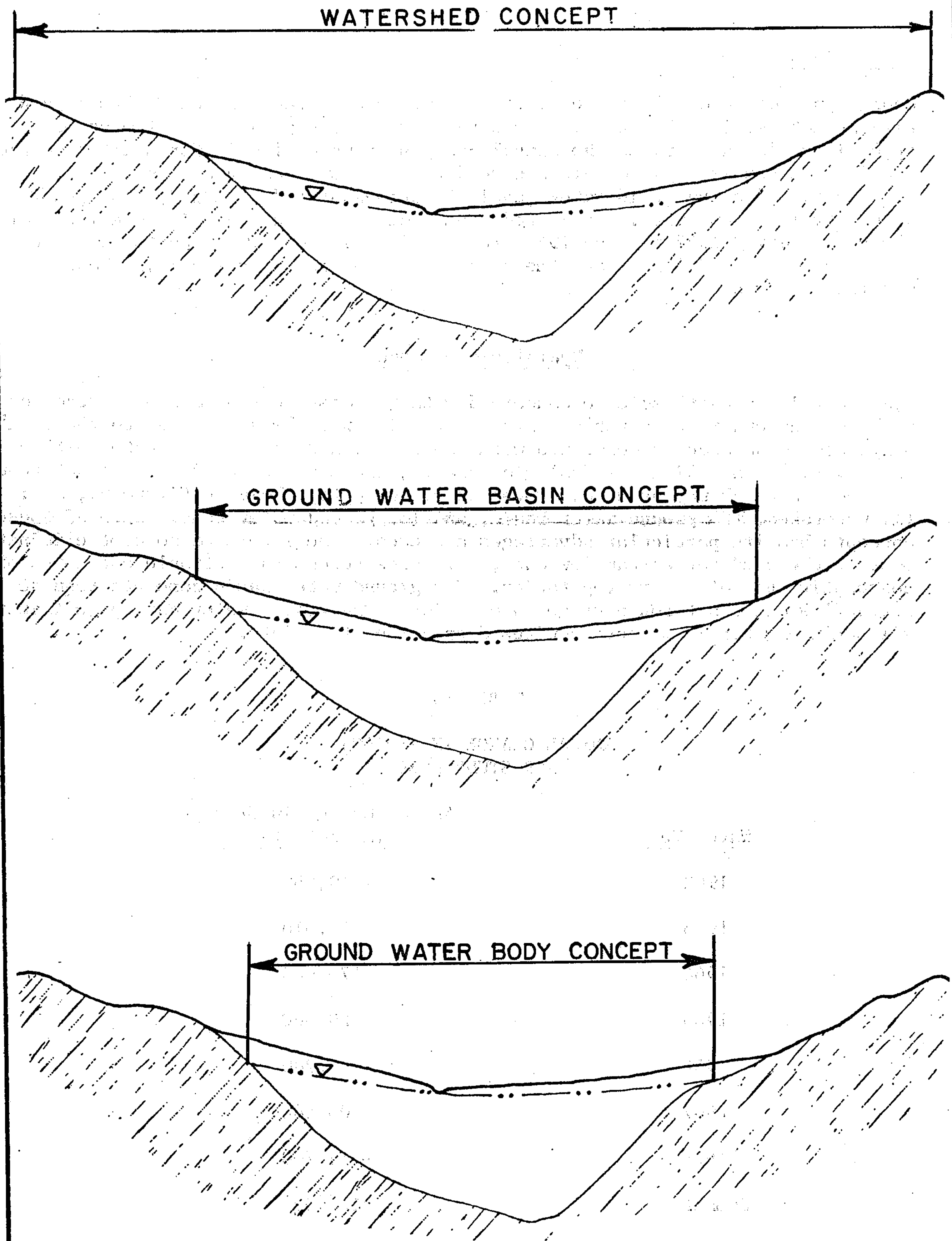


Figure 29. THREE CONCEPTS FOR HYDROLOGIC BALANCE

Since surface outflow data are not available, the reference chosen is the ground water body. The data required to determine the hydrologic equation are: (1) the change in storage of the ground water basin; (2) deep percolation (water reaching the ground water basin from precipitation, applied water, and streamflow); (3) ground water withdrawals (pumpage by all pumping plants -- municipal, agricultural, industrial, etc.); and (4) net amounts of subsurface flow into and from adjacent ground water areas.

