Ground-Water Appraisal of Santa Ynez River Basin Santa Barbara County California, 1945-52

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1467

Prepared in cooperation with the U. S. Bureau of Reclamation and the Santa Barbara County Water Agency

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By H. D. WILSON, Jr.

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GROUND-WATER APPRAISAL OF THE SANTA YNEZ RIVER BASIN, SANTA BARBARA COUNTY, CALIFORNIA, 1945–52

By H. D. Wilson, Jr.

ABSTRACT

Investigations of the ground-water resources of the Santa Ynez River basin prior to 1945 revealed that water levels had fluctuated only a little. Estimates of perennial yield therefore were based on the assumption that the base rate of ground-water inflow apparently was at least equal to withdrawals. Commencing in 1945, however, ground-water levels throughout the valley began to decline in response to increasing rates of withdrawal and extended drought, providing an excellent opportunity to check changes in ground-water storage in relation to withdrawals and replenishment.

Reappraisal of the ground-water resources of the Santa Ynez basin for the drought years 1945–51 shows that, for a period in which replenishment from rainfall and seepage loss was far below normal, storage changes were inconsistent with withdrawals. Additional replenishment, besides that estimated by previous investigators, was made possible through a lowering of the water table and the consequent steepening of gradients out of older deposits adjacent to the basin.

Accurate estimates of perennial yield must await the collection of additional basic data because little is known regarding the rechargeable storage capacity and permeability of all the deposits, the rate of replenishment of the older deposits, amount of return irrigation water, and deep penetration of rain. However, most of the elements of recharge, discharge, and storage change were estimated for the 7-year period 1945–52, and for the Lompoc subarea these data were extrapolated to estimate the order of magnitude of the quantity of water that could be pumped perennially.

PURPOSE AND SCOPE OF THE REPORT

This report is the third in a series of interpretive reports on the ground-water investigations of the Santa Ynez River basin by the U. S. Geological Survey, in cooperation with Santa Barbara County. The first investigation, begun in January 1941, included as its main objectives the estimation of the ground-water yield of the basin, the possible effects of regulating and diverting streamflow on the basin and an evaluation of the possibility of salt-water contamination of the ground-water body. These objectives were accomplished and reported on, insofar as available data would permit, in a comprehensive report by Upson and Thomasson (1951). Similar reports covering the Cuyama Valley, the Santa Maria Valley area, and the south-coast basins also have been released. Additional information concerning stream runoff is contained in a report by Troxell (1952).

Coincident with the investigational work of the Geological Survey, the Board of Supervisors, Santa Barbara County, authorized a contract with the Bureau of Reclamation to prepare a comprehensive water-resources plan that would utilize and develop all the available waters of the county. In 1944 this investigation resulted in the recommendation of the Santa Ynez-south-coast water plan as the first step toward full development of the county's water resources. The plan included a 210,000-acre-foot reservoir that would impound flood waters of the Santa Ynez River and a transmountain tunnel to deliver the water to the south-coast communities of Santa Barbara, Goleta, Montecito, Summerland, and Carpinteria. The dam, known as Cachuma Dam, was completed, January 7, 1953; completion of the tunnel, called Tecolote Tunnel, was delayed by high-pressure water and excessive temperatures. It was completed in March 1956.

Residents of the Santa Ynez River basin downstream from the dam expressed some concern regarding their rights to the waters of the river, and through their organization, the Santa Ynez River Valley Water Conservation District, they have entered into a 10-year interim contract with the Bureau of Reclamation to protect these rights. The 10-year contract would allow sufficient time subsequent to the completion of the dam to collect the data required for the preparation of a fair and equitable long-term operating agreement. During the tenure of the interim contract, the operators of the dam are specifically obligated not to store or divert any part of the flow entering the reservoir whenever it is deemed that a live stream does not exist. A live stream exists, as defined by the contract, whenever there is a visible stream of water flowing in the river channel at San Lucas Bridge, Mission Bridge, Buellton Bridge, Santa Rosa dam site, and Robinson Bridge, and there is a surface flow in the river of not less than 1 second-foot at the H Street Bridge north of Lompoc.

As the result of a series of conferences, which began in January 1949, the Geological Survey and the Bureau of Reclamation delineated the type of data that would be essential to the preparation of the long-term operating agreement and explored the areas of deficient information. Specific information was needed on the storage capacity of the valley fill downstream from Cachuma Dam; on the amount and distribution of runoff below the dam site; and on the amount, distribution, and rate of replenishment to ground water in the alluvial deposits from sources downstream from the dam site. The distribution of runoff below the dam has been presented by Troxell (1952). The rate of infiltration from the streams to the river-channel deposits can be studied best by the release of controlled flows from the dam down a dry channel, and some information regarding this phase of the study has been collected since the completion of the comprehensive report by Upson and Thomasson (1951).

The purpose of this report is to refine the estimates given in Water-Supply Paper 1107 by the analysis of geologic and hydrologic data collected during the drought period 1945–52. The study of the effects of the drought will be shown that ground-water storage in the reach of the river from San Lucas Bridge to Robinson Bridge was not depleted seriously, because full recovery was observed as a result of the above-normal precipitation and recharge that occurred in the winter of 1951–52 and that ground-water withdrawals on the Lompoc plain were sustained by sources other than the river, because ground-water withdrawals produced little change in storage beneath the plain during a period in which precipitation and streamflow were negligible. The report also contains a discussion of a test-well drilling program northeast of the Lompoc plain, the underflow of the Santa Ynez River in the vicinity of Cachuma Dam, the chemical quality of the ground waters of the Lompoc plain, and estimates of storage capacity for the Lompoc plain for the alluvial deposits of the Santa Ynez River between Cachuma Dam and Robinson Bridge.

This report was prepared by the Geological Survey, in cooperation with the Santa Barbara County Water Agency and the Bureau of Reclamation, under the supervision of J. F. Poland, district geologist for California.

David H. Wozab prepared original drafts for the sections on geology and geographic and hydrologic features, and most of the ground-water contour maps.

LOCATION OF THE AREA

The valley of the Santa Ynez River is in the southern part of Santa Barbara County, Calif., just north of the Santa Ynez Mountains which separate the valley from the county's southern coast line (fig. 1). The river originates in Juncal Canyon just inside Ventura County and follows the westward trend of the Santa Ynez Mountains for about 70 miles before emptying into the ocean at Surf.

The area studied in this report includes all the drainage area of the Santa Ynez River that lies downstream from Cachuma Dam, with particular emphasis on the Lompoc plain and the area between Cachuma Dam and Robinson Bridge (pl. 1), which are underlain by alluvial deposits.

ACKNOWLEDGMENTS

Thanks and appreciation are expressed to the many residents of the Santa Ynez River basin who permitted access to their lands to members of the Geological Survey and Bureau of Reclamation for

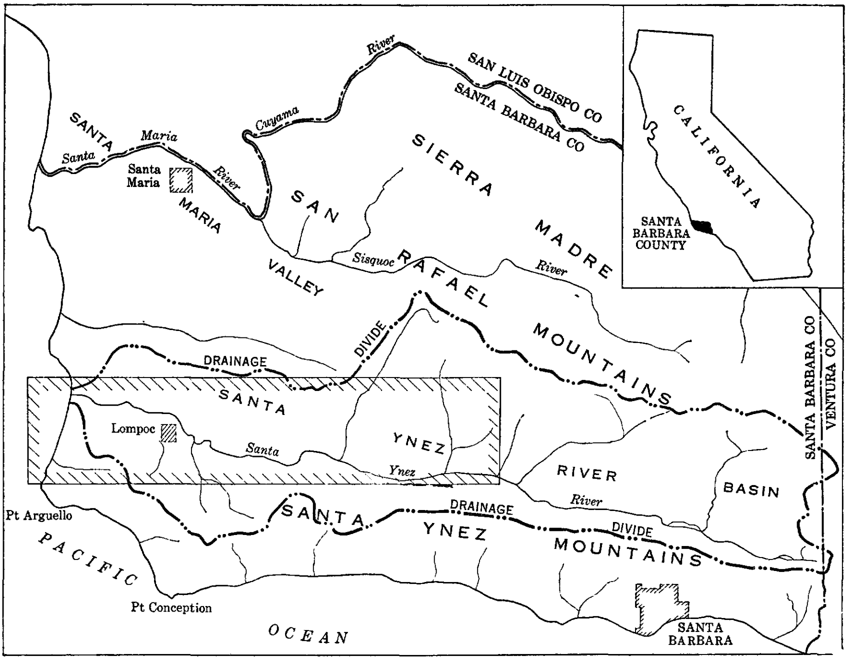

FIGURE 1.—Index map of Santa Barbara County, Calif.

the purpose of making measurements in wells, running pumping tests, and placing supplemental small-diameter wells on the profile lines.

Thanks are extended also to the Pacific Gas and Electric Co., which generously supplied data on pump-efficiency tests and power consumption that were extremely useful in estimating ground-water withdrawals for irrigation.

Chemical analyses, in addition to those made by the Geological Survey, were supplied by the University of California, College of Agriculture and by the U. S. Department of the Army, Camp Cooke Military Reservation.

GEOLOGY IN RELATION TO GROUND WATER

Two principal sedimentary units were recognized in the Santa Ynez River valley: The consolidated essentially non-water-bearing rocks and the unconsolidated water-bearing deposits. More information about the deposits is given in a comprehensive report by Upson and Thomasson (1951).

CONSOLIDATED ROCKS

Consolidated rocks underlie the unconsolidated deposits along the entire length of the river basin and crop out in the foothill areas. The rocks, largely of marine origin, consist of undifferentiated siliceous and diatomaceous shale, siltstone, and mudstone of Tertiary age. As the material is fine grained and compacted, it is essentially not water bearing, except for water in local fractures.

UNCONSOLIDATED DEPOSITS

The unconsolidated deposits include the Careaga sand of Pliocene age and the Paso Robles formation of Pliocene and Pleistocene (?) age, the Orcutt sand and terrace deposits of Pleistocene age, and the younger alluvium and river-channel deposits of Recent age. As stated by Upson (Upson and Thomasson, pls. 2 and 3), all are water bearing; however, only the terrace deposits and younger alluvium are tapped extensively by wells.

CAREAGA SAND AND PASO ROBLES FORMATION

The Careaga sand and the Paso Robles formation are exposed principally along the north side of the Santa Ynez River basin, although, in the Lompoc subarea, these deposits also underlie the younger alluvium of the Lompoc plain and crop out in small exposures on the south side.

The Careaga sand is of marine origin and consists of fine- to medium-grained massive sand, locally containing lenses of pebbles and fossil shells. The sand is of low permeability and usually is not tapped by wells. Nevertheless, this sand has a large storage capacity and is capable of transmitting water to the overlying formations.

The Paso Robles formation is of continental origin and consists of coalescing alluvial fans of lenticular beds of clay, sand, and gravel; generally it is of relatively low permeability. This formation, however, like the Careaga sand, is capable of storing large volumes of water and of transmitting it to the overlying formations.

ORCUTT SAND

The Orcutt sand is primarily north and southwest of the Lompoc plain. The sand is mainly of continental origin, the upper portion of eolian and beach sand. The formation consists of loosely consolidated lenticular zones of clay, sand, and gravel, and generally is of low permeability. Little runoff occurs from the areas underlain by the formation, and all the rainfall, apparently, is absorbed and evaporated or transpired. Although few wells tap this formation, perched water may be present locally, and a few springs flowing from it supply water for domestic use.

TERRACE DEPOSITS

Terrace deposits occur principally on the Santa Ynez upland area, as remnants along the Santa Ynez River basin, and on the foothills southeast of the Lompoc plain. The deposits consist of river-laid clay, sand, and gravel, and locally may be of moderate permeability.

Because these deposits are largely above the zone of saturation, they generally do not supply water to wells, except in the southern portion of the Lompoc plain where a segment of these deposits lies below the water table, and in the Santa Ynez upland where they supply water to irrigation, domestic, and stock wells.

YOUNGER ALLUVIUM AND RIVER-CHANNEL DEPOSITS

The younger alluvium and river-channel deposits underlie the flood plain and active channel of the Santa Ynez River and are of Recent age. The younger alluvium occurs principally as a thick deposit beneath the Lompoc plain, and thins upstream beneath the Santa Ynez River and its tributaries. At the coast it has a maximum known thickness of about 200 feet, but at Cachuma Dam it is only 60 feet thick.

The younger alluvium generally consists of interconnecting lenticular beds of clay, sand, and gravel and has been subdivided into two members—a lower member of cobbles, gravel, and sand, and an upper member extensively composed of clay and silt with some strata of sand. The coarse-grained lower member underlies nearly all of the Lompoc plain and has been identified in well logs upstream for several miles. It is tapped by many wells and constitutes the main water-bearing zone beneath the Lompoc plain. The upper fine-grained member of the younger alluvium overlies the lower member nearly everywhere, but it is thickest and most extensive in the Lompoc subarea. At the easternmost part of the plain the materials that form the upper member are slightly to moderately permeable, and, accordingly, there is interchange of water between the river and the main water-bearing zone. Beneath the central and western parts of the Lompoc plain, however, the upper member of the younger alluvium contains beds of clay, 10 to 60 feet thick (Upson and Thomasson, 1951, p. 47), which substantially retard the downward movement of water from the land surface.

The river-channel deposits east of the Lompoc plain are indistinguishable from the upper member of the younger alluvium and may be considered as part of it. The deposits are tapped by few wells and little information concerning them is available.

GEOGRAPHIC AND HYDROLOGIC FEATURES

The topographic and hydrologic details of the Santa Ynez River basin have been discussed in detail by Upson and Thomasson (1951). Briefly, the basin is a structural depression, phyiographically altered by erosion and deposition, into which the Santa Ynez River has incised itself along the south border close to the north flank of the Santa Ynez Mountains. For convenience of study, the basin has been separated into five subareas (fig. 2) based on hydrologic and topo-

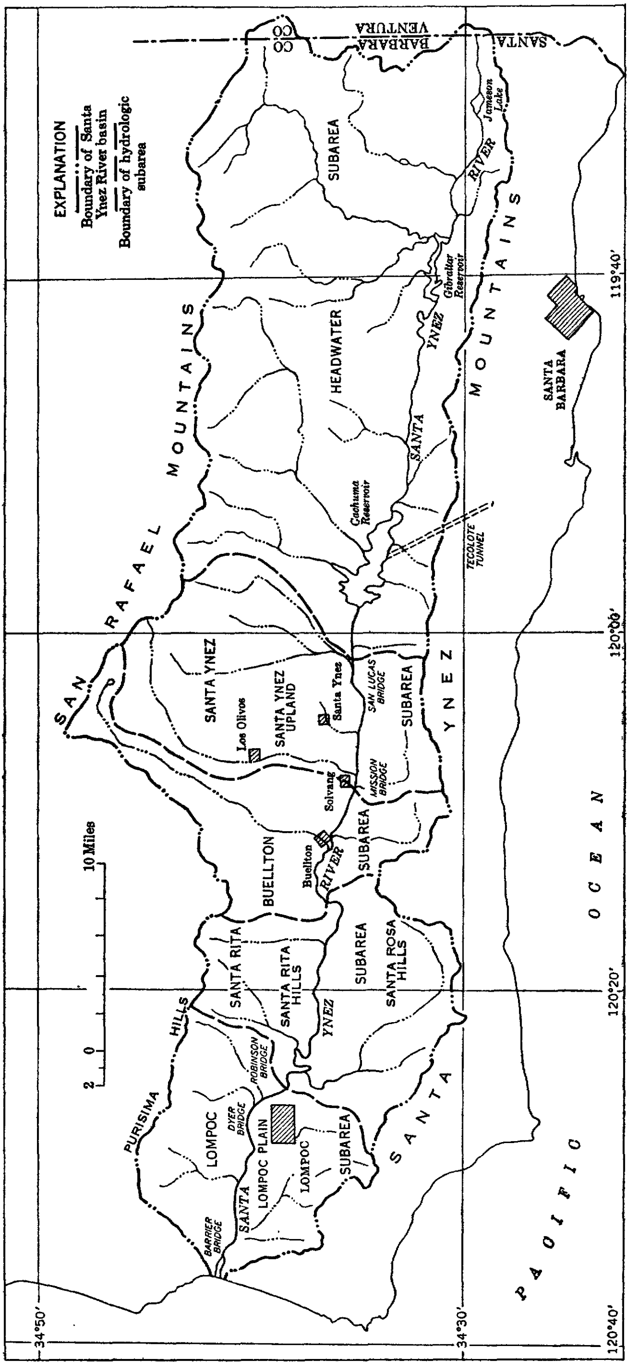

Figure 2.—Sketch map of the Santa Ynez River basin showing the hydrologic subareas.

graphic differences. The important features of these subareas are discussed in the following paragraph.

HEADWATER SUBAREA

The "Headwater subarea" (Upson and Thomasson, 1951, p. 24) extends from the source of the Santa Ynez River for some 34 miles to San Lucas Bridge. In this reach of the valley the river-channel deposits and younger alluvium are relatively thin, together averaging about 40 feet in thickness. Consolidated Tertiary rocks, which are essentially not water bearing, underlie the alluvial deposits and form the bottom and flanks of this portion of the ground-water basin. However, to the north the Careaga sand and Paso Robles formation are exposed and serve to catch rainfall and to contribute it as low-flow discharge to the tributary valleys of the Santa Ynez River. These tributaries includes Mono, Santa Cruz, and Cachuma Creeks.

Three surface reservoirs in this area—Jameson Lake, Gibraltar Reservoir, and the recently completed Cachuma reservoir—supply or will supply water to the coastal cities.

SANTA YNEZ SUBAREA

The Santa Ynez subarea extends from San Lucas Bridge some 6.5 miles downstream to about Mission Bridge near Solvang. The alluvium in this subarea, as in the Headwater subarea, is relatively thin, averages approximately 62 feet in thickness, and rests on and is bounded along the flanks by consolidated Tertiary rock. Tributaries to the Santa Ynez River in this subarea from the north are Alamo Pintado, Santa Agueda, and Zanja Cota Creeks, and from the south are San Lucas, Quiota, and Alisal Creeks.

BUELLTON SUBAREA

The Buellton subarea extends from about the Mission Bridge downstream to a point about 5 miles west of Buellton where the river takes a broad turn to the south. The alluvium in this subarea has a maximum thickness of about 92 feet and is bounded on the south by consolidated Tertiary rock and on the north by the water-bearing deposits of the Paso Robles formation and Careaga sand. Local sources of recharge to this subarea are the discharges from La Zaca Creek on the north and Nojoqui Creek on the south, underflow from the underlying Paso Robles formation and Careaga sand on the north, and direct penetration of rainfall.

SANTA RITA SUBAREA

The Santa Rita subarea extends downstream from the river bend 5 miles west of Buellton to The Narrows. The alluvium in the reach between San Lucas Bridge and The Narrows has a maximum thickness of 185 feet and is underlain by consolidated Tertiary rocks. Sources of inflow to this subarea, in addition to direct penetration of precipitation, are the discharges from Santa Rita and Santa Rosa Creeks on the north (however, they contribute very little) and Salsipuedes Creek on the south. Salsipuedes Creek has a perennial low flow and, during storms and wet periods, contributes a relatively large quantity of water to the downstream end of the subarea.

LOMPOC SUBAREA

The Lompoc subarea is a structural basin that forms the western and lower end of the Santa Ynez River basin. It is approximately 12 miles long, extending from the coast to the Santa Rita Hills, and averages about 10 miles wide.

In the Lompoc subarea is the Lompoc plain, which is bordered on the north by the Burton Mesa, on the northeast by the Purisima Hills, on the east by the Santa Rita Hills, and on the south by the steep foothills of the Santa Ynez Mountains which, to the west, give way to the broad Lompoc terrace. The plain is about 12 miles long and nearly 3 miles in maximum width. It is an alluvial plain underlain by the younger alluvium of Recent age, which ranges in maximum thickness from about 185 feet at The Narrows to 200 feet at the coast. Underlying the younger alluvium are the terrace deposits, Orcutt sand, Paso Robles formation, and Careaga sand, which are water-bearing formations and which, together with the lower member of the younger alluvium, contain the deep water body (Upson, 1943, written communication; Upson and Thomasson, 1951, p. 147). Bedrock in the area consists of consolidated undifferentiated Tertiary rocks (non-water-bearing) that underlie the unconsolidated deposits.

The Santa Ynez River enters the subarea at The Narrows in the southeast corner, crosses the plain to the north side, and flows west along the north side of the plain to the ocean. Chief tributaries to the Santa Ynez River that drain the south flank of the Purisima Hills are the intermittent streams located in Cebada, Purisima, and Santa Lucia Canyons. To the south of the basin the chief tributaries occur in San Miguelito, San Pascual, Rodeo, and Lompoc Canyons. The streams in these canyons, except for those in Lompoc Canyon, flow perennially to or nearly to the south edge of the Lompoc plain.

PRECIPITATION

The Santa Ynez River basin is bounded by a system of mountains that tend to complicate the distribution of precipitation. Generally, the mean annual precipitation ranges from 14 inches near the coast to about 40 inches along the eastern divide. Upson and Thomasson (1951, p. 9) suggest that about two-thirds of the precipitation in the valley as a whole occurs in the headwater subarea.

