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GROUND-WATER HYDROLOGY OF THE HOLLISTER AND SAN JUAN VALLEYS
SAN BENITO COUNTY, CALIFORNIA, 1913-68

By
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Prepared in cooperation with the
San Benito County Board of Supervisors

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GROUND-WATER HYDROLOGY OF THE HOLLISTER AND SAN JUAN VALLEYS

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ABSTRACT

The Hollister and San Juan Valleys are within the Gilroy-Hollister ground-water basin. That part of the ground-water basin underlying the valleys consists of three subbasins each of which contains two or more ground-water subunits. The subbasin and subunit boundaries are formed by known or postulated faults, folded sedimentary rocks, and igneous rocks.

The principal water-bearing units are lenticular beds of sand and gravel interbedded with clay, silt, sand, and gravel, or their locally consolidated equivalents, which range from Pliocene to Holocene in age.

Ground water occurs mainly under artesian or semiartesian conditions but also under unconfined (water-table) conditions in areas adjacent to most surface streams and, locally, under perched or semiperched conditions.

In 1968 the depth to water in wells ranged from approximately 20 feet above land surface to more than 200 feet below land surface. Water-level differences in wells across the boundaries of adjacent subunits ranged from about 10 to more than 100 feet.

Withdrawals of ground water for irrigation began in 1878. Since that time water levels in wells have declined more than 180 feet in the Hollister Valley and more than 100 feet in the San Juan Valley. Serious declines in water levels probably did not begin, however, in most of the area until after 1945. Since 1945 large cones of depression have formed in each of the major subbasins. The centers of the cones are approximately one-half mile northeast of Hollister in the Hollister subbasin, 1½ miles northwest of Hollister in the Gilroy-Bolsa subbasin, and one-half mile east of San Juan Bautista in the San Juan subbasin. Ground-water movement beneath both valleys is now toward and into the cones.

Ground water in the eastern part of the Hollister Valley locally contains objectionable concentrations of boron and chloride. However, available data indicate that significant changes in the distribution patterns of these constituents have not occurred since 1939.

INTRODUCTION

According to present plans, 273,000 acre-feet of water will be delivered annually through the U.S. Bureau of Reclamation's San Felipe Division of the Central Valley Project to be apportioned to Hollister and San Juan Valleys in San Benito County, to the Pajaro Valley area of Santa Cruz and Monterey Counties, and to Santa Clara County. The Bureau's feasibility report of the San Felipe Division of the Central Valley Project, California, recommended that 46,000 acre-feet of this water be allocated to San Benito County for supplemental irrigation of approximately 33,000 acres of land (County of San Benito Imported Water Advisory Commission, 1968, p. 15). Most of this water will be used for irrigation and municipal supply; the imported water will constitute nearly one-third of the total estimated water requirement of the area under conditions of anticipated development. Some of the imported water may be percolated to recharge the ground-water basin.

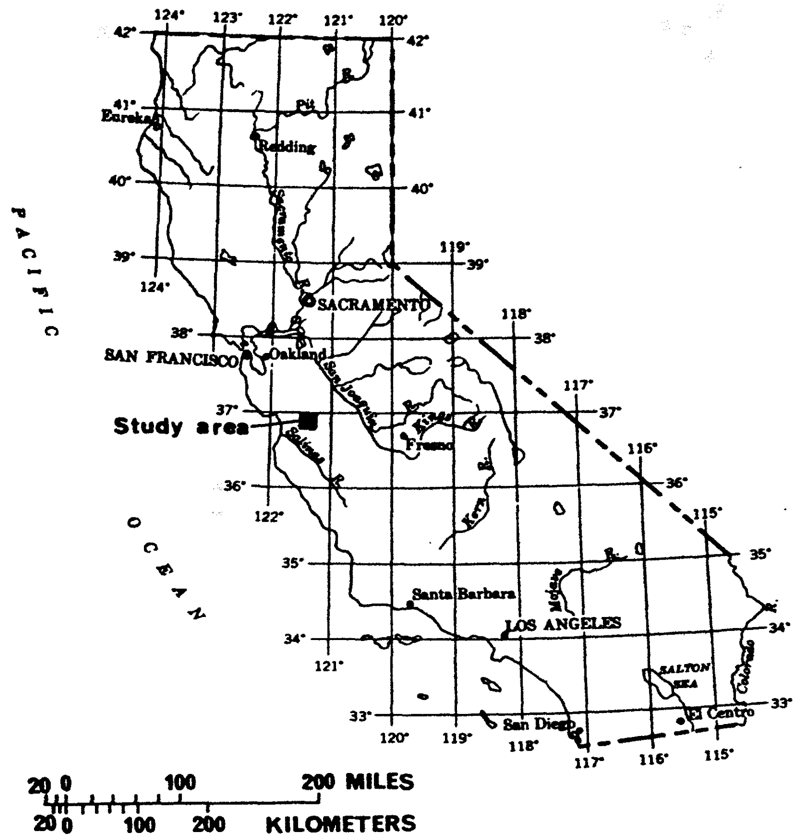
The County of San Benito Imported Water Advisory Commission recognized that complex geologic conditions affect the ground-water system underlying the Hollister and San Juan Valley areas and thought it necessary to acquire additional geologic and hydrologic data to assist those charged with designing the distribution system for the imported water. The Imported Water Advisory Commission requested data that would help define: (1) areas that have insufficient ground water for irrigation and where ground water in storage could not be readily increased through percolation of imported water, (2) areas that have ground water of a quality that is unsuitable for irrigation, (3) areas that have no well-water supply, (4) areas that have sufficient water from underground sources, (5) areas that would benefit if imported water were used for percolation to supplement local water already being percolated, and (6) areas where such water could be percolated (County of San Benito Imported Water Advisory Commission, 1968, p. 35).

The Commission asked the Geological Survey to make a study of the geology and hydrology of the valleys. A two-phase study was undertaken. In phase 1, November 1966 to April 1967, a review was made of all data available from prior studies, a water-level monitoring network was established, and data for the observation wells were released (Helley, 1967). Phase 2 was a 2-year study of the geology and hydrology based on available data and field investigations; fieldwork was done between November 1967 and November 1968. This report is the outcome of the phase 2 investigation.

Location

The Hollister and San Juan Valleys in the northern end of San Benito County encompass an area of approximately 102 square miles. The valleys lie within the Gilroy-Hollister ground-water basin as defined by the California Division of Water Resources (1952). The location of the area is shown in the index map (p. 4). The Hollister Valley, as defined in this report, is separated from Santa Clara Valley by the Pajaro River. The San Juan Valley is separated from the Hollister Valley by the Lomerias Muertos and Flint Hills and the Bird Creek Hills south of the San Benito River. The two valleys lie between the Diablo Range on the east and the Gabilan Range on the west (fig. 2).

The city of Hollister, the county seat of San Benito County, is in the southern part of Hollister Valley, about 90 miles south of San Francisco.


PACIFIC OCEAN
SACRAMENTO
SAN FRANCISCO
Oakland
Study area
Eureka
Redding
Fresno
Santa Barbara
LOS ANGELES
San Diego
El Centro
SALTON SEA
200 MILES
KILOMETERS

Index map.

Purpose and Scope

This report was prepared by the U.S. Geological Survey in cooperation with the Board of Supervisors of the county of San Benito as part of an investigation of the water resources of San Benito County.

The purpose of the investigation was to describe the geologic and hydrologic conditions that affect the ground-water reservoir underlying the Hollister and San Juan Valleys. A detailed knowledge of the water-bearing units and the geologic structures that affect the movement of ground water beneath the valleys is critical for the most advantageous development and management of the ground-water resources in these valleys.

The scope of the investigation consisted of: (1) a description of the geology, including the delineation of the lateral extent of ground-water subunits resulting from faulting, folding, or lithologic changes, (2) an evaluation of the hydrology, including the effects of faulting on the movement of ground water through and between ground-water subunits, the hydraulic relations within the individual ground-water subunits, and determination of the effect of long-term ground-water pumping on water levels, (3) delineation of areas favorable for artificial recharge of aquifers by percolation of applied surface water, including delineation of areas where percolation of water used for irrigation or artificial recharge might raise ground-water levels to a point that would be harmful to agriculture, (4) determination of the present distribution of ground water having a high concentration of boron or other undesirable constituents, and (5) an evaluation of waste disposal sites.

The investigation was a qualitative appraisal of the occurrence and movement of ground water in the aquifers underlying the Hollister and San Juan Valleys. The principal findings of the study are incorporated in: (1) a map showing the surface distribution of the principal water-bearing units, (2) a map showing the boundaries of the structurally controlled ground-water subbasins and subunits underlying the valleys, (3) geologic sections showing the postulated subsurface extent and structure of the water-bearing units, and (4) maps and graphs that show the effect of ground-water withdrawals on water levels in wells during August 1913 and October and November 1968 and the net change in water levels in wells between August 1913 and October and November 1968. Also included are maps showing the present concentrations of boron, chloride, and sulfate ions in ground water at the depths where most wells are screened.

Previous Studies

Two significant earlier studies of ground water in the Hollister and San Juan Valleys have been made. Clark (1924) made a study between 1913 and 1916 of the quantity of ground water available from various parts of the Santa Clara Valley (which included the Hollister and San Juan Valleys) and described the geology and hydrologic conditions as they were conceived at that time. The U.S. Bureau of Reclamation (1952a, 1952b, and 1954) made a study of land use and the water resources of the area from 1949 to 1952 to determine the amount of additional water needed for agricultural and municipal use; that agency formulated a plan to alleviate possible future water-supply deficiencies.

Burch (1925), Harding (1933), Pillsbury (1936), and Gross (1938) described ground-water conditions in the valleys during the years 1924-38. Their reports contain information on ground-water use and water-level data. Foresburg and Colvin (1947) described shallow ground-water conditions in the northern part of Hollister Valley.

The chemical quality of ground water in the Hollister area was described by Eaton (1941). His report makes special reference to the occurrence and possible source of boron in ground water along the eastern side of Hollister Valley, east of the Calaveras fault.

The geology of the Hollister and San Juan Valley area has been studied by many people. The geology of the Hollister 15-minute quadrangle was mapped by Taliaferro [1946?], and the San Juan Bautista 15-minute quadrangle was mapped by Allen (1946). The geologic map by Taliaferro includes mapping done by Washburn (1944). T. W. Dibblee, Jr., (written commun., 1969), mapped the geology of the area adjacent to the San Andreas fault zone. Rogers (1968a, 1968b) mapped the western half of the Hollister quadrangle and identified the traces of the Calaveras fault zone within this area and the city of Hollister. C. C. Bishop (written commun., 1969) is studying the geology of a part of the eastern half of the San Juan Bautista quadrangle to assist in the study of the geologic structures associated with the San Andreas and Sargent faults.

Subsurface geologic correlations between deep oil and gas test holes drilled in the San Juan and Hollister Valleys have been made by Christensen (1967) and Christensen and Knight (1964).

Acknowledgments

Thanks and appreciation are expressed to residents of the Hollister and San Juan Valleys who permitted access to their land and facilitated collection of the hydrologic data on which this report is based.

Various personnel of Federal, State, and local governmental agencies and private companies aided in this investigation by furnishing information and assistance. Among them are: D. E. Krider, work unit conservationist, U.S. Soil Conservation Service; Hibbard Richardson, U.S. Bureau of Reclamation; F. E. Bluhm, chief, Engineering Services Section, San Joaquin Section, California Department of Water Resources; Rocky Lydon, farm advisor, University of California, Agricultural Extension Service; J. P. Talbot, city manager, city of Hollister; M. B. Kludt, director of public works and assistant city manager, city of Hollister; Perry Morris, water department foreman, city of Hollister; W. P. Thomas, manager, Hollister District, Pacific Gas and Electric Co.; C. L. Morris, president, Harden Farms of California; William Mabie, president, Mabie Farms; F. W. Rohnert, president, Rohnert Seed Co.; Ideal Cement Co.; Ferry-Morse Seed Co.; Cullum Drilling and Pump Service; Valley Pump and Drilling Co.; and Edward Murphy and E. A. Ricotti. Their cooperation is gratefully acknowledged.

Special appreciation is expressed to the following persons: A. D. Krug of Petrolex Inc., for making available electrical logs of wells in the Hollister field; T. W. Dibblee, Jr., of the U.S. Geological Survey, for permission to use unpublished geologic data in the compilation of the geologic map in this report, and T. H. Rogers and C. C. Bishop, of the California Division of Mines and Geology, for making available unpublished geologic data, some of which are incorporated in the geologic map.

The writer would also like to acknowledge the assistance of his colleague L. C. Dutcher in formulating the conceptual geohydrologic model of the Hollister area that is given in this report.

Well-Numbering System

The well-numbering system now in common use in California has been used by the Geological Survey since 1940. Wells are assigned numbers according to their location in the rectangular system for the subdivision of public land. For example, the well number 12S/5E-22B1 M (fig. 1) was assigned to a well about 2 miles north of Hollister. The part of the number preceding the slash indicates the township (T. 12 S.); the number between the slash and hyphen indicates the range (R. 5 E.); the digits following the hyphen indicate the section (sec. 22); the letter following the section number indicates the 40-acre subdivision of the section as shown in the accompanying diagram. The wells are numbered serially within each 40-acre tract, as indicated by the final digit. The final letter, M, separated from the rest of the number by a space, indicates the base line and meridian. The base-line and meridian designation used in San Benito County is M, Mount Diablo. This letter is omitted from well numbers mentioned in the report.