The initial hydrologic balance shown on Table 20 was made, taking into account the relative reliability of the various data. The most reliable data are annual changes in the amount of water in storage, since this is based on measured water levels and estimated specific yields. The probable error in specific yields is slight.

Annual amounts of pumpage also are considered reliable, particularly during the last three years, because municipal and industrial pumpage is metered and the last three years of agricultural pumpage is based on power records. Earlier years of agricultural pumpage is an extension of the last three years, taking into account land use changes and weather changes. Domestic pumpage is relatively small and errors hence would be minimal.

Recharge from rain and applied water is considered less accurate than change in storage and pumpage. The annual amounts of recharge are the product of the unit depths of recharge and the acreage of the appropriate land use. The unit recharge values contain adjustments for the amount of water applied as a function of monthly rainfall, but are not adjusted for micro-climatic effects. The unit recharge values assume no impedence of percolation by the subsoil, a condition which may not prevail over the majority of the study area.

TABLE 20

INITIAL HYDROLOGIC BALANCE
(in 1,000 Acre-Feet)

Year	Pumpage	Change in Storage	Recharge: Irrigated Agriculture	Recharge: Urban	Recharge: Native	Recharge: Stream
1962	417.2	- 19.7	161.4	17.4	165.0	53.7
1963	317.6	51.5	137.4	14.9	124.5	92.3
1964	422.2	-171.0	93.0	8.0	82.8	67.4
1965	385.6	29.6	121.8	14.1	203.2	76.1
1966	449.4	-196.2	98.8	4.7	86.7	63.0
1967	337.5	303.4	160.1	48.7	336.7	95.4
1968	397.1	-157.7	80.0	4.9	71.6	82.9
Average	389.5	- 22.9	121.8	16.1	152.9	75.8

The least accurate item is the recharge from streams and runoff. Poor accuracy in estimates of runoff is due primarily to inaccuracy of some stream gages and the lack of gaging stations to measure total surface outflow from the study area. The stream and runoff recharge was therefore computed as the residual item in the initial hydrologic balance.

Mathematical Model

A mathematical model is a method of describing a physical system. It should react to stimuli exactly as does the real system. In the case of a ground water basin, it is often too expensive to operate on a trial and error basis. Some other means of determining how the ground water basin will react to differing conditions is necessary. Using a high speed digital computer and sophisticated modeling techniques, a mathematical model computer program was developed to simulate the ground water basin.

The model is a set of linear differential equations that define the flow and storage of ground water. The equations are used to determine the reaction of water levels in a ground water basin to annual amounts of net recharge (water inflow minus outflow). Items of inflow are recharge from precipitation, irrigation, and streamflow. Items of outflow are pumpage and subsurface outflow. To form the equations, the basin and its hydrologic history are subdivided into nodes, flow paths, and time increments. Given the initial water levels and a set of net recharge values, the model will operate over the study period.

A generalized ground water equation that could define the storage, transmissivity, and water inflow-outflow characteristics first was developed for the Los Angeles Coastal Plain study. A discussion of the details of the computer application and the derivation of the generalized ground water equation is presented in Attachment 5 to Appendix C, Bulletin 104, "Planned Utilization of Ground Water Basins: Coastal Plain of Los Angeles County", dated December 1966. The equation shown on Figure 30 defines the storage and transmissive characteristics of any unit area of the ground water basin.

