Geology and Ground Water of San Antonio Creek Valley Santa Barbara County California

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1664

Prepared in cooperation with the Santa Barbara County Water Agency

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By K. S. MUIR

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By K. S. Muir

ABSTRACT

This is the sixth in a series of interpretive reports prepared by the U.S. Geological Survey in cooperation with Santa Barbara County on the ground-water basins in the principal agricultural districts in the county. It deals with the San Antonio Creek valley in the west-central part of the county.

The dune sand, alluvium, terrace deposits, Orcutt sand, Paso Robles formation, and Careaga sand are composed of beds of unconsolidated clay, silt, sand, and gravel, 3,000 to 4,000 feet thick, which range in age from Pliocene to Recent. The Paso Robles formation and, locally, the alluvium yield most of the water pumped from wells in the area. Consolidated rocks of Tertiary age, not generally tapped by wells, underlie the unconsolidated formations. Formations older than the terrace deposits have been deformed by folding and faulting. The San Antonio Creek valley is a downwarp formed by two en echelon synclines, and the bordering highlands are areas of uplift, folding, and faulting.

Ground water in the area moves from the Solomon and Purisima Hills toward the center of the valley and then westward down the valley toward the ocean. A consolidated rock barrier several miles west of Harris causes almost all the ground water to move up to the land surface and to discharge into San Antonio Creek. The sources of recharge are the infiltration of rain and seepage from streams. Ground Water is discharged from the San Antonio Creek valley by natural means and by withdrawal from wells. Ground Water is discharged naturally by evapotranspiration, springs, and subsurface outflow to the ocean. Total net pumpage was estimated to have increased from 1,400 acre-feet in 1943 to 2,900 acre-feet in 1958, and the total net discharge for the same period averaged 7,600 acre-feet per year.

The preliminary estimate of perennial yield is about 7,000 acre-feet per year. To salvage the natural discharge, water development would be necessary at the downstream end of the basin west of Harris. Ground-water withdrawals from this area would increase the yield somewhat by providing additional subsurface storage space where recharge is now rejected and wasted by overland flow to the sea. The yield could be increased further by salvaging and using storm runoff that now flows to the ocean, provided sufficient water is available to warrant construction of a dam and diversion works at the ground-water barrier.

The quality of ground water in the Los Alamos and upper San Antonio Valleys is satisfactory for ordinary use, but ground water in the lower San Antonio Valley, where there is virtually no agriculture, is acceptable only for stock use because of its high dissolved-solids content (more than 3,000 parts

per million). Sea-water intrusion into the valley is not likely. The Sisquoc formation and possibly the Careaga sand underlying the lower valley contain saline connate water; however, the quality of water beneath the main area of withdrawal is unknown.

INTRODUCTION

PURPOSE AND SCOPE

Water, essential to all population growth, also is a vital commodity in economic expansion. Its mode of occurrence and its quality, in particular, are parameters that have a direct influence on land use. To facilitate the urbanization of the predominantly rural San Antonio Creek valley and to assist in planning military development in and near the area, it is important to know where water can be obtained and the reliability of the supply. The purpose of this report is to describe the distribution and extent of water-bearing rocks, evaluate the ground-water resources, and provide the geologic and hydrologic data necessary for the long-range planning and utilization of water resources in the rural San Antonio Creek valley area.

This report presents the geology of the San Antonio Creek valley with particular reference to the water-bearing deposits; it describes the source, occurrence, and movement of ground water, and estimates, insofar as the available data permit, recharge to and discharge from aquifers and potential yields of wells in the area. In addition, it describes the surface-water features and the quality of water with regard to use and the possibility of sea-water intrusion.

This is the sixth in a series of interpretive reports prepared by the U.S. Geological Survey in cooperation with Santa Barbara County on the geology and water resources of the ground-water basins in the principal agricultural areas of the county. The five preceding interpretive reports are shown on figure 1, and are listed in abbreviated form below:

Water-supply paper	Year published	Area and abbreviated title	Principal author
1000	1951	Santa Maria Valley	Worts
1107	1951	Santa Ynez Valley	Upson
1108	1951	Goleta and Carpinteria	Upson
1110–B	1951	Cuyama Valley	Upson
1467	1959	Santa Ynez reappraisal	Wilson

This report completes the appraisal of the principal ground-water basins in Santa Barbara County. Reappraisals of the water resources of the Goleta and Carpinteria basins and the Santa Maria Valley began in 1960.

Work by the Geological Survey on the area was begun in 1942 by G. F. Worts, Jr., who canvassed the wells and mapped the geology in parts of the valley, particularly the terrace deposits and the area near the coast (pl. 1). Work was suspended in 1943 and resumed by the author in 1957; fieldwork was completed in 1958.

The investiagtion by the U.S. Geological Survey was completed under the direction of H. D. Wilson, Jr., district engineer in charge of ground-water investigations in California. The project was under the immediate supervision of R. E. Evenson, geologist in charge of the Santa Barbara subdistrict office. P. M. Merritt assisted in the collection of basic data used in this report.

LOCATION AND EXTENT OF THE AREA

The San Antonio Creek valley lies in the west-central part of Santa Barbara County, about 55 miles northwest of Santa Barbara and 15 miles south of Santa Maria (fig. 1). It lies between the Santa Maria Valley (Worts, 1951) and the Santa Ynez Valley (Upson and Thomasson, 1951, and Wilson, 1959).

The area, which coincides with the drainage basin of San Antonio Creek, includes the Los Alamos Valley in the upstream part of the creek and the San Antonio Valley in the downstream part. Because San Antonio Creek flows the full length of the valley, the

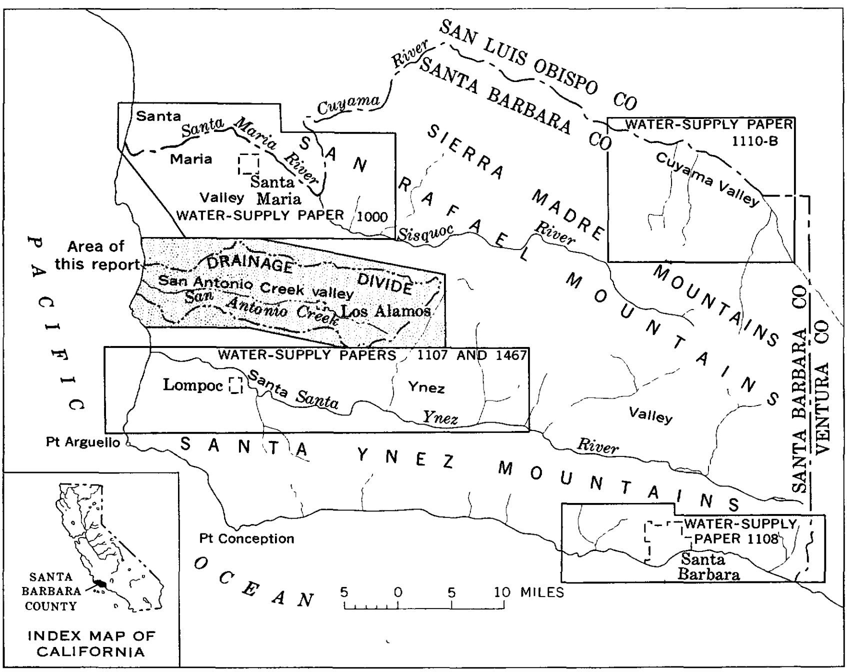

FIGURE 1.—Map of Santa Barbara County, Calif., showing the San Antonio Creek valley.

area is referred to in this report as the San Antonio Creek valley. It includes about 154 square miles and lies between lat 34°40′ and 34°50′ N. and between long 120°10′ and 120°40′ W.

PREVIOUS WORK

Arnold and Anderson (1907) were the first to describe in detail the geology and petroleum resources of the San Antonio Creek valley; previous to this time only brief reconnaissance examinations had been made of the valley. The work of Woodring and Bramlette (1950) is the most comprehensive study made to date of the geology and paleontology of this section of Santa Barbara County. A small part of the area was mapped by Dibblee (1950).

A brief discussion of the general geologic and hydrologic features of the area was presented by La Rocque and others (1950, p. 365). That report (La Rocque and others, 1950, p. 377–381) also described the wells in the valley, as of 1943.

WELL-NUMBERING SYSTEM

The well-numbering system used in Santa Barbara County investigations conforms to that used in nearly all ground-water investigations made by the Geological Survey in California since 1940. It has been adopted as official by the California Department of Water Resources and by the California Pollution Control Board for use throughout the State.

The wells are assigned numbers according to their location in the rectangular system for the subdivision of public land. For example, in the number 8/33–21L1 the part of the symbol that precedes the hyphen indicates the township and range (T. 8 N., R. 33 W.). The one or two digits following the hyphen indicate the section (sec. 21), and the letter indicates the 40-acre subdivision of the section as shown in fig. 2.

The wells are numbered serially within each 40-acre tract as indicated by the final digit of the symbol. Thus well 8/33–21L1 is the first well to be listed in the NE¼SW¼ sec. 21. As almost all

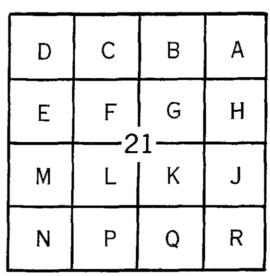

FIGURE 2.—Well-numbering system.

of Santa Barbara County is in the northwest quadrant of the San Bernardino base and meridian lines, the foregoing abbreviation is sufficient for the county. Some parts of the county have never been public land; for these, the rectangular system of subdivision has been projected.

ACKNOWLEDGMENTS

Thanks are expressed to the residents of the San Antonio Creek valley who permitted access to their lands for the purpose of making measurements in wells and mapping the geology. The collection of data on wells and the use of water was greatly facilitated by the cooperation of well drillers, well owners, and public officials, who supplied information freely. Thanks are extended also to the Pacific Gas and Electric Co., which supplied data on pump-efficiency tests and agricultural power consumption.

Chemical analyses, in addition to those made by the Geological Survey, were supplied by the California Department of Water Resources and by the Shell Oil Co. of California.

GEOGRAPHIC FEATURES

CLIMATE

The climate of the San Antonio Creek valley is characterized by a wet and a dry season. About 95 percent of the precipitation occurs during the wet season, November to May, and the rainfall pattern is extremely uniform. Lowlands and bordering highlands receive about the same amount of rain, but the inland areas receive slightly more than areas adjacent to the coast. The coastal area, for example, has an average annual rainfall of about 14 inches, and 20 miles inland near the town of Los Alamos the annual rainfall is about 15 inches.

Winter and summer temperatures are mild. Temperatures during the winter generally range from about 40°F to 60°F, and seldom drop below freezing. The number of days without killing frost averages about 272 per year. Summer temperatures average between 60°F and 70°F, and temperatures reach 100°F only on a few days.

Prevailing winds are from the northwest, and coastal winds are nearly continuous. Fog and high humidity are common in the coastal area during the summer. Generally, the fog moves in from the ocean during the late afternoon or evening and lasts until late morning, when the sun and wind combine to dissipate it.

Table 1 shows the yearly rainfall at five stations in the San Antonio Creek watershed. Figure 3 shows the location of the stations.

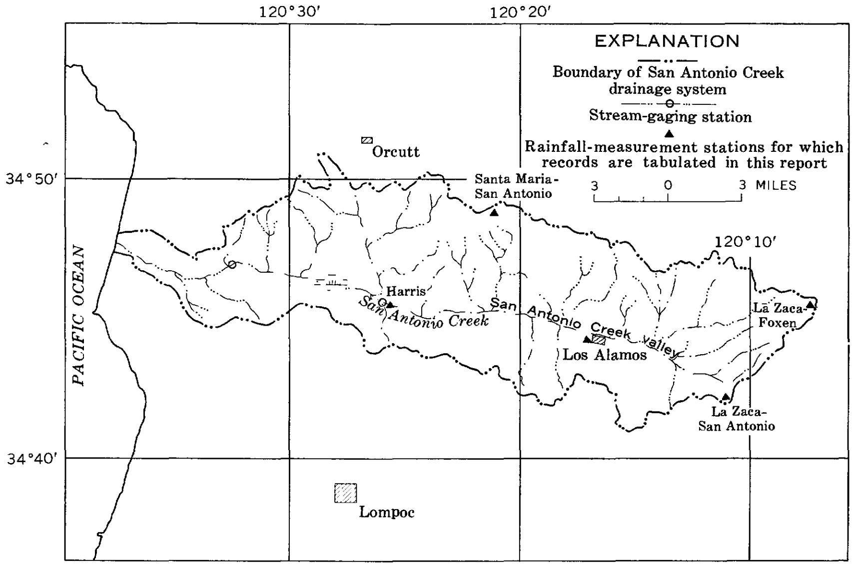

FIGURE 3.—San Antonio Creek drainage system showing location of stream-gaging stations and rainfall-measurement stations.

LANDFORMS AND DRAINAGE

The San Antonio Creek valley trends westward and lies between bordering uplands. Its topography reflects major geologic structures—the hills being areas of uplift having a core of older resistant rocks and the lowlands lying along synclinal troughs that are occupied by downwarped, soft sediments.

TABLE 1.—*Precipitation, in inches, at five stations in and adjacent to the San Antonio Creek valley*

Season ending Sept. 30	Harris (alt 297 ft)[2]	Los Alamos (alt 600 ft)[1]	Santa Maria-San Antonio (alt about 1,000 ft)[2]	La Zaca-San Antonio (alt about 1,250 ft)[2]	La Zaca-Foxen Divide (alt about 1,500 ft)[2]
1942–43	----	16.30	15.93	16.94	----
1943–44	14.00	17.36	15.31	15.78	17.93
1944–45	12.71	12.25	13.77	14.75	----
1945–46	10.49	13.41	11.85	13.67	13.49
1946–47	9.20	8.92	8.85	11.31	11.30
1947–48	6.93	8.08	9.13	----	----
1948–49	----	11.68	----	----	----
1949–50	12.38	12.43	8.50	15.37	14.39
1950–51	8.20	10.20	8.36	10.89	----
1951–52	20.20	21.69	19.51	22.69	24.35
1952–53	14.37	12.51	11.78	12.73	14.56
1953–54	14.36	13.46	11.03	11.96	----
1954–55	12.93	13.24	12.03	15.44	----
1955–56	16.09	16.79	----	----	----
1956–57	8.94	10.27	10.82	----	----
1957–58	25.67	29.17	24.64	28.04	----

[1] For 1909–42 see Water-Supply Paper 1107. Average precipitation for 1909–58 is 15.35 inches, and for 1943–58 is 14.23 inches.
[2] No averages figured—incomplete data.