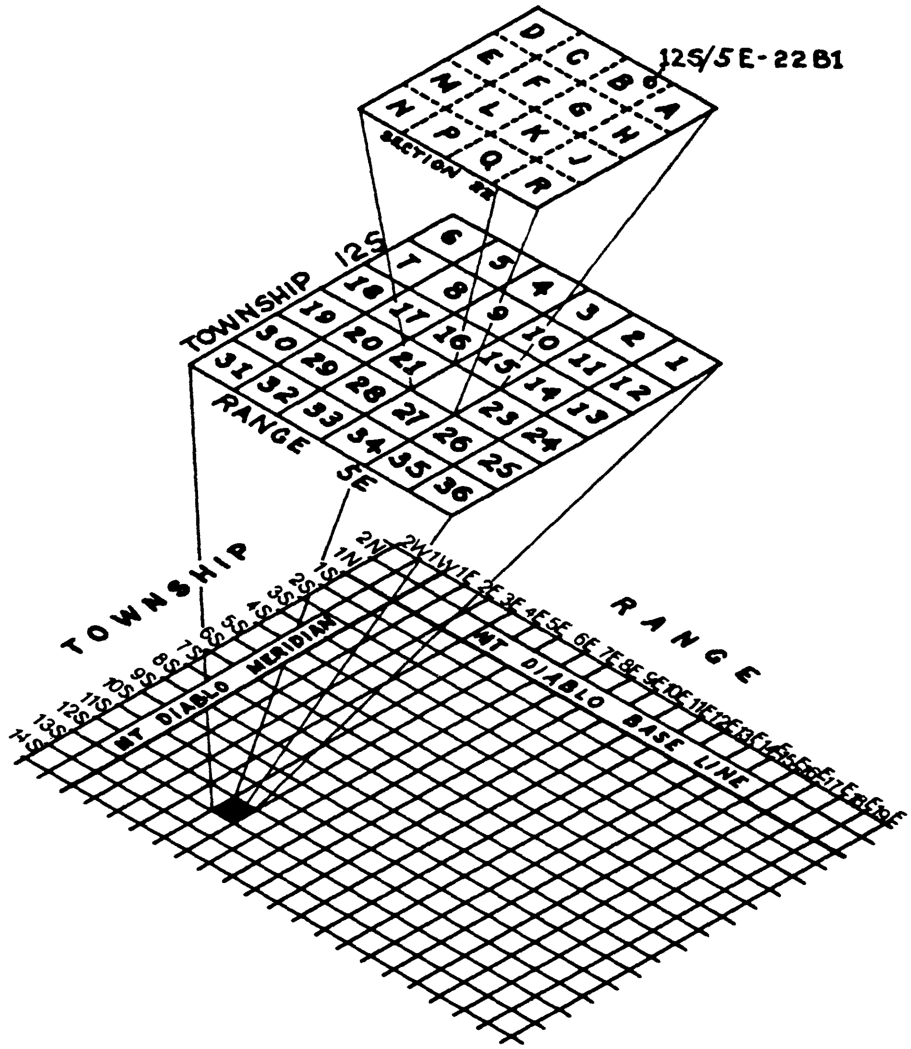


FIGURE 1.--Well-numbering system.

GEOLOGY

Geologic Setting and Structure

The sedimentary sequence in the Gilroy-Hollister ground-water basin that contains the principal aquifers underlying the Hollister and San Juan Valleys ranges in age from Tertiary to Holocene and consists mainly of clay, silt, sand, gravel, and their consolidated equivalents. The oldest of these deposits unconformably overlie consolidated bedrock of Jurassic, Cretaceous, and early Tertiary age. Sedimentary rocks of Tertiary age were deposited in a deep, narrow structural basin or trough mainly east of and parallel to the San Andreas fault (Flynn, 1963, p. 27-34). The trough formed a seaway connecting the San Joaquin Valley with the coast via the Santa Cruz-Hollister basin during late Miocene and Pliocene time. The occurrence of marine strata of Eocene and early Miocene age near Hollister and Tres Pinos, mapped as consolidated bedrock, indicates that seas were present in the area during parts of these times also. No rocks of Oligocene age have been found east of the San Andreas fault. During the late (?) part of the Pliocene, uplift and folding with subsequent withdrawal of the seas ended marine deposition. Deposition during Pliocene and Pleistocene time is represented by extensive flood-plain deposits of clay, silt, sand, and gravel that compose the San Benito Gravels of Lawson (1893). Wilson (1943, p. 247) reported that these deposits overlap and lie uncomformably on the older rocks and may reach a thickness of as much as 2,000 feet in the San Benito area, several miles south of Tres Pinos. The Tertiary deposits attain a maximum thickness of approximately 10,000 feet in the area just west of Hollister near the entrance to the San Juan Valley.

The Hollister Valley area was subjected several times during Tertiary and Quaternary time to episodes of faulting and folding that raised various parts of the basin above sea level. Two major fault systems, the San Andreas and the Calaveras, have been active since at least Eocene time. Estimates of lateral displacement along the San Andreas fault range from 50 to more than 300 miles. Lateral displacement along the Calaveras fault was much smaller--possibly only a few tens of miles. Vertical displacements of rocks on either side of the faults probably are as much as several thousand feet.

The Gilroy-Hollister ground-water basin within the mapped area is situated between the Gabilan Range on the southwest and the Diablo Range on the northeast. The rocks underlying the main part of the basin are separated from the consolidated bedrock of the Gabilan Range by the San Andreas rift zone and from the Diablo Range by the Ausaymas fault. The Calaveras fault separates the basin into two parts: the Hollister subbasin on the east and the Gilroy-Bolsa and San Juan subbasins on the west. The Gilroy-Bolsa subbasin is separated by faults and folds in the Lomerias Muertas and Flint Hills from the San Juan subbasin to the south. These hills reflect a relatively broad post-Pliocene uplift of Jurassic or Cretaceous bedrock along several faults. The relations of various subbasins and geologic structures are shown in figure 2.

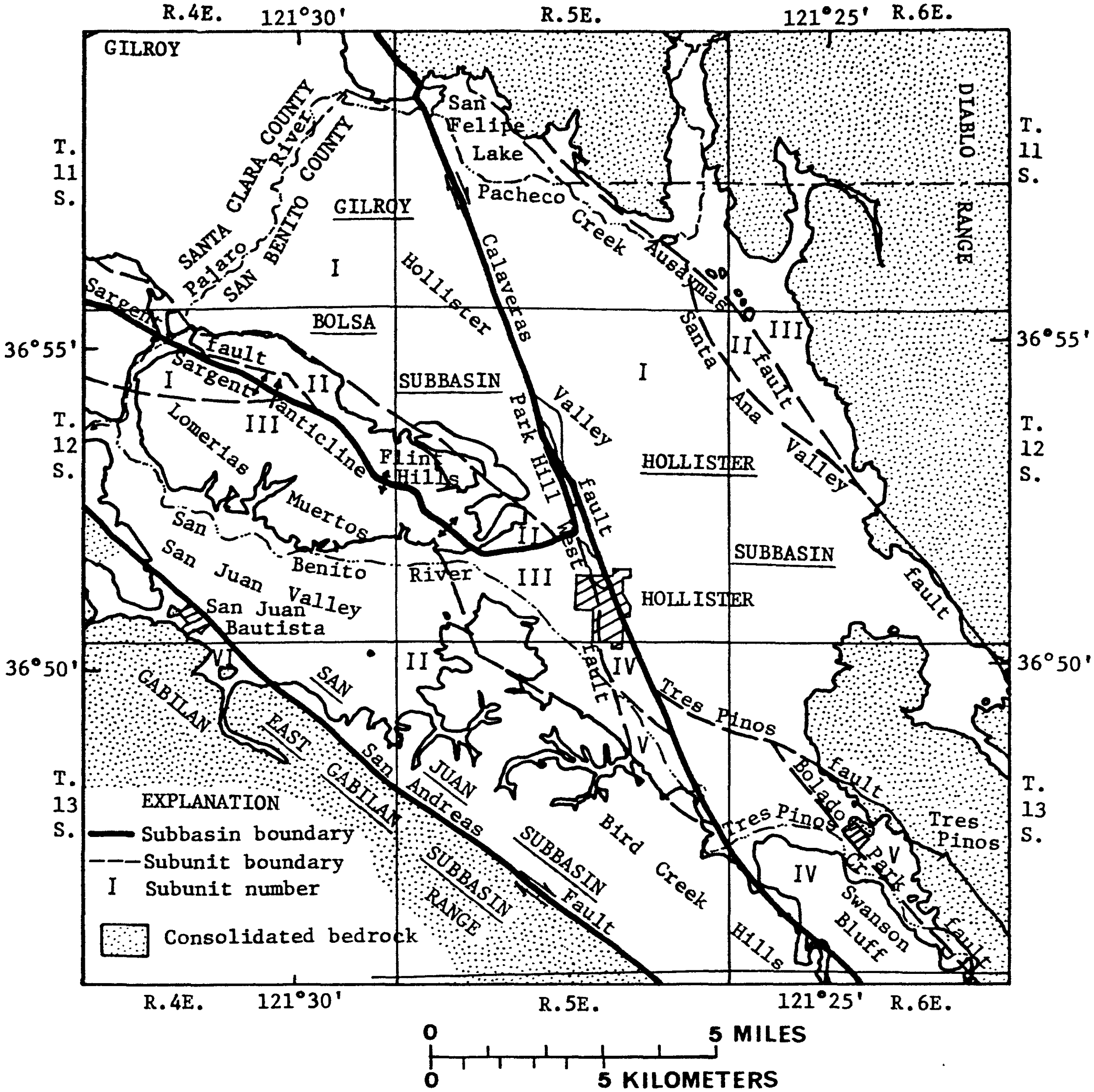


FIGURE 2.--Relation of ground-water subbasins and subunits to geologic structures.

Stratigraphic Units

Surface Units

The surface geology of the Hollister and San Juan Valleys is shown in figure 3. The map was compiled from published and unpublished maps by Taliaferro [1946?], Allen (1946), T. W. Dibblee, Jr. (written commun., 1969), Rogers (1968b), C. C. Bishop (written commun., 1968), and photogeologic mapping and information furnished by A. D. Krug (oral commun., 1968). The geologic map, as compiled, is generalized. The formations shown constitute the hydrologically significant rock units that crop out in the valleys.

A summarized description of the water-bearing units is given in table 1, which was compiled from the work of Allen (1946), T. W. Dibblee, Jr. (written commun., 1969), Wilson (1943), Dempster (1949), and Griffin (1967).

The alluvium, San Benito Gravels of Lawson (1893), and Purisima Formation, or their concealed equivalents beneath the valley floors, are the principal water-bearing units in the Hollister and San Juan Valleys and primarily consist of unconsolidated or poorly consolidated deposits of clay, silt, sand, and gravel or loosely unconsolidated sandstone.

The basement rocks, Eocene to Miocene rocks, and the Purisima Formation have been highly folded--in some places overturned--and have been extensively broken and tilted by faulting. The San Benito Gravels of Lawson (1893) unconformably overlie the Purisima Formation and older Tertiary rocks and are, in general, much less deformed except near some faults where dips may be steep. The alluvium of Holocene age is probably not folded, but it is broken by currently active faults.

Subsurface Units

The correlation of surface units with their subsurface equivalents throughout the Hollister Valley is difficult and, in many cases, highly uncertain. Deposits comprising the alluvium, San Benito Gravels of Lawson (1893), Santa Clara Formation, and the Purisima Formation are similar in composition and cannot everywhere be distinguished in drillers' logs and electrical logs. The San Benito Gravels and the Santa Clara Formation could not be differentiated in the subsurface during this study. The correlation and postulated structural relations of the units underlying the Hollister and San Juan Valleys are shown by the geologic sections in figure 4.

TABLE 1.--*Summary of the principal water-bearing units underlying the Hollister and San Juan Valleys*