EQUATIONS

INFLOW — OUTFLOW = ± CHANGE IN STORAGE

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

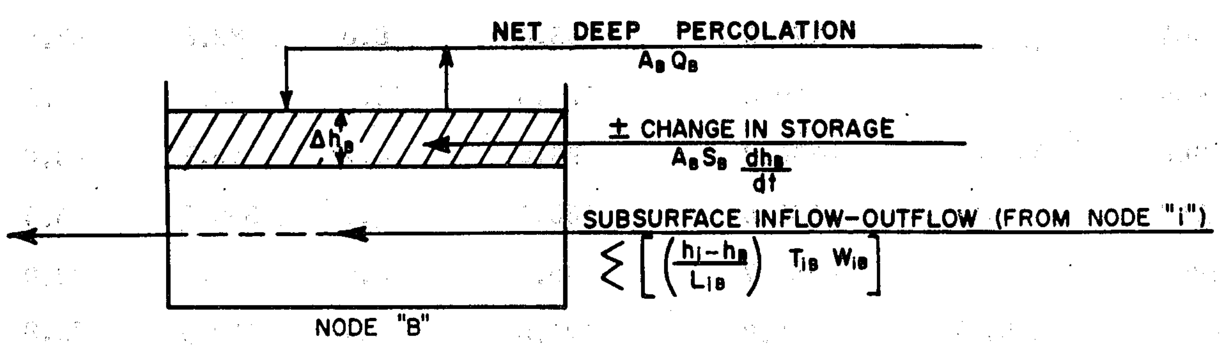


Fig. 30. SCHEMATIC SKETCH OF GENERALIZED GROUND WATER FLOW EQUATION

Figure 30 also shows the relation of the items in the equation. The symbol definitions are as follows:

h_i = water level elevation associated with node i, in feet

h_B = water level elevation associated with node B, in feet

$T_{i,B}$ = transmissivity at midpoint between nodes i and B, in $\frac{\text{acre-feet}}{\text{year foot}}$

$W_{i,B}$ = length of perpendicular bisector associated with nodes i and B, in feet

$L_{i,B}$ = distance between nodes i and B, in feet

A_B = area associated with node B, in acres

Q_B = flow rate net deep percolation per unit area at node B, in $\frac{\text{acre-feet}}{\text{year acre}}$

S_B = storage coefficient of polygonal zone associated with node B (dimensionless)

t = time, in years

The first term on the left-hand side of the equation shown in Figure 30 is the summation of the subsurface flows between a given unit area and its surrounding areas. The second term describes the surface flow rate from the ground surface into or out of the zone of saturation of the given unit area. The rate of change in storage is given by the right-hand expression. A set of these differential equations, one for each unit within the basin, with proper coefficients, forms the mathematical model of the ground water basin.

The mathematical model for Sacramento County contains 102 polygonal areas or nodes. The entire modeled area contains 618,860 acres, of which 59,495 acres are in Yolo County. The model has an average nodal area of 6,067 acres. Figure 31 shows the nodal pattern. The original pattern was on a 3-mile by 3-mile grid. As the study progressed, this pattern was modified to its present form by combining standard size nodes with very small nodes along the edges. The nodes on the northern boundary are irregular because of the irregular county line. Nodes along the eastern boundary are irregular because of the contact between the water-bearing and nonwater-bearing rocks.

The model treats the County as a free ground water body. This is not strictly correct because there are areas in the County where drillers have found a rise in water levels after further drilling, a condition indicative of some confinement of ground water. Due to insufficient water level and pumpage data, input for a model of two or more layers could not be developed. Analysis of water levels for separate aquifers indicated very small differences in water levels, thus modeling