Because the water supply of the valley is largely dependent on precipitation, the magnitude and time distribution of the precipitation are important to the water user. Figure 3 shows the precipitation record for Santa Barbara for the period 1868–1952. Although

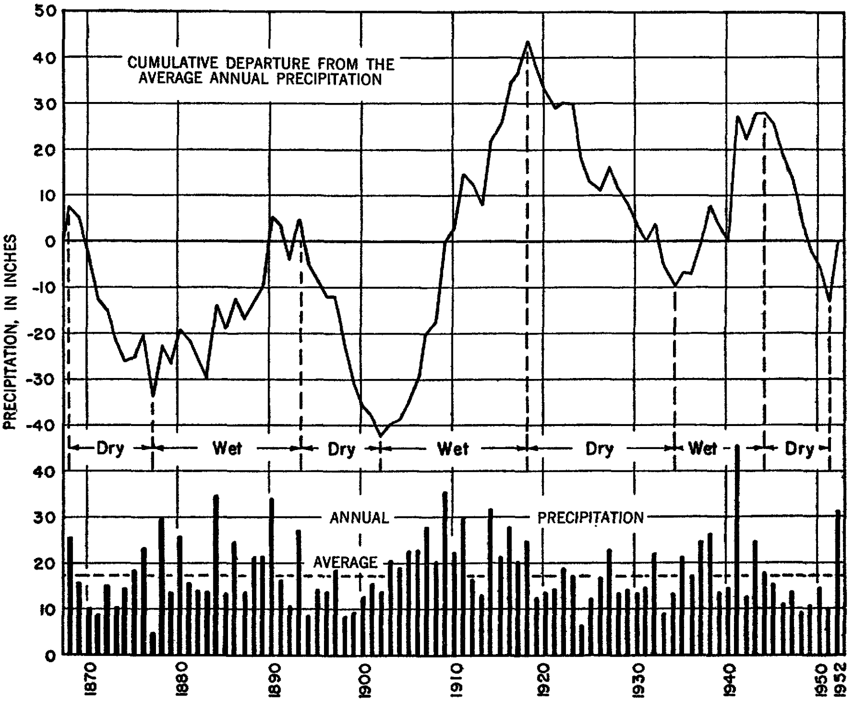

FIGURE 3.—Precipitation at Santa Barbara, showing cumulative departure from the average, 1868–1952.

precipitation recorded at Santa Barbara has no quantative relation to precipitation in the Santa Ynez River basin, it does serve to illustrate the variability of precipitation. At this station, for instance, the 85-year average precipitation is 18.03 inches. If this amount of rainfall occurred each year, a dependable water supply would be little or no problem. Unfortunately, precipitation (fig. 3) has tended toward a grouping of wet years followed by dry years. Precipitation has ranged from a low of 4.49 inches in the season ending September 1877 to a high of 45.25 inches in the season ending September 1941.

Data recorded at various rainfall stations within the drainage area of the Santa Ynez River show the same variable character of precipitation as the Santa Barbara record (Upson and Thomasson, 1951, p. 10–23). The following table lists precipitation for the season ending September 30 at Santa Barbara, Lompoc, Buellton, Solvang, and Gibraltar Dam.

Precipitation, in inches, 1945–52 at stations in and adjacent to the Santa Ynez River valley

Season ending Sept. 30	Santa Barbara	Lompoc	Buellton	Solvang	Gibraltar Dam
1944–45	15.29	11.40	13.99	18.40	21.01
1945–46	11.33	12.40	13.34	12.58	24.68
1946–47	13.41	7.93	10.47	11.40	17.25
1947–48	9.20	7.82	7.34	6.96	12.39
1948–49	10.95	13.54	12.40	12.59	15.29
1949–50	14.40	10.22	12.41	12.56	16.84
1950–51	10.06	7.92	10.66	9.75	11.07
1951–52	31.25	21.07	24.94	19.12	50.17
Average for dry period 1945–51	12.09	10.18	11.52	12.03	16.93
Long-term average, period of record	18.03	14.58	16.08	15.81	24.91
Years of record	85	42	15	25	33

The table shows that between 1945 and 1951 precipitation throughout Santa Barbara County was consistently below normal but that in 1952 precipitation was considerably above normal. Because the report by Upson and Thomasson (1951) was based primarily on data collected during the wet period 1935–44, an evaluation of the hydrologic data for the dry period 1945–51 shows a significant change in the hydrologic regimen of the basin. The effects on ground-water levels of this prolonged drought and its sudden interruption in the wet year 1951–52 are the main subject of this report.

SURFACE-WATER FEATURES

RUNOFF

Precipitation falling on the earth's surface is absorbed by the earth (infiltration), remains on the earth's surface and runs off overland (direct runoff), is evaporated from vegetation (transpiration), or is evaporated directly. Quantitatively the precipitation increment apportioned to these items varies with many factors, such as temperature, intensity of rainfall, time distribution, moisture content of the soil, slope, type of soil, and type of vegetative cover. In the Santa Ynez River basin storms are few, and, at times, the intensity of rainfall is so great that large quantities of surface runoff occur, varying greatly from subarea to subarea, in accordance with these factors.

Measurements of runoff are made at several gaging stations along the Santa Ynez River, enumerated and described in the progress report by Troxell in 1952 in the files of the U. S. Geological Survey's Ground Water Office at Santa Barbara, Calif. They provide information on the average annual quantities of surface water available for use, and are useful in determining the gain and loss to the groundwater reservoir by effluent or influent seepage.

The major runoff from the subareas occurs during periods of excessive precipitation, about 50 percent of the runoff originating in

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about 1 to 4 percent of the time (Troxell, 1952, p. 8). Because inflow of river water to the ground-water reservoirs is controlled by the permeability and the cross-sectional area of the deposits and by the hydraulic gradient, this extreme concentration of the runoff exceeds the absorptive capacity of the deposits and results in enormous waste, as is evidenced by the large quantities of river flow known to pass the gaging station at Surf. Maximum utilization of the available supply requires surface reservoirs large enough in capacity to detain sizable flood flows for slow release to recharge the downstream ground-water basins.

The progress report by Troxell in 1952 describes the magnitude and distribution of the surface-water outflow from the four subareas of the Santa Ynez River basin above Robinson Bridge for the period 1928–49. Table 1 shows the magnitude of the below-normal runoff during the dry period 1945–51.

TABLE 1.—*Annual runoff, in acre-feet, for Santa Ynez River at selected measuring sites, 1945–52*

[Data from Surface Water Branch, U. S. Geological Survey]

Water year ending Sept. 30	San Lucas Bridge, Santa Ynez River near Santa Ynez	Mission Bridge, Santa Ynez River at Solvang	Santa Ynez River near Buellton (estimated)	Robinson Bridge, Santa Ynez River near Lompoc	H Street Bridge, Santa Ynez River at H Street	Santa Ynez River, Barrier near Surf
1945	39,450	44,000	43,000	50,700	(1)	(1)
1946	34,120	38,000	36,000	38,970	(1)	(1)
1947	10,670	14,920	12,000	13,940	[2] 1.6	[3] 19
1948	0	2,400	500	50	0	175
1949	420	2,900	1,800	2,040	1,490	1,720
1950	1,550	3,220	1,900	1,460	643	500
1951	0	1,490	400	0	0	190
1952	199,300	239,100	245,000	261,900	256,700	295,200
Long-term average	73,900	37,500	43,000	96,400	51,700	59,500
Years of record	22	14	8	27	5	5

[1] No record.
[2] April through September only.
[3] May through September only.

MEASUREMENTS OF RUNOFF

SAN LUCAS BRIDGE

At San Lucas Bridge, at the lower end of the headwater subarea, the measured runoff has varied widely. In the dry period 1945–51 the magnitude of runoff ranged from zero in 1948 and 1951 to 39,450 acre-feet in 1945. The average annual runoff for the period 1945–51 was 1,235 acre-feet. Runoff for the wet year 1952 was 199,300 acre-feet, and the average annual runoff for the period of record 1928–52 was 73,900 acre-feet.

MISSION BRIDGE

At Mission Bridge, lower boundary of the Santa Ynez subarea, measurement of runoff for the dry period 1947–51 shows a range from 1,490 acre-feet in 1951 to 14,920 acre-feet in 1947. Average annual runoff for the periods 1928–36 and 1946–52 was 37,500 acre-feet. These figures include the combined runoff for the Headwater and Santa Ynez subareas.

NEAR BUELLTON

The gaging station near Buellton, at the lower boundary of the Buellton subarea, measures the outflow from the subarea in the low-flow period. The station was established in June 1948 by the Geological Survey in cooperation with the Bureau of Reclamation and has been in continuous operation since that date. Prior to June 1948 a few miscellaneous measurements were made commencing in 1946.

Because this station has been in operation only a short time, and mostly during periods of low flow, discharges prior to 1946 and for times other than low flow were estimated. Discharge estimates, made by Harold C. Troxell of the Geological Survey, were based on an attempt at balancing the surface inflow and outflow of the Buellton subarea. As pointed out by Troxell in 1952 (also written communication, Feb. 14, 1955), the primary weakness in this method is the lack of consideration for subsurface inflow and changes in groundwater storage.

Outflow from the Buellton subarea (observed discharge "near Buellton") is plotted versus computed inflow to the subarea (observed flow "at Solvang" plus estimated runoff from tributary streams). From this graph (fig. 4) any computed inflow to the Buellton subarea will yield an estimate for outflow or discharge past the "near Buellton" station. Estimates of the discharge "at Solvang" were made wherever data on flow were lacking. To obtain the 1944–45 and 1945–46 outflow from the Buellton subarea, for example, it was necessary first to compute the primary surface inflow "at Solvang" by a comparison of duration curves of daily discharge for the stations "near Santa Ynez" and "near Lompoc" (fig. 5). In this procedure the percentage of time of the monthly discharge at these two stations is assumed to be identical with that "at Solvang." In October of the 1944–45 water year the average flow "near Santa Ynez" was 1.01 cfs and at the station "near Lompoc" it was 1.78 cfs. From figure 5 the percent of time that the flow is equal to or greater than these flows is 51.5 percent and 55.5 percent respectively or an average of 53.5 percent. The flow past the station "at Solvang," therefore, is 6.8 cfs which flow is equalled or exceeded 53.5 percent of the time.

In order to obtain total inflow to the Buellton subarea, values of primary surface inflow (discharge "at Solvang") obtained from figure 5 are added to the estimated inflow from tributary streams. For the purpose of estimating tributary inflow the observed runoff from La Zaca Creek has been assumed to be an index of the inflow from the north side, whereas Nojoqui Creek has been assumed to be representative of runoff from the south side.

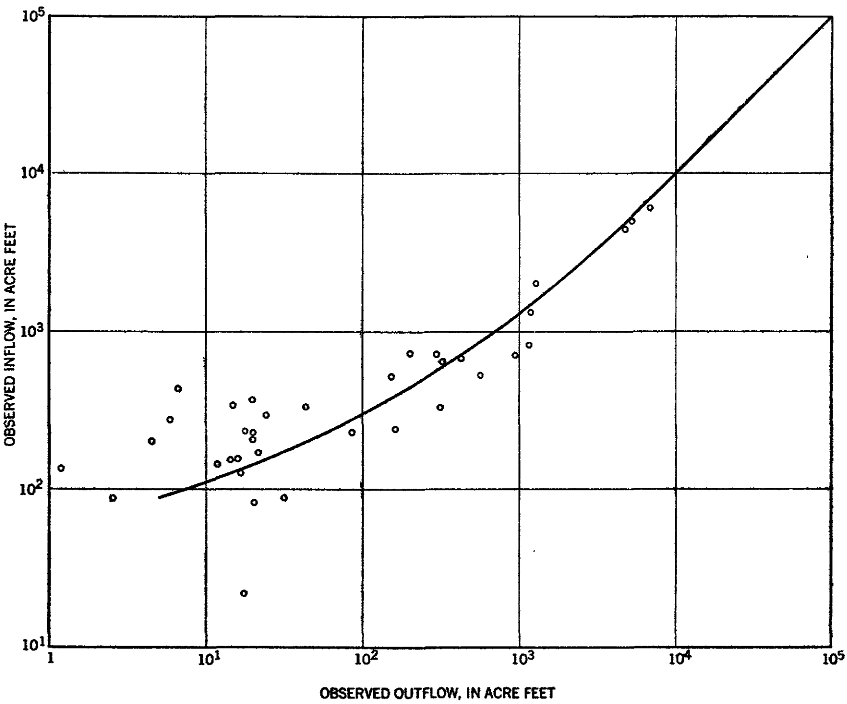

FIGURE 4.—Observed outflow from Buellton subarea, in acre-feet.

The range in estimated runoff at the station "near Buellton" for the period 1945–51 was from about 400 acre-feet in 1951 to about 43,000 acre-feet in 1945. Average annual runoff for the same period was about 14,000 acre-feet.

ROBINSON BRIDGE

At Robinson Bridge, just below the lower boundary of the Santa Rita subarea, the runoff for the period 1945–51 ranged from zero in 1951 to 50,700 acre-feet in 1945. The average annual runoff for the period 1945–51 was 15,300 acre-feet; but for the most critical period, 1947–51, it was only 3,500 acre-feet. Average annual runoff for the period 1925–52 was 96,400 acre-feet. The Robinson Bridge station measures the combined outflow of all the subareas above the bridge—a drainage area of 790 square miles.

In the Lompoc subarea runoff results from precipitation and from effluent seepage from the Santa Ynez River. In the river reach be-

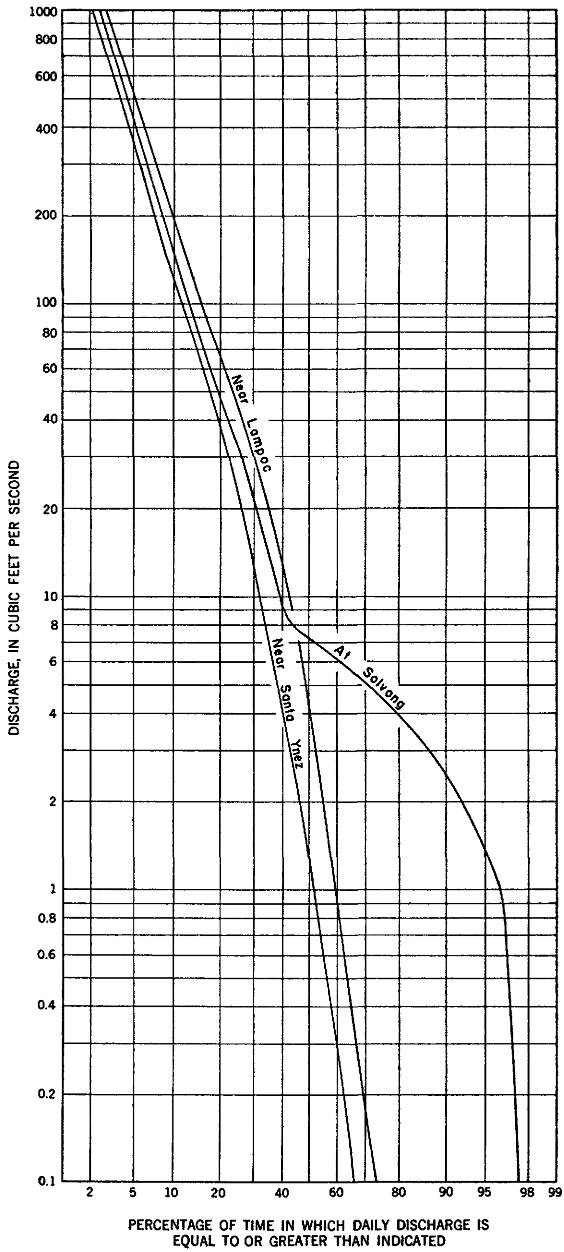

FIGURE 5.—Duration curves of daily discharge for the Santa Ynez River.

tween Robinson and H Street Bridges the river contributes to ground-water storage, thus decreasing runoff; however, downstream from H Street Bridge the water table at times is higher than the river channel. Thus, the river receives water from storage and an increase in runoff results.

SURF

The gaging station at The Barrier at Surf measures the combined runoff of the Lompoc, Santa Rita, Buellton, Santa Ynez, and Headwater subareas—a drainage area of 900 square miles. The magnitude of the runoff at Surf for the period 1947–51 varied from 19 acre-feet in 1947 to 1,720 acre-feet in 1949. Mean annual runoff was 520 acre-feet for the period 1947–51. Average annual runoff for the period 1947–52 is 59,500 acre-feet.

Between H Street Bridge and The Barrier bridge at Surf sewage effluent from the city of Lompoc and Camp Cooke Military Reservation is discharged to the Santa Ynez River. In the period 1945–51 the combined total effluent from these two sources averaged about 1,000 acre-feet annually, much of which was lost by evaporation from the stream course, and some of which percolated to ground water.

GROUND-WATER APPRAISAL

CACHUMA DAM TO ROBINSON BRIDGE

GENERAL HYDROLOGY

The Santa Ynez River in the reach between Cachuma Dam and Robinson Bridge flows on a body of alluvial deposits that ranges in width from a few hundred feet to more than a mile and in maximum thickness from about 40 to about 185 feet. These deposits, which are in hydraulic contact with the river, form a ground-water storage reservoir from which water can be pumped to irrigate the agricultural lands adjacent to the river. Because the deposits are not extensive, pumping during the growing season generally lowers the water table throughout the valley, but a winter season of average precipitation and streamflow usually replenishes the reservoir to or nearly to capacity.

Figures 6 and 7 show water-level fluctuations observed in representative wells in the river reach between San Lucas Bridge and Robinson Bridge for the record commencing about 1931. They show also the discharge of the Santa Ynez River at San Lucas Bridge and Mission Bridge. In general, the hydrographs show the seasonal variation in water levels due to withdrawals for irrigation during the summer and fall and subsequent winter recoveries. For the period 1935–41, a wet period (fig. 3), water levels rose, reaching the highest level on record in 1941 as a result of record-high precipitation and streamflow. Between 1941 and 1945 water levels declined slightly or remained nearly the same; but, commencing about 1945, water levels declined considerably through the dry years 1945–51. However, the ground water in storage in 1945 was sufficient to supply the demand through these dry years. The above-average precipitation and runoff in 1952 was sufficient to recharge the ground-water reservoir fully.

In addition to seepage loss from streamflow and underflow through the alluvium, other sources of recharge are direct penetration of pre-

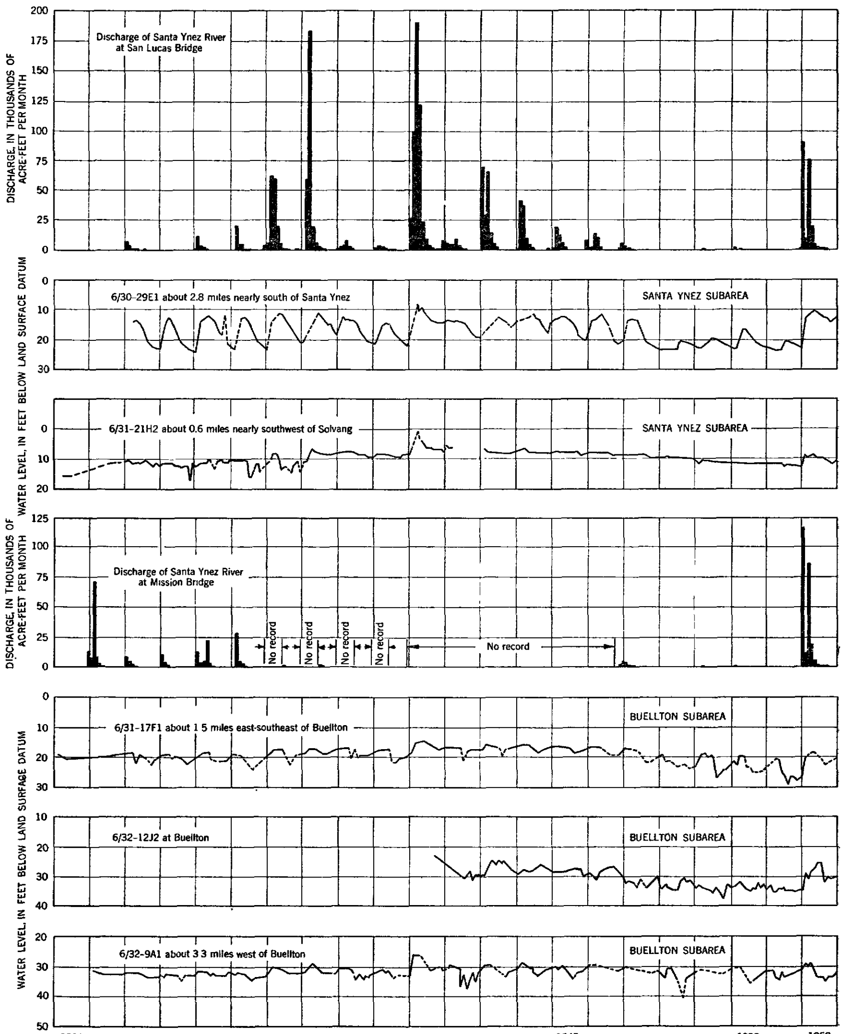

Figure 6.—Fluctuations of water levels in selected wells in the Santa Ynez and Buellton subareas, and discharge of Santa Ynez River at San Lucas and Mission Bridges, 1931–52.

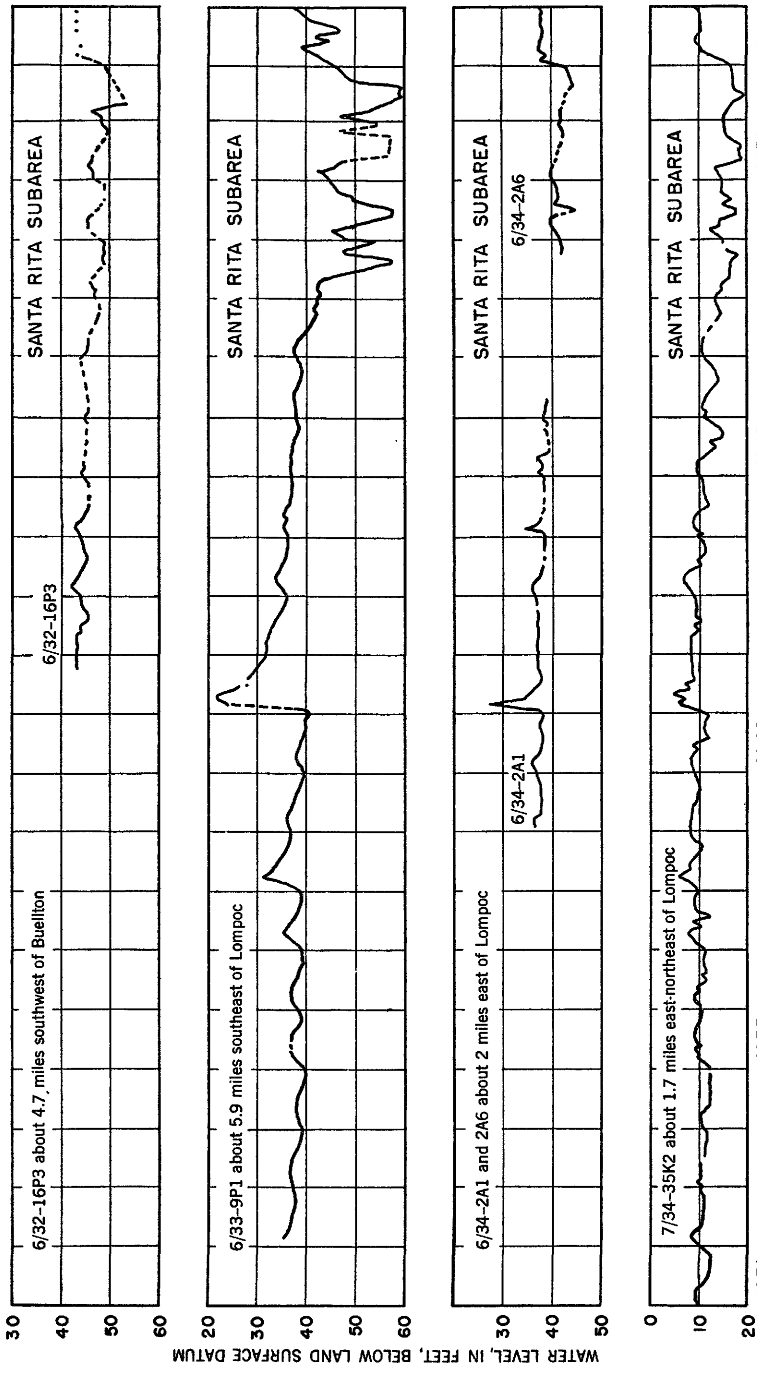

FIGURE 7.—Fluctuations of water levels in four wells in the Santa Rita subarea, 1931–52.

cipitation on the valley floor and underground transfer of water to the alluvium, principally from the Paso Robles formation and Careaga sand, which underlie an extensive area north of the river in the vicinity of Buellton.