Age		Water-bearing unit	Thickness (feet)	Lithology and geologic formations included	Occurrence, structure, and hydrologic significance
QUATERNARY	Holocene	River-channel deposits (Qrc)	0-50(?)	Unconsolidated sand and gravel	Occur in channels of San Benito River and Tres Pinos Creek. Contain water only in the western end of the San Juan Valley near the junction of the San Benito River with the Pajaro River, and in a few reaches of Tres Pinos Creek only in the spring when ground-water levels are highest. A minor aquifer. Should yield small to moderate quantities of water to wells. Allow large quantities of water to percolate downward into the underlying aquifers.
QUATERNARY	Holocene	Alluvium (Qal)	0-250(?)	Unconsolidated lenticular beds of gravel, sand, silt, and clay deposited by streams as flood-plain, alluvial-fan, slope-wash, and terrace deposits. May also include some lake beds. Includes Dos Picachos Gravels of Taliaferro [1946?].	Underlies the valley floors of the Hollister and San Juan Valleys and smaller tributary valleys. Flat lying. Cannot be distinguished from the underlying units on driller's or electrical logs. May locally be dewatered. Probably is combined, in some areas, with underlying permeable units to form a single hydrologic unit.
TERTIARY AND QUATERNARY	Pliocene and Pleistocene	Older alluvium (QTal)	Unknown	Unconsolidated lenticular beds of gravel, sand, silt, and clay. Mapped as San Benito Gravels by Taliaferro [1946?].	Forms hills along Calaveras fault from Hollister northward. Folded into small anticlinal structures. Subsurface distribution unknown.
TERTIARY AND QUATERNARY	Pliocene and Pleistocene	San Benito Gravels of Lawson (1893) (QTsb)	0-1,400±	Lenticular beds of gravel, sand, and clay, locally consolidated into conglomerate, sandstone and clay-shale. Clays may contain occasional beds of impure lignite. Conglomerate contains material of sand to boulder size.	Recognized in Hollister Valley only. Exposed at the surface mainly to the east and southeast of Hollister. Probably occur in the subsurface beneath much of the central and western parts of the Hollister Valley. May consist of strata deposited by the ancestral San Benito River system. Moderately folded and faulted and rest with angular discordance upon the underlying older formations. Dips rarely exceed 25 degrees except near faults. Are a major aquifer in the Hollister Valley. Probably act as a single hydrologic unit with the overlying alluvium. Yield moderate to large amounts of water to most wells.
TERTIARY AND QUATERNARY	Pliocene and Pleistocene	Santa Clara Formation (QTsc)	Unknown	Compact lenticular beds of clay, sand, and gravel. Mapped as San Benito Gravels by Taliaferro [1946?].	Exposed in hills along Calaveras fault northwest of San Felipe Lake in Santa Clara County. Yields small to moderate quantities of water to wells in Santa Clara County.
TERTIARY	Pliocene	Purisima Formation: Upper member (Tpu)	±2,000-3,000	Predominantly friable, porous, light-gray, pebble gravel and sand. Well bedded, locally crossbedded. Pebbles well rounded, mostly of chert, quartzite, porphyry, granitic rocks, graywacke, and sandstone. Some beds contain cobbles. Contains some interbedded soft greenish- to reddish-gray siltstone in places. All terrestrial in origin. May be lithologic equivalent to San Benito Gravels of Lawson (1893).	Recognized at the surface only in the Lomerias Muertos and Flint Hills. Underlies the alluvium throughout much of the San Juan Valley. Extent beneath the alluvium in the area northeast of the Flint Hills and west of the Calaveras fault is unknown, but probably occurs mainly in the southern half of this area. Probably the major aquifer underlying the San Juan Valley. Moderately folded and may be faulted in some areas. Locally contains water under artesian head. Yields moderate to large amounts of water to most wells.
TERTIARY	Pliocene	Purisima Formation: Middle member (Tpm)	±4,000-5,000	Friable light-grey to greenish-gray bedded to massive sandstone, and interbedded green to locally reddish-gray gypsiferous clay. In places contains friable pebbly sandstone or pebble conglomerate. In a few places unit contains fresh-water and brackish-water molluscan fossils. Whole unit is weakly consolidated and generally poorly exposed. Contact with underlying lower member gradational.	Directly underlies the alluvium in the southeastern part of the San Juan Valley. Folded and faulted and dips as much as 90 degrees. Sand beds are more silty, finer grained, and compact than in the upper member and the alluvium and permeabilities are lower. Locally yields sufficient water for domestic and stock use. Locally contains water under moderately high artesian head. Water may contain large concentrations of sulfate locally. Probably contains salt water at depth throughout the area.
TERTIARY	Pliocene	Purisima Formation: Lower member (Tpl)	±5,000-7,000	Mainly friable to semifriable, bedded, fine- to medium-grained arkosic sandstone and interbedded micaceous siltstone. Sandstone is light gray, buff, and rusty yellow. In places some beds contain pebbles. Siltstone is light gray, weathers brownish gray; sandy argillaceous, micaceous, poorly bedded. Slightly fossiliferous. Marine.	Probably underlies the alluvium in the San Juan Valley only along the northeast side of the San Andreas rift zone. Folded and faulted and dips as much as 90 degrees; locally overturned along San Andreas rift zone. Sand beds are probably less permeable, as a whole, than in middle member because of greater compaction. Information on well yields is lacking. May locally furnish sufficient water for stock and domestic use. Contains salty water at shallow depths in some parts of the Lomerias Muertas. Probably contains water of poor chemical quality at depth throughout the area.
TERTIARY		Unnamed unit 2 (Tu_2)	0-1,700±	Electrical and driller's logs indicate unit consists of from one to four thick-bedded sand or sandstone sequences with interbedded clay, shale, and siltstone. May contain some gravel and limestone.	Not known to be exposed at surface. Beds may have moderate to steep dips toward center of valley. Not present west of Calaveras fault. Permeability is probably low.
TERTIARY		Unnamed unit 1 (Tu_1)	0-1,100±	Electrical log of Dark, Garcia No. 1, located in sec. 30, T. 12 S., R. 6E., water-well driller's logs, and outcrops indicate unit consists of thick to medium beds of clay, silt, sand, and gravel. Character of unit in the subsurface may be different north of Fallon Road.	Exposed in hills at northwest end of Santa Ana Valley. Beds may have moderate to steep dips toward center of valley. Not present west of Calaveras fault. Permeability is probably low.
TERTIARY, CRETACEOUS, AND JURASSIC		Consolidated bedrock (TKJb)	Unknown	Sedimentary, igneous, and metamorphic rocks. Includes Franciscan Formation, Panoche Formation, Indart Sandstone of Taliaferro [1946?], Los Muertos Creek Formation of Wilson (1943), Tres Pinos Sandstone of Wilson (1943), Vaqueros Formation, Quien Sabe Volcanics of Taliaferro [1946?], San Lorenzo Formation of Arnold (1906), Monterey Group, and Santa Lucia Granite of Lawson (1893).	Crops out in the hills along the southeast, east and north sides of the Hollister Valley and in the hills on the west side of the San Andreas fault zone. Underlies the Hollister and San Juan Valleys at depth. Formations are highly folded and faulted. Rocks are dense and compact and yield only small quantities of water to wells from fractures, joints, and weathered zones. May be a source of ground-water recharge to overlying water-bearing formations. Locally may contain water of poor chemical quality.

Units east of the Calaveras fault.--The unconsolidated or poorly consolidated Tertiary or Quaternary rocks underlying the alluvium in the Hollister Valley east of the Calaveras fault and north of the Tres Pinos fault have been divided into three units with the aid of electrical logs. Electrical logs of four deep oil and gas test holes have been made in the Hollister basin east of the fault. The locations of these test holes are shown in figure 3. These logs show a thick sequence of clay, silt, sand, and gravel; they have been grouped into the following unnamed units, from oldest to youngest: unnamed unit 1, unnamed unit 2, and an undifferentiated unit.

Unnamed units 1 and 2 are not known to occur west of the Calaveras fault. Unit 1 crops out and is believed to form the low hills at the north end of Santa Ana Valley and to underlie unit 2. Unit 1 is well defined on the electrical log of Dark, Garcia No. 1 (sec. 30, T. 12 S., R. 6 E.), which shows the unit to be approximately 1,200 feet thick in this area. The electrical log of well 12S/5E-23A3 penetrated the top of the unit at 420 feet below land surface and bottomed in it at 940 feet. The drillers' log describes this material as clay, sand, and gravel. The electrical log indicates that the individual beds are not more than 5 to 10 feet thick. The unit was not definitely recognized in electrical logs of wells north of well 12S/5E-23A3.

Electrical logs of Monterey Oil and Gas Exploration Co., Grant No. 2, (sec. 6, T. 12 S., R. 6 E.) and V. I. Gandrup, O'Connell No. 1 (sec. 9, T. 12 S., R. 5 E.) indicate that unit 2 consists of three or four thick sand sequences separated by thinner clay intervals. In the Gandrup well unit 2 is approximately 1,700 feet thick.

The undifferentiated (nonsubdivided) unit may include one or more of the following units: alluvium, older alluvium, San Benito Gravels of Lawson (1893), and alluvial-fan material that may occur in the subsurface along the front of the Diablo Range. The unit is believed to overlap and rest unconformably on an older erosion surface formed on units 1 and 2.

Units west of the Calaveras fault.--The area west of the Calaveras fault is underlain mostly by alluvium and rocks of the Purisima Formation, which are believed to lie directly upon consolidated basement rocks of Jurassic age.

T. W. Dibblee, Jr. (written commun., 1969) divided the Purisima Formation in the area east of the San Andreas fault into three units. In this report these units are informally referred to, from oldest to youngest, as the lower member, middle member, and upper member. He considered the upper member as being possibly the lithologic equivalent of the San Benito Gravels of Lawson (1893).

HYDROLOGY

Hydrologic Framework

Ground-Water Basin and Subbasins

The Hollister and San Juan Valleys lie within the Gilroy-Hollister ground-water basin as defined by the California Division of Water Resources (1952). The study area of this report is restricted to that part of the ground-water basin in San Benito County. That area is divided into three subbasins, which are here named (1) the Hollister ground-water subbasin, (2) the Gilroy-Bolsa ground-water subbasin, and (3) the San Juan ground-water subbasin. The subbasin boundaries are defined by bedrock outcrops and the trace of the San Andreas, Calaveras, and Sargent faults and the crest of the Sargent anticline in the Lomerias Muertas and Flint Hills (fig. 2). The ground-water subbasins are further subdivided into ground-water subunits or compartments.

Ground-Water Subunits

The ground-water subunits are identified by Roman numerals in this report and are characterized by having (1) known boundaries, (2) hydraulic continuity throughout, (3) reasonably uniform or predictable hydraulic properties, and (4) by being separated from other subunits by definite hydraulic discontinuities.

Some of the subunits, as defined in this report, are geologically complex and probably could be further subdivided if additional data were available.

Subunit boundaries are formed by faults, folds, and consolidated bedrock. Subunit boundaries in the valleys are distinguishable by differences in water levels in wells on either side of the boundary. Water-level differences between subunits range from about 10 feet to as much as 100 feet.

Most of the subunit boundaries enclose areas of low permeability, and ground-water flow across them is accompanied by a decline of hydraulic head or differences of water level. The lower the permeability of the boundary, the greater the head decline will be as water flows through the boundary. However, the magnitude of the head decline by itself does not indicate if the quantity of flow across the boundary is large or small.

Subunit boundaries formed by large fault zones, such as the San Andreas and Calaveras faults, may be relatively impermeable. These zones may contain large numbers of crumpled slivers of rock fragments and clay that can form a nearly impervious vertical barrier to ground-water movement. These faults probably form the most nearly impermeable barriers to ground-water movement in the Hollister and San Juan Valleys.

Subunit boundaries made up in part of folded sedimentary beds, such as those occurring along the boundary between the Gilroy-Bolsa and San Juan subbasins and probably between subunits II and III of the San Juan subbasin, affect ground-water movement because the permeability of the sands measured in a direction parallel to the bedding may be several times greater than the average vertical permeability of the formation measured normal to the bedding. If a bed of sand is folded in such a way that ground water must flow across the bed, more or less in the direction of the lower vertical permeability, then the resistance to flow will be greater. The compartment boundaries caused by folding alone, therefore, are probably less effective ground-water barriers than faults but, nevertheless, cause water-level changes where water flows through folded deposits.

Water-level differences in the Hollister subbasin between subunits I and II are caused by the barrier effect of the Santa Ana Valley fault and between subunits II and III by consolidated bedrock that underlies subunit III east of the Ausaymas fault at shallow depth south of Pacheco Creek. Ground water in the thin layer of permeable deposits, which overlies the bedrock south of Pacheco Creek, is prohibited from percolating downward by the relative impermeability of the bedrock and is, therefore, perched upon it.

Occurrence and Movement of Ground Water

Occurrence and Movement in 1913

Ground water in much of the area underlying the San Juan and Hollister Valleys, prior to development of wells, occurred under artesian conditions.

Ground-water supplies for irrigation were first developed in the northern part of the Hollister Valley in the Lovers Lane area (Eaton, 1941, p. 6). The first well was drilled in 1878. It was a flowing artesian well 90 feet deep. Other wells drilled in this area after 1880 obtained artesian flows from depths of 50 to 100 feet. By 1898, however, the head had been reduced and pumping was started. The first successful irrigation well in the Hollister area was completed in 1898, about 2 miles northeast of Hollister, and reportedly was 80 feet deep. The water level in the well was reported to be 35 feet below land surface.

Clark (1924) reported that approximately 126 pumping plants were in operation during the period 1913 through 1915 in the Hollister and San Juan Valleys, and he listed water-level data for 202 wells. The water-level map shown in figure 5 was made using Clark's water-level measurements of August 1913. Land-surface altitudes at wells were obtained from recent topographic maps.

The heavy solid line in figure 5 shows the approximate boundary of the area of intermittently flowing wells in August 1913. The dashed line shows the approximate boundary of the area of natural ground-water discharge (Clark, 1924, pl. 19) prior to ground-water development in 1878. Wells in the area between the dashed and solid lines did not flow in 1913 even at the highest stage of ground water. The areas of natural ground-water recharge and discharge that existed prior to 1878 are described below and have been inferred from figure 5. The conceptual flow lines in the figure show the probable direction of ground-water flow during August 1913. They are also believed to indicate the approximate direction of ground-water movement that prevailed prior to 1878 when virtual steady-state conditions existed.

Hollister subbasin.--Ground water in the Hollister subbasin in general moved northwestward, mainly through the undifferentiated unit Qtu, from recharge areas in the southern and eastern sides of the basin and discharged from wells in the area of artesian flow into streams and marshes in the northern half of the subbasin. Probably little, if any, ground water flowed across the Calaveras fault into the San Juan or Gilroy-Bolsa subbasins north of the Tres Pinos fault.

San Juan subbasin.--Ground-water recharge to subunit V (figs. 2 and 5) in 1913 was derived from underflow from subunit II of the San Juan subbasin and subunit IV of the Hollister subbasin and from infiltrated water from the San Benito River. The water moved northward into subunit IV in response to pumping in the subunit in the area south of Hollister. Ground-water discharge from subunit IV in August 1913 was mainly by pumping, but some probably left subunit IV as underflow into adjacent subunit III of the San Juan subbasin and possibly into subunit I of the Hollister subbasin.

Ground-water recharge of subunit III was probably derived mainly from infiltration from the San Benito River with some derived from rainfall and underflow from subunits II and IV. Part of this water moved northward into the southern end of the Gilroy-Bolsa subbasin; the rest moved into the San Juan Valley part of subunit II as underflow or as surface flow in the San Benito River. Ground-water underflow derived from subunit IV moved northward through subunit III as underflow into the Gilroy-Bolsa subbasin. None of this water flowed into subunit II of the San Juan subbasin. The depth to water beneath the reach of the river crossed by the 260-foot water-level contour in August 1913 was probably only a few feet. Upstream from this contour the depth to water beneath the river may have increased to about 30 feet at the boundary of subunit V near Union School. The amount of storage space available for recharge from the river during the winter months was limited and was probably rapidly filled so that later in most seasons recharge from the river was rejected. During August 1913, ground water in subunit III discharged into the San Benito River beginning at the point where the 240-foot water-level contour crosses the river. From this point to the junction with the Pajaro River, the San Benito River was very probably perennial; that is, the river flowed throughout the year.