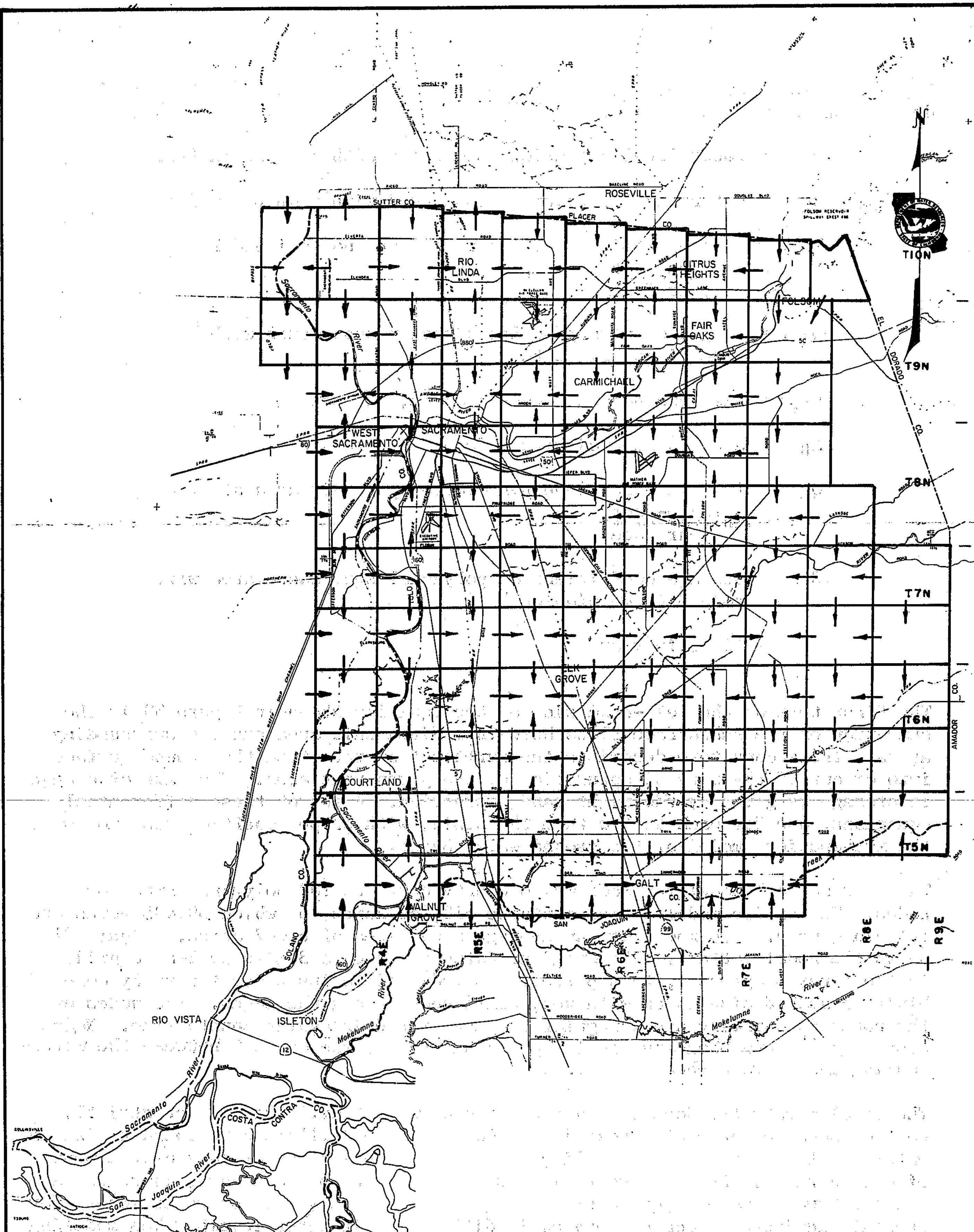


FIGURE 31. DIRECTIONAL FLOW OF BRANCHES FOR THE GROUND WATER MODEL

the ground water system as a single-layer free ground water body is reasonable, particularly when the time interval between data points is one year.

Transmissivity values were estimated using a relationship between specific yield and permeability. This relationship was derived for the digital model of Livermore Valley and is described in some detail in Department of Water Resources Bulletin 118-2, "Livermore and Sunol Valleys: Evaluation of Ground Water Resources", January 1974. The values for permeability which were used in the current study are presented on Table 21.

TABLE 21

PERMEABILITY

Specific Yield (percent)	Permeability (gal/day/ft^2)
3	1
5	30
10	400
15	800
20	1,200
25	1,500

If the above values for permeability are plotted on a chart, a curve results. Equations describing the curve were derived for input into the computer. The curved portion of the graph, for specific yield values from 3 to 10, is described by the equation:

$$\Delta T = \Delta D \cdot 10^{\,3.5319 - \frac{7.16288}{|SY| - 0.84}}$$

and the straight-line portion, for specific yield values greater than 10, is described by the equation:

$$\Delta T = \Delta D \cdot (100\ |SY|\ - 500)$$

where: ΔT = incremental transmissivity,
ΔD = incremental depth, and
$|SY|$ = absolute value for average specific yield for given interval.

A computer program was written to accept the specific yield data which had been coded for the geological deposition program. Output of the program was transmissivity values for each node to the bottom of the data. These transmissivity values were for flows along the depositional channels; these were modified to apply to each nodal branch. For this study a transmissivity modifying ratio of ten to one was adopted, i.e. ten in the direction of the deposition channel to one at right angles to that direction.

For most of the nodes there were insufficient well data to define the transmissivity values to the bottom of the Mehrten Formation, which is considered the base of fresh water. In these cases, the data to extrapolate the transmissivity values to the base of the Mehrten Formation were obtained from the upstream or upslope nodes.

Development and Verification of Mathematical Model

The general steps taken in the development and verification of the mathematical model were as follows:

1. The Sacramento County ground water area was subdivided into nodes on 3-mile by 3-mile centers (see Figure 31).

2. Geologic data were analyzed and the transmissivity factors between nodes and the storage factors within each node were determined, using the directional stream channel deposition patterns shown on Figures 3 and 5.