LOWLANDS

ALLUVIAL VALLEY

The San Antonio Creek valley extends 25 miles westward from 4 miles east of the town of Los Alamos to the ocean (pl. 1). The valley floor has an area of 10,000 acres, it is a mile wide at its widest point and slopes gently toward San Antonio Creek, which follows the valley through its entire length. The valley has a maximum altitude of 750 feet east of Los Alamos and a westward gradient toward the ocean that ranges from 50 feet per mile east of Los Alamos to 25 feet per mile between Los Alamos and the ocean. Alluvium extends up tributary canyons along both sides of the valley (pl. 1). Soils in the valley floor are deep, medium textured, moderately permeable, and of uniform profile; soil in the tributary canyons are only moderately deep, light to coarse textured, and very permeable, and rest on poorly consolidated bedrock.

The valley and tributary-canyon floors have 9,600 acres of land that can be cultivated; about 80 percent was being farmed in 1960. A variety of crops is grown—about 30 percent require irrigation and the remainder are dry farmed. Sugar beets, beans, alfalfa, corn, and flowers are the principal crops requiring irrigation, and grain and hay are the principal dry-farmed crops. Grass covers the remainder of the valley.

CREEK CHANNELS

San Antonio Creek is the principal stream of the area. It drains an area of about 154 square miles and is approximately 28 miles long. It has a gradient that conforms closely to that of the valley floor—50 feet per mile above Los Alamos and 25 feet per mile between Los Alamos and the ocean. The creek is entrenched along most of its course, especially along its lower course several miles upstream from the Marshallia Ranch, where it has cut about 20 feet into the valley floor. All other creeks in the area are tributary to San Antonio Creek.

La Zaca Creek, just east of the area of study (pl. 1), probably drained into the San Antonio Creek valley at one time. Its present course was established in recent time by the piracy of a south-flowing tributary of the Santa Ynez River (Woodring and Bramlette, 1950, p. 113).

The outlets to the sea of several creeks along the coast on Burton Mesa are choked off by drifting sand. Topographically these choked outlets appear as long narrow closed depressions (pl. 1).

All creeks in the valley are intermittent except parts of San Antonio Creek. Consolidated Tertiary rocks that cut across and underlie the valley at a shallow depth below Harris (pl. 1) form a subsurface barrier that causes almost all ground water to move upward to the land surface, where it discharges into San Antonio

Creek. The creek has perennial flow from the barrier to the ocean (table 3). The narrowing of the Los Alamos Valley in the vicinity of sec. 21, T. 8 N., R. 33 W., also causes ground water to rise to the surface. The amount of ground-water seepage into San Antonio Creek in this part of the valley varies inversely with the amount of ground water being pumped upvalley; effluent seepage ceases during periods of heavy withdrawal of ground water, and, conversely, the effluent seepage is greatest when pumping is least.

TERRACES

Terraces occur along both flanks of the San Antonio Creek valley and along the tributary canyons; they form the flat uplands that border the valley adjacent to the sea. The terraces along the coast were produced by wave erosion during high stands of the sea. The terraces upvalley are the result of lateral erosion of streams. The terrace deposits were left standing above present drainage levels by downcutting of the streams.

The most prominent terrace in the valley is San Antonio Terrace and its southward continuation, Burton Mesa (pl. 1). The San Antonio Terrace–Burton Mesa is an erosional platform that formed during a series of different stands of the sea in middle and late Pleistocene time (Upson, 1949). The surface of the platform is obscured by a veneer of younger deposits, but it probably is a series of terraces—possibly as many as 15. This terrace series is implied from the observations of Upson (1951, p. 415, 438), who recognized, from terrace remnants, at least 20 different stands of the sea during Pleistocene time along the coast near Gaviota—about 40 miles down the coast from the San Antonio Creek valley.

The San Antonio Terrace has an area of about 20 square miles between the San Antonio Creek valley and Shuman Canyon (pl. 1). The terrace ascends gently eastward from an altitude of about 50 feet near the ocean. Dune sand covers about 60 percent of the terrace and is so permeable that no drainage pattern has developed because of the lack of runoff.

Burton Mesa has an area of 50 square miles and flanks the south side of the lower San Antonio Valley. It extends south along the coast to the Lompoc plain, which is not shown on plate 1. The Mesa has a average altitude of 50 feet along the coast and 750 feet near the Purisima Hills, which are about 7 miles inland. Drifting sand near the ocean has formed dunes that extend inland about 1 mile and choke the outlets of several of the intermittent streams that drain the Mesa.

The most extensive stream terraces are along U.S. Highway 101 northwest of Los Alamos (pl. 1). Other stream-terrace remnants are scattered along the flanks of the valley from above Los Alamos to below Harris.

The San Antonio Terrace and Burton Mesa have a deep, coarse-textured, very permeable soil and moderately permeable subsoil. Because the terrace and mesa are within Vandenberg Air Force Base, farming is not allowed. For the most part they are covered by grass and brush. The stream terraces are rather small, and no attempt was made to identify their soils. They either are planted in grain or support native grass.

SAND DUNES

Sand dunes are conspicuous features along the coast on Burton Mesa and San Antonio Terrace. On San Antonio Terrace, the dunes are extensive, reaching inland as much as 4 miles and mantling an area of about 12 square miles. They are less extensive on Burton Mesa, where they extend inland only about 1 mile.

The formation, shape, and movement of the dunes is controlled by the prevailing winds, which blow from the northwest and give the dunes an elongate pattern that strikes northwest. The dunes have a gentle slope on the windward sides and rather steep slopes on the lee sides. When the prevailing winds are blowing with sufficient velocity, sand is moved across the dunes and down the lee face. This movement of the sand causes an advancement of the nose of the dune. In this way, the active dunes continue to move inland. Beach sand is the source of the dune sand. Where the source beach is narrow, sand dunes extend inland only a short distance, but where the beach is wide, the sand dunes extend inland for several miles (pl. 1).

BORDERING HILLS AND MOUNTAINS

SOLOMON AND CASMALIA HILLS

The Solomon and Casmalia Hills reach an altitude of 1,600 feet and form the northern drainage divide for the San Antonio Creek valley (pl. 1). They extend along the north side of the valley from Zaca Canyon to a point northwest of Harris and are separated by a structural low that forms the Harris-Graciosa Canyon. The consolidated Tertiary rocks that make up the core of the hills have been folded into a series of en echelon anticlines striking northwest; these structures are reflected in the topography of the hills.

Erosion has formed well-rounded hills that have numerous landslides along their south flanks, where unconsolidated rocks crop out. Soil in the central part of the hills is moderately deep, light textured, and very permeable; it rests on weakly consolidated bedrock. In the east and west parts of the hills, the soil is shallow and heavy textured; the subsoil, which rests directly on bedrock, is poorly permeable. The area has numerous rock outcrops. Grass is the principal ground cover on the gentle slopes, whereas scrub oak and brush are the principal ground cover on the steep slopes.

PURISIMA HILLS

The Purisima Hills form the southern divide of the San Antonio Creek valley (pl. 1). The hills extend from Zaca Canyon on the east to Burton Mesa on the west. Redrock Mountain attains an altitude of 1,950 feet, the highest point in the hills.

The geologic history of the Purisima Hills is similar to that of the Solomon and Casmalia Hills. Compressional forces acting on the subsurface rocks produced uplift and folding. The axes of the folds are parallel to the general trend of the San Antonio Creek valley, except in the vicinity of Redrock Mountain (pl. 1), where the axes trend northwest. Erosion has altered the hills to their present shape and has produced the same type of topography as that in the Solomon and Casmalia Hills—rounded hills in areas underlain by unconsolidated Tertiary rocks and sharp ridges and steep canyons in areas underlain by consolidated Tertiary rocks. The streams that drain the Purisima Hills cut across the trend of the hills at right angles.

Most of the Purisima Hills area has a shallow, heavy-textured soil, poorly permeable subsoil, and numerous rock outcrops on bedrock. Grass and scrub oak grow on the lower slopes of the hills and thick brush on the upper slopes.

GEOLOGY

GEOLOGIC FORMATIONS AND THEIR WATER-BEARING PROPERTIES

In this report, the geologic formations in the San Antonio Creek valley area have been divided into two groups: unconsolidated water-bearing deposits of Tertiary and Quaternary age, and consolidated, virtually non-water-bearing rocks of Tertiary age.

Consolidated non-water-bearing rocks are grouped as consolidated rocks of Tertiary age, and thus they are represented on the geologic map and geologic sections (pls. 1, 2) as one unit. This grouping was made because the consolidated rocks are virtually non-water-bearing and are important only in that they delineate the boundary of the unconsolidated water-bearing deposits and, hence, define the limits of the ground-water reservoir.

The consolidated non-water-bearing rocks underlie the Careaga sand; they are Tertiary in age and have a combined thickness of about 10,000 feet. They are made up principally of siltstone, mudstone, and shale. The oldest of the consolidated rocks is the Monterey shale, and the Sisquoc formation and the Foxen mudstone, respectively, are successively younger.

In upward succession, the unconsolidated water-bearing deposits are the Careaga sand of Pliocene age, the Paso Robles formation of Pliocene and Pleistocene(?) age, the Orcutt sand of Pleistocene age, the terrace deposits of Pleistocene age, and the alluvium and dune sand of Recent age. They have a maximum aggregate thickness of about 3,600 feet and are composed of gravel, sand, silt, and clay.

Plate 1 shows the areal distribution of the various formations; plate 2 shows their stratigraphic and structural relations; and the table of stratigraphic units (table 2) summarizes their sequence, general character, and water-bearing properties.

CONSOLIDATED ROCKS

MONTEREY SHALE (MIOCENE)

The Monterey shale is middle and late Miocene in age and of marine origin. It is the principal source rock for petroleum in the valley area and in the Santa Maria area to the north. The formation underlies the whole area and forms the core of the Casmalia, Solomon, and Purisima Hills.

The Monterey shale crops out at four places in the mapped area —in the eastern Purisima Hills, along the coast at Purisima Point, in Foxen Canyon, and west of Casmalia (pl. 1). Woodring (Woodring and Bramlette, 1950, p. 25) described two members in the Monterey in the eastern Purisima Hills—a lower member composed of thin-bedded chert and cherty shale interbedded with porcelaneous shale, and an upper member of either porcelaneous shale containing layers of thin-bedded concretionary limestone or porcelaneous shale overlain by laminated diatomite and distomaceous shale. The upper member of the Monterey in the Purisima Hills is about 1,000 feet thick; the thickness of the lower member is not known. In the Foxen Canyon area, the Monterey is a porcelaneous shale overlain by laminated diatomite and diatomaceous shale. The outcrop thickness is about 750 feet, and the base is not exposed. Monterey shale also is exposed about 1 mile west of Casmalia. Here the lithology of the formation is similar to that in Foxen Canyon: porcelaneous shale overlain by laminated diatomite and diatomaceous shale. Because the base of the Monterey shale is not exposed in the mapped area, its relation to older, underlying rocks is not known.

SISQUOC FORMATION (MIOCENE AND PLIOCENE)

The Sisquoc formation of late Miocene and early and middle Pliocene age is a marine deposit that rests unconformably on the Monterey shale. It underlies all the valley area and is exposed

705-965—64——2

TABLE 2. *Stratigraphic units of the San Antonio Creek valley area*

System	Period	Formation	Thickness (feet)	General lithologic character	Water-bearing properties
Quaternary	Recent	Dune sand	0-100±	Sand, coarse to fine, well rounded, and in part actively drifting.	Unconsolidated; highly permeable, but yields only small amounts of water to wells because sand is mostly above zone of saturation
		—Unconformity—			
		Alluvium	0-100±	Sand, clay, silt, and gravel of fluvial origin except near the coast, where the clay and sands probably are marine.	Unconsolidated; highly permeable and yields water to wells. One of the major aquifers of the area. Tapped by most wells.
		—Unconformity—			
	Pleistocene	Terrace deposits	0-75±	Crossbedded sand, gravel, and clay. Fluvial origin east of Harris, marine origin west.	Unconsolidated; somewhat permeable but position causes rapid drainage, largely unsaturated.
		—Unconformity—			
		Orcutt sand	0-150±	Sand and clay interbedded with gravel. Locally has a cap rock of indurated sandstone underlain by sand and clay and a lower member of sand and gravel. Fluvial in origin but includes some marine deposits.	Unconsolidated; locally yields small quantities of water to wells.
—?—	—?—	—Unconformity—			
Quaternary (?) and Tertiary	Pleistocene	Paso Robles	0-2,000±	Gravel, sand, silt, and clay containing occasional thin limestone beds near base and a few indurated sandstone beds. Nonmarine in origin.	Unconsolidated; yields water fairly freely to wells. The best aquifer in the area. Tapped by most wells. Locally contains artesian water.
	—?—				
	Pliocene	Careaga sand	125-1,500±	Sand, and some silt and gravel. Two members locally; upper member is a coarse-grained sandstone and sand; lower member is a fine-grained fossiliferous sandstone and sand. Marine in origin.	Unconsolidated; yields small quantities of water to wells. Owing to caving, to difficulty in screening, and to its considerable depth beneath most of area, it is tapped by few wells.
		Local unconformity			
Tertiary	Pliocene to Miocene	Consolidated rocks. Includes Foxen mudstone, Sisquoc formation, and Monterey shale	0-10,000	Mudstone, siltstone, diatomaceous and porcelaneous shale, sandstone, and siliceous shale.	Consolidated or highly compacted; poorly water bearing, except for minor supplies in joints or fractures. Not tapped by wells.

along the north flank of the Purisima Hills, in Foxen Canyon, and in the Casmalia Hills. It also underlies the Burton Mesa and San Antonio Terrace and is exposed where creeks have eroded through thin overlying deposits. In the western part of the mapped area, the formation is covered by a veneer of younger deposits. Under the central and upper San Antonio Creek valley, the Sisquoc lies at considerable depth—possibly 3,000 to 4,000 feet below the land surface.