Ground-water recharge that entered subunit II south of the San Benito River moved northwestward and discharged into the river. Some water discharged from a small area of flowing artesian wells about a mile north of San Juan Bautista (fig. 5). Water from rain and runoff that percolated downward to the ground-water body underlying the Flint Hills and Lomerias Muertas moved generally westward and discharged into the San Benito or Pajaro Rivers.

Ground water in subunit VI was derived mainly from infiltrated rainfall and streamflow losses from San Juan Creek. Infiltrated rainfall that accumulated in the fractured sedimentary and volcanic rocks that underlie the adjacent hills moved into the alluvium, which is the main aquifer in the subunit, and either discharged at the surface into San Juan Creek or moved through the alluvium and across the San Andreas fault into subunit II of the San Juan subbasin.

Gilroy-Bolsa subbasin.--Clark (1924, pls. 16 and 18) suggested that the principal source of ground-water recharge to subunit I (figs. 2 and 5) of the Gilroy-Bolsa subbasin was from Santa Clara County, north and northwest of the Pajaro River. A much smaller amount of ground water moved into subunit I from subunits II, III, and IV.

Ground-water discharge in the Gilroy-Bolsa subbasin was chiefly by upward movement into streams, flowing wells within the area of artesian flow (fig. 5), evaporation from land surface, and transpiration by plants.

Summary of Ground-Water Development 1878-1968

As reported by the U.S. Bureau of Census (1894) there were 117 artesian wells in the northern end of San Benito County in 1889 (probably all in the Hollister and San Juan Valley). These wells ranged in depth from 29 to 329 feet and averaged 111 feet. The average rate of flow was reported to be 157 gpm (gallons per minute).

The development of irrigation wells and the acreage irrigated has continuously increased since 1878 as is indicated in table 2. The U.S. Bureau of Reclamation (1961, p. 90) estimated that the gross amount of ground water pumped for all purposes in 1958 was about 60,000 acre-feet. The long continued pumping of ground water, from the 1870's to the present, has significantly affected the direction of ground-water flow and has caused large cones of depression to form in each of the three major ground-water subbasins.

TABLE 2.--*Number of irrigation wells and approximate irrigated acreage, 1890-1968*

[Data from U.S. Bureau of Census (1894, 1932, 1952), Clark (1924), and U.S. Bureau of Reclamation (1954, 1961)]

Year	Irrigation wells		Year	Acreage irrigated
	Pumped	Flowing		
1890		117	1889	905
1915	135			
1920	365	4	1919	12,468
1930	444	17	1929	20,237
1940	479	2	1939	21,937
1950	670	7	1949	32,000
1960			1960	33,700
1968	[1] 700		1968	[1] 37,700

[1] Estimated.

Occurrence and Movement in 1968

Ground-water withdrawals have affected the occurrence and movement of ground water throughout the Hollister and San Juan Valleys. Unconfined ground water (water-table conditions) occurs in sand beds beneath and adjacent to the San Benito River and Tres Pinos Creek and probably along Pacheco Creek. Declining water levels have partly dewatered sand beds throughout much of the Hollister and San Juan Valleys. Unconfined or semiconfined ground water occurs in other sand beds throughout all or part of each year. The deeper sand beds throughout both valleys contain water under artesian pressure. Drillers' logs and water-level data indicate that semiperched, water-table, and artesian conditions probably are widespread in each of the two valleys.

Flowing artesian wells still occur in four areas:

1. In the Lovers Lane area north of Pacheco Creek, wells are reported to flow in some years during the late winter and early spring months. The head in some of these wells is sufficient to cause problems in pump seating, and drainage of the water that flows from the wells is necessary in some places. The head in well 11S/5E-21D2 (fig. 6), which is 146 feet deep, has been reported to be sufficient in some years to cause water to discharge naturally into a tank approximately 20 feet above the land surface.

2. Along the Pajaro River, in the area north of the Lomerias Muertas, wells are reported to flow during the early spring months of some years. In 1969, irrigation well 11S/4E-33K1 (fig. 6) was reported to have flowed at an estimated rate of 1,000 gpm (C. L. Morris, oral commun., 1969).

3. Well 13S/5E-13K1 (fig. 6), in the Southside School area, was reported to have flowed in 1967.

4. Well 13S/5E-10F1 (fig. 6), in the Union School area, probably would still flow the year round if not prevented from doing so by a float-type valve on the discharge pipe.

Sufficient ground water for stock and domestic use is available nearly everywhere in the area. Ground-water supplies sufficient for irrigation are available from wells throughout most of the area. Most irrigation wells yield from 200 to 800 gpm except in the area east of Fairview Road between the Airline Highway and Lone Tree Road. This area is underlain by unnamed geologic unit 1 that, according to available driller's logs of test holes, contains only small amounts of sand and gravel and, therefore, yields smaller amounts of water to wells than more permeable and thicker formations elsewhere in the subbasin. Ground water in this area also may contain high concentrations of boron and chloride that could make it unsuitable for irrigation of crops that have low tolerance levels to boron and chloride.

Our knowledge of the effects of ground-water withdrawals since 1878 is based mainly on an interpretation of the measured water levels in wells. Well-construction practices, however, limit the utility of water levels to determine hydrologic conditions. Prior to World War II most wells were drilled by cable-tool methods or were bored, and the well casing was perforated in the hole by a Mills knife or by some other method. Since World War II, most large capacity wells have been drilled by hydraulic rotary method, and factory-perforated casing is used. Most of these wells are also gravel packed. In an effort to get the maximum yield, most of the casing in a well is perforated adjacent to most water-bearing sands and admits water from several water-bearing units.

The water levels in most wells probably represent a composite of the pressure heads in two or more water-bearing units penetrated by the well. Nonpumping water levels, therefore, depend upon the depths, perforated intervals, number of water-bearing units penetrated, and intervals perforated; they may not be representative of the nonpumping head in any single unit.

Water-level records suggest that two poorly defined aquifers underlie the Hollister and San Juan Valleys: (1) a semiconfined aquifer that extends to a depth of possibly 300 feet below land surface; and (2) a confined aquifer of undetermined thickness below a depth of 300 feet. Water levels measured in October and November 1968 in nonpumping wells that ranged from about 100 to 300 feet in depth were used to prepare a water-level contour map (fig. 6) that shows the general configuration of the ground-water surface in the semiconfined aquifer. Because ground water moves down the hydraulic gradient, approximately at right angle to the water-level contours, the map (fig. 6) can be used to indicate the general direction of ground-water movement, show places where pumping depressions have developed, and outline areas where permeability barriers may hinder ground-water movement. In addition, the map shows the altitudes of water levels measured in deep wells that were screened or perforated below a depth of 300 feet. Those water levels reflect what is known about the head in the semiconfined aquifer and give some indication of its hydraulic gradient.

The sources of natural ground-water recharge in the Hollister and San Juan Valleys are infiltration from streams, direct infiltration of rain, and subsurface inflow from Santa Clara County and from the consolidated bedrock. The rate and amount of recharge from streams is related to runoff and varies considerably from year to year. Infiltration rates in some streams are discussed later in the report under artificial ground-water recharge. Recharge from penetration of rain varies from year to year but may average 20 to 40 percent of the total available recharge from all sources. Average annual rainfall ranges from 12 to 16 inches, most of which occurs between late autumn and early spring.

Ground-water pumping in the Hollister and San Juan Valleys has reduced the head in most places and has caused large water-level declines in some areas. Large cones of depression are present in each of the major ground-water subbasins. The approximate configurations of these cones are shown in figure 6. The probable minimum net change in water levels in wells that has occurred from August 1913 (fig. 5) to October-November 1968 (fig. 6) is shown in figure 7.

The depth to water has increased to such an extent that water from nearly all reaches of the San Benito River and other streams can now percolate to the underlying ground-water body during most of the time when the streams flow. Occasionally, however, the ground-water body beneath some reaches of Tres Pinos Creek, Pacheco Creek, and possibly the Pajaro River might be so shallow as to cause recharge from these sources to be rejected when the underlying sands become fully saturated.

Hollister subbasin.--Ground water throughout most of subunit I in the Hollister subbasin (fig. 2) moves toward and into a large cone of depression just east of Cottage Corners (fig. 6). Most of this water is derived from rainfall and streamflow probably from Arroyo Dos Picachos, Santa Ana Creek, and Tres Pinos Creek. Only a small amount of the water east of the Calaveras fault is obtained from the San Benito River. Ground water in the Southside School area is derived mainly from Tres Pinos Creek. Some water now flows across the Calaveras fault into the Hollister subbasin from subunit IV in the San Juan subbasin (fig. 6). Ground water in the northern part of subunit I in the Hollister subbasin is from inflow from subunit III and direct recharge from streams and rain. Water in subunit III is derived from percolation losses from streams draining the Diablo Range that cross subunit III. Most of this water probably moves southward toward or into the cone of depression east of Cottage Corners, and the remainder probably moves northward toward San Felipe Lake. A smaller cone of depression has formed in subunit II. Some ground water from subunit I may flow across the Santa Ana Valley fault and into this cone, but the main source of recharge probably is ground water that moves westward across the Ausaymas fault.

San Juan subbasin.--Streamflow measurements indicate that the reach of the San Benito River between the gaging station San Benito River near Hollister in sec. 24, T. 13 S., R. 5 E. and Blossom Lane is a gaining reach, that is, an area of ground-water discharge (table 3). The origin of this water is uncertain. The water may be derived from underflow of Tres Pinos Creek, from underflow of water lost from the San Benito River above the gaging station, or from ground-water discharge from the Purisima Formation. During months of low flow most, if not all, of the water in San Benito River again enters the ground-water system as percolated recharge in subunit V of the San Juan subbasin. During periods of high flow, however, some water from San Benito River flows out of the area through the San Juan Valley. Water that enters subunit V of the San Juan subbasin from surface sources or as subsurface flow from adjacent subunits II and III in the San Juan subbasin may move through subunit IV. Some water may move across the Calaveras fault and enter subunit I of the Hollister subbasin. However, because the Park Hill West fault (fig. 2) acts as a barrier to ground-water movement, and because hydraulic gradients have been modified by pumping, ground water in subunits IV or V cannot move into subunit III. Ground water in subunit III may move either into subunit II or into the southernmost end of the Gilroy-Bolsa subbasin (fig. 6). Most of the water in subunit II moves toward the large cone of depression that has formed as a result of pumping in the area northeast of San Juan Bautista. A small amount of ground water may discharge from subunit II by subsurface outflow in the area where the San Benito River joins the Pajaro River.

Ground-water recharge to subunit VI (fig. 6) is derived from infiltrated rainfall and streamflow losses from San Juan Creek. There has probably been little, if any, change in the ground-water regimen since 1913. The alluvium in the subunit is underlain at shallow depth by consolidated bedrock (fig. 4). Ground water in the subbasin probably moves through the alluvium across the San Andreas fault at shallow depth into subunit II.

Gilroy-Bolsa subbasin.--Ground-water recharge to the Gilroy-Bolsa subbasin (figs. 2 and 6) is derived from several sources. Recharge from surface sources is from rain and return irrigation water that percolates down to the ground-water body and possibly from water losses from the Pajaro River. The largest and most significant amount of recharge is from subsurface inflow from Santa Clara County north and west of the Pajaro River. Small amounts of ground-water inflow into subunit I are obtained from subunit III in the San Juan subbasin and from subunit II in the Gilroy-Bolsa subbasin; presumably some inflow is also derived from subunit IV in the San Juan subbasin. All the water that enters the subbasin now moves toward a cone of depression that has developed as a result of pumping in the southern part of subunit I. This represents a complete reversal in the direction of ground-water flow since 1913 (fig. 5).

Water-Level Trends

Since 1913 water-level measurements have been made periodically in the Hollister and San Juan Valleys by many persons and organizations. These measurements were used to make hydrographs of selected wells that show the trends in ground-water levels in the three subbasins (fig. 2). The hydrographs are shown in figure 8, and the locations of the wells are shown in figure 7. The hydrographs were compiled from water-level measurements made by Clark (1924), Burch (1925), Pillsbury (1936), the San Benito County Water Conservation and Flood Control District, the Hollister Irrigation District, the U.S. Bureau of Reclamation, and the U.S. Geological Survey. In most cases each hydrograph represents water levels measured in two or more wells that were drilled in the same area though not usually to the same depth.

The hydrographs show the probable long-term trend and net rise or decline of water levels in the areas of the wells during the period 1913-69. The long-term trends are the most significant features of water-level change because they reflect the summation of all seasonal and short-term variations in pumping and recharge. The long-term trends also reflect changes in ground-water storage.

The solid symbols show the depth to water in the wells when water levels were approximately at their highest levels in the spring or early summer season. The open symbols show the depth to water in wells when water levels were approximately at their lowest nonpumping levels in the autumn.

If the overall trend of the well hydrograph is downward, the total accumulated ground-water recharge was less than the total ground-water discharge, including pumping for the period shown. If the trend is upward the total accumulated ground-water recharge was greater than the ground-water discharge, including pumping. Where no up or down trend is indicated ground-water recharge has about equaled the ground-water discharge.

From 1945, when annual water-level measurements began, to 1969, the hydrographs show pronounced periodic recovery and decline trends that correlate with volume and time of streamflow in Pacheco Creek, the San Benito River, and probably other smaller streams. The available records of streamflow past gages on Pacheco Creek and the San Benito River are shown in figure 8. The hydrographs show a close relation between streamflow and water-level trends and indicate that water levels in wells are directly related to streamflow and total precipitation. Some hydrographs show that a time lag of as much as 1 year may occur before water levels respond to recharge from streams. For example, the hydrograph for well 12S/4E-35A2 in the San Juan Valley shows a definite rise during 1958-60, which was presumably caused by recharge that percolated into the deposits underlying the San Benito River during high runoff in the 1958 water year. Another rise, shown by some of the hydrographs, began in 1967 and has continued into 1969. This later rise is probably due to the greater than average recharge during high streamflow periods in the 1966-68 water years.