The quantity of recharge to the ground-water reservoir of the Santa Ynez River basin is dependent on three factors: the permeability of the deposits which governs the infiltration rate; the availability of a supply, as it has been under natural conditions, and as it will be with Cachuma Dam in operation; the availability of ground-water reservoir space.

The permeability of the deposits remains essentially constant from year to year, except for the decrease in percolation rates that results from the deposition of silt in the stream channel. Flood flows or scarifying the channel would restore the bed about to its maximum infiltration rate. The other factors will change in response to climatic and human influences. At the end of 1940, for example, the ground-water reservoir for all practical purposes was full and most of the runoff in 1941 consequently passed over the reservoir and wasted to the ocean. Some of the water that entered the ground-water reservoir did so in the form of temporary bank storage at an elevation higher than that of the river bed. As the flood stage receded, this water drained back to the stream and sustained its low flow.

Because the operation of Cachuma Dam will alter the natural stream regimen of the Santa Ynez River, the determination of a fair and equitable long-term operating agreement for the dam is necessary. There are four principal considerations as follows:

The extent to which downstream tributaries can recharge the ground-water basins to supply pumpage and natural discharge.

The usable ground-water storage capacity of the alluvial deposits from San Lucas Bridge to Robinson Bridge, which is the principal area of withdrawals dependent on river recharge upstream from the Lompoc plain.

The extent to which the deposits should be dewatered before any release of water from the reservoir.

The magnitude and duration of the release from the reservoir required to replenish fully or to sustain the levels in the ground-water basins at practical operating levels.

During years of above-average precipitation and, hence, recharge, the principal tributaries downstream may be able to replenish the ground-water basins without any release from Cachuma Dam. However, during dry years or protracted dry periods, it may be necessary to release water from the reservoir to sustain levels in the downstream basins at practical operating levels.

The total ground-water storage capacity of the deposits follows, and the storage space available at any particular time is determined from the periodic measurements of the water levels in a network of observation wells. The magnitude and duration of the release required to replenish the ground-water reservoir can be determined by comparing a succession of regulated releases with resulting storage changes during the life of the interim contract for the operation of the dam.

STORAGE CAPACITY

METHOD OF COMPUTATION

The storage capacity of the alluvial deposits within the reach from The Narrows to Cachuma Dam is based on two elements: the volume of saturated alluvium between these points and the specific yield of that alluvium. The first element must be based upon a thorough knowledge of the physical dimensions of the alluvium. In addition, the position of the water table must be known in order to locate the upper limit of the zone of saturation. The lower limit is defined, for purposes of this study, by the consolidated rocks at the base of the alluvial deposits. Water stored in the Paso Robles and Careaga formations may be significant in considering the storage capacity of all deposits adjacent to the river. However, the water table in these deposits would have to be drawn down considerably below present levels before any replenishment could take place from the river. Thus, for the present, the storage capacity of these deposits is not estimated. The alluvial deposits in tributary stream valleys were omitted from the study because they are small, their bases are above the low-water channel of the Santa Ynez River only a short distance upstream, and ground water in them is supplied largely by the local streams. The alluvium in the broad inlet in secs. 10, 11, 14, and 15, T. 6 N., R. 33 W. (pl. 2) in the Santa Rita subarea underlies about 214 acres and has 20 to 30 feet of material below the level of the low-water channel. This body was not included in the total storage volume, as the degree of hydraulic connection between it and the river is apparently poor. In secs. 20 and 21, T. 6 N., R. 31 W. and secs. 20 and 21, T. 6 N., R. 30 W. (pl. 2) alluvium south of the flood channel was omitted, as it is thought to be very thin, at best only a thin veneer on bedrock, deposited as slope wash off the adjacent hills. Most of the alluvium in secs. 15, 22, and 23, T. 6 N., R. 31 W., is evidently thin and deposited by Alamo Pintado Creek and as wash from adjacent hills, and most of it is probably above the low-water river level. This area too was excluded from the storage estimates.

After computing the total volume of saturated alluvium, it is necessary to apply a figure for specific yield (for definition, see p. 23) in order to obtain the total volume of water that will drain from pore spaces by gravity. The volume of saturated material times the specific yield for the material, expressed as a percentage, gives the volume of drainable water.

VOLUME OF SATURATED MATERIAL

Volume should be computed by using data from accurate contours drawn at the base of the alluvium. The data available, however, do not permit close delineation of this contact. Accordingly, the volume is estimated approximately. Plate 2 shows the areal extent of the younger alluvium and river-channel deposits, the location of wells having logs, and the location of bridge- and dam-site borings and resistivity probes for the Santa Rita subarea and for the Buellton and Santa Ynez subareas. For each location figures that give the altitude of the ground surface and the altitude of the base of the alluvium as known or interpreted at the location are given. These maps show that the data are very scanty. Wells for which a log is available are comparatively few. Resistivity probes were made only in about the western half of the Santa Rita subarea (pl. 2). Also, at a few places the resistivity probes were not entirely satisfactory, and there may be some doubt as to their interpretation.

At some places the data are sufficiently reliable and the points sufficiently closely spaced that reasonable cross sections can be drawn. The best are from borings for foundation studies at the Buellton Bridge (cross section *H—H'*, pl. 3) and borings at the Santa Rosa, Cachuma, and Tequepis Dam sites (cross sections *F—F'*, *I—I'*, and *J—J'*, pl. 3). From these cross sections a fairly reliable indication of the position of the lowest point on the base of the alluvium can be obtained. Using these fairly well established points as fixed and assuming an even grade for the older Santa Ynez River when it was flowing in the bottom of the eroded trench now filled with alluvium, the profile on figure 8 has been prepared, showing the deepest part of this trench at the base of the alluvium. From this profile it is possible to estimate approximately the lowest point on the base of the alluvium at any other cross section, although the horizontal position of the point in the plane of each section is not known. This lowest point is shown on each of the cross sections on plate 3 and aided greatly in determining the shape of the cross section where data are few.

The volume of alluvium was computed from surface area, a typical cross-sectional shape, and a maximum thickness as approximated ac-

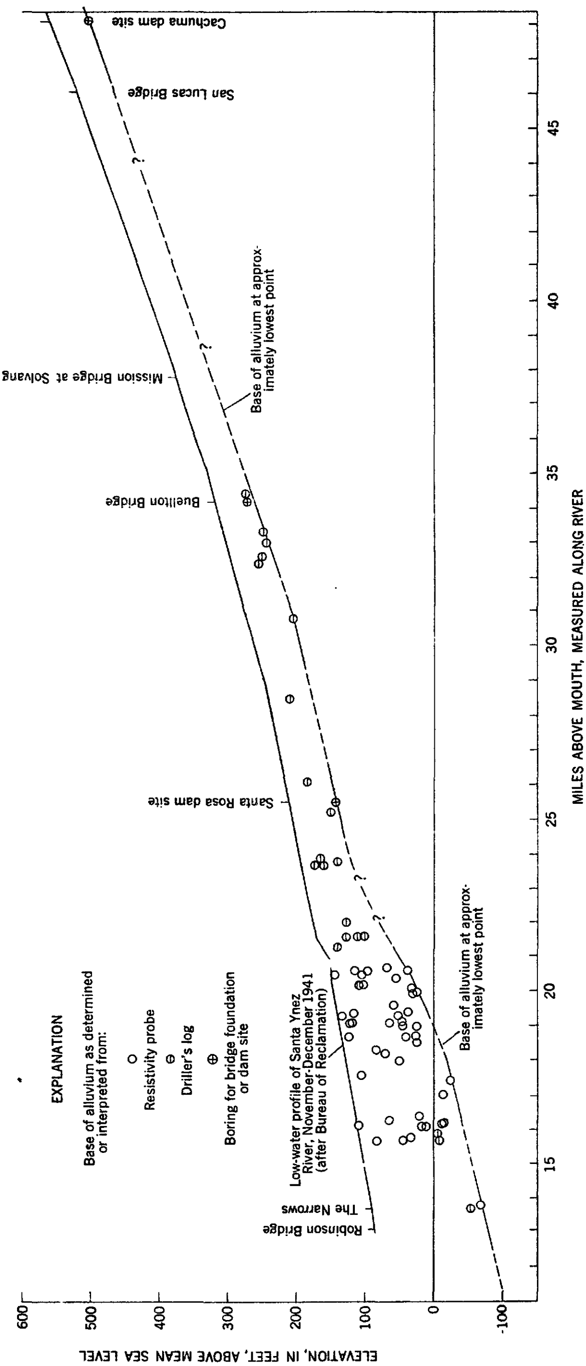

FIGURE 8.—Low-water profile and approximate lowest points on base of the alluvium along the Santa Ynez River basin between Robinson Bridge and Cachuma Dam site.

cording to the foregoing discussion. Because the typical cross sections are different in the different subareas, the method of computation differs accordingly. For convenience the volumes were computed for numerous adjacent small areas and these were totaled. The small areas are those areas of alluvium contained in each surveyed or projected land section or series of land sections traversing the width of the alluvium as shown on the maps, plate 2.

For the Santa Rita subarea, the cross sections (pl. 3) most nearly resemble a triangle in shape. Accordingly, a triangle is assumed to be the basic geometric shape for the typical cross section within this subarea. This assumption is considered a reasonable one because at all meander bends the cross-sectional shape is likely to approach a triangle and because some of the sections, such as *C—C′* and *D—D′* reveal the presence of buried ridges or benches whose true shape and extent are not known. It is believed that the straight-sided mathematical triangle makes adequate and conservative allowance for such irregularities.

For the Buellton subarea the cross sections (pl. 2) indicate that the alluvial tongue is more nearly rectangular in shape, and for purposes of computation at trapezoidal cross section was assumed.

For the Santa Ynez subarea, data are fewer than in the other two, and the alluvium is surrounded by consolidated rocks. Therefore, a triangular cross section was assumed for this subarea because it is thought to be conservative. A triangular cross section was assumed also for that part of the alluvium that lies in the Headwater subarea between Cachuma Dam and San Lucas Bridge.

The total volume of alluvium in these subareas below the top of the zone of saturation was computed for each land section or series of land sections traversing the width of the alluvium, from the planimetered area of the surface of the alluvium, the maximum thicknesses as obtained from the longitudinal profile (fig. 8), and the triangular or trapezoidal cross section assumed as applicable. Adjustment is made for the fact that the top of the zone of saturation has a somewhat smaller area than the surface of the alluvium. Total volume was computed, and also the volume of successively deeper layers, each 20 feet thick, down to a depth of 60 feet. The volumes are given in table 2.

SPECIFIC YIELD

The specific yield of a rock or soil is the ratio of the volume of water which, after being saturated, it will yield by gravity, to its own volume (Meinzer, 1923a). The ratio is stated as a percentage and may be expressed by the formula $Y=100(y)/V$, in which Y is the specific yield, y is the volume of water that the rock or soil will yield by gravity, and V is the volume of the rock or soil. Determinations of specific yield can be made in many ways. For example, a total of seven different methods are listed by Meinzer (1923b). The methods most commonly used are laboratory saturation and drainage of columns of material, such as some of those listed by Meinzer, and pumping tests on wells. Laboratory methods are subject to the usual errors inherent in any method involving sampling. Also, for the preliminary estimate it was not believed justified to sample the alluvial deposits in great detail.

Pumping-test methods are of doubtful value in obtaining specific-yield values for the alluvial deposits of the Santa Ynez River basin because field conditions are far different from the ideal conditions which must be assumed in the derivation of the equations expressing pumping-test theory. For example, the basic theory assumes an aquifer of infinite extent, whereas most of the wells that can be pumped for specific-yield tests in the Santa Ynez River basin tap aquifers that terminate against the bedrock canyon walls within half a mile or less. Nevertheless, it is believed that, despite the complications, estimates of specific yield by this method may be the best approximations obtainable. Two pumping tests were attempted in 1950, but unforeseen conditions of pump operation in the tested and nearby wells prevented a satisfactory interpretation of results.

For the preliminary estimates of this report, specific yield was approximated by estimating the proportion of different classes of material as reported in the available well logs and assigning arbitrary specific-yield values to each class. The results of the resistivity probes were not used in proportioning these classes. An approximation of specific yield in the Santa Rita subarea, based on the type of material according to the probes, was attempted but was not used because it gave a specific-yield value for the alluvium about 15 percent less than that determined from classes of material indicated by well logs. The classification of materials according to the resistivity probes is too generalized to give dependable results in an analysis of this sort.

The arbitrary specific-yield values selected for different classes of material as reported in the well logs were determined by comparison with other areas similar to the Santa Ynez River basin in which specific-yield values had been obtained from field and laboratory tests. The method is based in part on mechanical analysis of the material and was used rather successfully by Eckis (1934) in the south coastal basin of southern California. Eckis estimated specific-yield values for various types of subsurface material by comparing the results of cording to the foregoing discussion. Because the typical cross sections are different in the different subareas, the method of computation differs accordingly. For convenience the volumes were computed for numerous adjacent small areas and these were totaled. The small areas are those areas of alluvium contained in each surveyed or projected land section or series of land sections traversing the width of the alluvium as shown on the maps, plate 2.

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Alluvium	Specific yield, in percent						
	Gravel			Sand		Clay	
	Coarse (64–256 mm)	Medium (16–64 mm)	Fine (8–16 mm)	Coarse to medium (½–8 mm)	Fine (⅛–½ mm)	Sandy clay	Clay
Surface	14.2	20.5	26.5	30.9	21.2	10	1
Subsurface	14	20	25	28	16	5	1

In the Mokelumne area, California, estimates of specific yield by both the volumetric method and the drainage method were made by Piper (1939, p. 120–121). The results of these tests are tabulated below.

Method of analysis	Specific yield, in percent		
	Gravel and coarse sand (larger than 0.5 mm)	Medium and fine sand (0.5 to 0.125 mm)	Very fine sand, silt, and clay (smaller than 0.125 mm)
Volumetric	34.5	22.6	5.0
Drainage	35	26	3.5

The materials in the Santa Ynez River basin are roughly comparable to those in the south coastal basin. Accordingly, a specific-yield value of 25 percent was assigned to gravel, 30 percent to sand, 20 percent to fine sand, 10 percent to cemented or clayey gravel, and 5 percent to silt and clay. The deposits found in the south coastal basin are mostly in alluvial fans, whereas the deposits of the Santa Ynez are river-channel and flood-plain deposits in which the gravel is better sorted and contains less fine material. Possibly, therefore, the gravel has a slightly higher specific yield than 25 percent. Conversely, coarse gravel, such as in the alluvium of the Santa Ynez River, contains an assortment of large pebbles, cobbles, and boulders that have no specific yield and fill considerable space, tending to lower the specific yield of the material as a whole. For this reason the lower value, close to that used by Eckis, was considered more appropriate for this area than Piper's value of 35 percent for gravel and coarse sand.

To determine the general composition of the alluvium, the river course was considered by subareas. It was assumed that a composite log made up of all the logs in one subarea represents the average composition of the alluvium in that subarea. The materials reported in the logs were grouped into five classes: gravel, sand, fine sand, cemented gravel, and clay. The total thickness of each class was summed up for each 20-foot layer of saturated material, and reduced to a percentage of the total thickness of all classes in the particular 20-foot layer. For example, the logs of 48 wells and 6 borings (see following table) in the Buellton subarea showed that in the uppermost 20-foot layer, below the river channel, gravel amounted to 34.8 percent of the total thickness, sand 14.4 percent, fine sand 9.1 percent, cemented gravel 4 percent, and clay 37.7 percent. Specific-yield value for each 20-foot layer in the subarea, and also for the whole volume of material, was derived by combining the specific-yield values for each class of material in proportion to the relative amounts of the material in the particular layer or in the whole volume. The weighted specific-yield values for the upper three 20-foot layers in the Santa Rita and Buellton subareas are also given in the table. For the Santa Ynez subarea only two 20-foot layers are tabulated because the alluvium in that subarea is thinner.

Estimates of specific yield for several layers of alluvium in the Buellton, Santa Rita, and Santa Ynez subareas

Material logged	Assigned specific yield	Estimates of specific yield (percent) for layers of indicated depth (in feet)					
		0–20		20–40		40–60	
		Total logged material	Specific yield	Total logged material	Specific yield	Total logged material	Specific yield
Specific yield for Buellton subarea, based on logs of 48 wells and 6 borings							
Gravel	25	34.8	8.7	40.6	10.2	28.1	7.0
Sand	30	14.4	4.3	11.5	3.5	19.9	6.0
Fine sand	20	9.1	1.8	12.3	2.5	7.4	1.5
Cemented gravel	10	4.0	.4	3.7	.4	1.6	.2
Clay	5	37.7	1.9	31.9	1.6	43.0	2.1
Total		100.0	17.1	100.0	18.2	100.0	16.8
Specific yield for Santa Rita subarea, based on 24 well logs							
Gravel	25	45.1	11.3	56.3	14.1	33.5	8.4
Sand	30	15.3	4.6	6.4	1.9	23.1	6.9
Fine sand	20	9.2	1.8	.5	.1	0	0
Cemented gravel	10	11.9	1.2	7.5	.7	18.2	1.8
Clay	5	18.5	.9	29.3	1.5	25.2	1.3
Total		100.0	19.8	100.0	18.3	100.0	18.4
Specific yield for Santa Ynez subarea, based on 4 well logs							
Gravel	25	68.8	17.2	86.0	21.5		
Sand	30	12.5	3.8	0	0		
Fine sand	20	18.7	3.7	0	0		
Cemented gravel	10	0	0	0	0		
Clay	5	0	0	14.0	.7		
Total		100.0	24.7	100.0	22.2		

A determination of specific yield by the Eckis method in the reach of the river from Cachuma Dam to San Lucas Bridge was not possible because only a few logs were available. Specific yield for this reach of the river was assumed to be the same as that in the adjacent Santa Ynez subarea where the character of the deposits is similar to that in the Headwater subarea.

The total specific-yield values listed in tables on page 26 are based essentially on wells that tap the alluvium because few wells are located in the river-channel deposits. The channel deposits, however, may have more sand and gravel in the upper 20 to 40 feet of saturated material than the alluvium and hence may have a higher specific yield. An analysis of all logs in the river-channel deposits in the Santa Rita and Santa Ynez subareas shows that the percentage of sand and gravel in these deposits differs but slightly from that of the alluvium. In the Buellton subarea, however, the difference, based on four logs, is appreciable. The total volumes tabulated in table 2 for the 0–20 foot depth layer, therefore, may be somewhat in error because the channel deposits comprise a large part of the volume involved. No upward revision of specific-yield values was made in this depth layer because more logs in the channel deposits would be needed to substantiate the use of higher values.

ESTIMATES OF STORAGE CAPACITY

Table 2 summarizes the estimates of ground-water storage capacity of the alluvial deposits of the Santa Ynez River basin between Cachuma Dam and Robinson Bridge. The last column shows the estimated total storage capacity contained between the base of the alluvium and the top of the zone of saturation, when the ground-water reservoir is full, to be about 81,000 acre-feet. Because not all the water in this volume is economically recoverable, storage capacities also are listed in column 5 by selected 20-foot depth layers, so that the volume down to any specified depth is readily obtainable. Column 5 does not present the volume between 60 feet and the bottom in the Santa Rita and Buellton subareas, between 20 feet and the bottom in the Santa Ynez subarea, and between 20 feet and the bottom in the Cachuma Dam to San Lucas Bridge reach, because these volumes are not considered practicable to use. They may be computed, however, from the differences in the figures presented in the fourth and last columns. For example, the volume of water in storage between the bottom of the 60-foot depth layer and the consolidated rocks in the Santa Rita subarea is 8,000 acre-feet, obtained by subtracting 28,000 acre-feet (the volume in the 0–60 foot depth layer) from the total volume of 36,000 acre-feet.

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TABLE 2.—*Estimated gross ground-water storage capacity of alluvial deposits adjacent to the Santa Ynez River from Cachuma Dam to Robinson Bridge*

Subarea and depth layer (feet)	Surface area of alluvial fill (acres)	Specific yield (percent)	Estimated storage (acre-feet)	
			Volume in depth layer	Total to base of alluvium
Cachuma Dam to San Lucas Bridge 0–20	266	24.7	1,000	2,000
Santa Ynez 0–20	1,275	24.7	3,900	6,000
Buellton	4,243			37,000
0–20		17.1	13,200	
20–40		18.2	13,000	
40–60		16.8	10,600	
Santa Rita	4,425			36,000
0–20		19.8	12,500	
20–40		18.3	9,000	
40–60		18.4	6,500	
Totals			70,000	81,000

The depth layers or zones shown in table 2 can be used to compute storage depletion or replenishment from a consideration of the net change in elevation of the water table for any chosen period. A uniform drop in water levels of 20 feet in the Santa Rita subarea, for instance, would indicate a depletion of ground-water storage amounting to 12,500 acre-feet. Extensive use is made of this table in estimating storage changes for the periods 1945–51 and 1951–52.

PRACTICAL DEPTH OF DEWATERING

Although table 2 lists the gross storage capacity of the alluvial deposits between Cachuma Dam and Robinson Bridge, it gives little indication of how much water in storage would be economically recoverable. Lowering the water table to a depth approaching the full thickness of alluvium would increase the amount of electric energy consumed to overcome the increased lift, require the deepening of some wells, and cause the total dewatering of some areas and wells along the edge of the valley. Furthermore, because a well has to tap some saturated thickness for the pump to draw any water, it would be utterly impractical to dewater all the deposits completely. The actual determination of a practical limit of drawdown is a subject for future study, but enough data are available to show the effect that lowering the water table would have on wells now in existence.