In the Purisima Hills, the Sisquoc formation is predominantly a soft light-colored diatomaceous mudstone having porcelaneous shale and mudstone at the base. In the eastern part of the hills, laminated diatomite is exposed at the base. A large area of reddish burnt shale crops out on Redrock Mountain; the color is the result of the combustion of tar that had impregnated the shale. The base of the Sisquoc formation is not exposed in the Purisima Hills; Woodring (Woodring and Bramlette, 1950, p. 26) calculated its thickness, on the basis of subsurface data, to be at least 5,000 feet.

In Foxen Canyon and in the western Casmalia Hills, the formation is chiefly sandstone, containing diatomaceous siltstone near the top; but in the central Casmalia Hills the Sisquoc formation is made up of diatomaceous mudstone.

At the lower end of the San Antonio Creek valley, the Sisquoc formation is covered by a mantle of younger alluvium so thin that San Antonio Creek has cut through it in several places and flows on the Sisquoc formation.

FOXEN MUDSTONE (PLIOCENE)

The Foxen mudstone is of middle(?) and late Pliocene age and is marine in origin. It rests conformably on the Sisquoc formation and is exposed in the Purisima and Casmalia Hills.

In the Purisima Hills the formation is a mudstone and siltstone; it becomes more sandy west of State Highway 1. Woodring (Woodring and Bramlette, 1950, p. 37) estimated that the Foxen was 800 feet thick in the western part of the hills, but it thins toward the east and finally disappears in the central part of the Purisima Hills. The Foxen mudstone is exposed in the Casmalia Hills west of the Graciosa divide, where it is a mudstone and siltstone.

WATER-BEARING PROPERTIES

Although the consolidated rocks contain small amounts of water in joints and fractures, they do not store or transmit water in significant quantities and, therefore, are poor aquifers. Few water wells penetrate the consolidated rocks because they underlie the valley at considerable depth.

UNCONSOLIDATED DEPOSITS OF TERTIARY AND QUATERNARY AGE

CAREAGA SAND (PLIOCENE)

Areal extent.—The Careaga sand crops out extensively in the Purisima Hills and in large areas in the Solomon and Casmalia Hills. The sand is exposed in a continuous belt about 500 feet wide along the north flank of the Purisima Hills (pl. 1); it dips northward in the Purisima Hills and passes under the San Antonio Creek valley at a depth of several thousand feet (pl. 2).

Stratigraphy.—The Careaga sand is late Pliocene in age and is predominantly marine in origin. The formation has undergone considerable deformation in the Purisima Hills and in the western part of the Solomon Hills (pl. 1), but elsewhere in the mapped area the deformation has been slight. The sand lies conformably on the Foxen mudstone west of the Graciosa Canyon–Harris Canyon divide and in the central and western Purisima Hills. Elsewhere, the Careaga sand rests unconformably on the Sisquoc formation. The Careaga is overlain conformably by the Paso Robles formation. Woodring (Woodring and Bramlette, 1950, p. 42) demonstrated that the Careaga sand has two members—the fine-grained lower member called the Cebada and the coarse-grained upper member called the Graciosa. In this report, the two members are combined and mapped as one unit. The Careaga is distinguished from the underlying formations by its coarser grained texture and its lesser degree of consolidation. It is distinguished from the overlying Paso Robles formation by the uniformity of its grain size and its marine megafossils.

Lithology and thickness.—The Careaga sand is a gray-white to yellow-buff loosely consolidated massive fine- to medium-grained sand containing some silt and abundant well-rounded pebbles in the upper part. The pebbles are quartzite, porphyritic igneous rocks, and chert and shale of the Monterey. Numerous megafossils are contained in the formation.

The Careaga has its maximum exposed thickness in the Purisima Hills, where it is 1,425 feet thick. Northward it thins to about 1,000 feet, where it passes under the valley, and still farther north under the Solomon and Casmalia Hills it is about 700 feet thick.

Water-bearing properties.—The Careaga sand is penetrated by few wells in the San Antonio Creek valley. No tests of the hydrologic properties of the formation have been made in the valley area. However, laboratory tests made by Upson (Upson and Thomasson, 1951, p. 34) on samples of the Careaga sand collected in the Santa Ynez Valley, where the lithology of the Careaga is similar to that in the valley area, indicated that the coefficient of permeability averages about 70 gallons per day per square foot. Wenzel (1942, p. 7) states that

> This coefficient may be expressed in field terms as the number of gallons of water that would be conducted, were the temperature of the water 60°F., through each mile of water-bearing bed under investigation (measured at right angles to the direction of flow) for each foot of thickness of the bed and for each foot per mile of hydraulic gradient.

Because the Careaga sand contains much silt and fine sand and has the reputation of sanding up water wells, drillers generally do not perforate casings in the formation. Nevertheless, properly constructed wells in the Careaga would supply ample water for domestic use and locally for irrigation use. The sand has a large storage capacity and transmits water readily to the younger formations.

PASO ROBLES FORMATION (PLIOCENE AND PLEISTOCENE(?))

Areal extent.—The Paso Robles formation crops out in large areas on both flanks of the San Antonio Creek valley (pl. 1). It is downwarped in a syncline under the valley (pl. 2). It also crops out in large areas in the Solomon and Casmalia Hills and in the area of Zaca Canyon.

Stratigraphy.—The Paso Robles is the oldest nonmarine formation in the valley. Its age is Pliocene and Pleistocene(?). The overlying formations lie unconformably on the Paso Robles, which, in turn, lies conformably on the Careaga sand.

The Paso Robles is deformed over most of the mapped area (pl. 1), especially in the area about half a mile southwest of Los Alamos, where the Paso Robles formation has been overturned to the north. Heterogeneity and the lack of marine megafossils in the Paso Robles formation distinguish it from the underlying Careaga sand, and its greater degree of deformation sets it apart from the overlying younger formations.

Lithology and thickness.—The Paso Robles formation consists of poorly consolidated stream-deposited lenticular beds of gravel, sand, silt, and clay (pl. 2, log of well 8/32–30H6). Generally the sand is crossbedded and poorly sorted and silty and includes stringers of coarse sand and small pebbles. The lower part of the formation contains occasional beds of fresh-water limestone ranging in thickness from 1 to 30 feet. The Paso Robles formation is about 2,000 feet thick beneath the central part of the valley.

Water-bearing properties.—The Paso Robles formation is the best aquifer in the valley. The ability of the rocks to yield water to wells (permeability) is less than that of the alluvium but great enough so that good yields may be obtained if a saturated zone of sufficient thickness is penetrated. Most of the formation is below the zone of saturation, and it has large exposed areas north and east of the valley, which receive infiltration of rainfall. Yields of 500 gpm (gallons per minute) and specific capacities of 5 to 15 gpm per foot of drawdown are common. Near the town of Los Alamos, a well that is perforated through 350 feet of Paso Robles yields 1,200 gpm and has a specific capacity of 12 gpm per foot of drawdown.

Vertical variations in the water-bearing properties of the Paso Robles are the result of coarse-grained beds that yield water freely to wells alternating with fine-grained beds that do not. Good yields from the formation can be obtained only from those wells that penetrate many of the coarse-grained lenses. Thus, as the formation is about 2,000 feet thick, it is a major aquifer.

Artesian ground water occurs locally in the Paso Robles. Several wells were flowing in 1958 in secs. 15 and 16, T. 34 N., R. 8 W., and one was flowing in sec. 9, T. 8 N., R. 33 W., (pl. 1). Well 8/34–16G1, which is 750 feet deep, flows approximately 150 gpm and has a head of 7.5 feet above the land surface.

ORCUTT SAND (PLEISTOCENE)

Areal extent.—The Orcutt sand is exposed extensively on Burton Mesa and San Antonio Terrace (pl. 1). Exposures are scattered on the north flank of the San Antonio Creek valley near Harris and in the western Purisima Hills. In the Solomon Hills the sand is exposed near Roadamite and just north of the Graciosa Ridge.

Stratigraphy.—Although the Orcutt sand has been assigned a late Pleistocene age by Woodring (Woodring and Bramlette, 1950), its degree of deformation and stratigraphic relation to younger undeformed terrace deposits of late Pleistocene age suggest that it may be middle Pleistocene in age. No diagnostic fossils have been found in the deposits to substantiate or refute this hypothesis. The Orcutt sand is mostly nonmarine in origin and overlies the Paso Robles and older formations unconformably.

Lithology and thickness.—The Orcutt sand has a maximum thickness of about 150 feet in the mapped area and contains three recognizable zones. The upper zone is a loosely compacted massive medium-grained clean sand and some clay, which is stained reddish brown by iron oxide. In several places it is overlain by a cap rock which is an ancient soil zone of indurated sand. Below the upper zone, the Orcutt grades downward into sand and clay; it contains numerous well-rounded pebbles from the Monterey shale and Sisquoc formation. The basal zone of the Orcutt is composed of coarse sand and gravel.

Water-bearing properties.—Little is known concerning the permeability of the Orcutt sand in the area. The beds of sand are thin and are generally above the zone of saturation; therefore, they probably contain only small amounts of water. Spring 9/35–36C1 (pl. 1) issues from the Orcutt; thus, locally, the Orcutt contains perched water (ground water held above the main zone of saturation by impervious material). Only one well (stock well 8/34–15F1, pl. 1) is known to have penetrated the Orcutt. The yield is several gallons per minute.

TERRACE DEPOSITS (PLEISTOCENE)

Areal extent.—Terrace deposits are exposed along both flanks of the San Antonio Creek valley (p. 8; pl. 1). Scattered deposits also are exposed in the western Solomon Hills and in the vicinity of Foxen Canyon.

Stratigraphy, lithology, and thickness.—The terrace deposits are late Pleistocene in age. They are older than the alluvium, and they lie unconformably on the Orcutt sand and all older formations.

The terrace deposits, largely continental upstream from Harris and largely marine downstream from Harris, are made up of unconsolidated crossbedded gravel, sand, silt, and clay. Their maximum thickness probably does not exceed 75 feet (table 2).

Water-bearing properties.—The terrace deposits, although moderately permeable, are generally above the zone of saturation and are not a source of water supply to wells.

ALLUVIUM (RECENT)

Areal extent and stratigraphy.—The alluvium underlies the valley and its tributary canyons (pl. 1). It is Recent in age and overlies the older rocks unconformably. Except near the coast, where tongues of clay and sand were deposited by the sea, the alluvium was laid down by streams.

Lithology and thickness.—The alluvium is made up of unconsolidated clay, silt, sand, and gravel. The logs of wells show that the alluvium in the upper part of the valley (pl. 2, well-log 8/32–30H6) is generally coarser than that between Harris and the ocean (pl. 2, well-log 8/34–18C1). A fairly continuous gravel layer at the base of the alluvium ranges from 5 to 15 feet in thickness. The alluvium has a maximum thickness of about 100 feet and an average thickness of about 80 feet (pl. 2). Near the town of Los Alamos, the alluvium is about 90 feet thick, and it appears to thin to about 65 feet between Harris and the Marshallia Ranch. Along this stretch of the valley, the alluvium rests on consolidated Tertiary rocks. A log of well 8/35–15E2 (pl. 2), about 1 mile south of the Marshallia Ranch, shows the alluvium to be about 30 feet thick, but the well probably does not penetrate the thickest part of the deposit. The logs of two wells near the coast (pl. 2) show the alluvium to be about 90 feet thick.

The alluvium near the coast probably is considerably thicker than 90 feet. This assumption is based on the work by Upson (1951) and Worts (1951), which showed that, prior to the time the alluvium was deposited, the sea level stood about 200 feet lower than it does at present. The streams that drained the area carved valleys whose floors were at or near sea level adjacent to the coast. As the sea level rose, these former stream valleys became alluviated. The deepest parts of the former stream valleys are now buried under alluvium and dune sand, and their locations are not known. No attempt was made in this study to locate them.

Water-bearing properties.—The alluvium in the valley locally is permeable and yields water to wells. The lower two-thirds of the alluvium is saturated under most of the valley (pl. 2). It is completely saturated in secs. 16 and 17, T. 8 N., R. 34 W., in the area of rising water west of Harris (pl. 3).

Pump-efficiency tests, made by the Pacific Gas and Electric Co. on wells that penetrate only the alluvium in the San Antonio Creek valley, indicate that wells tapping alluvium in the upper end of the valley have specific capacities that average about 13 gpm per foot of drawdown and yields of about 350 gpm. The wells tapping alluvium between Los Alamos and Harris (pl. 2) have specific capacities that average about 8 gpm per foot of drawdown and yields of about 200 gpm. No tests were made between Harris and the ocean (pl. 2), but logs of wells in the area indicate the alluvium to be finer grained than it is upvalley; therefore, its permeability also would be lower. The volume of water in the alluvium in the San Antonio Creek valley is small because the volume of alluvium is small. Consequently, the deposits cannot support sustained pumping from wells.

DUNE SAND (RECENT)

Areal extent.—The dune sand extends several miles inland from the coast and covers parts of the San Antonio Terrace and Burton Mesa (pl. 1).

Stratigraphy, lithology, and thickness.—The dune sand, which is made up of fine to coarse well-rounded massive quartz sand, is Recent in age. It is eolian in origin and overlies all older formations unconformably. There are three sets of dunes whose relative ages can be identified in the lower San Antonio Creek valley—young, mature, and old. The young dunes migrate and support little or no vegetation, whereas the mature dunes are more or less anchored by vegetation and are perfectly preserved. Vegetation also anchors the old dunes, but their shapes are poorly preserved. The thickness of the dune sand is not known, but it is probably nowhere more than about 100 feet.

Water-bearing properties.—The dune sand is moderately permeable but probably contains little water because it lies above the zone of saturation. Small perched to semiperched water bodies within the dune sand locally could supply small amounts of water to wells for domestic or stock use.