The effect of a sequence of wet years, such as occurred between 1951 and 1958, on water-level declines in the Hollister and San Juan subbasins is shown by the hydrographs for wells 12S/5E-22R3, 13S/5E-3H1, 12S/5E-27E1, and 12S/4E-35A2. During these years the rate of water-level decline, which had increased abruptly beginning about 1945, decreased almost to zero or even reversed. This was due to increased recharge from surface sources and probably to a decrease in the amount of ground water pumped for irrigation.

The net long-term change of water levels in wells in the Hollister and San Juan Valleys from 1913 to 1968 is shown by the water-level change map (fig. 7). The rate and amount of water-level decline in the two valleys from 1913 to about 1945 were small except in the southern half of the Gilroy-Bolsa subbasin (fig. 2) where the rate of decline from 1913 to 1969 has been about 2.4 feet per year, as shown in the hydrograph for well 12S/5E-16Q2. In the northern half of the subbasin there has been little, if any, significant water-level decline, as shown by the hydrograph of well 11S/4E-24L1. In 1913, as shown in figure 5, any deep well near the present location of well 11S/4E-24L1 should have flowed.

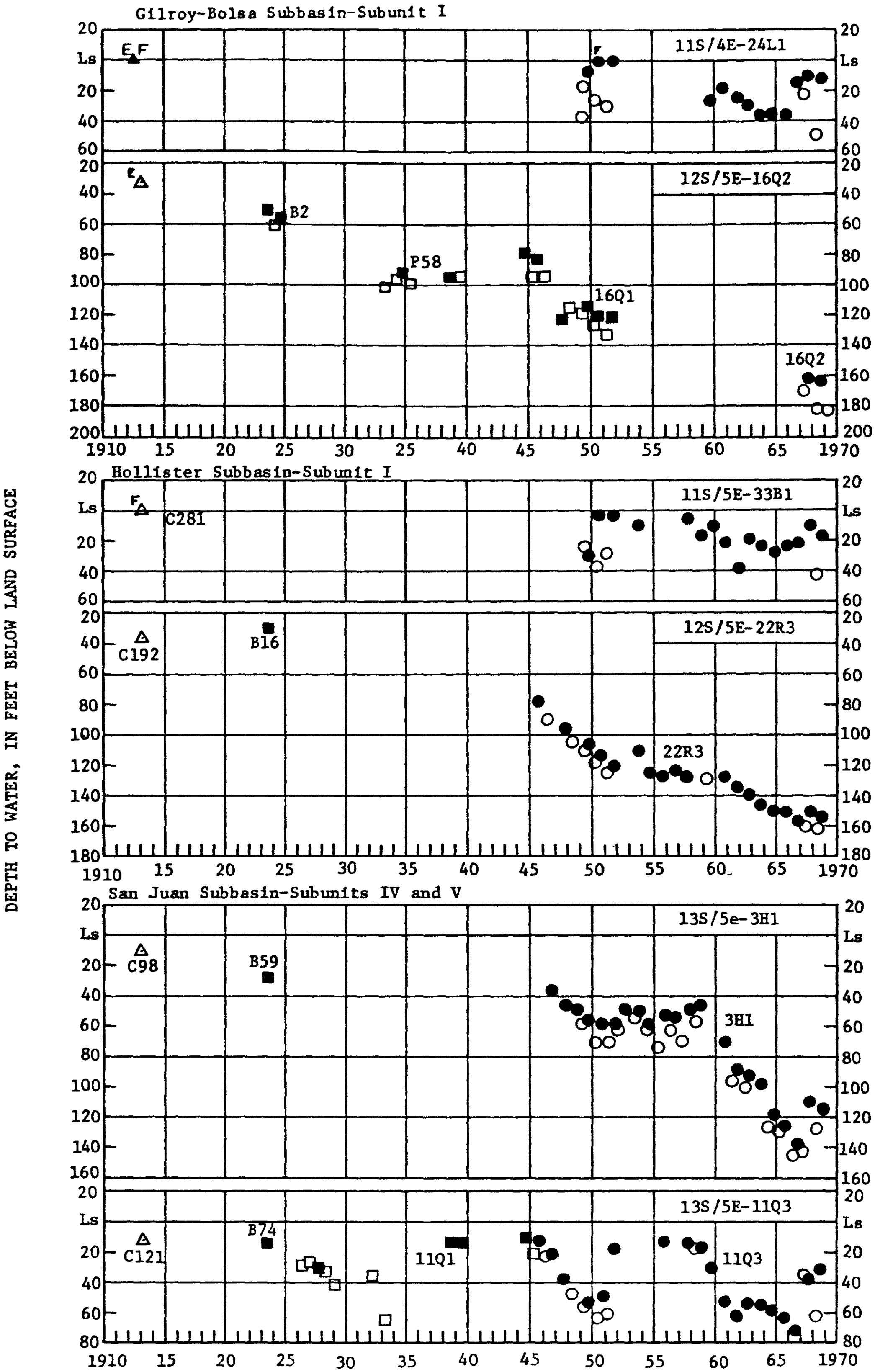
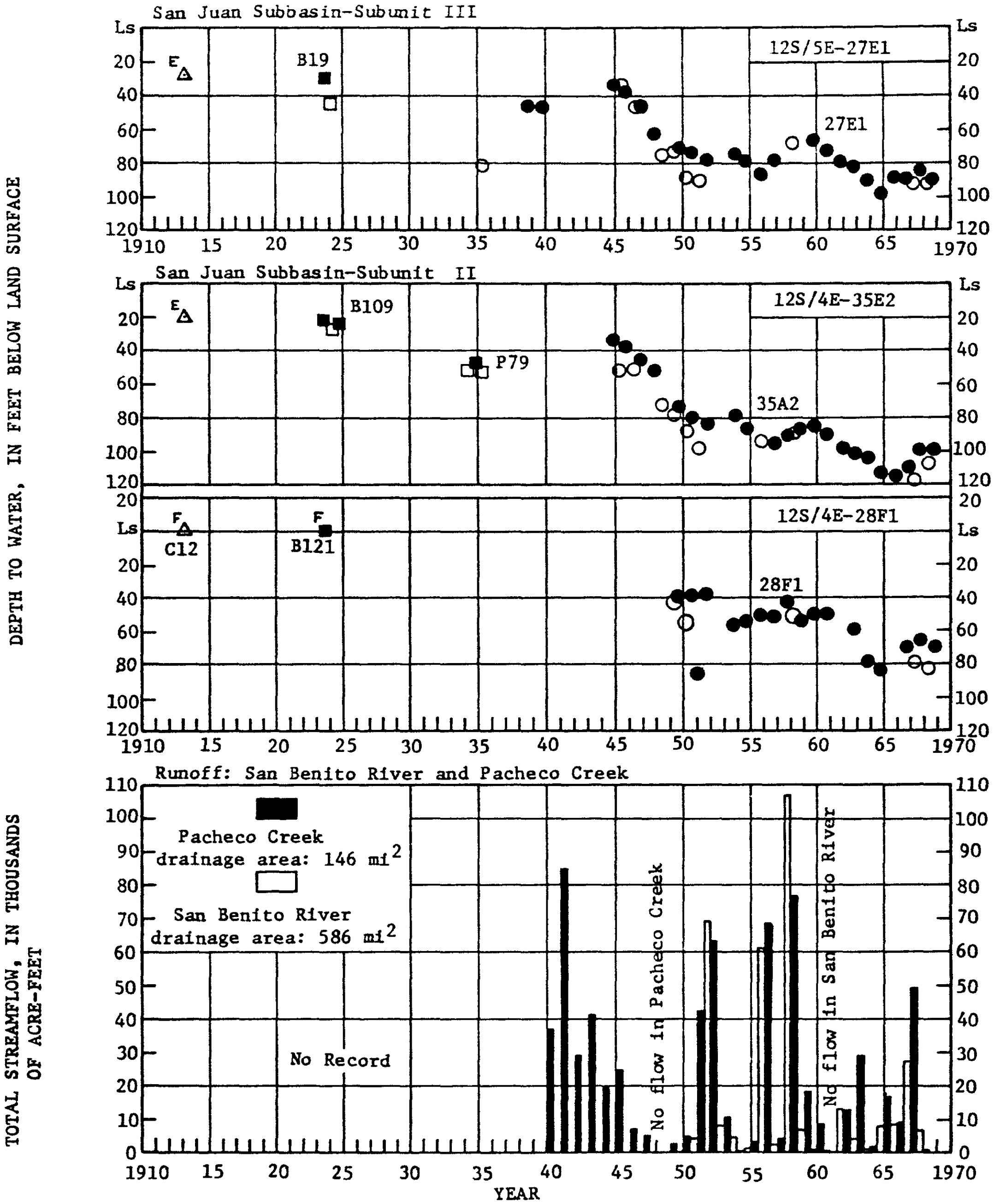


FIGURE 8.--Water levels in selected wells and annual runoff in the principal streams.



EXPLANATION

WATER LEVEL AND WELL NUMBER - Open symbols indicate water-level measurements made in the autumn or second half of year; solid symbols indicate water-level measurements made in the spring or first half of year. Water-level trends discussed in report are based on the spring measurements. Wells referred to in individual hydrographs were in the same general area and were not necessarily at the same depth or screened interval

▲E Water level only; estimated from water-level data (Clark, 1924)

▲C12 (Clark, 1924)

■□ B2 (Burch, 1925)

■□ P58 (Pillsbury, 1936)

■□16Q1 Measurements made by Hollister Irrigation District, U.S. Bureau of Reclamation, and San Benito County Water Conservation and Flood Control District

■□16Q2 Current water-level observation well measured by San Benito County Water Conservation and Flood Control District

F Flowing at land surface

FIGURE 3. - Continued

The rate and amount of water-level decline in wells in the Hollister and San Juan subbasins is probably controlled mainly by their proximity to surface streams or by location in centers of pumping. The hydrographs for well 11S/5E-33B1, near Pacheco Creek, and well 13S/5E-11Q3, near the San Benito River, show short-term declines and recoveries that correlate with streamflow, but the long-term trend from 1913 to 1969 is virtually flat. This indicates that the amount of ground-water recharge into that part of the subunits in which these wells are located has been equal to or greater than the amount of ground water withdrawn by pumping. The hydrographs for wells farther from streams show water-level declines, beginning about 1945, that indicate ground-water recharge in subunits where the wells are located was less than that withdrawn by pumping and suggest that part of the pumped water was obtained from storage. The greatest rate of decline from 1945 to 1969 was in subunit IV of the San Juan subbasin (fig. 2). The hydrograph for well 13S/5E-3H1 shows a water-level decline of about 10 feet per year between 1960 and 1967. This decline was followed by a period of recovery, estimated to be about 4.5 feet per year, that began in the autumn of 1967. This same period of water-level recovery is shown in most of the hydrographs in figure 8.

Depth to Water

The depth below land surface to water in wells at the end of the 1967-68 irrigation season ranged from less than 1 foot to approximately 235 feet. Figure 9 shows the approximate areas where the depth to water measured between October 9 and November 5, 1968, was less than 35 feet, 35-100 feet, 101-200 feet, or greater than 200 feet below the land surface. It should be pointed out that the map does not indicate that a well would necessarily first strike water within the depth ranges shown. The measurements were made at a time when nearly all pumping for irrigation had ceased, except from a few wells in the western part of the Gilroy-Bolsa subbasin between the Pajaro River and the Lomerias Muertas.

The water level in wells in the Hollister and San Juan Valleys fluctuates in response to ground-water pumping and recharge from rainfall and streams. The highest water levels normally occur in the spring or early summer (February-May), and the lowest occur at the end of the irrigation season (August or September). Helley (1967), however, indicated that the lowest water levels in some wells may occur as early as June or as late as the following January.

Water-level data compiled by Helley (1967) show that the depth to water in wells may vary considerably from year to year and from one well to another. Available water-level data needed to indicate the annual range of water-level fluctuations in wells are sparse. The water-level data available indicate that seasonal water-level fluctuations in wells may range from about 5 feet to as much as 55 feet. The average seasonal water-level fluctuation, however, probably ranges from 10 to 40 feet. The amount of this seasonal fluctuation depends to a large extent on the location of the well.

Analyses of water levels and water-level fluctuations in wells indicate that physical factors, such as the depth of perforated interval, can cause water levels in adjacent wells to differ by as much as 50 feet. The effect of well construction on water levels and the use of water levels in making the hydrologic interpretations were discussed in the section headed "Occurrence and movement of ground water."

The shallow depth to water in the area adjacent to the Pajaro River in the Gilroy-Bolsa subbasin and in the area adjacent to Lovers Lane in the northern part of the Hollister subbasin causes water logging of the soil and drainage problems during the winter and early spring months. Foresberg and Colvin (1947) found that shallow ground water in the Lovers Lane area was derived from two major sources: (1) artesian water originating from the Pacheco Creek drainage basin, and (2) surface and subsurface flow from the bed of Pacheco Creek.

The hydrographs for wells 11S/4E-24L1 and 11S/5E-33B1 (fig. 8) show that long-term water-level trends in the northern parts of the Gilroy-Bolsa and Hollister subbasins are virtually flat and indicate that water-logging and drainage problems in these two areas will continue unless ground-water pumping is increased substantially.

Water-logging problems are also reported along Tres Pinos Creek and San Benito River in the vicinity of the Southside School. These problems probably occur mainly during years of high runoff when permeable materials beneath the streams become saturated and the depth to water in areas adjacent to the two streams is minimal.

Other areas in the San Juan and Hollister Valleys that might develop drainage problems because of changes made in irrigated areas, excessive use of water for irrigation purposes, or changes in the volume of water pumped from large-capacity wells could not be adequately delineated during this study. Delineation of these areas would require more detailed information on (1) the geology and ground-water hydrology of the near-surface deposits, (2) the permeability and specific yield of the underlying deposits, and (3) a quantitative study of the ability of the aquifers to store and transmit ground water.