3. Historical surface hydrologic data were analyzed and the seasonal net deep percolation at each node was determined for the period 1961-62 through 1967-68. Also, hydrographs of representative ground water level fluctuations during the same period were prepared for each node based on measurements of historic ground water level elevations.

4. Using the DWR computer (CDC-3300), problem parameters were placed in the computer and the model was tested. The testing process consisted of matching the water level elevations generated by the computer, using historic hydrologic input data, with historic water level elevations.

5. Based on the information developed during the testing period, final verification was achieved when machine-computed water level elevations and historic water level elevations matched.

The method used by the Department for verification is a "trial and error" method, however, for the Sacramento County model the method was more "rational" than "trial and error". Many parameters are utilized by the model. Each of these parameters was estimated separately. The model integrates all parameters together in attempting to duplicate the historic water levels for the study period. There may be numerous possible combinations to reproduce the historic water levels for each node. By varying only a few values of a single parameter at one time, a "feel" for the sensitivity of the model can be obtained. Once that feeling is imparted to the verifier, the verification process is made by varying only those parameters which are sensitive to changing water levels.

For this model the net recharge values are the most sensitive parameter because of the discontinuous layers of hardpan which impede downward percolation. In estimating the unit rates of percolation from irrigation and precipitation, the hardpan layers were disregarded; although it was suspected from the beginning that the resulting net recharge values were too high. For those nodes requiring small changes in net recharge values, the assumption can be made that the hardpan layer is nonexistent. On the other hand, if large changes are required, a continuous hardpan layer probably exists.

After the first modeling run, computed water levels in some nodes differed 80 to 90 feet from historic water levels. In the eastern part of the County, nodes 75 through 84, computed water levels appeared to be building up. This caused a decline in the computed water levels to the west. At first it was believed that intervening transmissivity values were too low. Transmissivity values subsequently were increased, but the resulting increase in water movement was minimal. From this it was postulated that the values of net recharge needed to be modified.

Maps in "Soils of Sacramento County, California", by Walter W. Weir, April 1950, were used to determine if the infiltration portion of the net recharge should be changed. The soil maps showed that much of the southeastern portion of the County was underlain by San Joaquin, Redding, and Pentz-Redding soils, which diagnostically contain hardpan. In addition, the geologic portion of this study revealed that much of the hardpan area also contains an iron cemented topsoil. Thus there is very little chance for water to infiltrate the topsoil and reach the ground water body. Because of this, percolation values for native vegetation in the southeastern foothill nodes were modified to one-tenth foot per year. The deleted percolation then was added to stream percolation in the downstream nodes to the west. Nodes in the northeast quadrant of the County also were checked for soil infiltration characteristics. Here, nodes 34, 35, 41, 42, 43, and 44 were modified.

Table 22, "Ground Water Inventory", tabulated the revised recharge from the foregoing changes. Note the subsurface inflow as computed by the model is an average of 4,700 acre-feet annually for the study period. Originally the subsurface inflow was estimated qualitatively to be small with no quantitative estimate. Figure 32 plots the accumulative net recharge and change in storage.

After reviewing the printout which reflected the one-tenth foot per year infiltration rate, it was found that some further changes or adjustments still were necessary. It was decided that a limiting factor of one-tenth foot per month should be used as a maximum infiltration value. This would increase the infiltration during the wet years. With this adjustment, the computed water levels matched the historical levels fairly well.

After the above manipulations, transmissivity values were increased or decreased in each node to increase or decrease subsurface flow and thus match computed water levels with historic levels. In this study a threefold change of transmissivity values was used. Figure 33 presents the initial computer output for nodes 78 and 82; Figure 34 presents the output after all adjustments have been made.

The verified model had an average error of closure of plus 0.56 foot, with a range of minus 10 to plus 21 feet. The larger errors were in the foothill nodes where historic water levels were incomplete and ill-defined. It would have been possible to further adjust the historic water levels in these areas in order to decrease the error of closure. However, the foothill nodes have thin alluvium and only small ground water storage capacities. Therefore there was little need for a smaller error of closure in these areas. The model as it now exists with its present parameters is of sufficient accuracy to be used as a workable management tool for the study of the response of the ground water basin to any operational scheme that may be imposed upon it.