GEOLOGIC STRUCTURE

GENERAL REGIONAL STRUCTURE

The San Antonio Creek valley is an area of complex folding and faulting. The valley and surrounding hills are in the center of a wedge-shaped area between two geomorphic provinces: the California Coast Ranges (San Rafael Mountains) on the northeast and the Transverse Ranges of California (Santa Ynez Mountains) on the south (see fig. 1). Structural movements in the form of compressional forces between these two provinces have caused crustal shortening of the wedge-shaped area. The regional stress system of compressional forces acted from north-northeast and south-southwest directions (Dibblee, 1950, p. 51). The anticlines, synclines, and faults shown on the geologic map (pl. 1) are the result of these compressional forces.

CENTRAL SYNCLINAL FOLDS

The valley is the general topographic expression of a deep structural downwarp in the form of two en echelon synclines—the Los Alamos and San Antonio synclines (pl. 1). The Tertiary and Quaternary section attains its maximum thickness in this downwarp.

The Los Alamos syncline passes through the city of Los Alamos, and its axis is almost in the center of the valley. The trend of the axis is just slightly north of west. The north limb of the syncline has a gentle southward dip, whereas the south limb has a steep northward dip that is overturned in the vicinity of Los Alamos (pls. 1 and 2). Evidence of the syncline disappears about 3 miles west of Los Alamos. It passes eastward from the Los Alamos Valley and into the Santa Ynez Valley near Los Olivos.

The axis of the San Antonio syncline lies just south of Harris. The syncline trends slightly north of west as it passes under the valley. East of Harris, the axis lies along the south flank of the valley. Evidence of the syncline disappears in the vicinity of Cañada Laguna Seca. To the north, the axis of the syncline veers away from the valley about 3 miles west of Harris and trends northwestward, passing through the town of Casmalia (pl. 1). The limbs of the syncline generally have moderate dips.

BORDERING ANTICLINES AND FAULTS

The hills that flank the San Antonio Creek valley are anticlinal. They were formed where the sedimentary section thins away laterally from the deep synclinal trough of the valley (Dibblee, 1950, p. 51). In the Solomon and Casmalia Hills, the axes of the anticlines trend northwestward (pl. 1). The major anticlines in the Purisima Hills trend slightly north of west.

Small faults are numerous in the hills that flank the valley (pl. 1). They are not discussed in this report because they do not control the occurrence of ground water in the basin.

GEOLOGIC HISTORY

The evolution of the San Antonio Creek valley ground-water basin began in the Miocene epoch. The geologic history previous to this time is not discussed here. A more nearly complete history of the geology of the area is presented by Dibblee (1950, p. 60–65). The following is a summary of the geologic history as it applies to the development of the San Antonio Creek valley ground-water basin.

In middle and late Miocene time, a deep sea covered the entire valley area. It was at this time that the Los Alamos trough began to warp downward. The area subsided slowly, so that the trough received at least 4,500 feet of sediments, which make up the Monterey shale. In late Miocene time, strata in the area now occupied by the San Rafael Mountains were gently folded and tilted to the northeast. Local uplift, folding, and erosion are shown by an unformity between the Monterey shale and the Sisquoc formation. Subsidence resumed and continued through late Miocene time, and the area was covered by open seas during early Pliocene time. About 5,000 feet of diatomaceous mudstone of the Sisquoc formation was deposited along the Los Alamos trough. The Foxen mudstone was deposited during middle Pliocene time, and subsidence continued along the Los Alamos trough.

Late Pliocene was a time of widespread deformation, emergence, and erosion, although the Los Alamos trough was not affected. The Purisima Hills and the Burton Mesa-San Antonio Terrace were formed by anticlinal uplift, and the San Rafael and Santa Ynez Mountains were formed. After the orogeny, the land again subsided so that a shallow sea covered the area. It was in this shallow sea that the Careaga sand was deposited. Subsidence and deposition in the Los Alamos trough were rapid at this time. Toward the end of the Pliocene, the shallow sea became filled with sediments, and the land emerged. The Paso Robles formation, laid down at this time, was the first nonmarine deposit in the area and was derived from sediments from the San Rafael and Santa Ynez Mountains. This deposition was followed by a period of erosion and the deposition of the Orcutt sand, probably in late-early or middle Pleistocene time.

Beginning probably in the middle Pleistocene, compressional forces uplifted the Purisima, Solomon, and Casmalia Hills to their present heights. The Burton Mesa–San Antonio Terrace was elevated and partly dissected by streams. In late Pleistocene time, the area was subjected to several eustatic changes in sea level, probably caused by the alternate recession and advance of continental ice sheets. The several levels of terrace deposits along the coast are evidence of these changes in sea level. The last major advance of an ice sheet was at the close of the Pleistocene, and it resulted in a lowering of sea level about 200 feet below present sea level. A valley, at the present position of San Antonio Creek valley, was then eroded by streams. Sea level rose to its present position, and the valley was back-filled with alluvium in Recent time.

SURFACE-WATER FEATURES

RUNOFF

A part of the precipitation that reaches the land surface is absorbed (infiltration), a part is consumed by plants (transpiration), a part is evaporated directly from the land surface and vegetation (evaporation), and a part flows down the slope of the land surface into the streams (runoff). The amount of precipitation that becomes runoff is dependent upon many factors, the most important of which are the density and type of vegetation, the permeability of the soil, the geologic and topographic environments, the intensity and time distribution of rainfall, and the moisture content of the soil prior to the rainfall. Time distribution and intensity of rainfall are the two principal factors that influence runoff in the San Antonio Creek valley. Eighty percent of the rainfall occurs from December through March. The number of storms during this period are few, but the intensity of each generally is great. Thus, the bulk of the runoff is concentrated in a few short periods each winter.

Measurements of runoff have been made at two gaging stations on San Antonio Creek (fig. 3). The station at Harris was placed in operation in January 1940. In September 1955 this station was discontinued and a new station, called San Antonio Creek near Casmalia, was established about 5 miles downstream. The new station records the runoff from a drainage area of 137 square miles, compared to the 101-square-mile drainage area of the discontinued Harris station. Moreover, the new station is downstream from the ground-water barrier (pl. 3) and provides a record of the combined surface- and ground-water outflow from the valley.

The monthly and yearly runoff at the two stream-gaging stations for the period of record are given in table 3.

CHARACTER OF THE RUNOFF

Runoff past the gaging station at Harris varied widely during the 15 years the station was in operation (1941–55). The magnitude of the runoff ranged from zero in 1948 and 1951 to 20,650 acre-feet in 1941; the total for 1941 is not the full runoff because the records for the water year 1941 are incomplete (table 3). The average annual runoff for the period 1942–55 was 800 acre-feet. About 90 percent of the measured yearly runoff occurred from January through April, and generally the stream did not flow during the remainder of the year.

Runoff recorded at the new station, San Antonio Creek near Casmalia, follows the same general pattern as that recorded at Harris—most of the flow occurring from January through April. However,

TABLE 3.—*Measured runoff, in acre-feet, of San Antonio Creek at two gaging stations, 1940–58*

Water-year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Total
San Antonio Creek at Harris (drainage area 101 square miles)													
1940–41[1]	-----	-----	-----	239.0	5,650.0	10,260.0	4,340.0	134.0	12.0	6.1	6.1	6.0	20,650
1941–42	4.3	3.0	862.0	376.0	99.0	118.0	96.0	8.5	.2	.4	.8	.6	1,570
1942–43	.4	.2	13.3	962.0	200.0	1,050.0	45.0	.6	.2	0	.8	.1	2,270
1943–44	0	0	12.0	7.0	1,390.0	323.0	22.0	.3	.4	.4	.4	.2	1,760
1944–45	.6	0	0	.1	331.0	108.0	0	0	0	.4	.4	.3	441
1945–46	0	0	8.5	0	4.0	202.0	88.0	.8	0	0	0	0	303
1946–47	0	4.0	0	0	0	0	0	0	0	0	0	0	4
1947–48	0	0	0	0	0	.4	0	0	0	0	0	0	0
1948–49	0	0	8.1	0	0	91.0	4.8	0	0	0	0	0	104
1949–50	0	0	0	.4	3.6	.2	0	0	0	0	0	0	4
1950–51	0	0	0	0	0	0	0	0	0	0	0	0	0
1951–52	0	0	0	982.0	5.0	3,230.0	12.0	0	0	0	0	0	4,230
1952–53	0	14.0	221.0	64.0	.8	4.6	2.6	0	0	0	0	0	307
1953–54	0	14.0	0	51.0	2.4	59.0	0	0	0	0	0	0	126
1954–55	0	0	0	62.0	1.8	0	0	0	.4	.8	0	0	65
1955–56[2]	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
San Antonio Creek near Casmalia (drainage area 137 square miles)													
1955–56	83.0	197.0	649.0	1,850.0	320.0	214.0	251.0	143.0	66.0	64.0	69.0	63.0	3,970
1956–57	85.0	111.0	183.0	296.0	287.0	214.0	171.0	127.0	61.0	68.0	41.0	50.0	1,690
1957–58	78.0	142.0	283.0	377.0	1,240.0	2,080.0	8,850.0	187.0	93.0	76.0	102.0	112.0	13,620

[1] 1940–41 water-year total includes January through September only.
[2] Stream gage moved downstream approximately 5 miles. Gage now called San Antonio Creek near Casmalia.

the flow of the creek is perennial at the new station and intermittent at Harris (table 3). The perennial flow is caused by a barrier of consolidated rocks (pl. 3) that cuts across and underlies the valley at shallow depth. Ground water reaching this barrier is forced upward to the land surface, where it discharges continuously into the creek. This discharge is the base flow of the creek. The meager data suggest that for the 3 years of record the base flow of the creek below the barrier ranged from 40 acre-feet per month in the summer to 200 acre-feet in the winter. As of 1956–58, therefore, the ground-water outflow (overflow) from the basin was roughly 1,500 acre-feet per year. The average annual runoff of San Antonio Creek at the new station has not been calculated because the period of record is too short.

GROUND-WATER RESOURCES

OCCURRENCE

Ground water in the San Antonio Creek valley occurs in most of the unconsolidated deposits that have filled the San Antonio trough. The water-bearing deposits include the alluvium, the Orcutt sand, the Paso Robles formation, and the Careaga sand. The formations below the Careaga sand probably are too highly compacted or consolidated to contain appreciable quantities of water, and the dune sand and terrace deposits are largely above the zone of saturation.

The ground-water body extends westward from the Zaca–Foxen Canyon area (secs. 22 and 27, T. 8 N., R. 31 W.) to the ocean. Its south boundary is the consolidated rocks (pl. 3). The location of the north boundary of the ground-water body is uncertain, but it may lie approximately along a line drawn from sec. 29, T. 8 N., R. 33 W., to sec. 15, T. 8 N., R. 32 W. (pl. 3).

A small ground-water body is contained in the deposits that underlie Foxen Canyon (pl. 1). This water body extends from the head of Foxen Canyon northwestward into the Sisquoc Plain. It is contained within the alluvium of the canyon until it reaches the vicinity of sec. 35, T. 9 N., R. 32 W., (pl. 1); from here to the Sisquoc Plain it is contained within the alluvium, the Paso Robles formation, and the Careaga sand, as described by Worts (1951).

Most of the wells in the valley penetrate only part of the Paso Robles formation, primarily because the formation is about 2,000 feet thick in the center of the valley. In and near the outcrop area of the Careaga sand, however, a few wells tap the base of the Paso Robles. Most irrigation wells are about 300 feet deep. The head in wells tapping only the Paso Robles formation increases slightly with depth. This increase is due not only to the many almost impermeable clay lenses in the formation but also to the synclinal structures beneath the valley. Wells generally are perforated opposite both the alluvium and the Paso Robles formation; because any intraformational-head differences in these wells tend to be equalized by interformational movement of water in the casing, the water level is somewhere between the level in the alluvium and that in wells tapping only the Paso Robles formation.

Flowing wells were observed in two areas of the valley in 1958: four in the area of rising ground water between Harris and the consolidated rock barrier, and one in sec. 9, T. 8 N., R. 33 W. (pl. 3). In both areas the localized structural features (pl. 1), the stratigraphic variations in the Paso Robles formation, and the head of water are such that ground water within the formation is under sufficient hydrostatic pressure to cause flow over the top of some well casings.

Ground water impounded behind the consolidated rock barrier in the area of the four flowing wells leaks also upward to the surface, and that part of the water not consumed by the extensive growth of phreatophytes in the area of rising water (pl. 3) is discharged over the barrier largely as surface flow.

Springs and seeps discharge along both flanks of the valley east and west of Los Alamos and west of Harris (pl. 1). Ground water moves downgradient along bedding planes within the unconsolidated deposits in these areas, and, where these bedding planes intersect the land surface, springs and seeps appear.

Before 1947, several wells flowed that tap the base of the alluvium in sec. 30, T. 8 N., R. 32 W., and sec. 25, T. 8 N., R. 33 W. (pls. 3 and 4). These wells flowed because a high head of water was created below a fairly impervious clay layer near the base of the alluvium (pl. 2, well log 8/32–30C2). In recent years additional irrigation wells have been drilled in this area, and pumping from these wells has lowered the head to such an extent that in 1958 no wells flowed.

Perched water bodies, probably small, underlie Burton Mesa and San Antonio Terrace. No attempt was made to define the extent of these water bodies, but the two springs 8/35–11F1 and 9/35–36C1 (pl. 1) are direct evidence of their existence.

MOVEMENT

The movement of ground water beneath the valley is controlled by geologic structure and lithologic changes within the aquifers. Ground water in the upper and central parts of the valley has a westward hydraulic gradient that averages about 30 feet per mile. The gradient steepens abruptly in secs. 19 and 20, T. 8 N., R. 33 W. (pl. 3). A study of the logs of wells in this area suggests that the change in gradient is due either to a decrease in permeability in the vicinity of the wells or to structural control caused by the anticline that crosses the valley upstream from this area (pl. 1).