ARTIFICIAL GROUND-WATER RECHARGE

The amount of ground-water recharge within the Hollister and San Juan Valleys from natural sources since 1945 has been less than the amount of ground water pumped. To help alleviate this imbalance, artificial ground-water recharge operations are being carried on in the Hollister and San Juan Valleys.

The Pacheco Pass Water District augments recharge in Pacheco Creek during the spring and summer when water stored behind the North Fork Dam (not shown on maps in this report) on the North Fork of Pacheco Creek is released. The District also operates a small off-stream percolating pond maintained by diversions from Arroyo de Las Viboras.

The San Benito County Water Conservation and Flood Control District carries out artificial ground-water recharge operations during the spring and summer months in the natural courses of Tres Pinos Creek and the San Benito River. The water percolates downward from the natural stream channels and from spreading ponds prepared in the channels. The water for percolation in Tres Pinos Creek is diverted from the San Benito River and delivered by canal to the Paicines Reservoir (not shown on maps in this report) about 10 miles southeast of Hollister. Another canal delivers water from the reservoir to Tres Pinos Creek. Water can also de diverted from the Paicines Reservoir back to the San Benito River when desired.

Studies of the infiltration capacities of the San Benito River and other streams flowing into the Hollister Valley were made by the U.S. Bureau of Reclamation (1952a) during the two runoff seasons 1949-50 and 1950-51. The maximum rates of percolation for these streams, as reported by the Bureau of Reclamation and as measured by the Geological Survey, are summarized in table 3. The locations of sites where the measurements were made are shown in figure 6.

Percolation losses calculated from measurements of streamflow made by the Geological Survey on April 29, 1969, at points along Tres Pinos Creek below the gaging station, Tres Pinos Creek near Tres Pinos in sec. 35, T. 13 S., R. 6 E., and along the San Benito River upstream from the city of San Juan Bautista, are shown in table 3 and compared with estimated maximum percolation losses estimated by the Bureau of Reclamation along these same reaches.

TABLE 3.--*Percolation losses of streams*

Stream name, channel interval, and streamflow-measurement sites	U.S. Bureau of Reclamation[1] (loss in cfs)	U.S. Geological Survey: Streamflow[2] (cfs)	U.S. Geological Survey: Loss (-) or gain (+)[3] (cfs)
San Benito River			
San Benito River near Hollister gage site to State Highway 156 bridge			
San Benito River near Hollister gage site to Hospital Road	6		
At San Benito River near Hollister gage site		24.0	
South at Blossom Lane		25.9	+1.9
Near Hospital Road crossing		19.3	-6.6
			-4.7
Hospital Road to Nash Road	3		
Near Hospital Road crossing		19.3	
Near Cienega Road crossing		12.4	-6.9
Near Nash Road crossing		6.9	-5.5
			-12.4
Nash Road to State Highway 156 bridge	11		
Near Nash Road crossing		6.9	
Near State Highway 156 bridge		7.3	+.4
			+.4
Total	20		-16.7
San Benito River (continued)			
State Highway 156 bridge to Old U.S. Highway 101 bridge			
State Highway 156 bridge to Mitchell Road	9		
Near State Highway 156		7.3	
North of the end of Mitchell Road		4.5	-2.8
			-2.8
Mitchell Road to Bixby Road	10		
North of the end of Mitchell Road		4.5	
North of the end of Lucy Brown Road		No flow[4]	-4.5
			-4.5
Lucy Brown Road to Old U.S. Highway 101 bridge	11	No flow	
Total	30		-7.3
Tres Pinos Creek			
Tres Pinos Creek near Tres Pinos gage site to site near juncture of Tres Pinos Creek with San Benito River	17		
At Tres Pinos Creek near Tres Pinos gage site		14.5	
Near Airline Highway crossing		12.9	-1.6
Tres Pinos Creek south of Tres Pinos		13.4	+.5
Near Southside Road crossing near Tres Pinos		9.4	-4.0
At Southside Road crossing near juncture with Thomas Road		4.2	-5.2
Total	17		-10.3
Pacheco Creek			
State Highway 152 bridge to San Felipe Road	17		
Arroyo de Las - Los Viboras			
Pacheco Pass Water District Dam to a point near mouth of creek	2.0		
Dos Picacho Creek			
Lone Tree bridge to juncture of creek with Los Viboras Creek	6.0		
Santa Ana Creek			
Mansfield Road to McClosky Road	.75		

[1]Estimated maximum percolation losses of streams, U.S. Bureau of Reclamation (1952a, app. I, v. 2).
[2]Current-meter measurements made by U.S. Geological Survey on April 29, 1969. Location of measurement sites shown in figure 6.
[3]Percolation losses calculated from current-meter measurements.
[4]Point of no flow was upstream from end of Bixby Road.

The flow lines shown in figure 6 indicate the direction in which water moves from the channels and areas that benefit from the recharge. The map (fig. 6) is based on the author's interpretation of ground-water levels, aquifer units, and fault barriers. The Hollister subbasin derives the greatest benefit from water that percolates along streams that drain the east side of the Hollister Valley. Nearly all the water that percolates from Tres Pinos Creek and from the San Benito River upstream from Nash Road and is not removed by pumping moves toward the cone of depression near Cottage Corners in the Hollister subbasin. Most of the water that percolates from the San Benito River between Nash Road and the Highway 156 bridge 1.6 miles west of Hollister flows toward the southern end of the Gilroy-Bolsa subbasin. Water that percolates from the San Benito River downstream from the Highway 156 bridge moves toward the San Juan Valley. Based on measurements made on April 29, 1969 (table 3), streamflow past the gaging station, San Benito River near Hollister in sec. 24, T. 13 S., R. 5 E., would have to have exceeded 20 cubic feet per second before there could be surface flow in the channel at the upper end of the San Juan Valley. Although channel conditions and percolation rates may change with each runoff event, the channel conditions extant on April 29, 1969, were presumed to approximate average nonflooding conditions. Thus, the percolation data given in table 3 may be used as an index of the average percolation losses that will occur along the river when the flow is approximately 24 cfs at the San Benito River gaging station above Hollister.

At the present time (1969) the Gilroy-Bolsa subbasin probably receives only a small benefit from percolation losses from the San Benito River and none from Tres Pinos Creek. Drillers' and electrical logs of wells located in the southern end of the Gilroy-Bolsa subbasin suggest that geologic conditions in this area may be favorable for percolating water. The logs show that gravel deposits more than 200 feet thick occur within a few feet of the land surface. The depth to water in this area ranges from about 140 to 180 feet below land surface, and a large thickness of the gravel, therefore, contains no water. Any water recharged in this area would move toward the cone of depression (fig. 6) and would remain in that area until pumped from wells. On the basis of this information, the feasibility of carrying out artificial-recharge operations cannot be determined. The area should be thoroughly explored and tested before firm plans are made for constructing recharge facilities or water-delivery systems.

The results of the very limited study of the feasibility of artificial ground-water recharge suggest that present stream channels are the best places for recharging the ground-water reservoir.

Consideration should be given to a study of the feasibility of recharging imported or surplus surface water in the Fairview and Ausaymus areas in the eastern part of the Hollister Valley. Ground water underlying part of these areas contains objectionable amounts of boron. The percolation and storage of surplus surface water in sand beds that overlie the present water-bearing units should enable wells in these areas to obtain water containing lower concentrations of boron at shallower depths. Some deeper wells could be plugged back and completed at shallower depths in order to obtain the better quality water.

QUALITY OF GROUND WATER

The chemical quality of ground water in the Hollister and San Juan Valleys was first extensively studied by Eaton (1941) who found that in some places ground water in the eastern part of the Hollister Valley contained concentrations of boron and chloride that limited the suitability of the water for irrigation use. After 1941 the University of California Agricultural Extension Service made additional studies of the quality of ground water, but no reports of its findings have been published. The California Division of Water Resources (1953) made an industrial waste survey to determine if constituents in wastewater were affecting ground water in the vicinity of Hollister. The California Department of Water Resources (1964a) made a special water-quality investigation of the Hollister, San Juan, and Santa Ana Valleys to provide the California Central Coastal Regional Water Pollution Control Board with water-quality, hydrologic, and geological data for the area and to recommend wells suitable for monitoring ground-water quality. This report presented mineral-quality criteria needed by the Water Pollution Control Board to "establish mineral water quality objectives in the area and in governing the nature of sewage and industrial waste discharges and or conditions to be maintained in receiving waters" (California Department of Water Resources, 1964a, p. 2).

The disposal of wastewater in the Hollister Gas Field (California Department of Water Resources, 1964b) and the disposal of industrial wastewater in the vicinity of Hollister (California Department of Water Resources, 1966) were investigated to determine possible effects of such disposal on the quality of ground water and surface water.

The quality of ground water in the Hollister and San Juan Valleys has been monitored by the California Department of Water Resources since 1958, and the data have been published (California Department of Water Resources, 1961-64, 1966-68).

Data on the concentration of boron, chloride, and sulfate in water from monitor wells sampled by the California Department of Water Resources and from other wells for which two or more analyses are available are given in table 4. Figure 10 shows the location of wells listed in table 4, which also shows the minimum, maximum, and average concentration of the constituents for the period of record. The change in concentration of boron, chloride, and sulfate with time in selected wells is shown in figures 11 and 12.

TABLE 4.--*Range in concentrations of boron, chloride, and sulfate as determined from chemical analyses of water from wells*

[Location of the wells is shown in figure 10. Concentration of constituents: Number in parentheses indicates number of analyses reporting concentration]

Well number	Depth of lowest perforation or depth of well, in feet below land surface	Period of record		Number of analyses	Concentration of constituents, in milligrams per liter								
					Boron			Chloride			Sulfate		
		Begins	Ends		Low	High	Average	Low	High	Average	Low	High	Average
11S/4E-24C1	149	1961	1968	2	0.2	0.3	-	78	78	-	61	69	-
25H1	215	1961	1968	2	.8	.9	-	79	88	-	192	225	-
11S/5E-27M1	132	1958	1967	10	.1	.4	0.3	21	30	24	40	47(7)	43
35C3[1]	204	1958	1968	8	1.5	2.6(6)	2.1	19	193	115	12	30(5)	16
36P4	331	1957	1968	2	-	-	-	156	372	-	-	-	-
11S/6E-31M2	175	1965	1968	2	1.5	.4	-	-	-	-	-	-	-
12S/4E-34P2	288	1958	1967	10	.1	.8	.4	139	298	218	209	464(7)	314
35C1	141	1958	1967	10	.5	1.0	.8	94	120(8)	103	294	447	348
36G1	426	1958	1967	10	.7	1.4	1.2	96	160	108	351	510(7)	422
12S/5E- 2F1	840	1963	1968	2	1.2	1.8	-	98	284	-	87	118	-
8D1	340	1958	1960	3	.8	1.0	.9	97	106	100	237	244	241
8G1	200	1961	1968	2	.8	.9	-	89	104	-	235	252	-
9N2	452	1960	1967	5	1.1	1.6	1.3	163	189	178	388	422(3)	403
12M3	127	1959	1968	7	1.4	6.1	3.7	122	203	147	80	123(6)	98
14M3	337	1961	1968	3	.7	1.0	.9	77	88	81	132	169	156
24N3	336	1963	1968	2	.9	1.0	-	91	96	-	165	165	-
28P1[2]	110	1962	1965	11	.7	.9(3)	.8	82	93(7)	86	174	276	220
33A2[3]	224	1962	1967	6	.8	1.0	.9	88	103	98	227	255(3)	237
33C1[4]	189	1962	1965	11	.7	.8(3)	.7	73	76(7)	74	170	203	189
33D4[5]	150	1961	1965	12	1.0	1.3(4)	1.1	117	214(8)	162	388	470(11)	444
33F1[6]	90	1965	1968	10	.7	1.0(3)	.9	90	98(6)	94	216	309	264
33H2[7]	150	1961	1965	12	.8	1.2(4)	1.0	104	195(8)	132	210	453(11)	302
34F1	624	1964	1967	2	-	-	-	100	104	-	212	265	-
34N1[8]	178	1962	1965	11	.6	.8(3)	.7	72	84(7)	78	206	240	224
34P2	590	1964	1967	2	.9	1.0	-	112	130	-	212	315	-
36A1	330	1958	1968	11	1.3	3.2(10)	1.7	141	152	120	64	87(7)	71
12S/6E- 5M1	240	1958	1968	2	4.8	7.2	-	87	90	-	1	12	-
6B1	204	1961	1968	2	.5	.8	-	29	47	-	33	37	-
6P4	256	1967	1968	2	1.0	1.1	-	54	58	-	13	19	-
7M2	176	1958	1968	11	.6	.9(10)	.7	4	25	21	0	1(7)	<1
7P3	576	1962	1968	2	-	.7	-	30	33	-	-	9	-
19E2	186	1958	1968	10	7.2	19(9)	17.1	308	334	319	0	4(6)	<1
31B1	323	1958	1968	11	3.0	5.5(10)	3.6	352	503	466	109	142(7)	123
13S/5E- 3A2	648	1952	1967	3	-	1.0(1)	-	81	114	97	181	209	197
3J1	132	1958	1968	10	.7	1.1(9)	.9	90	128	111	238	273(9)	255
11B5	235	1958	1966	6	.8	1.0	.9	95	132	124	245	311	288
11G1	235	1958	1966	9	.5	1.4	1.0	110	124	117	244	269	256
13S/6E-19N1	149	1959	1961	3	1.4	1.6	1.5	192	339	286	367	472	429

[1] Formerly California Department of Water Resources well no. 11S/5E-26Q1.
[2] Sampled once in 1962 and monthly from March to December 1965.
[3] Formerly California Department of Water Resources well no. 12S/5E-33A1.
[4] Sampled once in 1962 and monthly from March to December 1965.
[5] Sampled annually 1961-62 and monthly from March to December 1965.
[6] Sampled monthly from March to November 1965 and once in 1968.
[7] Sampled annually 1961-62 and monthly from March to December 1965.
[8] Sampled once in 1962 and monthly from March to December 1965.