TABLE 22

GROUND WATER INVENTORY
SACRAMENTO COUNTY GROUND WATER BASIN
(In Thousand Acre-Feet)

Water Year	Recharge: Agricultural Water	Recharge: Urban Areas	Recharge: Native Areas	Recharge: Stream	Sub-Surface Inflow	Pumpage	Net Recharge	Change in Storage
1962	161.4	17.4	112.0	119.9	3.6	417.2	- 2.9	- 19.7
1963	137.4	14.9	94.4	109.7	3.5	317.6	42.3	51.5
1964	93.0	8.0	48.0	105.2	4.1	422.2	-163.9	-171.0
1965	121.8	14.1	121.3	158.7	5.4	385.6	35.6	29.6
1966	98.8	4.7	61.6	95.1	6.0	449.4	-183.2	-196.2
1967	160.1	48.7	220.0	172.1	5.9	337.5	269.3	303.4
1968	80.0	4.9	60.2	89.7	4.5	397.1	-157.8	-157.7
Average	121.8	16.1	102.5	121.5	4.7	389.5	- 22.9	- 22.9

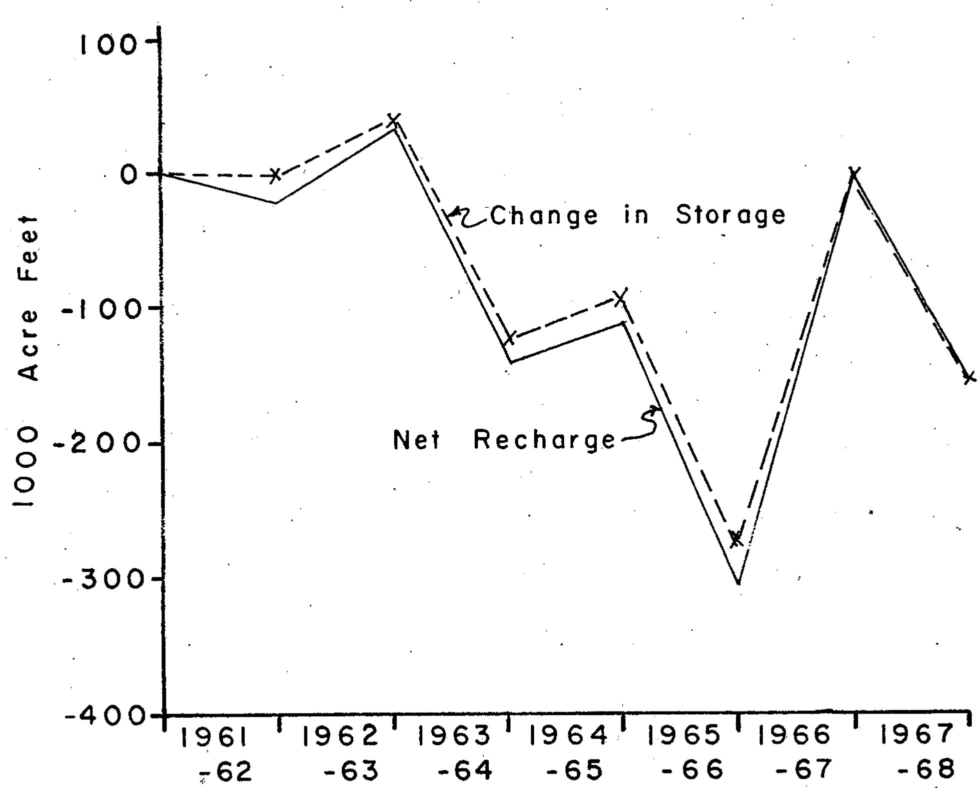
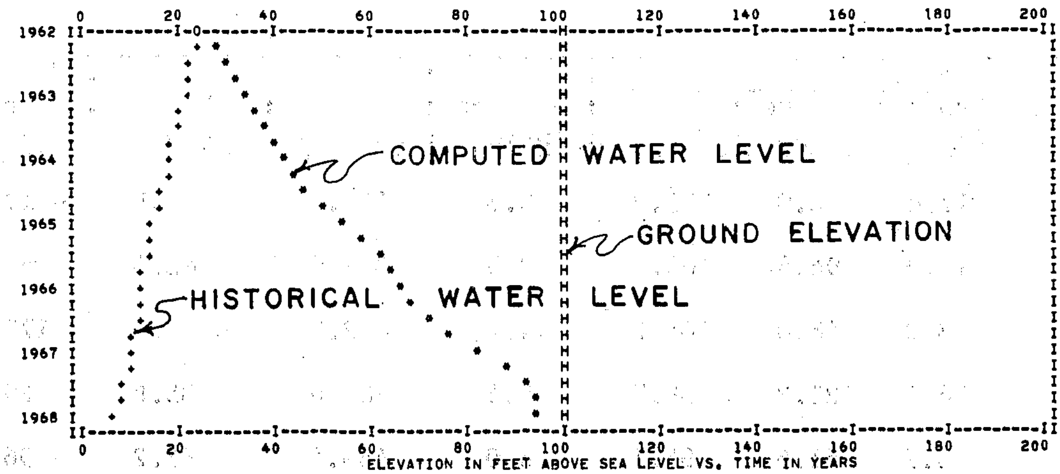