West of sec. 19, the gradient flattens to about 10 feet per mile. The hydraulic gradient again steepens abruptly 3 miles west of Harris (sec. 17, T. 8 N., R. 34 W., pl. 3), where the consolidated Tertiary rocks cut diagonally across and underlie the valley at a shallow depth (pl. 1). The movement of ground water west of the barrier is restricted to a thin, narrow strip of alluvium, which has filled a notch cut through the consolidated Tertiary rocks by San Antonio Creek (pl. 1). The creek locally flows on the Tertiary rocks; therefore, virtually all ground water that moves over the barrier becomes surface flow at this point and wastes to the ocean.

RECHARGE

The areas of ground-water recharge can be broadly defined if the direction of ground-water movement is known. Direction of movement can be determined from a water-level contour map that shows the movement of water from areas of recharge to areas of discharge. These maps are constructed by connecting points of equal head within an aquifer. The points are determined from measurements of the depth to water in wells.

Plate 3 shows water-level contours for December 1943 and January 1958. The contour lines were constructed by using static (nonpumping) depths to water in wells, and mean sea level as the datum. Altitude of the land surface at most wells was determined by use of an aneroid barometer, but a few altitudes were estimated by interpolation from topographic maps. The December 1943 contours show the water surface at the highest level on record, and the January 1958 contours show it at the lowest. Plate 3 also shows the area around Los Alamos that had flowing wells before 1947 and the area of rising ground water west of Harris.

Ground water moves normal to the contour lines from areas of high head to areas of low head; the contour lines on plate 3 show the ground water to be moving southwestward away from the Solomon and Casmalia Hills, northwestward from the Purisima Hills, and then westward down the valley. The main area of recharge is in the Solomon Hills. Because consolidated Tertiary rocks border the valley on the south side (pl. 1), the amount of ground water contributed by lateral movement to the valley is rather small. The deposits that border San Antonio Creek valley downstream from Harris (pl. 1) may contribute a small amount of water to the ground-water body in that area.

The ground-water body is recharged principally by infiltration of rain and seepage from streams. All recharge is local—that is, it occurs within the drainage area of San Antonio Creek.

INFILTRATION OF RAIN

The amount of rain that infiltrates a ground-water body can vary considerably, depending mostly upon the type of soil, density of vegetation, intensity of the rainfall, and terrain. Much of the infiltrating rain is held within the root zone that extends from the land surface to a depth of 10 to 15 feet; but, after the soil-moisture deficiency within this zone has been satisfied, the excess rain will continue downward until it eventually reaches the water table.

The measurement of rain infiltration requires special equipment; it is time consuming, and, to be of value, it must be continued over several years and under a variety of conditions. Measurements of this type were beyond the scope of the present investigation. To determine the amount of rain that became ground water in the San Antonio Creek valley, it was necessary to rely upon measurements made by Blaney (1933) in Ventura County. Climate and crop patterns and practices in the two areas are similar. Blaney tabulated the amounts of rain that became ground water, depending upon type of vegetation and seasonal precipitation, for several locations in Ventura County for a period of 5 years. Blaney's values of seasonal rainfall were plotted against his values of rain infiltration on land having cover similar to that in the San Antonio Creek valley, and smooth curves were drawn through these points. Values of rain infiltration corresponding to seasonal rainfall and cover in the San Antonio Creek valley were picked from these curves.

The area of rain infiltration in the San Antonio Creek valley is shown on plate 3; it includes all the areas within the boundary of the drainage divide, outside the boundary of the consolidated rocks, and east of the ground-water barrier. It encompasses an area of about 75,000 acres of which about 5,000 acres is brush covered, about 68,500 acres is covered with grass and weeds, and about 1,500 acres is planted with truck, garden, and alfalfa crops.

No allowance was made for infiltration in the areas where consolidated rocks crop out (pls. 1 and 3). Most of the rain on these areas runs off. The remainder is largely retained in the joints and fractures of the consolidated rock and never reaches the valley.

The amount of rainfall varies over the valley area; therefore, to calculate the rain infiltration, rainfall recorded at the station most representative of each land-cover subarea was used (table 4).

The amount of rain that infiltrated each of the land-cover subareas in the San Antonio Creek valley is given in table 4, as is the total amount for each year and the average for the 16-year period, 1943–58. The period 1943–58 had below-normal rainfall (table 1), and ground-water recharge by rain infiltration during these years also was below normal.

TABLE 4.—*Estimated yearly ground-water recharge by infiltration of rain in the water years 1943–58*

[All estimates rounded to two significant figures]

Year ending Sept. 30	Brush 5,000 acres			Grass and weeds 68,500 acres			Truck, garden, and alfalfa 1,500 acres			Recharge to the water body (acre-feet)
	Rainfall at La Zaca-San Antonio (inches)	Infiltration of rain		Rainfall at Santa Maria-San Antonio (inches)	Infiltration of rain		Rainfall at Los Alamos (inches)	Infiltration of rain		
		Inches	Acre-feet		Inches	Acre-feet		Inches	Acre-feet	
1943	16.94	0	0	15.93	0	0	16.30	3.5	440	440
1944	15.78	0	0	15.31	0	0	17.36	4.3	540	540
1945	14.75	0	0	13.77	0	0	12.25	0	0	0
1946	13.67	0	0	11.85	0	0	13.41	1.0	120	120
1947	11.31	0	0	8.85	0	0	8.92	0	0	0
1948	[1] 8.08	0	0	9.13	0	0	8.08	0	0	0
1949	[1] 11.68	0	0	[1] 11.68	0	0	11.68	0	0	0
1950	15.37	0	0	8.50	0	0	12.43	0.3	40	40
1951	10.89	0	0	8.36	0	0	10.20	0	0	0
1952	22.69	1.5	630	19.51	1.4	8,000	21.69	7.7	960	9,600
1953	12.73	0	0	11.78	0	0	12.51	0.4	50	50
1954	11.96	0	0	11.03	0	0	13.46	1.1	140	140
1955	15.44	0	0	12.03	0	0	13.24	1.0	120	120
1956	[1] 16.79	0	0	[1] 16.79	0	0	16.79	3.8	480	480
1957	[1] 10.27	0	0	10.82	0	0	10.27	0	0	0
1958	28.04	5.9	2,500	24.64	4.6	26,000	29.17	13.7	1,700	30,000
Total										42,000
16-year average										2,600

[1] No local records available; rainfall at Los Alamos used.

Table 4 illustrates that little or no rain infiltrates in years of average or below-average rainfall and that rain infiltrates in quantity only in periods of above-average rainfall.

The long-term average recharge by infiltration of rain in the San Antonio Creek valley, based on 49 years of rainfall records at Los Alamos (table 1), is about 4,500 acre-feet per year. This figure has been reduced 10 percent to allow for excessive runoff in seasons having more than 25 inches of rain. The average rain infiltration during the period 1943–58 (table 4) was about 2,000 acre-feet per year less than the long-term average.

SEEPAGE FROM STREAMS

Seepage loss from streams ordinarily is estimated by the decrease in streamflow between two gaging sites. It would not be economically feasible to establish gaging stations on all the creeks in the area. Accordingly, no direct estimates of the seepage loss from streams were made.

An approximation of the seepage loss for 1943–58 can be obtained by subtracting the estimated average infiltration of rain of 2,600 acre-feet per year (table 4) from the estimated total discharge of 4,500 acre-feet per year (p. 33, 34). This 2,000 acre-feet per year, of course, is an extremely rough estimate of seepage loss and may represent a minimum amount because no allowance has been made for water pumped.

TOTAL RECHARGE

Total ground-water recharge in the San Antonio Creek valley is the sum of the seepage loss from streams and the infiltration of rain; it cannot be estimated accurately because the seepage loss from streams can be only approximated. However, inasmuch as total discharge from the valley under natural conditions probably was at least 5,000 acre-feet per year and because under natural conditions recharge equals discharge, total recharge must be at least 5,000 acre-feet per year.

DISCHARGE

Ground water in the San Antonio Creek valley is discharged both artificially and naturally. Artificial discharge includes the artesian flow of water from wells and the withdrawal of water by pumping. Natural discharge is comprised of evapotranspiration, spring discharge, and outflow to the ocean.

ARTIFICIAL DISCHARGE

PUMPAGE

The history of the development of water wells in the valley dates to the founding of the town of Los Alamos. The town was surveyed in 1876 and 1 year later became a flourishing community having a hotel, three saloons, and several general merchandising stores. Rapid growth of the town brought about the demand for a dependable water supply, and, as a consequence, the first domestic water wells in the valley were dug. Before this time the water had been obtained from springs that bordered the valley.

The pumping of water for irrigation started at the turn of the century with the beginning of the sugar-beet industry. By 1943 there were 21 active irrigation wells in the valley, and by 1958 the number had increased about 86 percent to 39 wells. Records of the number of irrigation wells were not kept prior to 1943, but the rate of development of irrigation in the valley can be estimated for the period 1900–43 by a comparison with the Santa Maria Valley. In the Santa Maria Valley, irrigation developed slowly between 1900 and 1920 and rapidly between 1920 and 1930 (Worts, 1951, p. 84–85). From 1930 to 1943 development again was slow.

Table 5 shows the irrigated acreage in the San Antonio Creek valley for the years 1943–57. The irrigated-acreage data is based on information collected from the Soil Conservation Service of the U.S. Department of Agriculture, the Union Sugar Co., and the Santa Barbara County Agricultural Commissioner.

TABLE 5.—*Irrigated acreage in the San Antonio Creek valley, 1943–57*

Year	*Irrigated acreage*	*Year*	*Irrigated acreage*
1943	800	1951	1, 600
1944	900	1952	1, 700
1945	1, 000	1953	1, 800
1946	1, 100	1954	1, 900
1947	1, 200	1955	2, 000
1948	1, 300	1956	2, 100
1949	1, 400	1957	2, 200
1950	1, 500		

Several crops are grown in the valley. Table 6 shows the results of a crop survey made in 1957 by the State of California. Most of the fields are irrigated by furrow or flooding methods; only a few sprinkler installations are in operation.

Irrigation wells in the valley have an average depth of 300 feet and an average pumping rate of 400 gpm. The average total pumping lift is about 118 feet. The average specific capacity is about 11 gpm per foot of drawdown.

Water pumped for irrigation has been estimated indirectly by two methods. One method involves multiplying the amount of water applied per acre for each type of crop by the number of acres

TABLE 6.—*Irrigated acreage in the San Antonio Creek valley, 1957*

[From State of California Land-Use Maps]

Crop	*Acres*
Sugar beets	490
Field corn	67
Castor beans	184
Lima beans	115
Alfalfa	274
Mixed pasture	104
Sudan grass	18
Green beans	821
Flowers and nursery	80
Total	2, 153

planted; the product provides a rough estimate of the total net pumpage. The second method is based on the amount of kilowatt-hours of electrical energy that is required to pump an acre-foot of water and the total electricity used by an irrigation well during the irrigation season, May 1 to April 30. The amount of electrical energy consumed by irrigation wells for 1957 and 1958 in the San Antonio Creek valley was obtained from the Pacific Gas and Electric Co.

Pump-efficiency tests supplied by the Pacific Gas and Electric Co. show that the average amount of electrical energy required to pump 1 acre-foot of water in the valley was about 200 killowatt-hours in 1957 and 1958. This energy factor will remain virtually constant as long as the pumping lift remains unchanged. An appreciable decline in water levels, for example, would increase the pumping lift, and the increase in lift would increase the amount of electrical energy required to pump an acre-foot of water. During the period of inventory, the water levels declined somewhat, but not enough to warrant any meaningful adjustment in the energy factor, considering the units of error involved in the method.

The total metered electrical power and the kilowatt-hours per acre-foot were used to estimate water pumped for irrigation for 1957 and 1958 (table 7). In 1957 there was data to estimate pumpage by both the duty-of-water method and the electrical-energy method; computations by these two methods gave identical values for this year.

The amount of water pumped for irrigation is not equal to the amount of water permanently removed from the ground-water reservoir. When water is applied to crops, part of the water is consumed by the plants, part is lost by evaporation and transpiration, part may run off on the surface, and the remainder percolates downward and is returned to storage. That part of the pumped water that does not return to the ground-water reservoir is termed the

TABLE 7.—*Estimated pumpage for irrigation in the San Antonio Creek valley, 1943–58*

Year	*Water pumped for irrigation (acre-feet)*	*Total net pumpage for irrigation (acre-feet)*
1943	1, 700	1, 400
1944	1, 900	1, 500
1945	2, 100	1, 700
1946	2, 300	1, 800
1947	2, 500	2, 000
1948	2, 700	2, 200
1949	2, 900	2, 300
1950	3, 100	2, 500
1951	3, 400	2, 700
1952	3, 600	2, 900
1953	3, 800	3, 000
1954	4, 000	3, 200
1955	4, 200	3, 400
1956	4, 400	3, 500
1957 [1]	4, 600	3, 700
1958 [1]	3, 600	2, 900
Total, about	50, 000	40, 000
16-year average	3, 100	2, 500

[1] Estimates for 1957 and 1958 by electrical-energy method; all others by crop-use method.

"net pumpage." Estimates made by Upson and Thomasson (1951, p. 125) in the Santa Rita–Buellton area of the nearby Santa Ynez Valley suggest that the water returning to the ground-water reservoir is about 20 percent of that applied. The irrigation practices, soils, climate, and crop patterns of the Santa Rita–Buellton area and the San Antonio Creek valley are similar, and it is assumed that about 20 percent of the pumped water also returns to the ground-water reservoir in the San Antonio Creek valley. Thus, the net pumpage is about 80 percent of the water pumped for irrigation. Annual estimates of pumpage for irrigation are given in table 7.

Table 7 shows that, except for 1958, the net pumpage for irrigation in the valley has increased steadily since 1943. Water pumped since 1957 for irrigation in the valley has been calculated from the amount of electricity used by irrigation pumps (p. 30). This method, which adjusts automatically for double cropping and for wet and dry years, gives the amount of water pumped. Table 7 shows these adjustments by a decrease in the 1958 net pumpage due to a wet year (table 1). Because power figures were not available before 1957, irrigation pumpage for the years 1943–57 was determined by multiplying the number of acres planted by 2.1 feet, the average quantity of applied water based on average rainfall. The figures used for quantity of applied water are based on data supplied by the Santa Barbara Agricultural Extension Service and are weighted to reflect the usual crop pattern and agricultural practices in the valley. This method gives approximate amounts of water used and does not adjust for double cropping and for wet and dry years.