The question under consideration during a preliminary study of the practical depth of dewatering was: "How far can water levels be lowered before wells must be deepened or abandoned?" To answer this question, the land-surface elevation and bottom elevations of all wells for which data were available were plotted to scale by subarea on cross-section paper. The water level as of March 1952, when the basins were full, was superimposed on these plots and then theoretically lowered in increments of 20 feet, which would correspond to the depth layers in table 2. Lowering the water table in this manner revealed the wells that were not deep enough to reach to newly assumed water-table elevations. Data collected in this study are summarized in the table below, which shows the percentage of wells that would become inoperative with each increment of water-table decline.

Percent of wells in the Santa Ynez River basin that would become inoperative by lowering the water table to selected depths below highest levels

Subarea	Selected water-level depths below highest level of March 1952 (feet)	Percent of wells becoming inoperative	
		Irrigation wells	Domestic wells
Santa Ynez	20	0	0
	40	10	33
	60	90	67
Buellton	20	3	21
	40	24	59
	60	70	68
Santa Rita	20	0	59
	40	23	88
	60	71	100

From the above table it is obvious that any lowering of the water table to a depth of more than 40 feet below the level of March 1952 would have serious consequences on the existing wells. At a depth of 40 feet below the level of March 1952, for example, 10 to 24 percent of the existing irrigation wells would be inoperable.

STORAGE CHANGES

METHOD OF COMPUTATION

Admittedly, the best method of computing storage change for any desired period would be by the preparation and comparison of water-level contour maps based on measurements of water levels in as many wells as possible. By superimposing these maps, contours could be drawn showing the net water-level change. For the years 1945–52, insufficient wells and a lack of complete areal coverage, however, make the drawing of such contours for the area upstream from Robinson Bridge difficult, if not impossible. Most wells have been drilled close to the winding course of the river in order to take advantage of the shallow depth to water and proximity to the principal source of recharge, and as a result the control of contours near the outer limits of the alluvium is poor. In 1953 the Bureau of Reclamation installed additional observation wells in deficient areas in response to the Survey's request. Measurements from these supplementary wells will be available for control and for analysis of future changes in storage.

In the absence of sufficient data to prepare water-level contour maps, average water-level changes, weighted areally within each subarea, were computed on the basis of all available water-level measurements. The total volume of the material in which the change of water level took place is the product of the average water-level change and the average area of the dewatered alluvial deposits. This product multiplied by the appropriate specific-yield figures in table 2 gives a reasonable estimate of the net change in ground-water storage.

DEPLETION OF STORAGE, 1945-51

In the period 1935-44 precipitation and streamflow were above normal, and as a result the ground-water reservoir between Cachuma dam site and Robinson Bridge was fully replenished each winter after having been drawn down by withdrawals during the preceding growing season (figs. 6 and 7). Beginning with 1945, however, 7 consecutive years of below-normal precipitation and recharge resulted in the yearly withdrawal of ground water at a rate exceeding the rate of replenishment. Throughout the valley declining water levels attested that ground-water storage was being depleted. Short-term depletion in itself is not a serious consequence of pumping in excess of recharge unless the "safe" or perennial yield of the ground-water basin is exceeded.

The perennial yield of a ground-water basin is the rate at which water can be pumped from wells year after year without decreasing storage to the point where the rate becomes economically infeasible, physically impossible to maintain, or causes intolerable chemical deterioration of the ground water.

In the Santa Ynez River basin the perennial yield has been estimated by Upson (Upson and Thomasson, 1951, p. 113-114 and 118-119) to be at least 7,600 acre-feet in the Buellton subarea and at least 7,500 acre-feet in the Santa Rita subarea. No estimate was made for the Santa Ynez subarea. Although withdrawals plus natural discharge in an individual year have exceeded the recharge for that year, they have not exceeded the long-term average annual recharge. Similarly, ground water was depleted somewhat during years of overdraft, but the storage was sufficient to supply all the needs of the valley for a period of 7 dry years. At no time during this period were pumping lifts increased excessively or, so far as is known, were waters of questionable quality drawn into the underground reservoir.

Table 3 shows the estimated net changes in storage in the three subareas during the period 1945-52. The net changes were computed by the method previously outlined. Because there were no water-level records prior to 1954 for the reach between Cachuma Dam and San Lucas Bridge, no estimates of the storage changes could be made.

TABLE 3.—*Estimated net changes of ground-water storage in Santa Ynez, Buellton, and Santa Rita subareas, 1945–52*

Subarea	Number of wells used in average	Average net water-level rise (+) or decline (−) (feet)	Area of alluvium at top of saturated section (acres)	Volume of material (acre-feet)	Estimated average specific yield (percent)	Storage change: net increase (+) or decrease (−) (acre-feet)	Amount remaining in storage [1] (acre-feet)
For the 6-year period April 1945–April 1951							
Santa Ynez	3	−9.06	1,000	9,100	24.7	−2,200	1,700
Buellton	19	−2.62	4,000	10,500	17.1	−1,800	35,200
Santa Rita	4	−5.70	3,500	20,000	19.8	−4,000	24,000
Total						−8,000	60,900
Cumulative storage change						−8,000	
For the 7-month period April–November 1951							
Santa Ynez	12	−4.04	1,000	4,000	24.7	−1,000	2,900
Buellton	57	−3.70	4,000	14,800	17.1	−2,500	32,700
Santa Rita	27	−2.32	3,500	8,100	19.8	−1,600	22,400
Total						−5,100	58,000
Cumulative storage change						[2] −13,100	
For the 4-month period November 1951–March 1952							
Santa Ynez	12	+12.53	1,000	12,500	24.7	+3,100	6,000
Buellton	58	+4.94	4,000	19,700	17.1	+3,400	36,100
Santa Rita	34	+6.63	3,500	23,200	19.8	+4,600	29,000
Total						+11,100	71,100
Cumulative storage change						[3] −2,000	
For the 7-year period April 1945–March 1952							
Santa Ynez	3	+0.47	1,000	500	24.7	+100	3,900
Buellton	18	−0.88	4,000	3,500	17.1	−600	36,400
Santa Rita	3	−1.85	3,500	6,500	19.8	−1,300	26,700
Total						−1,800	67,000
Cumulative storage change						−1,800	

[1] To 20-foot depth in Santa Ynez subarea and to 60-foot depth in Buellton and Santa Rita subareas (see table 11).
[2] April 1945 to November 1951.
[3] April 1945 to March 1952.

Table 3 shows that, starting with the basins nearly full in 1945, there was a total net depletion for the two periods, April 1945 to April 1951 and April 1951 to November 1951, of 13,100 acre-feet. Also, in November 1951 there was 58,000 acre-feet of water remaining in storage. During the short 4-month period November 1951 to March 1952 the basins were recharged by an estimated net increase in storage of 11,100 acre-feet. This indicates that the basin lacked about 2,000 acre-feet of being restored to the storage level of April

1945. Similarly, table 3 shows a net depletion for the overall 7-year period April 1945 to March 1952 of 1,800 acre-feet—only 200 acre-feet less than that obtained by the separate study of the 2 periods of depletion and 1 of replenishment.

The data contained in table 3 are accurate only if the specific-yield figures chosen and the average water-level changes computed are truly representative. Of the two weaknesses in the compilation, the computed average water-level change is probably subject to greatest error, especially in the tabulations for 1945. Fewer wells were measured periodically during the early years of the investigation than are now being measured, and, as a consequence, average water-level changes for these early years are based on measurements in only a few wells.

The rapid replenishment of the basins from November 1951 to March 1952, after 7 years of depletion was produced by two severe storms in January and March 1952 in the valley. Had the effects of the storms been of short duration, much of the available recharge would have been lost as surface-water outflow, because, for infiltration to take place, the recharge must move through the unsaturated materials above the water table. As stated by Meinzer (1942, p. 401):

> The proportion of the precipitation (and resulting runoff) that becomes ground water increases with the precipitation up to a certain limit. If precipitation occurs in light scattered rains, it may all be absorbed by the soil; the rains that occur after the deficiency of soil moisture has been satisfied are those that count for ground-water recharge.

Fortunately, the December-January storm was sufficient in magnitude and duration not only to make up the soil-moisture deficiency but also to permit substantial recharge to ground water. Succeeding rains during February and early March 1952 were closely spaced, and therefore the soil moisture once replenished remained so; each storm contributed some replenishment to ground-water storage. However, storage was almost fully replenished by March 11, and thereafter essentially all available recharge was rejected; floodwaters of the March 18 storm, for example, were largely wasted to the ocean.

One of the most significent features shown by table 3 is the relatively small depletion of ground water during the dry period 1945–51. Although the depletion of storage in the Santa Ynez subarea was about 50 percent, the depletions in the Buellton and Santa Rita subareas were only about 12 and 16 percent, respectively. For the area as a whole the total net depletion was only 17 percent.

All the foregoing statements are based on conditions before the closure of Cachuma Dam. A similar set of data collected subsequent to the operation of the reservoir will record the effect on the river regimen and the resultant rates of ground-water depletion and recharge. A study of controlled releases from the reservoir during the tenure of the interim contract ultimately should provide a basis for an equitable operational procedure.

GROUND-WATER GRADIENTS

Many of the data on depletion and replenishment presented in the preceding section were based on water-level measurements made in shallow observation wells constructed along five profile lines across the river beginning in January 1951. Water-level measurements in these wells, together with measurements in existing wells, was begun to obtain information concerning ground-water gradients under various conditions of river flow, on depletion and recharge of storage, and on the direction of movement of underground waters.

To obtain this information, five lines were selected across the alluvial deposits of the basin (pl. 4). The wells along these lines consisted principally of irrigation or domestic wells already in existence, supplemented by 1¼-inch wells placed where needed to provide full coverage along each line across the basin. The supplemental wells, placed by the Bureau of Reclamation, were constructed in most cases with the aid of a power auger. After an 8-inch hole had been drilled to a depth of at least 10 feet below the record-low water table, a 1¼-inch pipe with a well point then was lowered into place and the hole backfilled with sand and gravel.

PROFILE LINE 1

Profile line 1, about 2½ miles downstream from San Lucas Bridge, was inaccessible during the January 1952 flood stage of the Santa Ynez River, but sufficient data were collected to draw the water-level profiles shown on plate 11. Because the water in storage in this subarea is considerably less than that in any of the subareas downstream from the Headwater subarea, ground-water withdrawals during the drought years lowered the water table considerably. Along line 1 the record low levels on December 5, 1951, were nearly 20 feet lower than the levels on April 1, 1952, which are believed to be nearly as high as the high levels in the winter of 1944 (fig. 6).

Recovery of the water table in this subarea, as evidenced by the profiles and hydrographs, was swift and essentially complete. Prior to the winter rains of 1951–52 the ground-water gradients sloped toward the south-central part of the basin where pumping and natural downstream drainage of ground water are greatest. With the arrival of flood waters in January, however, the depleted storage was replaced almost completely as shown by the April 1, 1952, water-level profile. The profiles show further that pumping produces a depression in the water table during times of no flow in the river, but at times of river flow pumping is sustained in part by induced infiltration from the river.

PROFILE LINE 2

Profile line 2 is about 1½ miles upstream from Buellton Bridge near the east end of the Buellton subarea (pl. 4). The ground-water gradient on December 5, 1951, based on the record low levels, was generally southward across the profile (pl. 4). Little is known regarding the gradient on the south side of the river because only one well is accessible for measurement and that well is close to the river. The storm and recharge of January 1952 resulted in a gradient away from the river in a northerly direction, indicating that a mound of recharge was moving north; the greatest recoveries were observed in wells near the river, whereas smaller recoveries were observed in wells 6/31-17C1 and 6/31-17F1 some distance away from the river. For description of the well-numbering system see page 107.

With the passage of time, however, riverward gradients were reestablished (March 17 and November 18 profiles on pl. 4) and recoveries at the edge of the basin reached the same magnitude as those close to the river. The overall recovery along the profile line from December 1951 through March 1952 was about 10 feet. The riverward gradients established in March sustained the summer low flow of the Santa Ynez River.

PROFILE LINE 3

Profile line 3 is about 1½ miles downstream from Buellton Bridge. Like line 1, line 3 shows a gradient toward the area of large withdrawal along the river flood plain as of the record low of December 1951 (pl. 4). At the flood stages of January 18 and March 17, 1952, the gradients were to the river, indicating that there was ground-water discharge to the river in this section. The Paso Robles formation and Careage sand underlie a large area north of the river and doubtless contribute some water to the younger deposits adjacent to the stream channel. The net rise in water level along the profile from December 1951 through March 1952 was about 7 feet.

Plate 4 shows that by the end of the pumping season in November 1952 the river was contributing some replenishment to ground-water storage, which had been depleted during the preceding summer. The ground-water profile for November 18, 1952, shows that the gradients both north and south of the river were away from the river.

PROFILE LINE 4

Profile line 4 at the western limit of the Buellton subarea and the gradients shown are unique among those on the 5 profiles in that, regardless of river stage, they always have been southward to the river, indicating discharge from the Paso Robles formation and Careaga sand north of the river (pl. 4). At this profile water has always been visible in the river bed. Even during a drought the river bed is marshy and supports a luxurious growth of phreatophytes.

The profiles for December 1951 and November 1952 illustrate an unusual phenomenon in that, after the floods of 1951–52 with the river flowing continuously and with little pumping, there was a net depletion instead of replenishment in ground-water storage during the period in the vicinity of this cross section. The profiles on plate 4 show that the water levels during February and part of March were below those of January. The hydrograph for well 6/32–9A2 (pl. 5) shows the decline from January to November 1952 more clearly. In explanation, there was very little storage depletion prior to the heavy precipitation of January 1952. The peak flow of the Santa Ynez River quickly replenished this storage, but at the same time the river bed was scoured out to a depth of 1 to 2 feet below what it had been before the storm. After the passage of the storm, the stream was gaining through this reach and, because the stream channel was cut deeper into the water table, the ground-water level declined to a level lower than it had been prior to the storm.

PROFILE LINE 5

Water-level profiles plotted on profile line 5 (pl. 4) are questionable because the floodwaters of January 1952 washed out wells 6/32–17D1 and 6/32–17D2. In addition to the loss of two wells, well 6/32–8N3 was inaccessible during December, January, and part of February. The profiles do show, however, that the river was gaining water from or losing water to the north, depending on the position of the water levels relative to the river. The net rise along the profile from December 1951 to March 1952 was about 8 feet.

RELATION BETWEEN RUNOFF AND GROUND-WATER RECHARGE

The relation between runoff and ground-water recharge is depicted in figure 9. The bar graph shows the discharge of the Santa Ynez River at San Lucas Bridge for the period January through March 1952. Above the bar graph is a composite hydrograph based on water-level measurements in 24 of the 29 profile wells. The hydrograph was constructed by averaging, for any particular date, the total rise of water level in each individual observation well above its level of December 30, 1951. As shown by the hydrograph, the bulk of the recovery and hence recharge occurred as a result of the January 1952 storm and, indeed, nearly 5 feet of the total 8-foot recovery occurred between January 10 and 20.

SEEPAGE LOSS FROM THE SANTA YNEZ RIVER

A study of regulated releases from Cachuma reservoir down a dry channel would aid in determining seepage-loss rates from the Santa Ynez River. This study would yield much valuable information in the future, and it is planned that many such releases will be made; but, in the meantime, the storms of January and March 1952 give an imposing idea of how fast large quantities of water can be recharged to the younger alluvium and river-channel deposits.

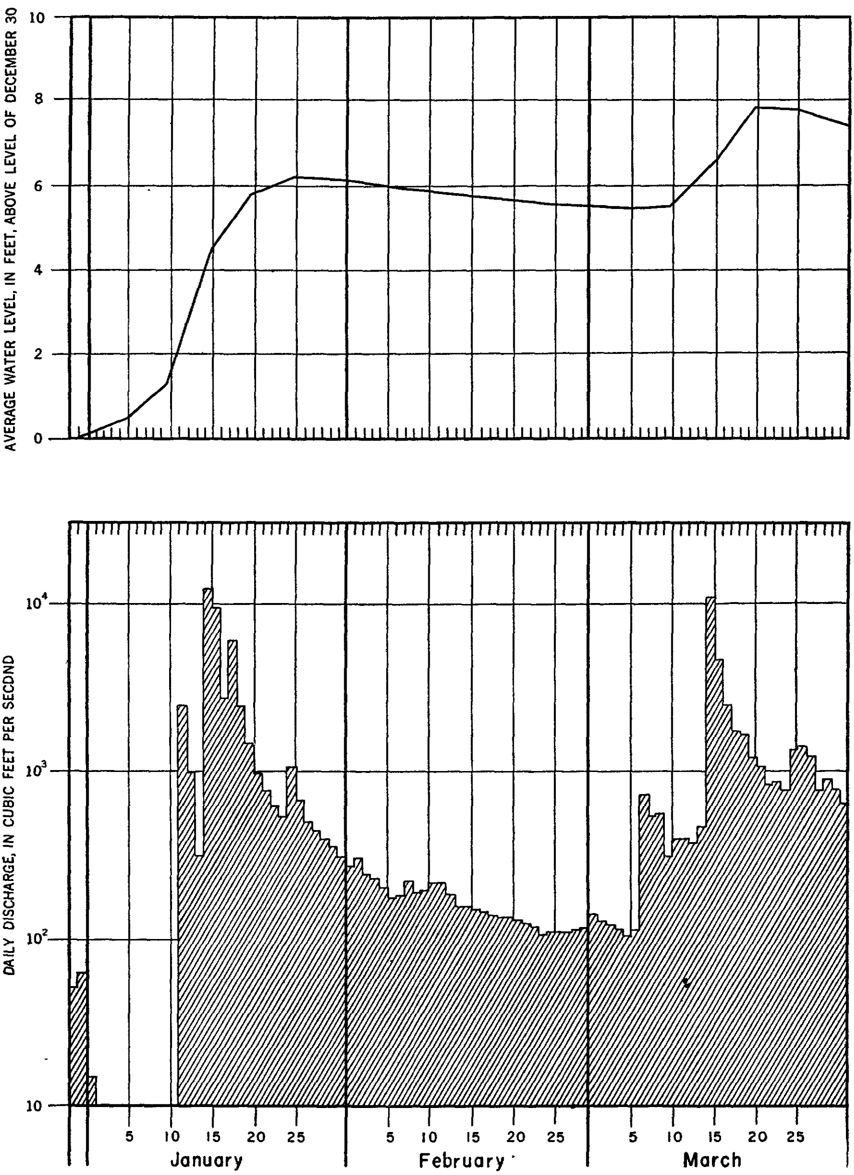

FIGURE 9.—Average rise of water level in 24 wells in the Santa Ynez River basin, and daily discharge at San Lucas Bridge, January–March 1952.

Commencing January 14, 1952, water-level measurements were made daily for a period of about 2 weeks in almost all the wells comprising profile lines 1 to 5. It was intended that these measurements would be used to compute the storage change by subarea over a 2- or 3-day period. From a consideration of storage change and the wetted acreage of the river bed, infiltration rates could then be determined. Of course, due consideration would have to be made for recharge from sources other than the river. This analysis showed extremely low seepage-loss rates, because much of the recharge occurred prior to January 14 (pl. 16). With a ground-water mound already built up beneath and adjacent to the river as of January 14, most of the river flow was passing overland and out of the area. An estimate of seepage rates by this method might have been possible if water-level measurements had been obtained daily prior to January 14. Also, inasmuch as flood flows were too large to measure in determining seepage losses, a check of storage-volume changes versus seepage losses between gaging stations was unsuccessful.

In the absence of seepage-loss rates, however, it is still interesting to note that tremendous quantities of water were recharged to the alluvial deposits in the relatively short period of 11 days. The following table shows the volume of water contributed to the ground-water reservoir in the Santa Ynez, Buellton, and Santa Rita subareas during the period January 7 to 18, 1952.

Estimated increase in ground-water storage in the Santa Ynez, Buellton, and Santa Rita subareas, January 7 to 18, 1952

Subarea	Average rise of water level (feet)	Area at top of zone of saturation (acres)	Volume change of saturated section (acre-feet)	Estimated specific yield (percent)	Increase in storage (acre-feet)
Santa Ynez	9.76	1,000	9,800	24.7	2,400
Buellton	3.86	4,000	15,400	17.1	2,600
Santa Rita	5.50	3,500	19,300	19.8	3,800
Total, San Lucas Bridge to Robinson Bridge					8,800

Plate 4 shows the fluctuations of water level in all wells on the profile lines for the months of December 1951 through April 1952, but they are not sufficient in detail to show the day-to-day rise or the frequency of measurement. Plate 5 contains one representative hydrograph from each of the five profile lines and the daily precipitation at Santa Barbara. The hydrographs clearly show the rapid response of ground-water levels to precipitation. The rains of October, November, and December, 1951, were sufficient to restore soil moisture, but they added little to ground-water storage, as indicated by only the slight upward trends of the hydrographs during this period. The rise in part is due to the decrease in pumpage and evapotranspiration. Thereafter, runoff occurred as a result of above-average precipitation on a soil whose moisture content probably was close to a maximum. A part of the precipitation became recharge to ground water by deep penetration, but only roughly 5 percent of the runoff was utilized to replenish storage to essentially full capacity.

REGULATED RELEASE OF WATER FROM CACHUMA DAM

The Cachuma Dam closed on January 7, 1953, and all waters entering Cachuma reservoir were stored commencing that date, because a live stream existed as defined by the terms of the contract. By March 15, however, it became evident that the "live stream" would be short lived and that, by the terms of the contract, it would be necessary to release through the diversion tunnel all waters entering the reservoir. On March 25 releases were begun at an initial rate of 17 second-feet. Releases continued thereafter at a rate equal to the inflow to the reservoir, averaging about 16 second-feet during the following 40 days.

Prior to the release a dry channel, except for isolated pools, existed between the dam and a point about 1¼ miles upstream from Refugio Pass road—a distance of about 7 river miles. At this point the flow of Zanja Cota Creek reached the Santa Ynez River and provided a perennial low flow for some distance downstream. The alluvial deposits of the river are separated from the older water-bearing deposits to the north, which form an extensive catchment area, by the essentially non-water-bearing consolidated Tertiary rocks. Precipitation falling on the catchment area percolates to the ground-water body and then flows southward until it reaches the consolidated rocks where ground water is forced upward in the lower reaches of Alamo Pintado, Zanja Cota, and Santa Agueda Creeks to become surface flow that crosses the Tertiary rocks and empties into the Santa Ynez River.