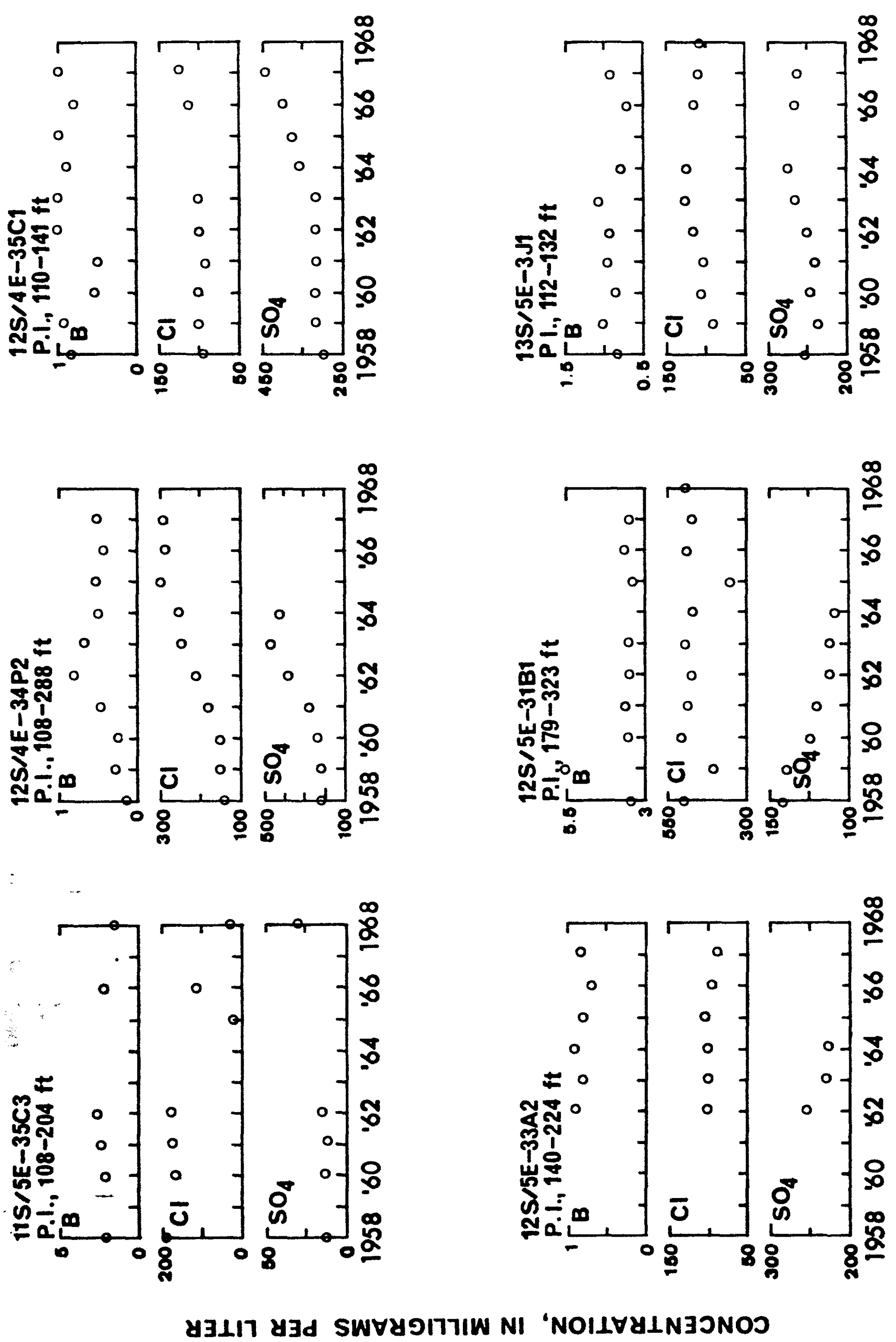


FIGURE 11.--Changes in concentration of boron (B), chloride (Cl), and sulfate (SO_4) with time in water from monitor wells in the Hollister and San Juan Valleys. Location of wells is shown in figure 10. P.I. is perforated interval.

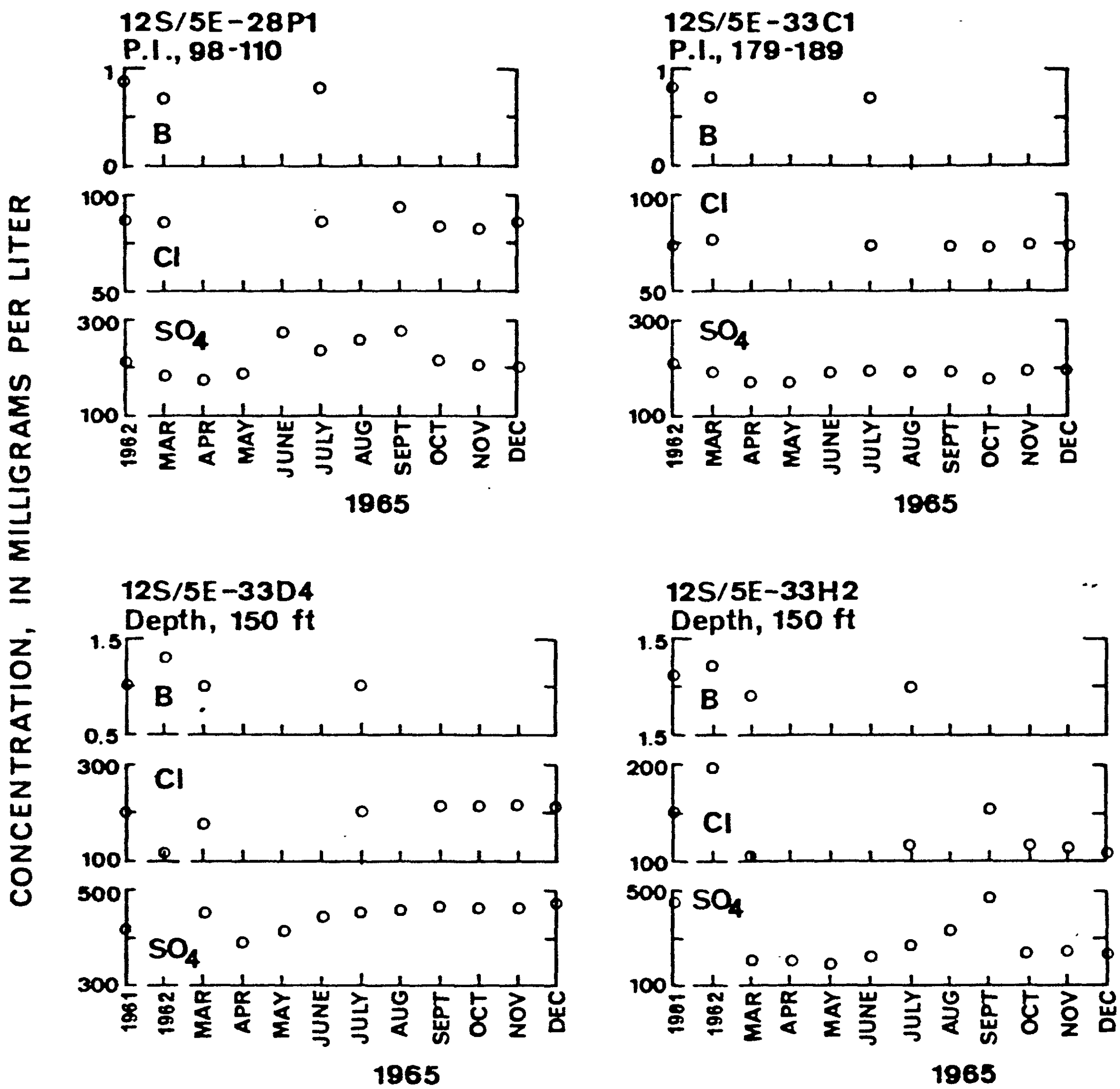


FIGURE 12.--Changes in concentration of boron (B), chloride (Cl), and sulfate (SO_4) with time in water from monitor wells adjacent to the Hollister industrial-waste disposal site. Location of wells and disposal site is shown in figure 10. P.I. is perforated interval.

During the present study samples of ground water from 60 selected wells were collected and analyzed to provide data on the conductance and the concentration of boron, chloride, sulfate, and dissolved solids in ground water in the area lying generally north of Hollister. The sodium content of some of the samples was also determined. The analysis for boron, chloride, and sulfate was suggested by Rocky Lydon, area farm advisor, University of California Extension Service, because these constituents locally may limit the suitability of ground water for irrigation purposes. The wells sampled were selected on the basis of location, depth, and perforated interval. Few wells in this area, however, are perforated adjacent to only one water-bearing unit, and the samples collected, therefore, are composites of water from all units yielding water to the wells. Approximately half of the samples were collected during May 1968, and the rest were collected in the latter part of August and early part of September 1968. The partial chemical analyses for these wells are given in table 5. The location of the wells is shown in figure 10.

Quality-of-water data for the years 1960-68 collected by companies, private well owners, and the California Department of Water Resources, and data collected in 1968 by the Geological Survey, were used to compile maps shown in figures 13, 14, and 15. Only the most recent data are shown on these maps.

The concentration of boron, chloride, and sulfate in the water pumped from a particular well is dependent upon one or more of the following factors: (1) total depth; (2) screened or perforated intervals in well casings; (3) rate and duration of pumping before sample was collected; (4) location of the well; (5) water-bearing unit or units yielding water to the well; (6) proximity to faults; (7) quality of water that recharges the water-bearing units tapped by the well; and (8) length of shutdown period that immediately preceded the period of pumping during which the sample was collected.

Boron.--The concentration of boron in water obtained from wells sampled between 1960 and 1968 in the Hollister and San Juan Valleys is shown in figure 13. Shown also is the area where the concentration of boron exceeded 1.5 mg/l during the period 1931-50 (U.S. Bureau of Reclamation, 1952b, map 12A). The high, low, and average concentration of boron in selected wells is given in table 4. Changes in the concentration of boron during the 11-year period (1958-68) are shown by graphs in figure 11.

The source of the boron is not known, but it may be derived from water that moves upward from marine sedimentary rocks (table 1 and figs. 3 and 11) that constitute the consolidated bedrock that underlies the Hollister and San Juan Valleys east of the San Andreas Rift zone.

In the eastern part of the Hollister Valley, boron is probably a constituent in water contained in units 1 and 2 (table 1 and figs. 3 and 11). The boron may be derived from units 1 and 2 or it may be a constituent in water that moves upward from underlying marine sedimentary rocks that constitute bedrock in this area.

TABLE 5.--*Partial chemical analyses of water from wells in the northern half of Hollister Valley*

Well number	Date of collection	Temperature (°C)	Sodium (Na)	Sulfate (SO_4)	Chloride (Cl)	Boron (B)	Dissolved solids (residue at 180°C)	Specific conductance (micromhos)
			(concentration in milligrams per liter)					
11S/4E-13A2	8-26-68	18	--	185	406	0.27	1260	2020
11S/4E-23Q1	8-24-68	24	--	35	30	.27	352	570
11S/4E-24C1	8-24-68	18	--	61	78	.22	524	904
11S/4E-25H1	8-23-68	--	--	192	88	.91	764	1240
11S/4E-34G1	9-25-68	17	--	135	33	.28	504	838
11S/4E-35R1	9-27-68	21	--	125	156	.74	708	1160
11S/5E-17R1	9-03-68	17	--	121	46	.65	464	735
11S/5E-21K1	9-04-68	17	--	67	41	.41	332	599
11S/5E-21N1	9-03-68	18	--	73	30	.40	384	656
11S/5E-28B1	8-23-68	18	--	47	28	.72	358	593
11S/5E-29R1	6-23-68	18	--	93	44	.70	472	762
11S/5E-30H1	8-23-68	23	--	215	88	.70	680	1090
11S/5E-31F2	8-24-68	22	--	395	156	.99	1170	1660
11S/5E-31R1	8-23-68	18	--	1025	290	1.0	2450	3020
11S/5E-33B2	8-22-68	18	--	46	24	.33	332	551
11S/5E-34Q1	9-03-68	18	--	46	38	.58	380	650
11S/5E-35B4	5-16-68	19	143	21	152	2.2	556	1030
11S/5E-35C3	5-16-68	17	91	30	58	1.5	264	665
11S/5E-36A2	5-16-68	21	39	35	36	.74	376	668
11S/5E-36M10	5-16-68	18	66	38	184	.71	792	1250
11S/5E-36M11	5-20-68	21	178	3.0	113	2.1	688	1320
11S/5E-36P4	5-16-69	17	163	21	156	1.9	620	1150
11S/6E-31M2	5-15-68	17	34	30	26	.41	326	540
12S/4E-2J1	9-26-68	25	--	50	148	.59	592	1000
12S/4E-3C2	9-26-68	21	--	63	75	.39	500	780
12S/5E-1H2	5-20-68	20	87	36	72	1.4	552	781
12S/5E-1N2	5-17-68	18	100	45	131	2.4	660	1200
12S/5E-1Q2	5-17-68	22	244	1.0	182	5.0	812	934
12S/5E-2F1	5-20-68	19	233	87	284	1.8	992	1660
12S/5E-5A3	8-22-68	22	--	156	88	.85	740	1180
12S/5E-7N3	8-22-68	26	--	3.0	192	.42	624	1040
12S/5E-8B1	8-22-68	17	--	228	120	.96	924	1480
12S/5E-9J1	8-22-68	18	--	236	94	.93	780	1280
12S/5E-10R2	9-04-68	18	--	240	152	.95	876	1460
12S/5E-12A5	5-17-68	--	148	1.0	136	3.1	556	934
12S/5E-12M3	5-18-68	18	70	95	129	2.3	772	1190
12S/5E-12M6	5-18-68	18	90	79	130	3.3	644	1150
12S/5E-12P3	5-15-69	18	178	7.0	218	9.4	664	1220
12S/5E-14M3	5-17-68	19	120	169	78	.93	612	1000
12S/5E-14R2	5-17-68	23	282	86	262		980	1610
12S/5E-16F2	8-22-68	17	--	252	136	.89	804	1540
12S/5E-16Q2	8-23-68	18	--	208	100	.82	812	1290
12S/5E-17D1	8-22-68	31	--	20	288	.24	712	1290
12S/5E-21A2	9-04-68	18	--	236	110	.78	864	1370
12S/5E-21P1	9-04-68	21	--	212	98	.70	772	1260
12S/5E-22C1	8-24-68	18	--	348	188	1.1	1200	1790
12S/5E-23P2	5-18-68	18	133	271	115	.80	892	1440
12S/5E-24A4	5-17-68	19	59	17	74	2.0	356	652
12S/5E-24N3	5-17-68	20	144	165	96	1.0	560	1060
12S/5E-25F1	5-17-68	22	149	167	90	.75	372	1010
12S/5E-28G1	9-07-68	16	--	296	120	.85	992	1500
12S/5E-36N2	9-20-68	22	--	168	100	1.2	672	1100
12S/6E-5M1	5-15-68	23	138	12	87	4.8	562	1010
12S/6E-6B1	5-16-68	17	35	37	29	.51	308	648
12S/6E-6P4	5-16-68	20	81	13	54	1.1	384	684
12S/6E-7J1	5-20-68	19	77	26	64	.83	452	759
12S/6E-7P3	5-15-68	25	9.0	90	30	.65	302	477
12S/6E-18G1	5-15-68	19	30	25	24	.21	222	404
12S/6E-18P1	5-15-68	21	70	16	65	4.4	288	593
12S/6E-30L5	5-18-68	20	317	229	275	4.3	1240	2140