Figure 32. ACCUMULATED NET RECHARGE AND CHANGE IN STORAGE

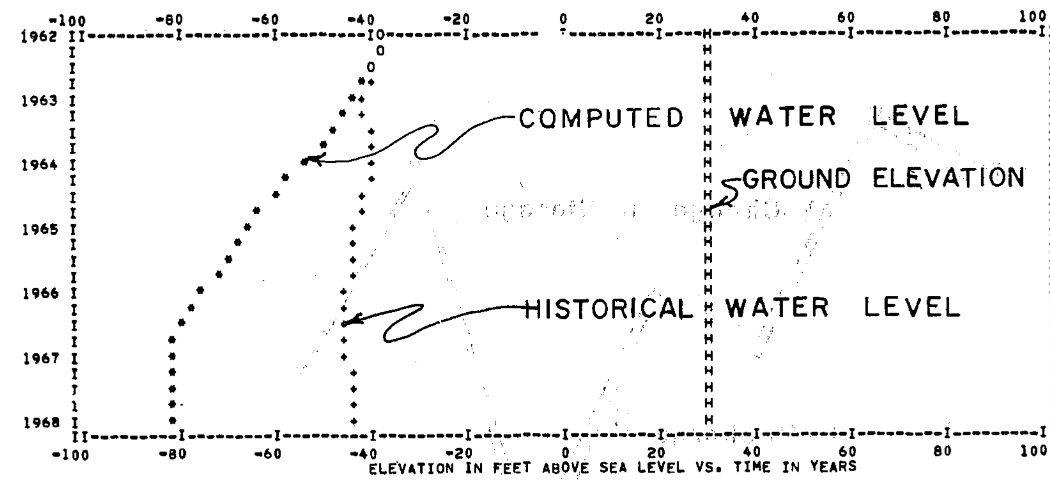
SACRAMENTO COUNTY GROUND WATER MODEL ORG TR + AQ TAILORING RUN



COMPT.	HIST.
24	24
27	23
29	22
32	21
34	21
36	20
37	19
39	18
41	18
43	17
46	16
50	15
54	14
58	13
61	13
64	12
66	12
68	11
71	11
76	10
82	10
87	9
91	8
93	7
94	6
(*)	(+)