During the period January 7 to March 25 when the dam was closed, water levels in the river reach from Cachuma Dam to 1¼ miles upstream from Refugio Pass road dropped steadily (fig. 10). It was anticipated that certain hydrologic data, collected simultaneously with the release of water, would afford a means of estimating not only seepage-loss rates but also specific yield. To this end, water-level measurements were made daily in all existing wells in which measurements could be made with a tape, electric meters on all pumping plants were read daily, and the progress of the streamflow downstream was recorded. The Bureau of Reclamation made streamflow measuments at a number of miscellaneous sites. Plate 6 shows the location of wells used to determine storage changes and the progress of streamflow downstream in response to controlled releases from the dam after March 25, 1953.

The rate of seepage loss, shown graphically on figure 11, was

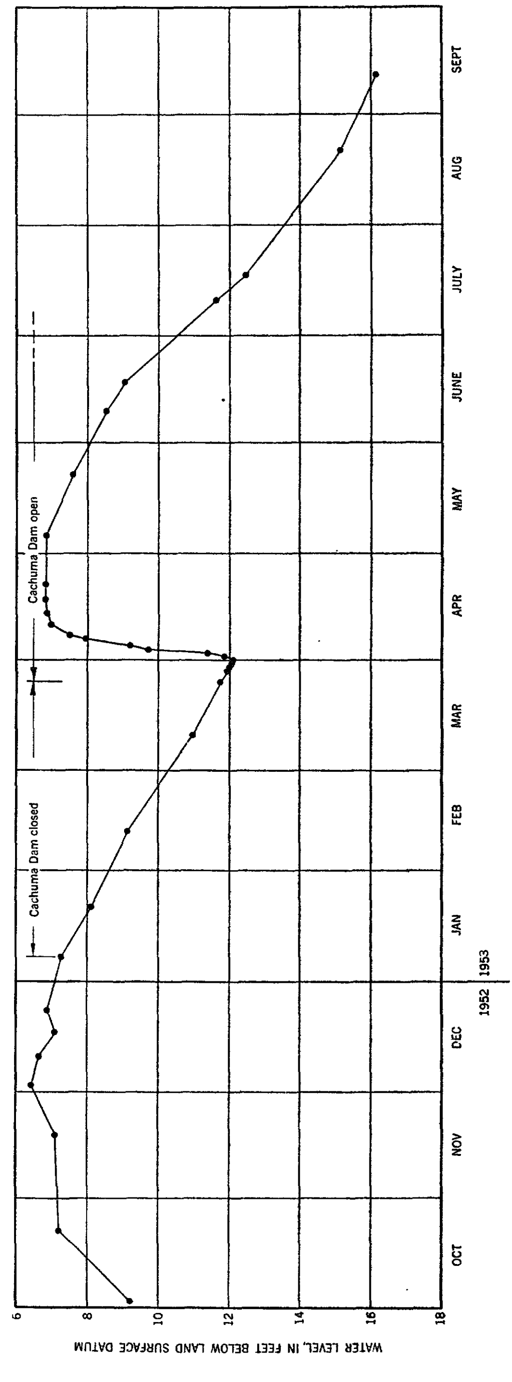

FIGURE 10.—Fluctuations of water level in well 6/30–20N2, 1952–53.

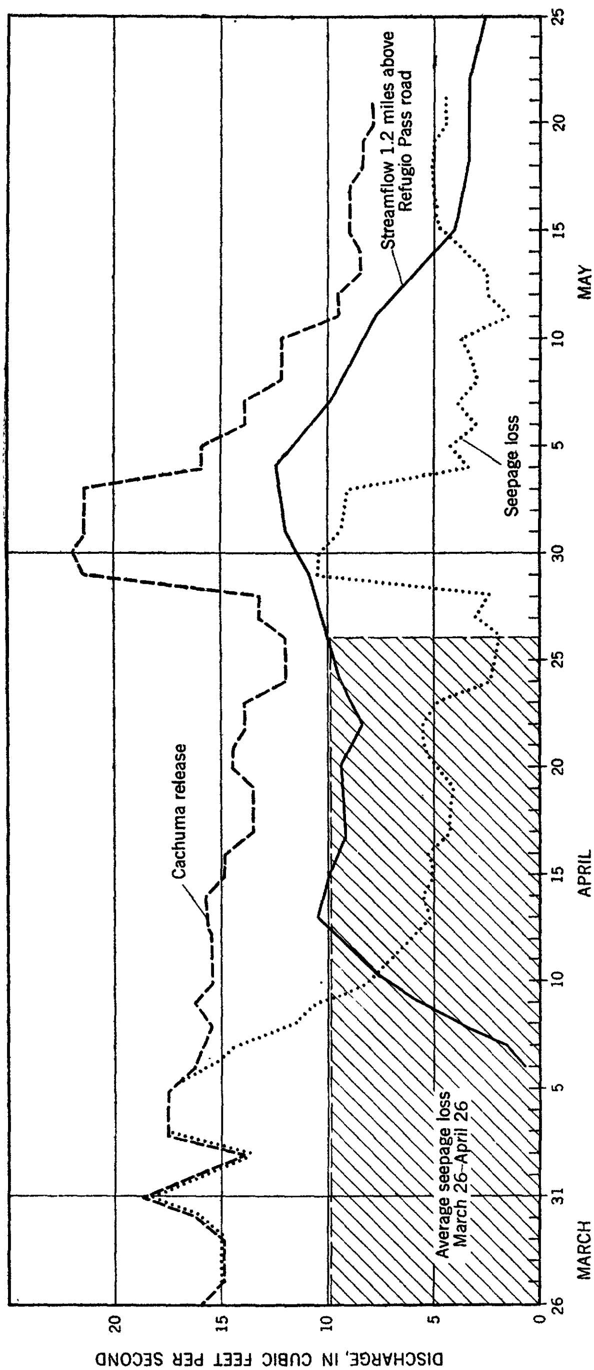

FIGURE 11.—Discharge from Cachuma reservoir, streamflow 1¼ miles above Refugio Pass Road, and seepage loss, March 25 to May 25, 1953.

measured between the dam and a point 1¼ miles upstream from Refugio Pass road. All the released water, except that standing on the surface and the water released to fill the stilling basin, percolated to the water table during the first 12 days of the operation. On the twelfth day the flow joined the live section of the stream maintained perennially by Zanja Cota Creek. The maximum rate of seepage loss was about 18 second-feet, but it probably would have been greater had the release been greater. As a ground-water mound continued to be built up in the vicinity of the river, the rate of loss declined to a minimum of about 2 second-feet.

During the release of water from Cachuma reservoir, changes in the volume of subsurface saturated material were computed by measuring the depth to water in a number of wells along the stream course and computing the area of the top of the saturated section. A comparison of these volume changes with the amount of water known to produce the change provided the information necessary to estimate specific yield. For example, in the 10-day period, March 25 to April 4, the average release from the reservoir was 16 second-feet or a total of 318 acre-feet. Of this total, 28 acre-feet was used to fill the stilling basin at the foot of the spillway and 22 acre-feet was discounted as having been pumped for irrigation. The pumpage estimate was based on the total power consumed by pumping plants (based on meter readings) and an average figure for the kilowatt hours required to pump 1 acre-foot (based on pump-efficiency tests). It is assumed, therefore, that 268 acre-feet was contributed directly to ground-water storage, disregarding bank storage, evapotranspiration, and the water on the surface. The volume of material saturated during this period, based on water-level measurements in wells, increased by 1,140 acre-feet; the computed specific yield, therefore, is about 23.5 percent.

UNDERFLOW AT CACHUMA DAM SITE

METHOD OF COMPUTATION

The 10-year interim contract between the Bureau of Reclamation and the Santa Ynez River Valley Water Conservation District (p. 2) stipulates that no water may be stored in Cachuma reservoir unless a live stream exists. When a live stream does not exist, the downstream users are entitled to the natural flow of the river including both surface- and ground-water flow. Surface flows are gaged at a stream-gaging station maintained above the reservoir but, because direct measurement of subsurface flow is not possible, an indirect method based on Darcy's law is used.

Darcy's law, as it applies to the flow of water through a porous media, may be expressed:

$$Q = PIA$$

where, in units most suitable for ground-water use, Q is the discharge, in gallons per day; P is the coefficient of permeability, in gallons per day per square foot; I is the hydraulic gradient, in feet per foot; and A is the cross-sectional area, in square feet. To evaluate Q, therefore, we need to know the saturated cross-sectional area of the younger alluvium and river-channel deposits through which the underflow is moving, the hydraulic gradient responsible for the movement, and the permeability of the saturated material.

TEST PUMPING FOR AQUIFER COEFFICIENTS

In order to determine permeability, an aquifer test was made on April 30, 1951, about 1½ miles upstream from the dam site (fig. 12). Well 6/29–20F3 was pumped at a rate of 1,100 gpm (gallons per minute) for a period of 25 hours, and wells 6/29–20F1, 20F2, 20F4, and 20F5 were used as observation wells. An automatic water-level recorder was operated on well 6/29–20F4, and tape measurements were taken on the remaining observation wells. At the completion

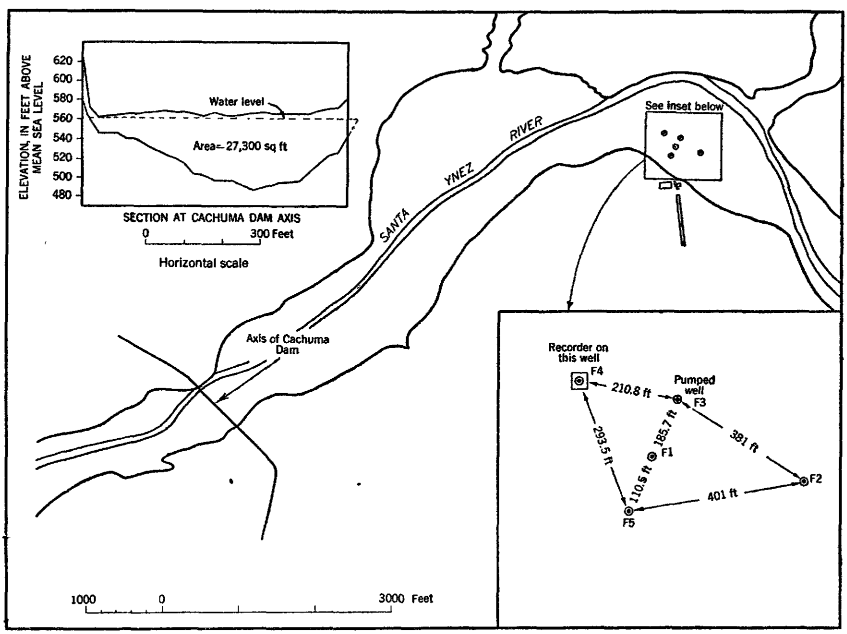

FIGURE 12.—Sketch map showing location of observation wells, and cross-sectional area at Cachuma dam site.

of the test, an analysis was made in conformance with the nonequilibrium formula developed by Theis (1935).

$$T=\frac{114.6Q}{s}\int_{\frac{1.87r^2S}{Tt}}^{\infty}\frac{e^{-u}du}{u}$$

where T is the coefficient of transmissibility, in gpd (gallons per day) per foot; Q is the discharge of the pumped well, in gpm (gallons per minute); s is the drawdown, in feet; r is the distance from the pumped well to the point of observation, in feet; S is the coefficient of storage, expressed as a decimal; and t is the time since pumping started, in days. That part of the equation that lies to the right of the integral sign is not directly integrable, but it can be evaluated as a series:

$$\int_{1.87r^2S/Tt}^{\infty}\frac{e^{-u}du}{u}$$

$$=W(u)=-0.577216-\log_e u+u-\frac{u^2}{2.2!}+\frac{u^3}{3.3!}-\cdots\cdots\cdots$$

In its simplest form, the nonequilibrium formula may be written:

$$T=\frac{114.6Q}{s}W(u)$$

where $W(u)$ is a symbol used to represent the series that evaluates the exponential integral and is generally read "well function of u."

Similarly, in its simplest form, the coefficient of storage can be expressed:

$$S=\frac{uTt}{1.87r^2}$$

Logarithmic plots of s versus r^2t were made for each of the observation wells, and all were similar to that shown for well 6/29–20F5 (fig. 13). The observed-data plots were matched against a type curve of u versus $W(u)$ for a graphical solution of the values of u and $W(u)$ that could be inserted in the nonequilibrium formula. The coefficient of transmissibility was computed to be about 140,000 gpd per foot and the coefficient of storage was computed to be about 0.07.

The figure 140,000 gpd per foot is considered representative of the average coefficient of transmissibility of the aquifer, but the computed average coefficient of storage probably is low, because of slow drainage in the aquifer and a longer test would have been required to

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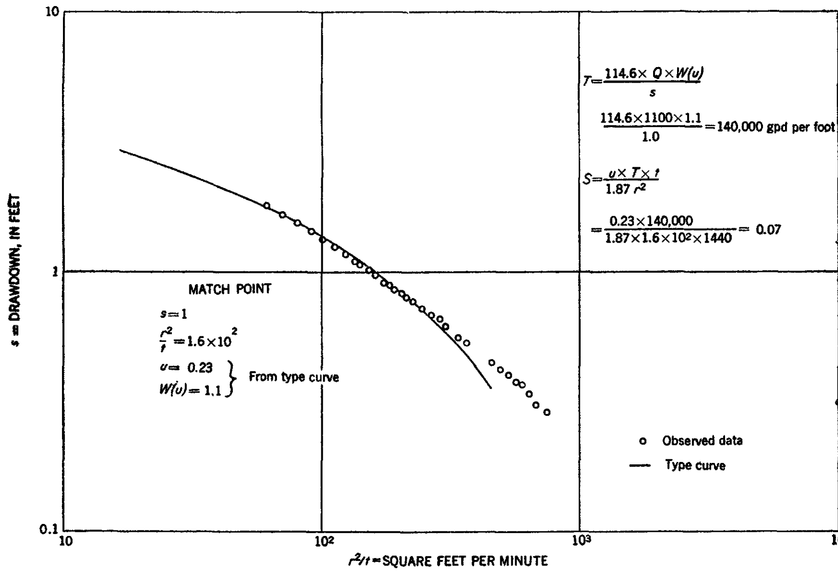


FIGURE 13.—Logarithmic plot showing drawdown of water level in observation well 6/29–20F5 by pumping well 6/29–20F3.

overcome the effects of this slow drainage. In the final analysis of the data, the storage coefficient obtained for well 6/29–20F4 was not used, because this well was known to be a "sluggish well" not entirely open to the aquifer.

All the plotted data for the early part of the test show some divergence from the type curve, suggesting that the cone of depression was influenced by an impermeable barrier or at least by the pumping of one or more nearby wells. In the final analysis, however, the possibilities were overruled. No other wells existed in the area and, by trial analysis, it was determined that a longer time of pumping would have been required for the known impermeable barrier, the consolidated rock at the south edge of the alluvium, to produce any appreciable drawdown in the observation wells. The departures of the observed-data curves from the type curves are probably due to slow drainage of ground water during the first few hours of pumping through fine-grained, dirty sediments or at least through a material that was highly heterogeneous. As a result, the water levels in wells were unduly depressed.

DETERMINATION OF UNDERFLOW

Up to this point the coefficient of permeability has been ignored, and in its place the coefficient of transmissibility has been determined because it is the more convenient term to use throughout the mathematical and graphical treatment of the test-pumping data. By definition, the coefficient of permeability is the rate of flow of water in gallons per day through a cross-sectional area of 1 square foot, whereas transmissibility is the rate of flow through a vertical strip of the whole aquifer 1 foot in width. The coefficient of permeability, therefore, can be obtained by dividing the transmissibility by the thickness of the saturated aquifer. The thickness of the saturated section in the vicinity of the pumping test is approximately 45 feet and therefore the permeability is about 3,000 gallons per day per square foot of aquifer.

The saturated cross-sectional area at the dam site has remained essentially constant at about river-bed level, and, from test borings made in connection with foundation studies for the dam, the area plotted on the cross section (fig. 12) is about 27,300 square feet. The hydraulic gradient was determined from water-level measurements taken in test borings and borrow pits upstream from the dam site and was found to be essentially parallel to the river-bed gradient of 0.0033 feet per foot (17.4 feet per mile).

Substituting in the equation based on Darcy's law:

$$Q=PIA$$

$$Q=3{,}000\ \frac{\text{gpd}}{\text{ft}^2}\times 0.003\ \frac{\text{ft}}{\text{ft}}\times 27{,}300\ \text{ft}^2$$

$$=270{,}000\ \text{gpd}$$

This is about 0.42 second-foot or about 300 acre-feet a year.

HYDROLOGIC EQUATION, APRIL 1945 TO APRIL 1951

FACTORS IN THE EQUATION

With Cachuma Dam in place, the quantity of water originating from sources below the dam becomes a critical item in the replenishment of the ground-water reservoir. An estimate of this quantity can be made by evaluating the general hydrologic equation during a period in which the contribution of surface water past San Lucas Bridge is negligible.

Between 1946 and 1952 there was very little flow past San Lucas Bridge; so, for all practical considerations essentially the same hydrologic conditions existed as though Cachuma Dam were already in place. With this condition, changes in storage, as a result of pumping, are a reflection of the adequacy of replenishment from local sources below the dam.

In any hydrologic unit, the quantity of water entering the unit must equal the quantity of water being withdrawn and discharged from the unit plus or minus any changes in storage within the unit. In the hydrologic unit formed by the water-bearing deposits of the alluvial fill between San Lucas Bridge and Robinson Bridge the inflow-outflow factors are:

Inflow		*Outflow*
Precipitation		Surface flow of Santa Ynez River past Robinson Bridge
+		+
Surface flow of Santa Ynez River past San Lucas Bridge		Underflow of Santa Ynez River at The Narrows
+		+
Underflow of Santa Ynez River at San Lucas Bridge	=	Pumpage
+		+
Surface flow of tributary streams		Evapotranspiration
+		+ or −
Underflow from adjacent aquifers		Net change in storage
+		
Return irrigation water		

Estimating the various items of the hydrologic equation is difficult and at times uncertain, but some items, such as surface flow, can be measured directly. Others, such as underflow, the precipitation increment, return irrigation water, pumpage, and evapotranspiration, must be computed by indirect methods.

The author proposes to estimate all the items on the outflow side of the equation and only the surface flow and underflow of the Santa Ynez River past San Lucas Bridge on the inflow side of the equation. The remaining items of inflow are the precipitation increment, surface flow of tributary streams, underflow from adjacent water-bearing deposits, and return irrigation water, which together comprise the total contribution from sources below the dam. By selecting a period in which surface flow and precipitation are negligible, nearly all the recharge from local sources can be attributed to underflow from adjacent deposits and return irrigation water—two of the items most difficult to estimate. By treating the equation in this manner, however, the balance between inflow and outflow will not serve as a check on the accuracy of the estimates.

An examination of streamflow and precipitation records indicates that the ideal period for analysis would be the period covering the water years 1947–48 through 1950–51, during which only 1,970 acre-feet of surface flow passed San Lucas Bridge. Insufficient water-level measurements in 1947, however, make it impossible to estimate storage changes for this period, and therefore, it was necessary to use a longer time span that includes two years of considerable streamflow (1945 and 1946) but which is nevertheless well below average. The period selected is spring 1945 to spring 1951 when 53,960 acre-feet of surface flow passed San Lucas Bridge (table 1). The spring of the year is selected because water-level measurements at this time of the year most nearly represent true "static" levels—levels not drawn down by pumping. Consequently, storage changes based on spring-to-spring measurements are more accurate.

Another difficulty is the selection of the hydrologic unit itself. Because the area lends itself to division into three distinct hydrologic subareas, it would be best to deal independently with the hydrologic equation for each subarea. The advantage of such treatment is readily apparent in the Buellton subarea, where the alluvial deposits that underlie the valley floor are in hydraulic continuity with a large catchment area to the north underlain by the Paso Robles formation and Careaga sand. An estimate of recharge from the Paso Robles formation and Careaga sand would be of benefit in determining the perennial yield of the Buellton subarea. To treat the subareas independently, gaging stations at the boundaries of each subarea would be required. Gaging stations have been maintained at San Lucas Bridge, Mission Bridge, and Robinson Bridge. These stations practically limit the definition of hydrologic units to the Santa Ynez subarea independently and to the Buellton and Santa Rita subareas combined. Despite the lack of gaging stations, an attempt is made to deal with each subarea independently by estimating the outflow from the Buellton subarea in the manner described on page 13. The overall equation for the three subareas combined, however, will be considered first.

OUTFLOW

SURFACE FLOW AT ROBINSON BRIDGE

A gaging station has been operated continuously at Robinson Bridge since April 1925, and the records have been published in Geological Survey water-supply papers. From these records the outflow is computed as 9,200 acre-feet for the period April 1 to September 30, 1945; 38,970 in 1945–46; 13,940 in 1946–47; 50 in 1947–48; 2,040 in 1948–49; 1,460 in 1949–50; and no flow for the period October 1, 1950 to April 1951. The total flow for the 6-year period April 1945 to April 1951 was 65,660 acre-feet.

UNDERFLOW AT THE NARROWS

Upson and Thomasson (1951, p. 80) estimated the underflow at The Narrows to be 600 acre-feet per year. This estimate was made by use of the equation $Q=PIA$, which is explained on page 42. During the period 1935–44 the saturated cross-sectional area of the alluvial deposits at The Narrows was 87,000 square feet, the ground-water gradient was about 8 feet per mile, and the permeability of the deposits was estimated from aquifer tests to be on the order of 4,000 gpd per square foot. Thus, the underflow for the period 1935–44 was about 600 acre-feet per year. For the period 1945–51 the ground-water gradient was steeper, but the saturated cross-sectional area decreased. In 1951, on the basis of the averaged water-level measurements in wells 6/34–2A6, 7/34–35F2, 35F16, and 35L1, the water-table slope was about 22 feet in 0.85 mile or about 26 feet per mile. These same measurements show that the saturated section decreased about 7 feet in thickness, thereby resulting in a saturated cross section of about 84,000 square feet in 1951. From these data, and by use of the equation $Q=PIA$, the underflow is estimated to have been about 1,800 acre-feet in 1951. For the 6-year period April 1945 to April 1951 the hydraulic gradient increased from about 10 feet to 26 feet per mile and averaged 18 feet per mile, and the saturated cross-sectional area averaged about 85,000 square feet. Thus, for the period, the total estimated underflow was about 8,000 acre-feet.