The amount of water pumped for domestic, stock, and industrial use in the valley is small compared to that used for irrigation. The possibility of obtaining ground water from the valley for use on Vandenberg Air Force Base has been explored, but as of 1958 no water was being pumped for this purpose. The Los Alamos Community Service District, which supplies water to the town of Los Alamos, was the largest nonirrigation water user in the valley in 1958. The District pumped about 80 acre-feet of water in 1958. The total amount of water pumped for uses other than irrigation in the valley probably did not exceed 200 acre-feet in 1958 and probably has not varied appreciably in the past 20 years.

FLOWING WELLS

The flow from artesian wells is classed as artificial discharge. In 1958 there were five flowing wells in the San Antonio Creek valley—8/33-9H2, 8/34-15R1, 16G1, 17B2, and 17K1 (pl. 1). The total flow from the artesian wells was estimated to be about 30 acre-feet in 1958. It may have been as much as 100 acre-feet in the early 1940s before pumping for irrigation increased substantially.

NATURAL DISCHARGE

Ground water is discharged naturally in the valley by (1) evaporation and transpiration by native vegetation in areas of high water table, (2) spring discharge, and (3) ground-water outflow to the ocean.

EVAPOTRANSPIRATION

Evapotranspiration is the use of water by growing vegetation plus water evaporation from adjacent soil. In the San Antonio Creek valley, evapotranspiration takes place in the area of rising ground water and along the channel of San Antonio Creek (pl. 3). There is considerable native vegetation and a high water table in both of these areas. Elsewhere in the valley, the native vegetation either has been cleared by man or is sparse because of a low water table.

The native vegetation in the area of rising ground water is saltgrass, wire rush, tules, and cottonwood and willow trees—all phreatophytes. A phreatophyte is a plant that habitually obtains its water from the zone of saturation, either directly or through the capillary fringe, and generally has a high water use. These phreatophytes cover about 550 acres. The average evapotranspiration in this area is about 4.7 acre-feet of water per acre per year. This figure is derived by prorating the density and water use of each type of vegetation, on the basis of work by Young and Blaney (1942, p. 39–51) in the Santa Ana River valley, California, where the climate and native vegetation is similar to that in the San Antonio Creek valley.

Cottonwood trees, willow trees, and tules grow profusely along the channel of San Antonio Creek from 5 miles east to 1 mile west of Harris. An estimate of evapotranspiration of 3.0 acre-feet of water per acre per year, as derived by Wilson (1959, p. 50) in his studies along the Santa Ynez River valley, California, was assigned to this area of 130 acres. This figure of evapotranspiration differs from that of the area of rising ground water because the two areas have different types and densities of native vegetation.

The following table gives the estimated average yearly evapotranspiration in the San Antonio Creek valley. No attempt was made to adjust the figures to include the amount of rainfall consumed directly by the phreatophytes. These plants use very little water during the rainy season because they generally are dormant. Aerial photographs of the valley show little change in the area and density of the phreatophytes since the early 1940s.

Location	Type of vegetation	Average yearly evapotranspiration (acre-feet per acre)	Area (acres)	Total yearly evapotranspiration (acre-feet)
Area of rising ground water	Saltgrass, wire rush, tules, and willow and cottonwood trees.	4.7	550	2,600
Area along San Antonio Creek	Tules, and willow and cottonwood trees.	3.0	130	400
Total			680	3,000

SPRING DISCHARGE

About 50 acre-feet of water per year was discharged by springs in the valley area during 1943–58: a time of deficient rainfall. This estimate is based on field checks of springs in 1957 and 1958 and on information from property owners. Spring discharge probably would increase during a series of wet years. Most of the spring discharge seeps back into the ground or flows into San Antonio Creek. A small amount is evaporated, transpired, or consumed by stock. Thus, the bulk of spring discharge returns to the ground-water reservoir and does not appreciably alter the natural regimen of the ground-water system.

GROUND-WATER OUTFLOW

Ground-water outflow is the underflow in the Recent alluvium and the base flow of San Antonio Creek measured at the ground-water barrier (pl. 3). Because underflow in the alluvium, which is fine grained in the barrier reach, probably is negligible, the base flow of the creek constitutes virtually all the ground water discharged over the barrier from the extensive basin upstream.

The base flows for the water years 1956–58 were taken directly from the surface-water records (San Antonio Creek near Casmalia) for months when no storm runoff occurred and were interpolated for months when storm runoff occurred (U.S. Geological Survey Water-Supply Papers 1445, 1515, and 1565). These values are tabulated as follows:

Water year	Average base flow, cubic feet per second												Average	Total (acre-feet)
	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.		
1955–56	1.3	[1] 1.8	[1] 3.5	[1] 4.0	[1] 3.5	3.5	[1] 2.7	[1] 2.2	1.1	1.0	1.1	1.0	2.2	1,600
1956–57	1.4	1.9	3.0	[1] 3.5	[1] 3.8	[1] 3.2	[1] 2.3	2.0	1.0	1.0	0.7	0.8	2.0	1,400
1957–58	1.3	2.4	[1] 3.2	[1] 3.5	[1] 4.0	[1] 4.0	[1] 4.0	3.0	1.6	1.2	1.6	[1] 1.8	2.6	1,900

[1] In part estimated.

The base flow was about 1,500 acre-feet in the relatively dry years 1956 and 1957 and about 1,900 acre-feet in the wet year 1958. The average for the period is rounded to 1,500 acre-feet, which is used in the following sections of the report. Under natural conditions the long-term base flow, or ground-water outflow, probably was more than 2,000 acre-feet per year.

TOTAL DISCHARGE

The total net discharge is the sum of the natural discharge and the net artificial discharge and is the amount of ground water permanently removed from the basin. It includes the discharges by net pumpage for irrigation, pumpage for other uses, flow from wells, evapotranspiration losses, and ground-water outflow to the sea (table 7; p. 32–34).

Table 8 indicates a steady yearly increase in the amount of ground water discharged from the valley since 1943. This increase is the result of increases in pumpage for irrigation (table 7). Discharge in 1958 was less than that in 1957 because the net pumpage for irrigation for that year was adjusted to the wet year 1957–58 (table 1 and p. 31).

WATER-LEVEL FLUCTUATIONS

Water-level fluctuations must be known before it is possible to evaluate the ground-water hydrology of an area. Regular water-level measurements may be used to (1) indicate the status of ground

TABLE 8.—*Estimated total net ground-water discharge from the San Antonio Creek valley, 1943–58*

Year	Total net ground-water discharge (acre-feet)	Year	Total net ground-water discharge (acre-feet)
1943	6, 700	1952	8, 000
1944	6, 800	1953	8, 000
1945	7, 000	1954	8, 200
1946	7, 100	1955	8, 300
1947	7, 300	1956	8, 300
1948	7, 500	1957	8, 500
1949	7, 500	1958	7, 600
1950	7, 700		
1951	7, 900	Total	122, 400
		16-year average	7, 600

water in storage, (2) estimate the base flow of streams, (3) assist in the management of basins requiring drainage, (4) provide records for use in project studies, and (5) evaluate land-management and water-conservation programs in artificial recharge of ground-water basins.

Monthly water-level measurements have been made in four wells in the San Antonio Creek valley since December 1943. In addition to these, a large number of miscellaneous measurements were made in 1943 (La Rocque and others, 1950) and 1958. The locations of these four wells are shown on plate 1, and their water-level fluctuations are shown on plate 4. Plate 3 shows the water-level contours for December 1943 and January 1958, respectively—the highest and the lowest water levels on record.

Water levels in the upper Los Alamos Valley (east of Los Alamos) declined about 30 feet between December 1943 and January 1958. The hydrograph of well 8/32–30K2 (pl. 4) is representative of water-level fluctuations in this area. The water level in this well changed little from 1943 until the spring of 1947, when water levels began to decline in response to increased withdrawals for irrigation and because of a series of dry years. In the period 1947–53, the water level declined an average of about 5 feet each summer and had a net decline of about 1 foot a year. The drought continued through 1957, and water-level declines became more pronounced. Summer lows during this period averaged 20 feet below spring highs, and net yearly declines averaged about 2 feet. In the winter of 1957–58, above-average rainfall provided considerable recharge to the ground-water reservoir (table 4), and the water level in well 8/32–30K2 recovered to a level 3 feet higher than the previous year's high.

Wells 8/33–20Q1 and 8/33–20R1, about half way between Los Alamos and Harris, are a shallow and deep pair; well 8/33–20R1 is 75 feet deep and well 8/33–20Q1 is 351 feet deep. The hydrographs for these wells (pl. 4) indicate that ground water in the

Paso Robles formation is artesian at depth. The altitude of the water level in deep well 8/33–20Q1 during 1943–46 was 403 feet above sea-level datum, whereas the altitude of the water in shallow well 8/33–20R1 was 383 feet. Well 8/33–20Q1 was used for irrigation from 1943 to 1951, and the heavy withdrawal of water is reflected by a water-level decline that averaged about 22 feet during each summer. The annual net decline during the same period was about 4 feet. In 1951, the well casing collapsed at about 200 feet, and the well has not been used for irrigation since. Continued water-level measurements in well 8/33–20Q1, however, show that the total net decline of water level between 1943 and 1958 was about 23 feet.

In contrast, the water level in shallow well 8/33–20R1 declined only 2 feet between the years 1943–58. The fluctuations during each year reflect pumping of the well or nearby wells.

Water-level fluctuation in well 8/34–23B1 at Harris (pl. 1) is representative of fluctuation in the water level near the area of rising ground water (pl. 3). The hydrograph (pl. 4) shows that the water level has declined only about 2 feet during the period of 1943–58; this decline indicates that the draft in this area is small and that the head has changed little in the area of rising water. Nevertheless, the relatively small decline in head may have been accompanied by a significant decrease in ground-water outflow.

Plate 2 is a longitudinal section of the San Antonio Creek valley. Water-level profiles for three different dates have been drawn on the section. The December 1943 profile was constructed by using the earliest water-level measurements available; the January 1958 profile was drawn to show the lowest level during the drought, and the June 1958 profile was included to show the water-level recovery after the above-average rainfall in the spring of 1958. The profiles show that during 1943–58 water levels declined in the upper Los Alamos Valley in the vicinity of Los Alamos and in the area midway between Los Alamos and Harris, and they declined slightly downstream in the area of rising water.

PERENNIAL YIELD

By G. F. Worts, Jr., and H. D. Wilson, Jr.

The perennial yield of an aquifer or a ground-water basin may be defined as the rate at which water can be pumped from wells years after year without decreasing the stored water to the point where the rate becomes economically infeasible or where the quality of water deteriorates. The San Antonio Creek valley area has a large amount of stored water that can be used before the economic limits of pumping are approached. When those limits are finally approached, the perennial yield of the basin will be equal to the average annual recharge or to original average natural discharge, provided all natural discharge can be salvaged. To salvage as much of the natural discharge as is possible, substantial depletion of water in storage near the area of rising ground (pl. 3) would be necessary. Moreover, recharge, now rejected in this area of high water table and wasting to the ocean, would be accepted.

The perennial yield of the area is difficult to estimate. This difficulty exists principally because of lack of complete data on recharge and discharge. Also contributing to the difficulty are the lack of information concerning the change in stored water in large remote parts of the recharge area and the fact that the east and northeast boundaries of the area, which probably do not coincide with the topographic divides (pl. 3), cannot be delineated. Deterioration of the quality of ground water as storage is depleted also may limit the perennial yield, but this potential deterioration cannot be evaluated at this time because the quality of water in the deeper zones beneath the basin is unknown. Despite these limitations and unknown factors, three methods are available to estimate the perennial yield:

If proper water development and management can salvage virtually all the natural discharge and prevent a significant deterioration in chemical quality, the perennial yield is equal to the long-term recharge or the long-term natural discharge. The first estimate of yield is based on incomplete recharge estimates. The estimated recharge from infiltration of precipitation, adjusted to the long term, is roughly 4,500 acre-feet per year (p. 28). Recharge from streams was not estimated, but the stream-channel geology, rainfall in the recharge area, and records of runoff at "San Antonio Creek at Harris" and "San Antonio Creek near Casmalia" (table 3) indicate that the opportunity for recharge is moderately good. The total long-term natural recharge, and hence the perennial yield, is considerably in excess of the estimated 4,500 acre-feet from rain alone.

The second estimate of perennial yield, based on estimates of discharge, can be derived by assuming that the total natural discharge of 4,500 acre-feet in the period 1956–58 has been decreased below the full natural discharge by an amount equal to the average net pumpage of about 2,500 acre-feet for the period 1943–58 (table 7). This discharge data suggests a natural discharge under native conditions of about 7,000 acre-feet per year and also a perennial yield of the same magnitude. This estimate may be in error in two ways: First, it may be somewhat high if the 16-year period is too short for the average net pumpage to decrease the natural discharge by a like amount; experience in other alluvial ground-water basins suggests that the time is ample to produce the average effect. Second, the estimate may be too low, because recharge for the period was below average and hence would have resulted in a somewhat reduced natural discharge even under nonpumping conditions.

The third method used to estimate the perennial yield was to compute the average annual total net discharge during a period when the net change of ground water in storage was nearly zero and when recharge was about equal to the long-term average. The hydrographs of water levels in four wells (pl. 4) show that ground-water altitudes in the spring of 1954 were slightly higher than those in 1958 and that a small net depletion in stored water occurred for the period.

For this 4-year period, the total net discharge averaged about 8,000 acre-feet per year (table 8). The average annual recharge was above average, as indicated by the recharge from rain of about 36,000 acre-feet for the 4 years (table 4), but, by the spring of 1958 and before pumping resumed, the water levels apparently had not fully recovered in response to the large recharge in 1958. These estimates and analysis suggest that the perennial yield probably is less than 8,000 acre-feet per year.