Sulfate.--The concentration of sulfate in water obtained from wells sampled between 1960 and 1968 in the Hollister and San Juan Valleys is shown in figure 14. The high, low, and average concentration in selected wells is given in table 4. Changes in the concentration of sulfate in monitor wells during the 11-year period (1958-69) are shown by graphs in figure 11.

The source of the sulfate is not known, but it probably was derived from gypsiferous clay and selenite masses in the Purisima Formation. Undoubtedly, some sulfate is added to ground water as a result of the application of gypsum to the land surface for soil-conditioning purposes.

Chloride.--The concentration and distribution of chloride in water obtained from wells between 1960 and 1968 in the Hollister and San Juan Valleys is shown in figure 15. The high, low, and average concentration in selected wells is given in table 4. Changes in the concentration of chloride in monitor wells during the 11-year period (1960-68) are shown by graphs in figure 11.

The source of the chloride is not known. However, it may be from water that has moved upward into deposits tapped by wells from sedimentary rocks of marine origin that constitute the consolidated bedrock (table 1 and figs. 3 and 11) in most parts of the Hollister and San Juan Valleys.

In an area located generally east of Fairview Road and south of Lone Tree Road (fig. 15) most of the wells yield water containing chloride concentrations that exceed 200 mg/l. In this area, the chloride is a constituent in water contained in units 1 and 2 (table 1 and figs. 3 and 11). However, the chloride-bearing water probably was derived from marine sedimentary units that constitute part of the consolidated bedrock.

The chloride in water from wells located near the south end of the Flint Hills (fig. 3), west northwest of Hollister, may have been derived from oil-field brines that formerly were disposed of in salt-water-disposal pits or from saline water contained in the Purisima Formation.

WASTE-DISPOSAL SITES

Waste-disposal sites that have affected or might affect ground-water quality are shown in figure 10. The effect of salt-water discharge from oil and gas wells in the Hollister gas field, of industrial wastes from canneries, and of liquid wastes from municipal sewage-treatment plants have been studied by the California Department of Water Resources (California Division of Water Resources, 1953; California Department of Water Resources, 1964b and 1966). During this study no attempt was made to determine the effects of those disposals on the quality of ground water in the vicinity of the disposal sites. The discussion below is limited to the possible effects of those disposals on the concentrations of boron, chloride, and sulfate that were found by the California Department of Water Resources during their studies of the disposal sites.

The location of the salt-water disposal sites of the Hollister Gas Field investigated by the California Department of Water Resources in 1963 is shown in figure 10. These disposal sites were in use in 1963 but were reported to have been inactive for several years previous to this study (1968). During the State's study, water samples for partial chemical analyses were collected from six wells in September 1963. The boron and chloride concentrations found in the vicinity of the disposal sites are shown in figures 13 and 15. The analyses indicated that water from the six wells ranged from good to unsatisfactory for irrigation purposes. According to the California Department of Water Resources (1964b, p. 8) the water from the six wells was of poor mineral quality and probably would not be used for domestic or agricultural purposes if a better quality water were available.

In 1963, 3,349 barrels of highly mineralized water of the sodium chloride type was extracted from the producing gas wells. The chloride concentration of this water ranged from 7,830 to 11,400 mg/l, and boron concentrations ranged from 30 to 87 mg/l (California Department of Water Resources, 1964b, table 3). The water was discharged into shallow pits (fig. 10) and allowed to percolate downward to the top of the saturated zone in the alluvium or the upper member of the Purisima Formation, both of which may have moderate permeability. The water-level contours shown in figure 6 indicate that the water from the northern three pits probably moved northeastward toward Wright Road. The water from the two pits located near the San Benito River probably moved toward the San Juan Valley. The quality of water in wells downgradient from the pits should be monitored if the pits are ever reactivated.

The effects of the disposal of cannery wastes in percolation ponds on the bed of the San Benito River west of Hollister (fig. 10) on the quality of ground water were studied by the California Department of Water Resources in 1953 and 1965 (California Division of Water Resources, 1953; California Department of Water Resources, 1966). In this area the San Benito River is an important source of recharge for the San Juan Valley. In 1953, the State reported on the organic character of the wastes, the quantities of food processed, and the chemical character of the wastewater. In 1965 the State provided additional information on the quality and quantity of the waste discharges and obtained data on water levels in wells. The quality of water in wells located near the disposal sites was monitored by the California Department of Water Resources on a monthly basis from March to December 1965. Figure 12 shows the monthly concentration of boron, chloride, and sulfate in four wells during this period. The concentration of these constituents in 1961 and 1962 is also shown for comparison with the concentration in 1965. Changes in the concentration of these constituents in years 1962-67 at monitor well 12S/5E-33A2 are shown in figure 11. The location of the well is shown in figure 10.

The main source of water for the canneries is ground water obtained in part from the city of Hollister and in part from wells owned by the canneries. During the apricot- and tomato-canning season caustic soda (NaOH) is used as a peeler. After peeling is completed, the caustic-soda solution is mixed with wash-down and cooling water and discharged to the waste-disposal site near the San Benito River.

The cannery effluent does not differ significantly in chemical quality from the water that is pumped from the cannery's wells except when the caustic-soda solution is being discharged. Chemical analyses of ground water pumped by the city of Hollister in November 1952 (composite of three wells), and analyses of water pumped by the canneries, showed that concentration of boron ranged from 0.10 to 0.72 mg/l, chloride ranged from 19 to 73 mg/l, and sulfate ranged from 14 to 225 mg/l (California Division of Water Resources, 1953, table 4). Analyses of water pumped in 1967-68 from wells owned by the city of Hollister and by the canneries showed that the concentration of chloride ranged from 82 to 112 mg/l, and the concentration of sulfate ranged from 120 to 212 mg/l; boron concentration reported only for Hollister City Well No. 5 was 0.95 mg/l. These analyses indicate that there has been little significant change in the concentration of boron, chloride, and sulfate in the water going into the waste-disposal sites since 1952.

The California Department of Water Resources (1966, p. 13) concluded that water from wells 12S/5E-28P1 and 12S/5E-33C1 was representative of the general ground-water quality in the area and was not affected by the waste discharges, but that water quality in wells 12S/5E-33D4 and 12S/5E-33H2 was affected by the waste discharges.

Most of the discharged waste, after it enters the underlying ground-water body, probably moves toward the San Juan Valley, but some possibly moves toward Wright Road (fig. 6) and into the southern end of the Gilroy-Bolsa subbasin.

SUMMARY AND CONCLUSIONS

Hollister and San Juan Valleys are within the Gilroy-Hollister ground-water basin, as defined by the California Department of Water Resources. In this report, the Hollister and San Juan Valleys were divided into three ground-water subbasins that are named the (1) Gilroy-Bolsa subbasin, (2) Hollister subbasin, and (3) San Juan subbasin. Each subbasin is further subdivided into ground-water subunits that (1) have known boundaries, (2) have hydraulic continuity throughout the subunit, (3) have reasonably uniform or predictable hydraulic properties, and (4) are separated from adjacent subunits by definite hydraulic discontinuities.

The subbasin and subunit boundaries are formed by faults, folds, or consolidated bedrock. In the valleys, the boundaries are distinguishable by water-level differences which range from about 10 feet to as much as 100 feet in adjacent subunits. These water-level differences indicate that subunit boundaries are permeability barriers that impede the movement of ground water.

The aquifers that underlie the Hollister and San Juan Valleys consist mainly of lenticular beds of clay, silt, sand, and gravel--or their consolidated equivalents--that are early Tertiary to Holocene in age. All sedimentary deposits, except the most recent, have been subjected to episodes of faulting and folding.

Water-level records obtained by Clark (1924) indicate that in August 1913 (and possibly in 1878 when pumping started) ground water in the Hollister Valley moved in a north to northwesterly direction and discharged by upward flow into swamps, streams, and flowing artesian wells in the northern part of the Gilroy-Bolsa and Hollister subbasins. During the same period, ground water in the San Juan Valley moved in a westerly direction and discharged either into the San Benito and Pajaro Rivers or from flowing artesian wells in a a small area north of San Juan Bautista.

Ground-water supplies for irrigation were first developed in the Hollister Valley in 1878. By 1968 there were approximately 700 irrigation wells in the Hollister and San Juan Valleys. More than 30,000 acres were irrigated with ground water in the Hollister and San Juan Valleys in 1968.

Pumping of ground water since 1878 has affected the occurrence and movement of ground water throughout the area. Water-table conditions still occur in deposits adjacent to the San Benito River and Tres Pinos Creek and in the valley of Pacheco Creek above the point where the creek enters the Hollister Valley. Semiconfined conditions occur in most parts of the Hollister and San Juan Valleys. The deeper deposits in both valleys contain water under confined conditions. The decline of water levels caused by pumping has locally created semiperched bodies of ground water in sands at various depths between the land surface and the main ground-water body.

Wells flow periodically during the late winter and early spring months in the Lovers Lane area north of Pacheco Creek and along the Pajaro River in the area north of the Lomerias Muertas.

Water-level records suggest that two poorly defined aquifers underlie the valleys: a semiconfined aquifer that extends to a depth of about 300 feet below land surface and a confined aquifer at depths greater than 300 feet.

The long continued pumping of ground water has caused cones of depression to be developed in the southern end of the Gilroy-Bolsa subbasin, in an area east of Cottage Corners in the Hollister subbasin, and in an area east of San Juan Bautista in the San Juan subbasin. The approximate net water-level decline since 1913 has been about 100 feet in the San Juan subbasin and more than 180 feet in the Gilroy-Bolsa and Hollister subbasins.

Water-level records from selected wells indicate that in most of the area water levels began to decline sharply after 1945. The decline is directly related to increases in pumping and is modified by recharge from available runoff and precipitation. A significant part of the total ground water pumped in most of the area is now being obtained by depleting storage.

In 1968 the direction of ground-water movement was toward the cones of depression caused by pumping in each subbasin. The depth to water beneath the San Benito River, Tres Pinos Creek, and Pacheco Creek was such that water in these streams could percolate as recharge to the ground-water body throughout most of the year. Ground-water recharge from Tres Pinos Creek and from the San Benito River upstream from Nash Road moves towards the Hollister subbasin. Ground-water recharge from Pacheco Creek moves into the northern part of the Hollister subbasin and thence southward toward the cone of depression east of Cottage Corners. Little, if any, water percolated from Tres Pinos Creek reaches the San Juan Valley. Ground-water recharge along the San Benito River between Nash Road and State Highway 156 bridge moves toward the southern end of the Gilroy-Bolsa subbasin. Ground-water recharge from the San Benito River between State Highway 156 bridge and the entrance to San Juan Valley moves toward San Juan Valley. It was estimated that a flow of more than 20 cubic feet per second must be maintained at the San Benito River near Hollister gaging station in sec. 24, T. 13 S., R. 5 E. before San Juan Valley will benefit from water percolating downward from the river.

Ground-water recharge in the Gilroy-Bolsa subbasin is chiefly by subsurface flow from Santa Clara County north and northwest of the Pajaro River. Information obtained during this study suggests that artificial recharge by water-spreading ponds or similar facilities could be carried out in an area north of Wright Road in the Gilroy-Bolsa subbasin. However, test holes should be drilled and infiltration tests should be made to determine the suitability of the area as an artificial-recharge site.

The chemical quality of ground water pumped from wells in the Hollister and San Juan Valleys has widely dissimilar character and depends upon one or more of the following factors: (1) total depth; (2) screened or perforated intervals in well casings; (3) rate and duration of pumping before sample collection; (4) location of the well; (5) water-bearing unit or units yielding water to the well; (6) proximity to faults; (7) quality of water that recharges the water-bearing units tapped by the well; and (8) length of the shutdown period that immediately preceded the period of pumping during which the sample was collected.

A significant constituent that determines the suitability of ground water for irrigation is boron. A comparison of maps of concentration patterns compiled from water-quality data collected by Eaton (1941) and during this study indicated that little significant change in the boron, sulfate, or chloride content has occurred between the time of Eaton's study (1941) and 1968.

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