WITHDRAWALS FOR IRRIGATION

Estimates of pumpage for irrigation are based on total kilowatt-hour figures supplied by the Pacific Gas and Electric Co. for the aggregate seasonal use of electric power in the alluvial deposits adjacent to the Santa Ynez River from San Lucas Bridge to Robinson Bridge. The irrigation season is considered as commencing April 1 and extending through March 31 of the following year. In addition to power-consumption records, the power company also made available the results of more than 130 pump-efficiency tests for pump installations in the same area. From the latter records, a mean energy coefficient of 135 kilowatt-hours was derived as the power required to pump 1 acre-foot of water. Pumpage by electric power in the alluvial deposits adjacent to the river is then prorated for each subarea in proportion to the respective number of electrically operated pumps. To the pumpage by electric power is added an estimate for pumpage by diesel, gas, and gasoline-driven pumps. The following table shows the irrigation pumpage by subareas for the irrigation seasons 1945–52.

Pumpage for irrigation along the Santa Ynez River, largely from wells in the younger alluvium, 1945–52

Subarea	Pumpage, in acre-feet, for irrigation season, largely May–November, in —							
	1945	1946	1947	1948	1949	1950	1951	1952
Santa Ynez	1,500	1,600	2,100	1,700	1,900	2,100	1,600	1,900
Buellton	7,900	7,400	9,600	8,000	9,400	9,200	7,400	8,600
Santa Rita	3,900	3,700	5,500	5,500	6,600	6,300	4,900	5,500
Total	13,300	12,700	17,200	15,200	17,900	17,600	13,900	16,000

For the 6-year period April 1945 to April 1951 the pumpage from the three subareas was 93,900 acre-feet. The preceding table omits pumpage for miscellaneous uses because they compose only a very small part of the total water pumped. For the 6-year period April 1945 to April 1951 the estimated pumpage for domestic, stock, and industrial uses was about 3,000 acre-feet, which is equivalent to about 3 percent of the total pumped for irrigation.

EVAPOTRANSPIRATION

In the period 1935–44 evapotranspiration accounted for the greatest part of the total discharge, but in recent years the rapidly increasing withdrawals for irrigation have supplanted evapotranspiration as the primary item of discharge. For the period 1935–44 Upson (Upson and Thomasson, 1951, p. 114 and 118) estimated the average yearly evapotranspiration as 3,200 and 5,500 acre-feet for the Buellton and Santa Rita subareas, respectively, but no estimate was made for the Santa Ynez subarea. These estimates were based on a summarization of the work of Troxell (1933, p. 147–172) and Muckel's study in 1944 of consumptive use of water on the bottom lands of the Santa Ana River in Riverside and Orange Counties. A factor of 2.5 acre-feet of loss per acre was computed in the summarization, but this factor could hardly be applicable to the drought period 1945–51 wherein water levels declined as much as 10 feet.

Estimates of evapotranspiration from climatological data, covering the period 1945–51, are based on a method described by Blaney (1952, p. 61–66) for determining rates of water consumption in areas where evapotranspiration measurements are not available. By the use of Blaney's formula, known consumptive-use data may be transposed from one area to another by an adjustment based on the relationship of the product of daylight hours and temperature in the one area to a similar product in the other area. Consumptive use is affected by many variables, but, of the most commonly available climatological data, temperature and daylight hours probably have the greatest influence on growth. Disregarding the unmeasured factors, seasonal consumptive use may be expressed mathematically by the formula:

$$U=KF=\text{sum of } kf$$

where

U=consumptive use (or evapotranspiration) in inches for any period

F=sum of the monthly consumptive-use factors for the period (sum of the products of mean monthly temperature and monthly percent of daytime hours of the year)

K=empirical consumptive-use coefficient

t=mean monthly temperature, °F
p=monthly percent of daytime hours of the year
$f=t \times p/100$=monthly consumptive-use factor
k=monthly consumptive-use coefficient
$u=kf$=monthly consumptive use, in inches

Of the disregarded factors, humidity is probably the most serious. In a coastal valley fog might both diffuse and weaken the sunlight and maintain high humidity near the ground, reducing the transpiration accordingly. In the absence of humidity and pan records, however, there is not recourse but to ignore the effects of humidity as well as a number of lesser factors.

Acreages of phreatophytes in the river-bottom lands of the Santa Ynez River were plotted and measured from air photos and adjusted to acreages at 100-percent volume density—that is, that product of the areal and vertical densities (Gatewood and others, 1950, p. 25). Comsumptive-use values obtained from studies in the San Luis Rey Valley (Blaney, 1946, p. 211–226) were applied to these acreages after being adjusted by the ratio of the consumptive-use factor (f) in the San Luis Rey Valley to the consumptive-use factor in the Santa Ynez River basin. The San Luis Rey studies were conducted with the water level maintained at selected depths, and the results were integrated with known depth to water in the Santa Ynez River basin for the period 1945–51. Evaporation from bare land was computed in a similar manner by transposing data compiled by Veihmeyer and Brooks (1954) at Davis, Calif. Evapotranspiration estimates for the period 1945–51 are summarized in the following table.

Average yearly consumptive use of water by native vegetation and by evaporation from bare soil, Santa Ynez River basin, 1945–51

Subarea	Native vegetation		Bare soil		Total
	Area at 100 percent volume density (acres)	Consumptive use (acre-feet)	Area (acres)	Evaporation (acre-feet)	Consumptive use of native vegetation and evaporation from bare soil (rounded) in acre-feet
Santa Ynez	337	850	752	290	1,100
Buellton	788	2,800	535	220	3,000
Santa Rita	859	2,600	1,084	420	3,000
Total	1,984	6,250	2,371	930	7,100

Ordinarily phreatophytes will use moisture from either ground water or soil moisture as it is available, and, accordingly, the use attributed to ground water must be reduced by the amount of rainfall contributed to soil moisture and used by the plants. Along the Santa Ynez River, however, the predominant phreatophytes are willows and cottonwoods which are dormant during the winter months (within which most of the precipitation occurs) and, consequently, soil moisture as a source of supply is very small compared to the season-long use of ground water.

The preceding table, therefore, shows the estimated average annual evapotranspiration, nearly all of which was obtained from ground-water sources. The estimate of 7,100 acre-feet per year, or 1.6 feet per acre per year, amounts to 43,000 acre-feet in the Santa Ynez, Buellton, and Santa Rita subareas for the 6-year period.

INFLOW

SURFACE FLOW AT SAN LUCAS BRIDGE

As in estimating the discharge of the Santa Ynez River past Robinson Bridge, stream-gaging records are available for a station maintained at San Lucas Bridge. From these records, the inflow of the Santa Ynez River is computed as 7,200 acre-feet for the period April to September 30, 1945; 34,120 in 1945–46; 10,670 in 1946–47; no flow in 1947–48; 420 in 1948–49; 1,550 in 1949–50; and no flow for the period October 1, 1950 to April 1951. The total inflow for the period April 1945 to April 1951 was 53,960 acre-feet.

UNDERFLOW AT SAN LUCAS BRIDGE

Underflow of the Santa Ynez River at San Lucas Bridge was estimated by Thomasson (Upson and Thomasson, 1951, p. 80) as 640 acre-feet per year. No attempt is made to refine this estimate because water-level measurements in the area are not sufficient to permit a reappraisal of the ground-water gradient and change in saturated section. Estimated total underflow for the 6-year period April 1945 to April 1951 was about 3,800 acre-feet.

RECHARGE FROM LOCAL SOURCES

In addition to surface flow and underflow at San Lucas Bridge, a large quantity of local recharge is contributed by precipitation, surface flow in tributary streams, underflow from adjacent aquifers, and return of excess irrigation water. The total recharge from all local sources combined is the quantity required to balance the hydrologic equation after estimating the total outflow, the total Santa Ynez River inflow (both surface and underground), and the storage change. In summary form, the hydrologic equation for the 6-year period from April 1945 to April 1951 may be computed as follows:

Hydrologic equation evaluated for the Santa Ynez River valley from San Lucas Bridge to Robinson Bridge, 1945–51

	Acre-feet
Outflow:	
Surface flow at Robinson Bridge	65, 600
Underflow at The Narrows	8, 000
Withdrawals for irrigation	93, 900
Evapotranspiration	42, 000
Total	210, 000
Inflow:	
Surface flow at San Lucas Bridge	53, 960
Underflow at San Lucas Bridge	3, 840
Net depletion in storage	8, 000
Subtotal	66, 000
Recharge from local sources,[1] by difference	144, 000
Total	210, 000

[1] Includes precipitation, seepage loss from tributary streams, return irrigation water, and underflow supplied from adjacent aquifers.

In order to balance the hydrologic equation, it was necessary to assign 144,000 acre-feet to recharge from local sources as defined above, and consequently all the errors of estimation are included in this one item. The average yearly inflow from local sources by difference between San Lucas Bridge and Robinson Bridge, therefore, was about 24,000 acre-feet.

Upson (Upson and Thomasson, 1951, p. 125) estimated that about 20 percent of the pumped irrigation water returned to the ground-water reservoir. If this figure is tentatively accepted, pending more intensive quantitative studies, about 3,000 acre-feet of the average yearly inflow was derived from the return of excess irrigation water, and the balance of about 21,000 acre-feet is attributed to precipitation, tributary streams, underflow from adjacent deposits, and, of course, to any errors in the estimated elements of inflow and outflow. Nevertheless, assuming the errors to be relatively small, it is significant that, during the dry period April 1945 to April 1951, local resources contributed about 70 percent of the total inflow or about 24,000 acre-feet per year. Average yearly ground-water withdrawal for irrigation was only about 65 percent of the estimated recharge from local sources, including return irrigation water.

The equations for the subareas in general show the same features as the overall equation and suggest that a high percentage of the total inflow originated from local sources. In the Buellton subarea the total inflow from local sources computed by difference, consisting of recharge from precipitation, seepage loss from tributary streams, return irrigation water, and underflow from adjacent aquifers, was 54,000 acre-feet or 40 percent of the total inflow. The estimated combined recharge in the Buellton subarea, attributable to deep percolation of precipitation, inflow from tributary streams, and return irrigation water, was roughly 12,000 acre-feet for the period 1945–51. Consequently, assuming no errors in the estimated elements of inflow and outflow, about 42,000 acre-feet of ground water must have been contributed as underflow from adjacent aquifers.

Table 4 has been prepared to show the method of balancing the hydrologic equation for the Santa Ynez River basin by subareas for the period 1945–51.

TABLE 4.—*Hydrologic equation evaluated for the subareas, Santa Ynez River basin, April 1945–April 1951*

	Outflow and inflow for indicated subareas in acre-feet		
	Santa Ynez	Buellton	Santa Rita
Outflow:			
Santa Ynez River	73,000	62,000	65,660
Underflow	5,300	2,800	8,000
Pumpage	10,900	51,500	31,500
Evapotranspiration	6,600	18,000	18,000
1. Total outflow	96,000	134,000	123,000
Inflow:			
Santa Ynez River	53,960	73,000	62,000
Underflow	3,800	5,300	2,800
Storage depletion	2,200	1,800	4,000
2. Subtotal	60,000	80,000	69,000
Recharge from local sources by difference (1−2) [1]	36,000	54,000	54,000
Total inflow	96,000	134,000	123,000

[1] Local sources include precipitation, seepage loss from tributary streams, return irrigation water, and underflow from adjacent aquifers.

This analysis suggests that rocks in contact with the alluvium, principally the Paso Robles formation and the Careaga sand along the north side of the valley, contributed an average yearly underflow to the alluvium of about 7,000 acre-feet.

In the Santa Ynez and Santa Rita subareas the total inflows from local sources were 36,000 and 54,000 acre-feet, respectively, estimated by difference and consisting of recharge from precipitation, inflow from tributary streams, return irrigation water, and underflow from adjacent aquifers. The estimated recharge in the Santa Ynez and Santa Rita subareas was roughly 24,000 and 13,000 acre-feet, respectively, attributable to precipitation, inflow from tributary streams, and return irrigation water. Thus, assuming no errors in the estimated elements of inflow and outflow, the results suggest that about 12,000 acre-feet in the Santa Ynez subarea and 41,000 acre-feet in the Santa Rita subarea were contributed by underflow from the adjacent areas north and south of the river which are underlain by consolidated rocks. However, it does not seem possible that average yearly underflows of about 2,000 acre-feet in the Santa-Ynez subarea and nearly

7,000 acre-feet in the Santa Rita subarea could have been supplied from these consolidated rocks to the younger alluvium.

Although the consolidated rocks may be sufficiently fractured to store water and to yield it to the valley alluvium in moderate amounts, it seems more likely that the above figures for underflow from the consolidated rocks (which, of course, were computed by difference as a part of the underflow from the adjacent rocks and deposits) in all three subareas are high because of errors in the estimated elements of inflow and outflow. The estimates subject to significant error are return irrigation water and deep penetration of rain. The above analysis suggests that these estimates are low, but further detailed studies would be necessary to refine them and, in turn, to obtain a more accurate estimate of the underflow from adjacent rocks.

SANTA YNEZ UPLAND

As stated previously, the water-bearing deposits in the Santa Ynez subarea underlie two main areas that are separated by a nearly continuous westward-trending barrier of impermeable consolidated rocks (p. 38). The smaller of the two areas, along the Santa Ynez River between San Lucas Bridge and Mission Bridge, is not in hydraulic continuity with the larger area to the north, termed the Santa Ynez upland, which is 150 to 200 feet above the river (Upson and Thomasson, 1951, p. 25). Consequently, the upland receives no replenishment from the river; rather, water percolating beneath the upland flows southward until it reaches the impermeable barrier, then rises to the surface in the lower reaches of Alamo Pintado, Zanja Cota, and Santa Agueda Creeks, and discharges southward across the barrier into the Santa Ynez River. The upland, therefore, is a hydrologic unit separate and distinct from the alluvial deposits of the river, unless there is some transfer directly through the barrier.

Depletion and replenishment have not been computed for the upland because of the paucity of data, but some general conclusions can be drawn from a comparison of figures 6 and 14. Hydrographs of wells 6/30–29E1 and 6/31–21H2 (fig. 6) show essentially a complete recovery of ground-water levels in 1952 in the alluvial deposits contiguous to the Santa Ynez River; whereas the hydrographs of wells in the Santa Ynez upland (fig. 14) do not. Although water-level data for the Santa Ynez upland are available only since 1942, they are sufficient to show that withdrawal for irrigation during the period 1945–51 exceeded replenishment, with little recovery as a result of the 1952 above-average precipitation. The greatest declines were observed in about the center of the upland, and the least at the south end of the upland near the impermeable rock barrier.

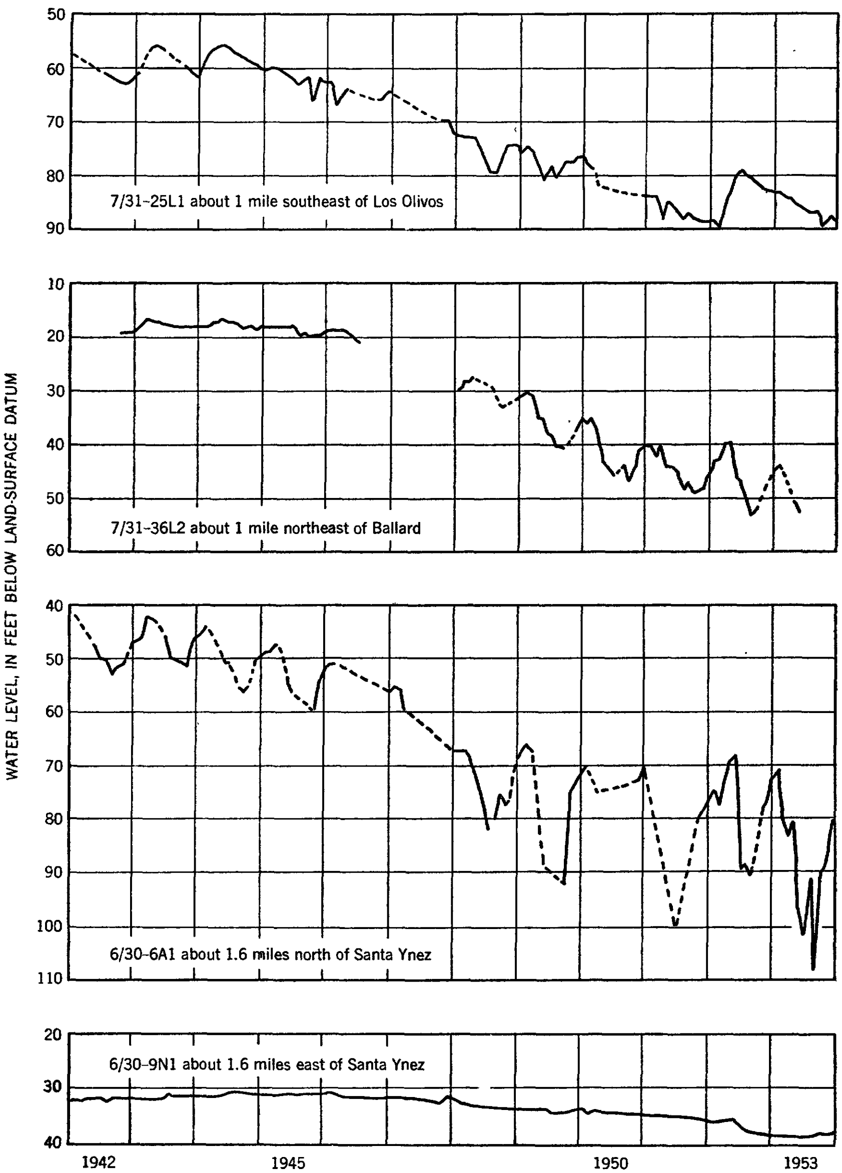


FIGURE 14.—Fluctuations of water levels in four wells in the Santa Ynez upland.

The above evaluation suggests an overdraft, at least for the period 1945–52, but whether the long-term perennial yield is being exceeded cannot be determined until water-level fluctuations can be observed over the next wet period. If depletion of storage should continue during the next period of above-average recharge, the perennial yield of the basin will be shown to have been exceeded. This is a critical problem with regard to the maximum development of the water resources of the Santa Ynez River basin as a whole, and its solution is dependent on the ultimate needs of the upland, the long-term rate of replenishment to the upland, and the cost of developing supplemental water if needed.

A few wells in the upland draw water from the Careaga sand and the terrace deposits, but most wells are perforated in the Paso Robles formation. The main source of replenishment is an extensive catchment area north and east of the upland where the Paso Robles formation and Careaga sand crop out. A large part of the recharge must be supplied directly by deep infiltration of rain and seepage loss from streams. Other sources of replenishment may exist, but little is known regarding them. An intensive study to define the sources of recharge to this area should be undertaken.

Another potential source of recharge may be Cachuma reservoir, which, when full or nearly full, will extend northward into tributary valleys and inundate a part of the Paso Robles formation in the area east of the Santa Ynez upland. A record of water levels in wells along the east margin of the upland might possibly reveal an increase in gradient toward Santa Agueda Creek as the result of recharge from the reservoir.

LOMPOC SUBAREA

GENERAL HYDROLOGY

The Lompoc subarea, the lowermost reach of the Santa Ynez River basin, constitutes the area between The Narrows and the Pacific Ocean and between the Purisima Hills and the Santa Ynez Mountains. The principal tributary valleys are Cebada and Purisima Canyons on the north, and San Miguelito, San Pascual, Rodeo, and Lompoc Canyons on the south (pl. 3). Unconsolidated deposits underlie the Lompoc plain and are exposed in the adjacent and extensive low foothills to the north and in the structural trough between the Purisima and Santa Rita Hills. Consolidated rocks underlie the unconsolidated deposits at depth beneath the valley area and are exposed in the Purisima Hills to the north, in the Santa Rita Hills to the east, in the steep foothills of the Santa Ynez Mountains along the south side of the Lompoc plain, in The Narrows, and along both sides of the plain near and at the coast (Upson and Thomasson, 1951, pl. 3).

The unconsolidated water-bearing deposits contain two water bodies, namely: a shallow water body which is contained in the river-channel deposits and lenses of permeable material in the upper member of the younger alluvium, and a deep water body which is contained in the lower member of the younger alluvium and in the underlying unconsolidated deposits comprising the terrace deposits, Orcutt sand, Paso Robles formation, and Careaga sand.

SHALLOW WATER BODY

The shallow water body is considered separate from the deep water body because it is generally unconfined, the water level fluctuates to a lesser degree than the deep water, and, where comparisons can be made between the shallow and the deep water, the level in the shallow water body is usually a foot to several feet higher than that of the deep water body.

The shallow water body is continuous with the deep water body in the vicinity of Robinson Bridge, off the mouths of the side canyons along the southern part of the Lompoc plain from Lompoc Canyon eastward, and in the small area along the river in secs. 23 and 24, T. 7 N., R. 35 W. Elsewhere the shallow water body is more or less separated from the deep by overlapping lenses of relatively impermeable material that greatly retards the interchange of water.

DEEP WATER BODY

The deep water body is contained in the lower member of the younger alluvium and the underlying formations of unconsolidated material. The lower member of the younger alluvium, having the greatest permeability of the water-bearing formations, is termed the main water-bearing zone. The buried terrace deposits in the southern third of the plain also are of good permeability, and are termed the secondary water-bearing zone. The water in the Orcutt, Paso Robles, and Careaga formations is yielded less readily, and very few wells tap these formations. However, beneath the Lompoc plain, the water in these formations is probably interconnected with water in the main water-bearing zone where the containing formations are in contact with the lower member of the younger alluvium.