With regard to salvage of natural discharge to utilize most effectively the water resources in the valley, the distribution of pumping wells in 1958 precludes the possibility of salvaging much of the discharge in the near future. As the need for water increases, three procedures could be employed to reduce the natural discharge of ground water and the surface water lost from the area: (1) A pumping plant could be installed in a sump at the ground-water barrier (pl. 3) to use the ground-water overflow now wasting to the sea; (2) additional wells could be constructed in the area of rising ground water to lower water levels and salvage water now lost by evapotranspiration; and (3), after water levels have been depressed substantially in the area of rising water, a dam could be constructed at the site of the ground-water barrier to salvage storm runoff, which could be used to recharge the deposits underlying the surface reservoir or which could be diverted for use where needed.

Thus, the three estimates—more than 4,500, 7,000, and probably less than 8,000 acre-feet per year—show the magnitude of the perennial yield of San Antonio Creek valley, partly on the basis of natural conditions and partly on the basis of conditions in the period 1943–58, if the bulk of the natural discharge were salvaged.

Until the magnitude of the recharge from streams can be evaluated, the interim, or preliminary, perennial yield is considered to be about 7,000 acre-feet per year.

The perennial yield could be increased further by salvaging storm runoff that now wastes to the sea—the increase would be roughly proportional to the amount salvaged. Continued operation of the gaging station, "San Antonio Creek near Casmalia," is needed to determine the amount of storm runoff and, therefore, whether sufficient water is available to warrant construction and operation of a dam and diversion works at the general position of the ground-water barrier.

QUALITY OF THE WATER

All natural waters contain mineral matter dissolved from soils or rocks. The quantity of dissolved-mineral matter in a natural water depends primarily on the type of rocks or soils through which the water has passed and the length of time it has been in contact with the rocks or soils. Ground water generally has a higher concentration of dissolved solids than surface water, for it remains in contact with rocks and soils for a longer period of time. The value of a water supply depends, therefore, in part upon the character and quantity of this dissolved-mineral matter and the use for which the water is intended.

The dissolved-mineral matter in native water is usually in the form of ionized particles. Ionized particles are positively charged cations and negatively charged anions. The most common cations are calcium (Ca), magnesium (Mg), sodium (Na), and potassium (K). The commonest anions are bicarbonate (HCO_3), carbonate (CO_2), sulfate (SO_4), chloride (Cl), and nitrate (NO_3). Constituents generally present in smaller amounts include iron (Fe), fluoride (F), silica (Si), and boron (B). Silica in native water usually is colloidal, not ionic.

Most of the water pumped in the San Antonio Creek valley is used for irrigation, but lesser amounts are pumped for domestic and stock use. The chemical analyses of water collected from wells in the valley are given in table 9. Analyses data of water from San Antonio Creek are given in table 10. No tests have been made to determine whether the waters in the valley are bacteriologically safe.

The Collins (Hem, J. D., 1959, p. 171) bar diagram (fig. 4 shown on page 42) shows the absolute concentrations and hardness of six samples collected from selected wells in the valley—three in 1927 and three in 1958. The graphs show that the water quality in the valley has not changed appreciably between 1927 and 1958.

TABLE 9.—*Chemical analyses, in parts per million,*

Well	Owner	Date sampled	Temp. (° F)	Specific conductance (micromhos at 25° C)	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)
8/32-18P1	James Hopkins	12- 9-43	65	2,390					
28R1	Bernice Holt	12- 8-43		1,420					
29E1	Coast Counties Warehouse	12- 9-43		1,140					
29N1	Santa Barbara County	12- 9-43		532					
29R2	Raffoni	12- 8-43		960					
30C2	James Hopkins	12- 4-43		539					
30E1	John Parma	12- 8-43		457					
30G1	James Hopkins	5-28-58		848	50	65	30	58	2.5
30K1	John Parma	12- 8-43	62	807					
30K2	do	12- 9-43	61	780					
34G1	Confaglia Brothers	12- 8-43		599					
35Q1	Frank F. Barham	12- 8-43		553					
8/33-14R1	Tognazzini Brothers	12- 9-43		646					
19E1	Careaga School	11-26-27		[2]1,240	8	91	26	122	
19G1	E. M. Carr	12- 8 43		1,690					
19H1	Careaga Estate	12- 9-43		1,970					
19L3	A. B. Hanson	12- 8 43		1,380					
19R1	Tony Careaga	12- 9-43		1,270					
20K1	Manuel Luis	12- 8-43		1,000					
20M1	Walter Barca	12- 8-43		1,850					
20Q1	Virginia Barca Estate	11-26-27		[2]1,065	7	86	25	78	
20R1	do	9-26-57		1,039	50	73	54	79	2.4
Do	do	5- 7-58		1,200	20	114	44	93	2.8
Do	do	9-17-58		1,283	43	113	51	93	2.8
21G1	Carl Jensen	12- 9-43		916					
21M1	Shell Company of Calif.	11-26-27		[2]1,185	7	96	40	74	
22N1	Luis Scolari	12- 8-43		874					
23P1	James Richard	12- 8-43		665					
24R1	James Hopkins	12- 9-43	59.5	814					
25B2	Carl Abeloe	12- 8-43		649					
25D3	James Hopkins	12- 9-43		573					
29D1	Tony Careaga	12- 9-43		1,140					
8/34-17B1	U.S. Government	12- 8-43	63	730					
17K1	do	5-28-58		5,240	50	36	31	1,025	50.0
22G1	Virginia Barca Estate	12- 8-43		1,420					
23B3	Josephine Harris Estate	12- 8-43	61.5	1,210					
Do	do	5- 7-58		1,200	40	71	41	117	4.6
Do	do	11-10-58		1,329	39	70	45	117	5.3
24K1	A. B. Hanson	12- 8-43		1,170					

[1] 1943 dissolved solids determined from fig. 5.
[2] From fig. 5.
[3] Calculated by K. S. Muir.

of water from wells, San Antonio Creek valley

Carbonate (CO_3)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids [1]	Hardness as $CaCO_3$	Noncarbonate hardness as $CaCO_3$	Percent sodium	pH	Laboratory
------	------	------	30	------	------	------	1,600	40	------	------	------	U.S.G.S.
------	------	------	150	------	------	------	951	525	------	------	------	U.S.G.S.
------	------	------	79	------	------	------	764	390	------	------	------	U.S.G.S.
------	------	------	76	------	------	------	356	130	------	------	------	U.S.G.S.
------	------	------	84	------	------	------	643	275	------	------	------	U.S.G.S.
------	------	------	63	------	------	------	361	145	------	------	------	U.S.G.S.
------	------	------	58	------	------	------	306	110	------	------	------	U.S.G.S.
0	201	149	73	0	6.6	0.06	595	286	121	30	8.3	State of Calif.
------	------	------	90	------	------	------	541	215	------	------	------	U.S.G.S.
------	------	------	95	------	------	------	523	230	------	------	------	U.S.G.S.
------	------	------	88	------	------	------	401	135	------	------	------	U.S.G.S.
------	------	------	47	------	------	------	370	220	------	------	------	U.S.G.S.
------	------	------	91	------	------	------	433	160	------	------	------	U.S.G.S.
Tr.	268	176	139	------	Tr.	------	837	[3] 336	116	22	------	Shell Co. of Calif.
------	------	------	147	------	------	------	1,130	575	------	------	------	U.S.G.S.
------	------	------	217	------	------	------	1,320	600	------	------	------	U.S.G.S.
------	------	------	163	------	------	------	925	350	------	------	------	U.S.G.S.
------	------	------	111	------	------	------	851	310	------	------	------	U.S.G.S.
------	------	------	67	------	------	------	670	365	------	------	------	U.S.G.S.
------	------	------	161	------	------	------	1,240	625	------	------	------	U.S.G.S.
0	275	185	51	------	0	------	718	[3] 320	94	17	------	Shell Co. of Calif.
0	293	183	117	0.1	4.7	0.1	737	[3] 402	162	30	7.2	State of Calif.
0	387	174	123	0.2	0	0.5	781	465	318	30	7.4	State of Calif.
0	407	175	122	0	0	0.2	941	491	158	29	7.7	State of Calif.
------	------	------	82	------	------	------	614	320	------	------	------	U.S.G.S.
0	275	216	82	------	0	------	800	[3] 405	180	14	------	Shell Co. of Calif.
------	------	------	70	------	------	------	585	315	------	------	------	U.S.G.S.
------	------	------	62	------	------	------	446	215	------	------	------	U.S.G.S.
------	------	------	119	------	------	------	545	160	------	------	------	U.S.G.S.
------	------	------	63	------	------	------	435	130	------	------	------	U.S.G.S.
------	------	------	61	------	------	------	384	175	------	------	------	U.S.G.S.
------	------	------	106	------	------	------	764	340	------	------	------	U.S.G.S.
------	------	------	42	------	------	------	489	18C	------	------	------	U.S.G.S.
0	1,299	60	1,060	0	26	8.4	3,045	219	------	89	7.8	State of Calif.
------	------	------	188	------	------	------	951	390	------	------	------	U.S.G.S.
------	------	------	196	------	------	------	811	290	------	------	------	U.S.G.S.
0	178	122	220	0.2	20	0.14	775	350	204	42	8.1	State of Calif.
0	203	118	220	0.10	12	0.4	864	360	194	41	8.0	State of Calif.
------	------	------	135	------	------	------	784	240	------	------	------	U.S.G.S.

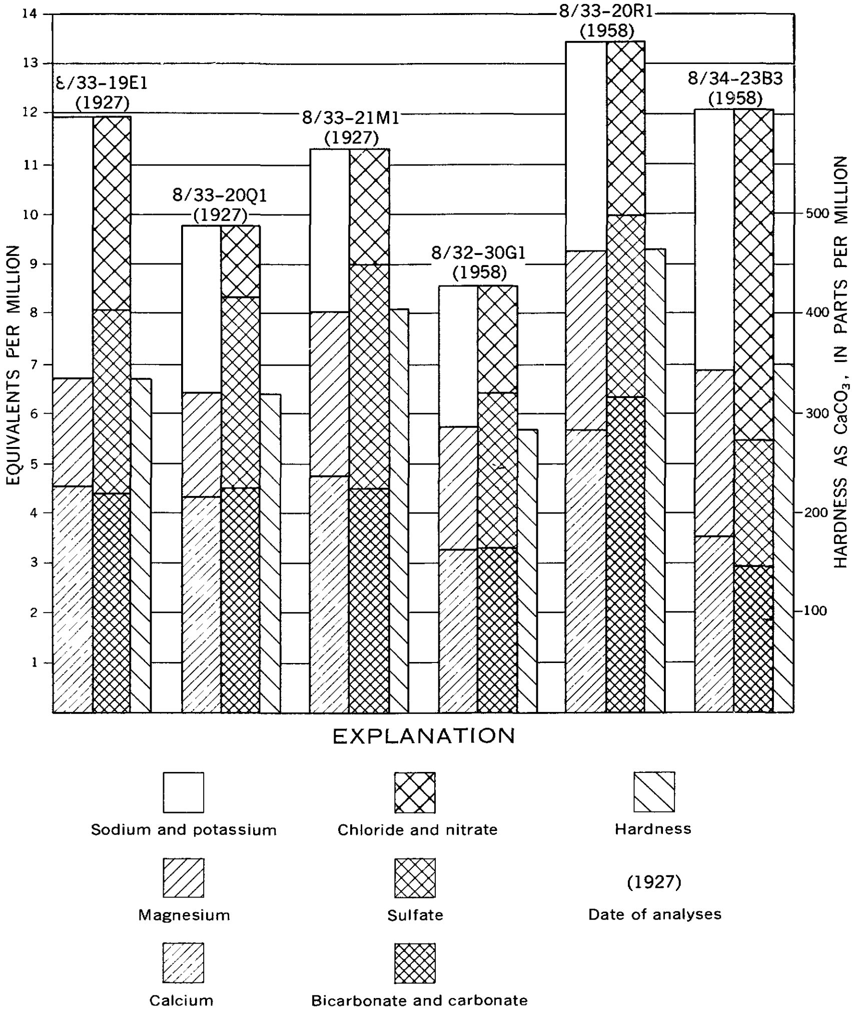

FIGURE 4.—Composition of representative ground waters in the San Antonio Creek valley.

SUITABILITY OF THE WATER FOR VARIOUS USES

Water-quality standards are based on the type and amount of dissolved solids in water and on the intended use of the water.

IRRIGATION

The most important factors that affect the quality of water for irrigation are the dissolved-solids content, the ratio of sodium to the other principal positively charged ions (calcium, magnesium, and potassium), and the boron content.