NODE NO. 82 BOTTOM AQUIFER ELEVATION= -300 TOP AQUIFER ELEVATION= 100 (COMPT)-(HIST)= 88

SACRAMENTO COUNTY GROUND WATER MODEL ORG TR + AQ TAILORING RUN

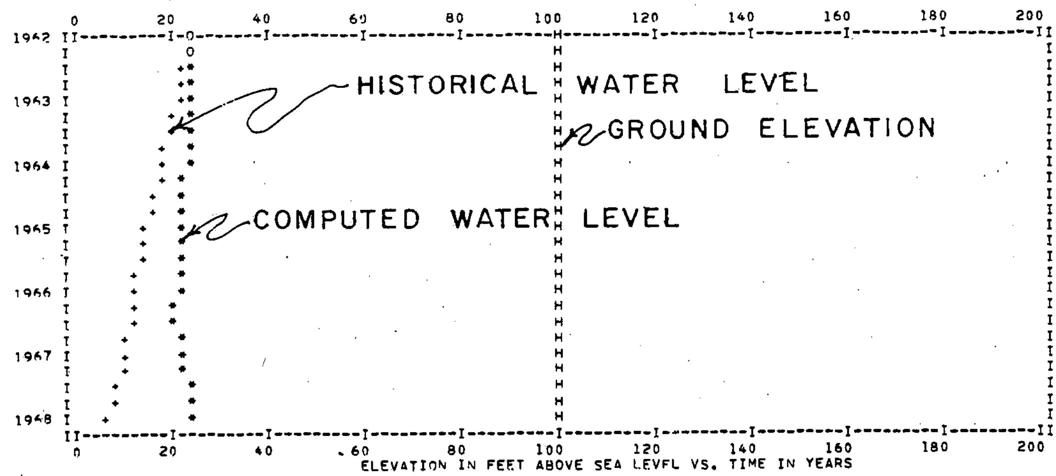


COMPT.	HIST.
-39	-38
-39	-39
-41	-40
-43	-41
-44	-43
-46	-42
-48	-41
-51	-40
-55	-40
-58	-41
-61	-42
-64	-43
-66	-45
-68	-45
-70	-45
-73	-45
-76	-46
-79	-46
-81	-46
-82	-46
-82	-46
-82	-45
-82	-45
-82	-44
-83	-44
(*)	(+)

NODE NO. 78 BOTTOM AQUIFER ELEVATION= -1050 TOP AQUIFER ELEVATION= 30 (COMPT)-(HIST)= -39

FIGURE 33. INITIAL RUN COMPUTER OUTPUT FOR NODES 78 AND 82

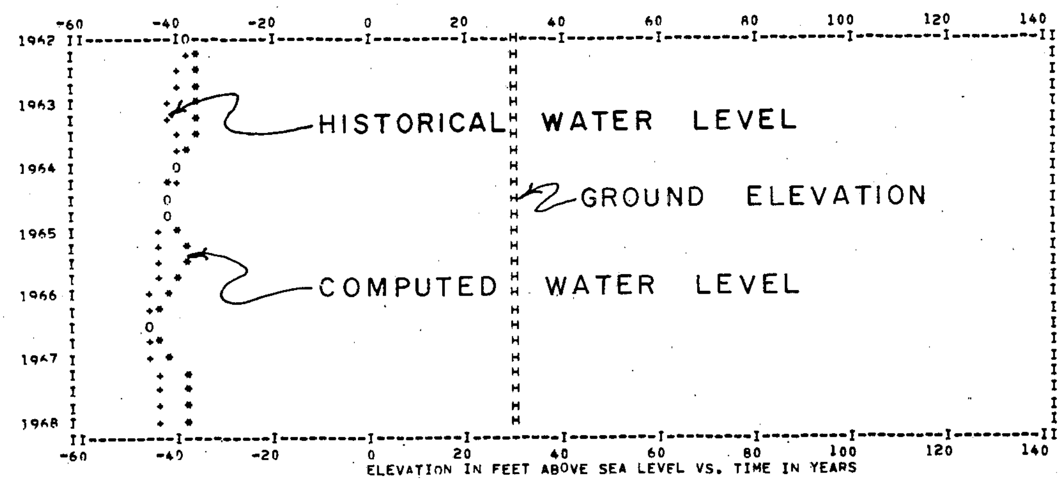
SACRAMENTO COUNTY GROUND WATER BASIN MODEL



COMPT.	HIST.
24	24
24	23
24	22
24	21
24	21
24	20
24	19
23	18
23	18
22	17
22	16
21	15
21	14
21	13
21	13
21	12
21	12
20	11
20	11
21	10.
22	10
22	9
23	8
23	7
23	6
(*)	(+)

NODE NO. 82 BOTTOM AQUIFER ELEVATION= -300 TOP AQUIFER ELEVATION= 100 (COMPT)-(HIST)= 17

SACRAMENTO COUNTY GROUND WATER BASIN MODEL



COMPT.	HIST.
-38	-38
-37	-39
-37	-40
-37	-41
-36	-43
-36	-42
-37	-41
-38	-40
-40	-40
-42	-41
-42	-42
-42	-43
-40	-45
-39	-45
-39	-45
-40	-45
-43	-46
-45	-46
-46	-46
-45	-46
-42	-46
-39	-45
-38	-45
-38	-44
-39	-44
(*)	(+)

NODE NO. 78 BOTTOM AQUIFER ELEVATION= -1050 TOP AQUIFER ELEVATION= 30 (COMPT)-(HIST)= 5

FIGURE 34. FINAL RUN COMPUTER OUTPUT FOR NODES 78 AND 82

APPENDIX A

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