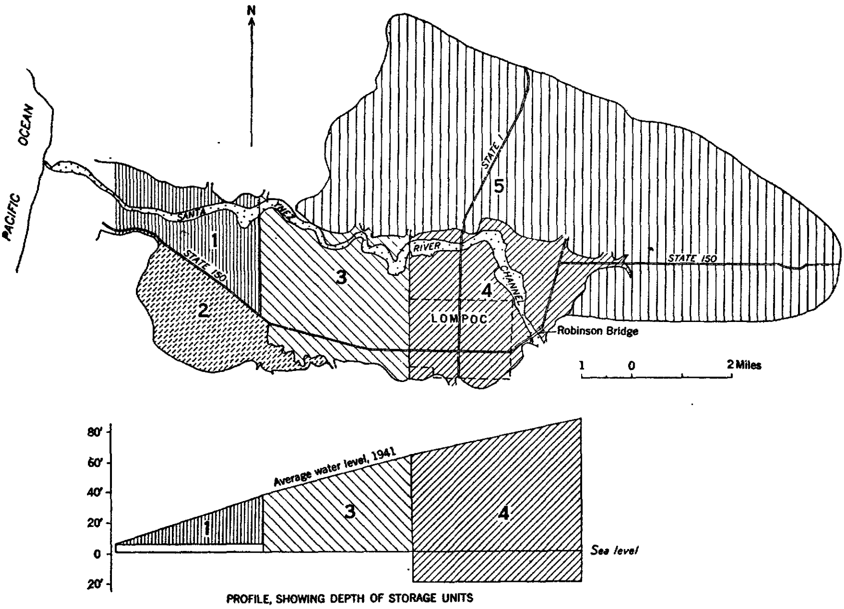
For the most part, the main water-bearing zone is overlain by the relatively impermeable deposits of the upper member of the younger alluvium, which forms a confining bed beneath which the water in the main zone is held under artesian pressure. Only in local areas, already mentioned, does free interchange occur between the deep and shallow water.

Water in the main water-bearing zone percolates westward through the lower member of the younger alluvium, is discharged through a natural submarine outlet offshore from the mouth of the Santa Ynez River, and additional discharge takes place artificially by withdrawals from wells. Water so transmitted through the zone to points of discharge is believed to be replaced from four principal sources (Upson and Thomasson, 1951): from the Santa Ynez River by percolation downward through the river-channel deposits; from tributary streams by percolation through pervious deposits at the mouths of the several canyons along the south margin of the Lompoc plain; from the shallow water body by downward drainage and leakage across the contact between the upper and lower members of the younger alluvium; and from contiguous parts of the older alluvial deposits and Careaga sand by movement of ground water toward the Lompoc plain. It will be shown in later paragraphs that the recharge by seepage loss from the Santa Ynez River formed only a small part of the total replenishment and that the bulk of the recharge must have come from local sources, principally from the area contiguous with the main water-bearing zone.

STORAGE CAPACITY FOR GROUND WATER

The total volume of unconsolidated deposits overlying the Careaga sand beneath the Lompoc plain was estimated by Upson in a preliminary report of water storage in 1943, to be slightly more than 2 million acre-feet, but the main, secondary, and shallow water-bearing zones were estimated to contain only about 30 percent of this total. In a coastal valley the quantity of water available for recovery, however, is dependent, not on the total volume of water stored in the water-bearing aquifers, but rather, on the volume of stored water that can be utilized without causing salt-water intrusion into the basin. The main water-bearing zone at the western end of the Lompoc plain is in direct contact with the Pacific Ocean, and because the recorded hydraulic gradient has remained seaward, the encroachment of salt water has been prevented. Lowering the piezometric surface below sea level near the coast would permit a reversal of the hydraulic gradient and ultimate contamination of the potable supply. Without an effective artificial ground-water barrier at or near the coast, the maximum depth to which the ground-water reservoir beneath the Lompoc plain can be dewatered is limited by the minimum water-level altitudes necessary to prevent the landward advance of sea water. In the seaward segment of the Lompoc plain this minimum water-level altitude is about 5 feet above sea level, and farther inland the piezometric surface can be drawn down to or even below sea level without endangering the supply.

To compute the storage capacity of the Lompoc subarea, the area underlain by water bearing deposits were divided into five storage units, as shown on figure 15. Units 1, 3, and 4 are composed of the younger alluvium and river-channel deposit; unit 2 includes elements of younger alluvium, terrace deposits, Orcutt sand, and Careaga sand; and unit 5 includes terrace deposits, Orcutt sand, Paso Robles formation, and Careaga sand. In storage units 1 to 4 the upper limit of ground-water saturation is taken as the highest of record in the spring



ESTIMATED GROUND-WATER STORAGE CAPACITY

Storage unit	Base of storage unit above or below mean sea level, in feet	Surface area, in acres	Volume of deposits, in acre-feet	Specific yield, in percent	Storage capacity, in acre-feet
1	5	2980	58,000	12.2	7100
2	5	2820	93,000	8.0	7400
3	0	5060	262,000	12.2	32,000
4	20	5440	520,000	18.4	96,000
5	*	22,660	1,130,000	8.0	90,000
	Total	38,900	2,063,000	11.2	230,000

*50 ft below average water level in 1948

FIGURE 15.—Sketch map showing areas, depths, and volume of recoverable water in the Lompoc subarea.

of 1941. The base of the storage units was set at 5 feet above sea level in units 1 and 2, for reasons previously described, at sea level in unit 3, and at 20 feet below sea level in storage unit 4. For storage unit 5 the depth zone or layer used was the 50-foot interval below the highest water levels of record in the period 1948–52.

Table 5 and figure 15 also show a tabulation of the surface area, volume of saturated deposits, estimated specific yield, and estimated storage capacity for each of the five units. The surface area of each unit was plotted and measured and multiplied by the average depth of the storage zone to obtain the total volume of the storage unit.

The specific yield of the storage units was estimated by the same method used for calculation of the water-storage capacity of the alluvial deposits along the Santa Ynez River above The Narrows, following the method used by Eckis (1934) in the south coastal basin. Briefly, the procedure required an analysis of all well logs within

TABLE 5.—*Estimated ground-water storage capacity of the Lompoc subarea.*

Storage unit	Base of storage unit above (+) or below (−) mean sea level (feet)	Surface area (acres)	Volume of deposits (acre-feet)	Estimated specific yield (percent)	Storage capacity (acre-feet)
1	+5	2,980	58,000	12.2	7,100
2	+5	2,820	93,000	8	7,400
3	0	5,060	262,000	12.2	32,000
4	−20	5,440	520,000	18.4	96,000
5	(1)	22,660	1,130,000	8	90,000
Total		38,900	2,063,000	11.2	230,000

1 50 feet below average water level in 1948.

each storage unit, using only that part of the log contained in the respective depth zone. Materials reported in the well logs were grouped in five broad classes: gravel, sand, fine sand, cemented gravel, and silt and clay. The specific-yield value assigned to each class in storage units 1, 3, and 4 was the same one used earlier to calculate the storage capacity above The Narrows: 25 percent to gravel, 30 percent to sand, 20 percent to fine sand, 10 percent to cemented gravel, and 5 percent to silt and clay. In storage units 2 and 5, however, lower specific-yield values were assigned as follows: 20 percent to gravel, 20 percent to sand, 15 percent to fine sand, 5 percent to cemented gravel, and 1 percent to silt and clay. The total thickness of each class of material was obtained and reduced to a percentage of the total thickness of all classes. A specific-yield value was then derived by obtaining specific-yield values for each class of material in proportion to the relative amounts of the material in the whole volume.

Specific-yield values obtained by this method appeared reasonable in all units, except units 2 and 5 where the relatively few well logs available were not necessarily representative. The calculated specific yield based on 8 well logs was 9.8 percent, but the percentage was arbitrarily and conservatively reduced to 8 percent.

Storage units 1, 3, and 4, comprising the major part of the Lompoc plain, have an estimated ground-water storage capacity of about 135,000 acre-feet. Units 2 and 5 northeast and southwest of the plain have an estimated storage capacity of about 97,000 acre-feet, the five units together making an aggregate total of 230,000 acre-feet.

CHANGES IN GROUND-WATER STORAGE

During the 7-year period 1945–52 changes in ground-water storage occurred beneath the Lompoc plain and beneath the foothill areas covering some 35 square miles to the north and east and about 5 square miles to the south and west. The changes that occurred beneath the plain can be estimated from data on more than 100 wells, whereas the changes beneath the extensive foothill areas can be approximated only roughly from meager data on a few wells.

CHANGES BENEATH THE LOMPOC PLAIN

Ground-water storage changes beneath the Lompoc plain have been limited essentially to the depletion and replenishment of the shallow water body contained in the upper member of the younger alluvium and the river-channel deposits. At no time has the highly productive main water-bearing zone, contained in the lower member of the younger alluvium, been dewatered. However, at the conclusion of the dry period ending in 1951 the pressure head was reduced to the record low. Of course, there was a loss in storage, but one that was negligible in comparison to the loss in the shallow water body, because the coefficient of storage is much smaller in a confined than in an unconfined water body.

WITHDRAWALS IN RELATION TO REPLENISHMENT

As shown by Theis (1938), water withdrawn from a confined water-bearing zone is drawn initially from storage by a compression and compaction of the water-bearing zone itself, by compaction of the enclosing fine-grained strata, and also to a slight extent by expansion of the water itself. If pumping continues a sufficient time, the cone of depression in the piezometric surface eventually will intercept the area or areas where the aquifer emerges from beneath the upper confining bed and the water is under water-table conditions. When this occurs, water will be drawn from the water-table areas, where measurable storage changes will occur. Essentially no change in volume will be observed in the confined-water area because the water-bearing zone, under pressure, remains saturated. Declining water levels in wells perforated or screened in this zone indicate a change in head, but only a minor change in volume. Storage changes in the Lompoc plain are measured, therefore, by observing the depth to water in both deep and shallow wells in the recharge area at the eastern end of the plain, and only in shallow wells perforated in the shallow water body that overlies but is separated to some degree from the confined water body beneath the western two-thirds of the plain. All the contour maps showing storage change presented in this report were constructed on this basis.

The hydrograph of well 7/34–27L1 (fig. 16) shows typical water-level fluctuations in the recharge area of the Lompoc plain. Between 1930 and 1941 withdrawals of ground water were balanced by an equal amount of recharge, and ground water in storage remained nearly constant, except for a small increase in storage during the last few years of the period. After the unusually wet years 1935–41, withdrawals nearly doubled during the dry period 1945–51. As a result, the water table dropped a maximum of about 20 feet to the lowest

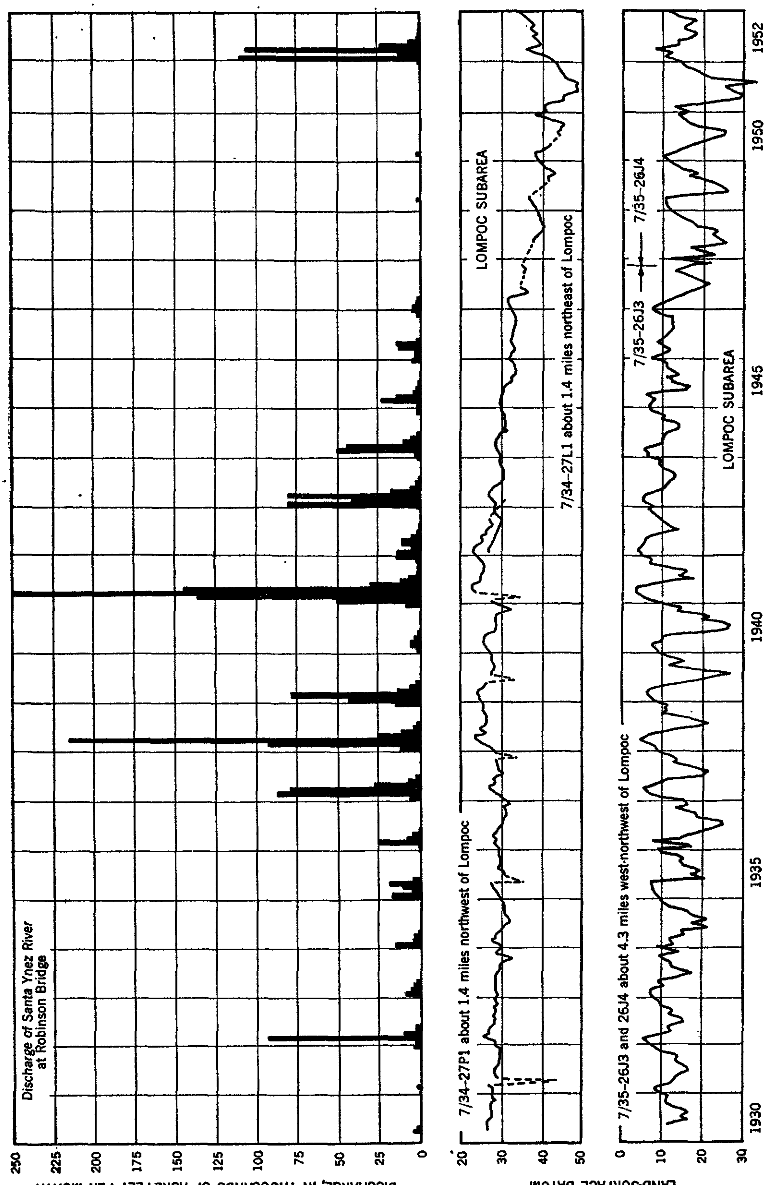


FIGURE 16.—Fluctuations of water levels in two wells in the Lompoc subarea, and stream flow at Robinson Bridge, 1930–52.

level on record. Lesser declines during the same period were observed in the shallow water body which overlies the confined water at the western end of the plain. In the main water-bearing zone the hydrographs of wells 7/35–26J3 and 7/35–26J4 (pl. 25) show that the piezometric surface declined about 8 feet between March 1945 and April 1951.

The period 1947–51 was particularly critical in that replenishment of the ground-water bodies from the Santa Ynez River was incomplete. Runoff past Robinson Bridge (pl. 25) was at an all-time low just when the withdrawal of ground water was at an all-time high. Had the river been the sole source of recharge, this coupling of diverse events would have been catastrophic to the Lompoc reservoir; but such was not the case. Ground-water replenishment from sources other than the river kept the rate of depletion at about 2,500 acre-feet per year. The large recharge in 1952 replenished much of the depleted storage beneath the Lompoc plain.

METHOD OF COMPUTATION

In an area of free ground water, the volume of water involved in the zone of water-level fluctuations during dewatering or resaturation is a measure of the change of ground water in storage. This change can be determined by multiplying the total volume of material in the zone of fluctuation by the specific yield of the material.

Determination of the volume changes of ground water in storage in the Lompoc plain is a less difficult task than it is above Robinson Bridge, because the measuring of water levels on the plain has been more extensive, and consequently, the areal coverage of wells is sufficient to permit drawing water-level contours for any desired dates since 1931. The change in storage can be computed for any selected period by superimposing one contour map upon the other. A comparison of the two water-level contour maps makes possible the construction of a "net-change" contour map showing the net change in ground-water storage for the period under consideration. The total volume of material that has been either dewatered or saturated is determined by measuring the areas of the net-change contours. Because the water that occupied this volume is a relatively small fraction of the total volume of material, it is necessary to multiply this total volume by a figure for specific yield of the deposits in order to obtain the volume of water involved in the storage change.

The specific yield was determined approximately from the physical composition of the material in the zone of water-level fluctuation during the period of 1945–52. The method is summarized on pages 29–30 and is discussed in detail in the determination of specific yield for the alluvial deposits upstream from Robinson Bridge. This method estimates the proportions of the different classes of material in an area, as revealed by well logs, and assigns a specific-yield value to each of five classes. The proportions of the various classes of material were determined for 10-foot intervals or layers in the zone of water-level change. To insure complete coverage of the zone of fluctuation, the 5-foot layer above the high water level and the 5-foot layer below the low water level also were included in the study.

In the unconfined area, or area of recharge, which covers about 5,000 acres, the weighted specific yield for the full zone of water-level fluctuation is 14.1 percent. The highest specific yield occurs in the layer 20 to 30 feet below the uppermost limit of saturation wherein the largest quantity of gravel is found; the specific yield for this layer is 17 percent.

In the confined area, in which there is an abundance of clay and silt and which underlies approximately two-thirds of the Lompoc plain or about 10,000 acres, the average weighted specific yield for the zone of water-level fluctuation is 11.5 percent. The highest specific yield occurs in the layer 10 to 20 feet below the uppermost limit of saturation wherein there is a large quantity of gravel and a small quantity of clay. The specific yield for this layer is 13.2 percent.

The average weighted specific yield, based on the areal extent of the two areas, is 12.4 percent.

WATER-LEVEL CONTOURS

The Geological Survey began to measure wells in the Lompoc subarea in January 1941. Prior to that time and extending back to 1930 the city of Santa Barbara measured wells in this area in connection with the so-called Gin Chow water suit. The Geological Survey selected observation wells for the dual purpose of obtaining adequate areal control and of maintaining records on wells for which water-level measurements would be representative of the water levels in that area and in the zones tapped. Also, shallow wells were drilled, many of them close to deep wells, to provide water-level data on the shallow water body for comparison with levels in wells tapping the deep water body in studies of the relation between the shallow and deep water bodies.

In 1945, the beginning of the drought period, the discharge of ground water began to exceed the recharge and water levels began to decline. The resulting decrease in storage continued through the fall of 1951, but was followed by a wet year in which the trend was reversed, recharge exceeded discharge, and water levels rose to stages nearly as high as those in the last wet year of 1944.

Contour maps were constructed for March 1945, the first year of the drought period, and for April–May 1951, the last year of the continuous drought period. The water levels plotted on these maps were based on measurements by the Geological Survey and include measurements of wells tapping the main water-bearing zone in the unconfined area of the eastern and southeastern portions of the Lompoc plain, and of wells tapping the shallow water body in the confined area of the central, western, and northern portions of the plain.

The water-table contours on plate 7 show the configuration of the water table for March 1945, near the spring high level. East of the river, and for a short distance downstream from Robinson Bridge, the water-table slope was gentle and generally parallel to the river; but farther downstream, near H Street Bridge, there was a slope from the north, toward the river. West of the river the slope was much steeper, at least for the first 3,000 feet downstream from Robinson Bridge, and everywhere away from the river. The map indicates recharge from The Narrows and vicinity, from the northeast, east, and from the southeast. The altitude of the water table was everywhere above mean sea level, and the direction of the subsurface flow in general was parallel to the river and toward the coast.

During April–May 1951 water levels were considerably depressed as a result of below-normal precipitation and increased withdrawals. The water-table contours for this period on plate 7 show that east of the river the water-table slope was parallel to the river for a much shorter distance than in March 1945. Heavy withdrawals from the eastern end of the plain, with little or no surface flow in the river, steepened the ground-water gradients to the east and northeast, indicating increased recharge by subsurface inflow from these areas. Recharge was indicated from the southeast also. West of the river the slope of the water table was everywhere away from the river, but the gradient was somewhat gentler than that in 1945. The contours suggest also some recharge along the south side of the plain. The principal direction of subsurface flow was generally westward beneath the plain, and water levels were lower—the greatest declines being at the eastern end or recharge area of the plain.

Pumping during the irrigation season in 1951 lowered the water table to the lowest of record, as shown by the contours on plate 7 for October–November 1951. Gradients were steepened, but the same general features shown by the contour map of April–May 1951 were still in evidence. Even during this period of record-low levels, the contours show that ground water was moving westward toward the coast.

From a comparison of the water-table contours, net-change contours were prepared for the periods March 1945 to April–May 1951 and April–May 1951 to October–November 1951, and these are shown on plate 7. To determine the total volume of material dewatered between

April 1945 and October–November 1951, the areas of the net-change contours were measured and added.

DEPLETION, 1945–51

The total volume of material dewatered during the period March 1945 to April–May 1951, based on the net-change map (pl. 7), was about 127,000 acre-feet. By applying the average specific-yield value of 12.4 percent, previously determined, to the total volume, the estimated ground-water storage depletion was about 15,700 acre-feet. The net-change map shows that the greatest decrease in storage was in the recharge area of the plain just below Robinson Bridge where a craterlike depression in the water table was formed as a result of heavy withdrawals during a period in which there was little or no flow in the river. Water levels in wells near the center of this crater were more than 20 feet lower than they were in 1945. Depletion throughout the remainder of the plain was not as critical as in the recharge area. In the area of confined water, including most of the western two-thirds of the plain, maximum water-level declines in the shallow water body for this period were between 5 and 10 feet.

The contours of water-level change on plate 7 show that water levels were lowered an additional 6 feet immediately west of Robinson Bridge during the period April–May to October–November 1951. Thus, the lowest levels on record were observed in the fall of 1951 just prior to the heavy winter rains of January 1952. The volume of deposits dewatered from spring to fall 1951 was about 18,500 acre-feet which, times the specific yield of 12.4 percent, indicates an estimated depletion of 2,300 acre-feet. Thus, the estimated total depletion from spring 1945 to fall 1951 was 18,000 acre-feet.

REPLENISHMENT, 1951–52

Recoveries of water levels beneath the Lompoc plain during the early months of 1952 were not complete, as shown by a comparison of the contours of March 1945 with those for March–April 1952 (pl. 7). The above-average precipitation throughout the watershed produced a runoff at Robinson Bridge of 229,230 acre-feet during the months of January, February, and March. Much of this runoff passed overland and wasted to the sea, as evidenced by the fact that 265,260 acre-feet passed the gaging station at Surf. Nevertheless, considerable quantities percolated underground to recharge the ground-water reservoir.

The contours of water-level change for the period October–November 1951 to March–April 1952 (pl. 7) shows that the craterlike depression in the water table, which had formed just downstream from and west of Robinson Bridge, was almost eliminated during the winter storms of 1952. Locally water levels rose almost to the highest stages on record, but, for the most part, they were lower than those in 1944 and 1945. As computed from the storage change and a specific yield of 12.4 percent, a total of nearly 11,000 acre-feet percolated to storage.

EVALUATION OF STORAGE CHANGES

As in the river reach from San Lucas Bridge to Robinson Bridge, the storage changes computed for the Lompoc plain are accurate only to the extent to which the estimates of the volume change of water-bearing material and of the specific yield are accurate. For the Lompoc plain, the volume change in the saturated materials is based on the contouring of the water levels in about 75 wells so that the estimates derived should be reliable. Unfortunately, the determination of specific yield, of necessity, had to be by an indirect method.

The specific-yield estimate ordinarily can be refined by laboratory analyses of core samples, or by an aquifer test in which one well is pumped and the drawdown is observed in one or more observation wells. In the Lompoc subarea, refinement of specific yield values would not be warranted until better estimates of deep percolation from rainfall, return irrigation water, and evapotranspiration are obtained. As for aquifer tests, the few run on the plain to date show that artesian or semiartesian conditions prevail nearly everywhere throughout the plain. However, specific yield can be obtained only from a test performed under water-table, not artisan, conditions.

For the present, the estimates of ground-water storage changes in the shallow water body are considered the best approximations possible, and they are believed to be of the correct order of magnitude. Table 6 summarizes the storage changes during the period 1945–52.