TABLE 10.—*Chemical analyses, in parts per million, of water from San Antonio Creek, San Antonio Creek valley*

Location	Location on San Antonio Creek, in downstream order	Date sampled	Temp. (°F)	Specific conductance (micromhos at 25°C)	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Carbonate (CO_3)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids	Hardness as $CaCO_3$	Noncarbonate hardness as $CaCO_3$	Percent sodium	pH
8/32-30H	At Los Alamos	12- 9-43	------	1,170	------	------	------	------	------	------	------	------	80	------	------	------	------	415	------	------	------
30C	0.8 mile northwest of Los Alamos.	4-15-58	61	328	43	20	12	27	3.1	0	56	69	28	1	4	0.23	221	99	80	------	7.1
8/33-21L	4.4 miles west of Los Alamos	12- 9-43	------	1,740	------	------	------	------	------	------	------	------	139	------	------	------	------	700	------	------	------
8/34-14N	Bridge 0.5 mile west of Harris on road to Vandenberg Air Force Base.	2-21-58	59	1,190	29	100	44	99	8.2	0	220	312	98	0.66	13	0	830	430	250	------	7.5
8/35-11P	San Antonio Road bridge 0.6 mile above Lompoc-Casmalia Road.	3-28-58	56	1,340	37	94	35	143	8.6	0	281	211	184	0.2	5.9	0.46	883	378	148	44	------

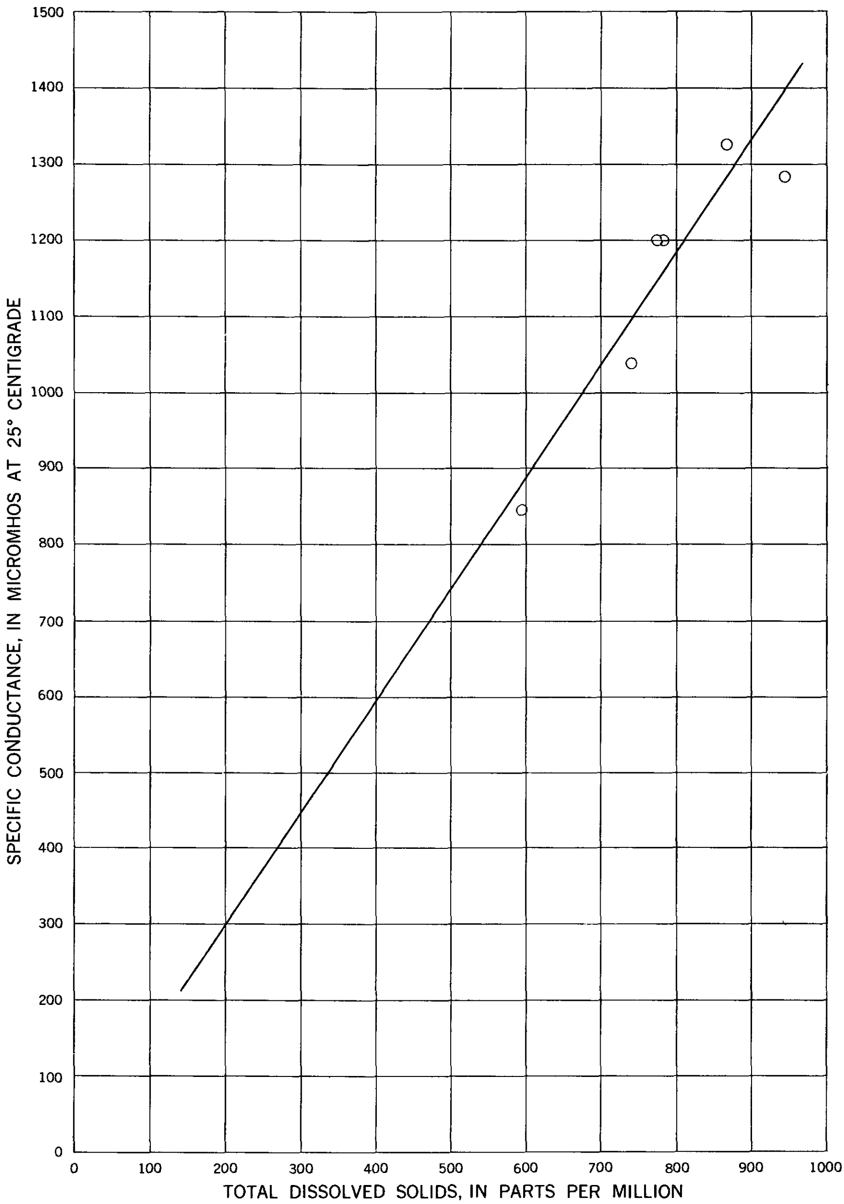

FIGURE 5.—Relations of specific conductance to total dissolved solids.

Because application of highly mineralized water to land having inadequate drainage may produce saline soil, the dissolved solids of a water should be known before it is used for irrigation. In this report only a few determinations of dissolved solids were made, but dissolved solids can be estimated roughly by the relation of dissolved salts to specific conductance. Specific conductance was plotted against dissolved solids for those few samples of water on which both determinations were made (fig. 5). From this plot, dissolved solids can be estimated for the many samples of water on which specific conductance has been determined, because the mean curve of figure 5 can be expressed as:

$$S = 0.67 \ (K \times 10^6)$$

where S=sum of dissolved solids in parts per million and K= specific conductance in micromhos at 25°C.

A high percent of sodium in irrigation water may affect the soil texture by ion exchange. In this process, sodium replaces calcium, magnesium, and potassium in the soil complex. The sodium-bearing soil particles are dispersed readily and may cause the soil to become almost impermeable to the infiltration of water. A decrease in the relative permeability would increase drainage problems and would result in the formation of a saline soil. There is also the possibility that the ionic exchange of sodium for calcium in the root tissues of plants may cause nutritional disturbance to plants.

Boron is essential to the normal growth of all plants, but the quantity required is very small. The amount of boron required for normal growth by one plant may be toxic to a more sensitive plant. Water having a boron concentration of not greater than 1.00 ppm is safe to use for even the most sensitive plants (Wilcox, 1948, p. 5).

Figure 6 shows, diagrammatically, a method for classifying irrigation water on the basis of sodium (alkali) hazard and salinity hazard. The sodium hazard is determined by the absolute and relative concentrations of cations in water. As previously stated, if the proportion of sodium is high, the alkali hazard is high. The salinity hazard is based on the relation of specific conductance of a water to its mineral content. A water having a high specific conductance also will have a high mineral content. If this water were used for irrigation, saline soils could be produced. The classification of irrigation water is that used by the U.S. Salinity Laboratory Staff (1954, p. 80). The diagram (fig. 6) is empirical in that the designation of classes and the conditions for satisfactory water use are based on field and laboratory observations.

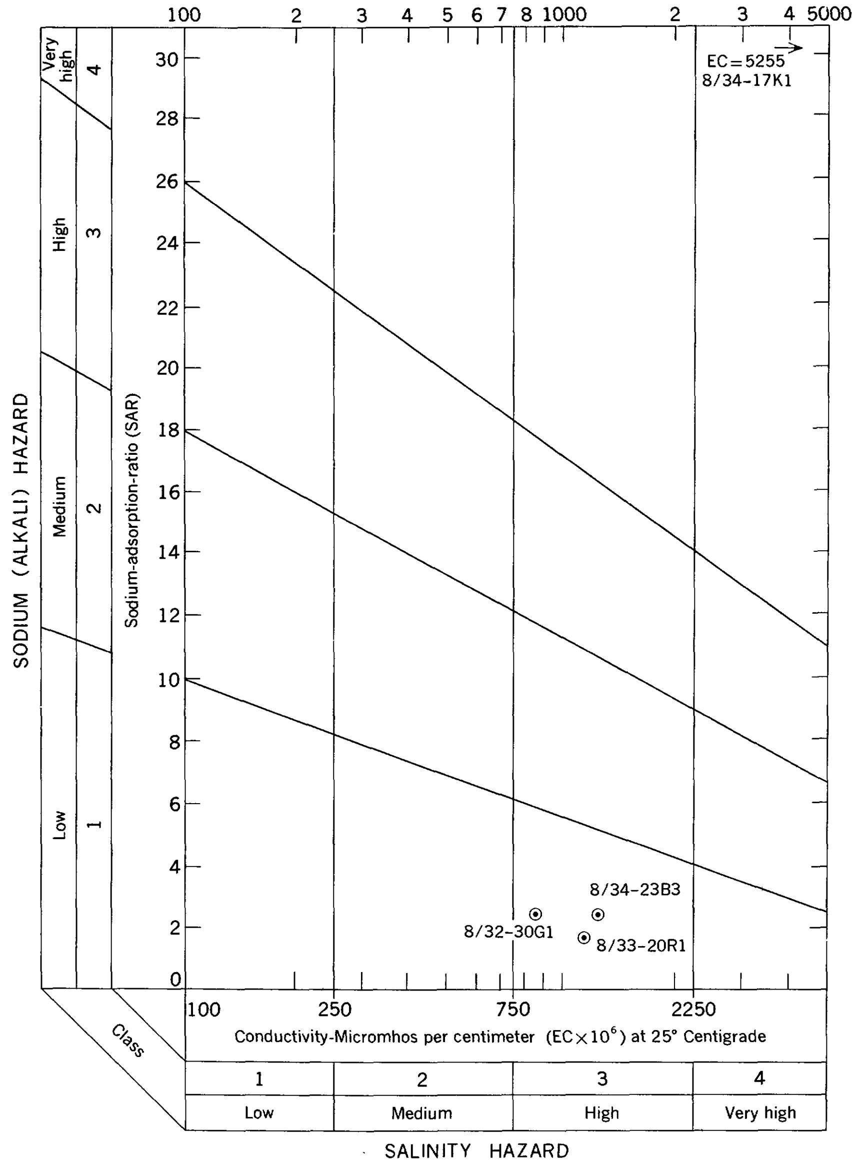

FIGURE 6.—Diagram for the classification of irrigation water (after U.S. Salinity Laboratory Staff).

Most of the ground water in the San Antonio Creek valley meets the standards set for irrigation use. The only exception is the ground water in the lower valley from the consolidated-rock barrier (pl. 1) westward to the ocean. The water in this area has a sodium hazard and a salinity hazard that are beyond the limits for safe irrigation use (fig. 6, well 8/34–17K1).

The analyses data of water samples collected in 1958 from wells in the main area of withdrawal in the valley show that the water has an average sodium-adsorption-ratio of 2.4 and an average specific conductance of 1,100 micromhos at 25°C (pl. 1 and fig. 6), that is, that it has a low sodium hazard and a high salinity hazard. The boron content of this water could be tolerated by even the most sensitive plants.

DOMESTIC SUPPLIES

The drinking-water standards of the U.S. Public Health Service (1962) are generally used to evaluate domestic-water supplies. Recommended limits for some of the more common constituents, in parts per million, are listed below:

Constituent	*Recommended limit (ppm)*
Nitrate (NO_3)	45
Fluoride (F)	1. 5
Chloride (Cl)	250
Sulfate (SO_4)	250

Dissolved solids should not exceed 500 ppm for a water of good domestic quality. However, if such a water is not available, a dissolved-solids content of 1,000 ppm may be permitted.

Hardness, generally mentioned in any discussion of domestic water supplies, is usually reported as total hardness, carbonate hardness, and noncarbonate hardness. Carbonate hardness is called "temporary hardness" and noncarbonate hardness "permanent hardness." These terms came into use because much of the carbonate hardness can be removed from water by boiling. Carbonates and bicarbonates of magnesium and calcium are the main causes of carbonate hardness and the sulfate and chloride salts cause noncarbonate hardness. Hardness in a water supply is objectionable for its scale-forming and soap-consuming properties. Actually, hardness is relative. A water that is considered hard in one area may be considered soft in another. Hem (1959, p. 147) states:

> Hardness of water to be used for ordinary domestic purposes does not become particularly objectionable until it reaches the level of 100 ppm or so.

Ground water in the San Antonio Creek valley area is suitable for domestic use, except for that water from the lower valley between the consolidated-rock barrier (pl. 1) and the ocean. In the lower valley the ground water has a dissolved-solids content of more than 3,000 ppm, which is considerably above the limits acceptable by the U.S. Public Health Service. Ground water in the remainder of the valley has dissolved solids that are well within the limits of potable water. The average hardness of the water in the valley is about 300 ppm, that is, the water is hard. Noncarbonate hardness averages about 200 ppm.

STOCK SUPPLIES

Water to be used for stock is under the same general quality limitations as drinking water for human consumption. However, if need be, animals are able to use water that would be unsatisfactory for human use. Hem (1959, p. 241) states:

> Range cattle in the western United States seem to be able to use water containing 5,000 ppm or more of dissolved solids, and animals that have become accustomed to highly mineralized water have been observed, in the course of investigations of water quality by the author, to drink water containing nearly 10,000 ppm of dissolved solids.

All ground water beneath the valley is suitable for stock use. Water from well 8/34–17K1 is high in dissolved solids (3,040 ppm), but the water probably could be consumed by stock with no ill effects.

POSSIBILITY OF SEA-WATER INTRUSION

Sea water is not likely to intrude into the San Antonio Creek valley. Inasmuch as ground-water levels adjacent to the coast have been above sea level for at least the period of record, fresh water probably migrates toward the ocean. Subsurface information indicates further that consolidated Tertiary rocks, which form the ground-water barrier, are nearly 150 feet above sea level at their highest point near well 8/34–17K1.

Between the barrier lip and the coast, large-scale pumping could cause sea-water intrusion. However, because the alluvium in this reach is poorly permeable, substantial ground-water development is not likely. Continued development of ground-water can be expected in the principal part of the ground-water basin upstream from the barrier. Even if water levels are ultimately drawn down below the barrier lip, sea-water intrusion into this part of the basin is not possible because, as mentioned above, the lip is nearly 150 feet above sea level.

SODIUM CHLORIDE FORMATIONAL WATERS

Ground water having high concentrations of sodium and chloride is contained in the Sisquoc formation in the area from about 3 miles west of Harris to the ocean. Wells 8/34–17K1, 8/34–18C1, 8/35–7R1, 8/35–15E2, and 8/35–17B1 penetrate the formation in this area (pl. 3). The analysis data of water collected from 8/34–17K1 in 1958 show sodium to be 1,020 ppm and chloride to be 1,060 ppm. The remaining four wells were destroyed shortly after being drilled because the water obtained from them was extremely salty.

If the seaward hydraulic gradient should be reversed as a result of large-scale development upstream from the barrier, these saline waters might be drawn inland to the pumping wells. However, the permeability of the Sisquoc formation is low, and the amount of saline water that might be drawn inland probably would be small.

The Sisquoc formation beneath the main area of ground-water withdrawal also may contain water of poor quality, but definite information is not available. Similarly, the marine-laid Careaga sand may contain unflushed saline water in the vicinity of the ground-water barrier. The saline water, having a greater density than the fresh water, would tend to remain at the base of the formation. The forces imparted by the downstream movement of fresh ground water would tend to move the saline water against the barrier, where it might remain as a body or be slowly dissipated by the eroding action of the fresh water moving along the fresh water-salt water interface.

If these waters of poor quality are present beneath the valley, it is conceivable that in time they may migrate upward into the pumping wells. In this event, the quality of water in the Paso Robles formation (the main aquifer in the area) may become progressively poorer with depth.

The origin of any water of poor quality in the Sisquoc formation and Careaga sand is probably coincident with the deposition of the formations. The area was covered by open seas at the time the formations were deposited, and it is likely that some sea water was trapped in the interstices of the sediments as they were being deposited. The water of poor quality is not the result of present-day sea-water intrusion, for the bottoms of three of the five wells (including 8/34–17K1) are considerably above present-day mean sea level (pl. 2).

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[Major references are in italic]

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