Table 6 shows that the estimated depletion in storage from March 1945 to October–November 1951 was 18,000 acre-feet and that the replenishment from October–November 1951 to March–April 1952 was

TABLE 6.—*Estimated net changes of ground water in storage beneath the Lompoc plain, 1945–52*

Period	Volume of material (acre-feet)	Average specific yield (percent)	Storage (acre-feet)
Depletion (saturated):			
Spring 1945 to spring 1951	127,000	12.4	15,700
Spring 1951 to fall 1951	18,500	12.4	2,300
1. Total	145,500	12.4	18,000
Replenishment (saturated):			
2. Fall 1951 to spring 1952	87,400	12.4	10,800
Net loss (spring 1945–52):			
By difference (1–2)	58,100	12.4	7,200
Net change determined by comparison of water-level contour maps (pls. 26, 31)	56,800	12.4	7,000
Difference in methods			−200

10,800 acre-feet, which indicates a net depletion for the period of 7,200 acre-feet. By spanning the entire period and comparing the contours for March 1945 with March–April 1952, the estimated net depletion was 7,000 acre-feet. As indicated, the error between the two methods is only 200 acre-feet, which is only 1 percent of the total depletion. Because the methods used were the same, the minor difference must be due to interpretation of the contours and compilation of net-change maps. Accordingly, the estimated net depletion for the period is considered to be about 7,000 acre-feet.

GROUND-WATER GRADIENTS

In order to provide data on the sources of recharge, the slope of ground-water gradients, the magnitude of water-level fluctuations, and the relation between ground-water levels and streamflow, six sections showing water-level profiles were constructed and are shown on plate 8. Four cross the Lompoc plain at right angles to the river, one extends through the length of the plain approximately parallel to the river, and one extends northeastward from the plain into the Purisima Hills area. All the profiles are based on measurements in wells perforated in the shallow water body or in the unconfined part of the main water-bearing zone, and they have been drawn and lettered to correspond with the geologic sections constructed by Upson (Upson and Thomsson, 1951, pl. 5), with one exception—section *K–K′*, which is an original section prepared for this report. The positions of the sections are shown on plate 1 and also in the schematic diagram in the left-hand corner of plate 8.

The water-level profiles on section *E–F–E′* on plate 8 show the highest and lowest water levels for the period 1945–52. The profiles show that in 1945 the water level at the western end of the plain was between 6 and 16 feet below land surface, the greater depth being to the east. The coastward hydraulic gradient at this time was about 5 feet per mile, and the water levels in some wells were essentially the same as in 1941 (the highest on record) and in others a little below (2 to 6 feet).

By fall 1951 water levels in the central part of the plain had dropped between 8 and 12 feet below the levels of 1945, and at the eastern end of the plain the maximum decline was about 20 feet. Between wells 7/35–23J3 and 22M2 the seaward gradient was 3 feet per mile.

The sections show graphically the range of water-level fluctuations during the period 1945–52, but they are even more important in demonstrating the existence of sources of recharge other than the river. Sections *K–K′* and *F–F′* both traverse the recharge area of the plain near Robinson Bridge at right angles to the river. The profiles show that a ground-water mound was established in the vicinity of the river during flood stages, such as occurred in the springs of 1945 and 1952. The ground-water mound is superimposed on a regional gradient that in general slopes from east to west. Hence, even during periods when seepage loss occurs from the Santa Ynez River, recharge still is coming from the east and northeast, as indicated by the overall gradient. Even more conclusive of the concept of recharge from the northeast is the slope of the water table during periods when there is no flow in the river. Ground-water gradients for April 1951 and November 1951, as shown on sections *F–F′* and *K–K′*, are predominantly from the area east and northeast of the river.

In the confined-water area of the plain, profiles of the shallow water body on sections *H–H′* and *I–I′* (pl. 8), show that the river has been losing or gaining, depending on the ground-water level in the shallow water body. The profiles on section *H–H′*, for instance, show that in 1945 and 1952 the water table sloped gently from the south to the river, and, because the water table was higher than the stream, water percolated from the shallow water body into the stream. During flood stages, it may be presumed that the river has contributed some water to bank storage, but, as the river stage has receded, the shallow water body has returned water to the stream channel. During prolonged droughts, when the water level in the shallow body was lower than stream-bed elevation, such as in the spring and fall of 1951, water was not contributed to the river. Changes in storage during such a period are the result of use by phreatophytes, minor pumping for domestic purposes, and downward leakage to the main water-bearing zone.

The profiles for 1945 and 1952 on section *I–I′* also show a component of slope from the south toward the river, although recharge from the river is more apparent than in section *H–H′*. This relatively large response to river recharge is possibly due to the fact that section *I–I′*, near its northern limit, extends across a recharge area as outlined by Upson and Thomasson (1951, pl. 3). In this area, the shallow water body is in fairly good hydraulic continuity with the underlying main water-bearing zone.

In summation, the large precipitation in the winter of 1952 caused water levels to rise everywhere throughout the plain. In the downstream part of the plain, the principal recharge to the shallow water body occurred from the south, and the river apparently had little recharging effect. The average rise in water level was about 7 feet. Coincident with the increase in storage in the shallow water body, water levels in the confined water body also rose. This rise in the deep water body, however, is an indication of an increase in head, and not an increase in storage.

In the recharge area, the river contributed large quantities of water to storage by building up a ground-water mound in the vicinity of the river. Although water from the recharge mound traveled in both directions away from the river, recharge from the northeast also was apparent.

CHANGES BENEATH THE LOMPOC UPLAND

The area north and east of the Lompoc plain is here termed the Lompoc upland. It is bounded on the north and southeast by the consolidated rocks in the Purisima and Santa Rita Hills, respectively, and on the east by the surface divide between Santa Rita Valley and the lower course of the Santa Ynez River, although hydrologically the area may extend into and include most of the Santa Rita Valley (Upson and Thomasson, 1951, p. 115–116 and pl. 7). The area as defined covers about 35 square miles (fig. 15) and is underlain by water-bearing deposits comprised of the Orcutt sand, Paso Robles formation, and Careaga sand. Although the deposits are tapped by only a few domestic and stock wells, the large ground-water storage capacity of the deposits is critical to the supply beneath the Lompoc plain because they are in contact with and underlie a large part of the main water-bearing zone.

The deposits generally are of low permeability, but they serve as a large catchment area of precipitation. Any rainfall that penetrates to ground water is transmitted slowly as subsurface flow to the water bodies underlying the Lompoc plain. In order to determine the quantity of water from these sources, information must be available as to the average permeability of the deposits, slope of the hydraulic gradient, and the cross-sectional area through which the underflow passes. From this information, the quantity of subsurface water inflow could be estimated mathematically by the equation $Q=PIA$.

Because there are few wells in the outcrop areas, hydraulic gradients, permeability, and cross-sectional areas are crude estimates at best. Upson (Upson and Thomasson, 1951, p. 153–155) evaluated this equation, using the meager data available at the time, and obtained an estimate of 2,500 acre-feet per year as the contribution from these older deposits. It must be noted, however, that this estimate is based almost wholly on data collected during a wet period. Lowering of the water level in the main water-bearing zone of the Lompoc plain during the dry period 1945–51, however, steepened the hydraulic gradients out of these older deposits and, thereby, increased their contribution to the plain. In an effort to evaluate this contribution, the Geological Survey arranged for the drilling of test wells in the Lompoc upland.

DATA FROM TEST WELLS

In 1948 at the request of the Geological Survey, the County of Santa Barbara contracted for the drilling of three wells in the Lompoc upland. Well 7/34–12E1 was drilled in Purisima Canyon, and wells 7/34–9H3 and 21E1 were drilled in Davis Canyon, 1 and 2 miles west of Purisima Canyon (pl. 1). The wells were drilled to obtain information on the gradient of the water table and the character of the materials to estimate the quantity of recharge contributed from this area, and to observe changes in ground-water storage.

Well 7/34–9H3, a cable-tool well, was completed on March 29, 1948, when the hole reached a depth of 105 feet and the casing was bottomed at 103 feet below land surface. On March 30 the well was bailed continuously, and then a mixture of fine gravel and coarse sand was placed in the 2 feet of open hole below the casing. Coarse crushed gravel was placed on top of the finer materials and extended up the casing to about 87 feet below the land surface. The casing is of 8-inch (inside diameter), double-stovepipe, 12-gage steel, welded watertight to a depth of about 36 feet below the land surface. The remainder of the 8-inch casing is unwelded with an open hole at the bottom. One 12-foot-4-inch length of conductor pipe, 10 inches in diameter, was driven to clay outside the 8-inch casing in an attempt to seal off the perched water.

On the first day of drilling, March 23, the driller reported that shallow water was tapped at 10 to 12 feet below the land surface. Later the drill penetrated "dry" material at about 25 feet below land surface, and then reached a water-bearing sand at 38 feet. On the morning of March 27, before drilling operations began, the water level was 8.18 feet below the land surface; but later in the day, and during drilling operations at depths between 80 and 86 feet, the water level was within 4 or 5 feet of the land surface. Before resuming drilling operations on the morning of March 29, the water

Log of well 7/34–9H3

[Unperforated 8-inch casing to 103 feet; open hole 103–105 feet. Geologic classification by R. E. Evenson]

	Thickness (feet)	Depth (feet)
Younger alluvium:		
Clay, black	30	30
Orcutt sand:		
Sand, white	6	36
Clay, sticky, light-colored	2	38
Sand, white	16	54
Sand, white; some clay	5	59
Clay, white and blue; some sand	3	62
Orcutt sand—Continued		
Sand, white; some blue clay	6	68
Paso Robles formation:		
Clay, green-gray	5	73
Clay, solid, blue	6	79
Clay, sandy, blue	4	83
Clay, sandy, brown	6	89
Clay, sandy, yellow	4	93
Sand; some clay	12	105

level measured 7.92 feet below the land surface, and on March 30 the level was 12.37 feet below the land surface; then the well was bailed. The following morning, March 31, after overnight recovery, the water level was 10 feet below land surface. The well log shows the materials penetrated.

The fluctuation in water level during drilling indicates that several different lenses of shallow water were tapped. The well apparently is bottomed in the Paso Robles formation and not in the Careaga sand as was intended. The water level in the well may be a compromise level between the water level in the Paso Robles and the water level or levels in one or more shallow perched zones.

Perched water zones occur where water, seeping downward, is stopped by an impervious layer of clay or shale and is supported by this layer above and independent of the free water table. The magnitude or areal extent of this perched water zone is unknown, but there are several springs located in this canyon and in Purisima Canyon that probably represent the discharge of perched water. The total dicharge has averaged 3 to 4 gallons per minute for the past several years. The contribution, if any, of subsurface water to the Lompoc plain from the springs, or perched water zone, is unknown.

Well 7/34–12E1 is northeast of Lompoc in the east fork of Purisima Canyon about two-thirds of a mile northward from the Union Oil Co.'s dehydration plant and about 100 feet west of the road at the left edge of an open field. Drilling of the well by a cable-tool rig commenced on April 6, 1948, and ceased on April 16 when 240 feet of casing had been placed in an open hole 278 feet deep. No water was found at any time during this drilling.

On June 12 drilling operations were resumed by the rotary method and continued until the hole was deepened from 278 feet to 385 feet below land surface. The hole was then reamed with a 7⅝-inch bit, the largest bit that would pass through the existing 8-inch casing. A string of electrically welded 6-inch casing, 168 feet long, with the bottom 40 feet perforated with 60-mesh slots, then was lowered into the hole, but the lower end of the 6-inch casing would only pass 20 or 30 feet below the bottom of the existing 8-inch casing. The difficulty was attributed to the fact that the 240 feet of 8-inch casing was not plumb. To remove the 6-inch casing, it was necessary to cut it into lengths as it was removed. After underreaming the hole with a 12½-inch underreamer, the 6-inch casing was again placed in the hole and bottomed at 384 feet without further difficulty. After circulating clear water in the well for 2 hours and bailing the well for 7 hours, about 7 feet of gravel was poured into the bottom of the

6-inch casing. The well log below shows the character of the materials penetrated.

Log of well 7/34-12E1

Unperforated 8-inch casing to 278 feet; 6-inch casing 278-384 feet, perforated 344-384 feet; open end at bottom. Well drilled to 278 feet by cable-tool equipment, and from 278 to 385 feet by rotary equipment. Geologic classification by R. E. Evenson]

	Thickness (feet)	Depth (feet)
Younger alluvium:		
Sand, hard, dark	30	30
Paso Robles formation:		
Clay, yellow, solid	3	33
Clay, yellow-green; some sand	4	37
Sand, yellow, medium	1	38
Clay, yellow, solid	6	44
Clay, yellow, and sand (alternating)	8	52
Sand, yellow (medium, free)	18	70
Sand, white	5	75
Clay, sandy (hard packed)	5	80
Sand, white, packed	10	90
Sand, yellow, heaving	8	98
Sand, white	5	103
Sand, yellow, heaving	2	105
Sand, white, free	12	117
Sand, yellow, free	6	123
Sand, white, free	57	180
Sand, white; some yellow clay	35	215
Sand, white; some yellow-green clay	6	221
Clay, light-blue, very sandy	24	245
Sand, yellow, free	7	252
Clay, blue, solid	6	258
Careaga sand:		
Sand, white, free	20	278
Careaga sand—Continued		
Clay-shale, hard, gray; occasional pebbles of shales; similar to the Monterey	4	[1] 274
Quartz sand; white, fine- to medium-grained; occasional strata of gray shale; sand packed hard below 295 feet	56	330
Clay-shale, light-blue-gray	5	335
Sea shells with some minor layers of gray shale	5	340
Quartz sand light-gray-white, fine- to medium-grained	10	340
Clay-shale, light-gray; some shells	5	355
Quartz sand light-gray-white, medium-grained	10	365
Quartz sand gray-white, fine- to medium-grained	10	375
Shale gray; shells with some intercolated white sand	5	380
Sand, white, fine- to medium-grained; some interbedded gray shale and shells	5	385

[1] Between the end of the cable tool drilling and the start of the rotary drilling the hole was filled in to 270 feet.

The static level measured a week after the well was completed was 301 feet below the land surface. For the period of published record, from 1949 through 1952, the highest daily water level was 301.70 feet below land-surface datum, June 25, 1949, and the lowest daily water level was 303.83 feet, measured December 21, 1952.

Well 7/34-21E1 is north of Lompoc, about 1 mile northwest of H Street Bridge in Davis Canyon at the north edge of an open field. Cable-tool drilling operations commenced on October 30, 1948, and were completed on November 8. The well was drilled to a total depth of 150 feet, cased with 8-inch 12-gage steel unwelded stovepipe casing to about 149 feet, cemented back to 145 feet, and perforated from 73 to 93 feet. A 10-inch conductor casing was put down outside the 8-inch casing to seal off any shallow water in the first 50 feet below land surface.

When the drill had reached a depth of 40 feet, the water level in the morning, before drilling resumed, was about 39 feet below the land surface; at a depth of 70 feet, it was 28 feet below land surface;

and at depths from 95 to 150 feet, it consistently stood about 20 feet below the land surface. For the period of published record from 1948 to 1952, the highest daily water level was 17.97 feet below land-surface datum on April 1, 1949, and the lowest daily water level was 25.02 feet below land-surface datum on August 10, 1951.

Log of well 7/34–21E1

[8-inch casing to 49 feet; perforated 73–93 feet; cement plug 145–150 feet. Geologic classification by R. E. Evenson]

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Younger alluvium:			Orcutt sand:		
Adobe	15	15	Clay, solid, blue	8	75
Clay, solid, yellow	10	25	Gravel	5	80
Gravel dry	4	29	Sand, blue and gravel	15	95
Clay, solid, yellow	5	43	Careaga sand:		
Gravel and clay	7	41	Sand, white	29	124
Gravel, water-bearing	26	67	Sand, black some black clay	17	141
			Sand, white	9	150

DATA FROM EXISTING WELLS

In addition to the three test wells drilled by the Geological Survey, well 7/34–14F1, an abandoned irrigation well in Purisima Canyon, also was available for water-level measurements.

Log of well 7/34–14F1

[Geologic classification by R. E. Evenson]

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Younger alluvium and Orcutt sand:			Paso Robles formation—Continued		
Top soil	76	76	Sand, white	34	190
Paso Robles formation:			Clay, blue (water)	20	210
Clay, yellow	20	96	Careaga sand:		
Clay, light-yellow	14	110	Sand	40	250
Gravel, dry	46	156			

This well and well 7/34–12E1 are shown on section *L–L′* (pl. 8). The section shows that both wells are bottomed in the Careaga sand, and the water-level profile for 1951 shows that the hydraulic gradient was about 10 feet per mile toward the Lompoc plain. This checks the hydraulic gradient that was assumed by Upson and Thomasson (1951, p. 154) and confirms, in addition to sections *K–K′* and *F–F′*, that ground water moves from the outcrop areas of the Orcutt sand, Paso Robles formation, and Careaga sand toward the Lompoc plain. Because water is contained in the older deposits and because the hydraulic gradient is favorable, pumping on the Lompoc plain induces water to move out of the older deposits principally into the main water-bearing zone beneath the plain. Any increase in pumping steepens the gradient and, thus, induces increased movement of water from the older deposits. How long this draft could be sustained is dependent principally on the volume of water in storage in the older deposits and the rate of replenishment to them.

DEPLETION, 1948–52

Because essentially all the pumpage in the Lompoc subarea is restricted to wells tapping deposits beneath the Lompoc plain, there are few wells in the Lompoc upland other than those previously discussed, and not all are accessible for measurement. As a result of the scarcity of observation wells it is difficult to estimate net water-level changes in the upland area. Water-level measurements in wells 7/34–12E1, 14F1, 21E1, and 9H3, however, suggest that the water table declined on the average about 1.3 feet per year in the period 1948–52. Assuming the total area of the upland to be 22,600 acres (storage unit 5, fig. 15) and the specific yield to be 8 percent, the total net change in ground-water storage amounted to a decrease of about 2,400 acre-feet per year for the period 1948–52.

CHANGES BENEATH THE AREA NEAR LOMPOC CANYON

South and west of the Lompoc plain, in an area that lies between Lompoc and Rodeo Canyons, the Orcutt sand and Careaga sand crop out to provide a catchment area of a little less than 5 square miles (storage unit 2, fig. 15). Water-level information in this area is very meager, owing to the scarcity of observation wells, just as it is in the Lompoc upland. A few wells along the northern edge of the area, however, have been available for water-level measurements since 1948. These measurements suggest a water-level decline of 1.2 feet per year in the period 1948–51. Assuming that this water-level change is representative of the area, the net change in ground-water storage, based on an area of 2,820 acres and a specific yield of 8 percent (fig. 15), amounts to about 300 acre-feet per year in the period 1948-51.

EVALUATION OF STORAGE CHANGES OUTSIDE THE LOMPOC PLAIN

Water level and geologic data for the period 1935–44 show that the areas underlain by unconsolidated deposits on both sides of the plain comprise about 20 square miles; but later information, particularly the discovery of noticeable ground-water gradients out of the Santa Rita Hills, has nearly doubled the area to be considered. As indicated in the two previous sections, the Lompoc upland now measures about 35 square miles and the area near Lompoc Canyon totals about 5 square miles. Ground-water storage changes in these areas are indicative of the contribution from the older water-bearing deposits to the main water-bearing zone of the Lompoc plain.

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Although Upson (Upson and Thomasson, 1951, p. 161–162) had little information as to the character of water-level fluctuation, he discussed the possible rates of replenishment to and transfer from the Orcutt, Paso Robles, and Careaga outcrop areas in general terms. In review he reasoned thusly:

> * * * let it be assumed that all the rain that percolates below the influence of vegetation outside the Lompoc plain on the outcrop areas of the Orcutt, Paso Robles, and Careaga formations, and within the area of favorable hydraulic gradient, is able to reach the deep-water body. The area of outcrop (see pl. 3) on both sides of the valley is roughly 20 square miles, or about 19.28 inches for the years 1935–44, but probably only a small part of it has penetrated to the deep-water body. Blaney (1930, p. 54) has shown that the consumptive use of water by native brush has been at least 1.5 acre-feet per acre per year in five areas in southern California.
>
> Thus, any excess of rainfall over 1.5 feet, or 18 inches, is considered available for runoff and for deep percolation. Subtracting 18 inches from the seasonal rainfall at Lompoc gives an excess of 2.46, 7.40, 2.69, and 0.47 inches in the years 1937, 1938, 1941, and 1942, respectively. In other years the rainfall was less than 18 inches. These excesses average 3.3 inches per year for the 10-year period, or 3,600 acre-feet a year on the whole area. Part of this amount probably runs off, and the deep infiltration may have averaged somewhat less. If it amounts to 3,000 acre-feet, the recharge to the deep-water body is little more than the amount computed to pass from the underlying deposits to the main water-bearing zone (p. 139). If the computed amount is much too small, a real deficiency may exist. Further, because the 10-year period here considered includes the year of greatest recorded rainfall, the long-term average may be appreciably less.
>
> If a deficiency exists, it would be represented by unwatering in the outcrop areas of these older formations. Taking the total areas as 13,000 acres and the specific yield as 14 percent (the value for the younger alluvium, p. 133, which may be high for the older formations), a deficiency of replenishment in the outcrop areas amounting to 1,000 acre-feet in a year would cause a decline of water level on the order of 0.6 foot average over the entire area. * * *

In the period 1948–51, the net storage change previously computed for the outcrop areas amounted to a decrease of about 2,700 acre-feet per year. Following the analysis of Upson, the 2,700 acre-feet a year decrease in storage represents a deficiency of replenishment in the outcrop areas of the older formations. From a later analysis (p. 85), estimated replenishment to the outcrop areas amounted to 900 acre-feet per year, therefore, the total contribution from the older deposits to the plain is estimated to be about 3,600 acre-feet per year during the period 1947–51. However, this approach is oversimplified and the water-level change in the wells used to compute storage changes does not truly represent the average water-level change throughout the 35 square miles of the catchment area.

More wells and geologic information in the outcrop area would be required to provide a more accurate answer to the question: "How much water is contributed to the plain from the older deposits?"; but, from the data now on hand, some general conclusions can be drawn. There is no question that ground water percolates from the older deposits to the plain. The southward hydraulic gradients on section *L—L'* (pl. 8) definitely show this movement; and the declining storage, shown by the hydrographs of wells 7/34–9H3, 12E1, and 14F1 on figure 17 indicates depletion in the area for the period of record, and well 7/34–21E1, near the river, shows the depletion through 1951.

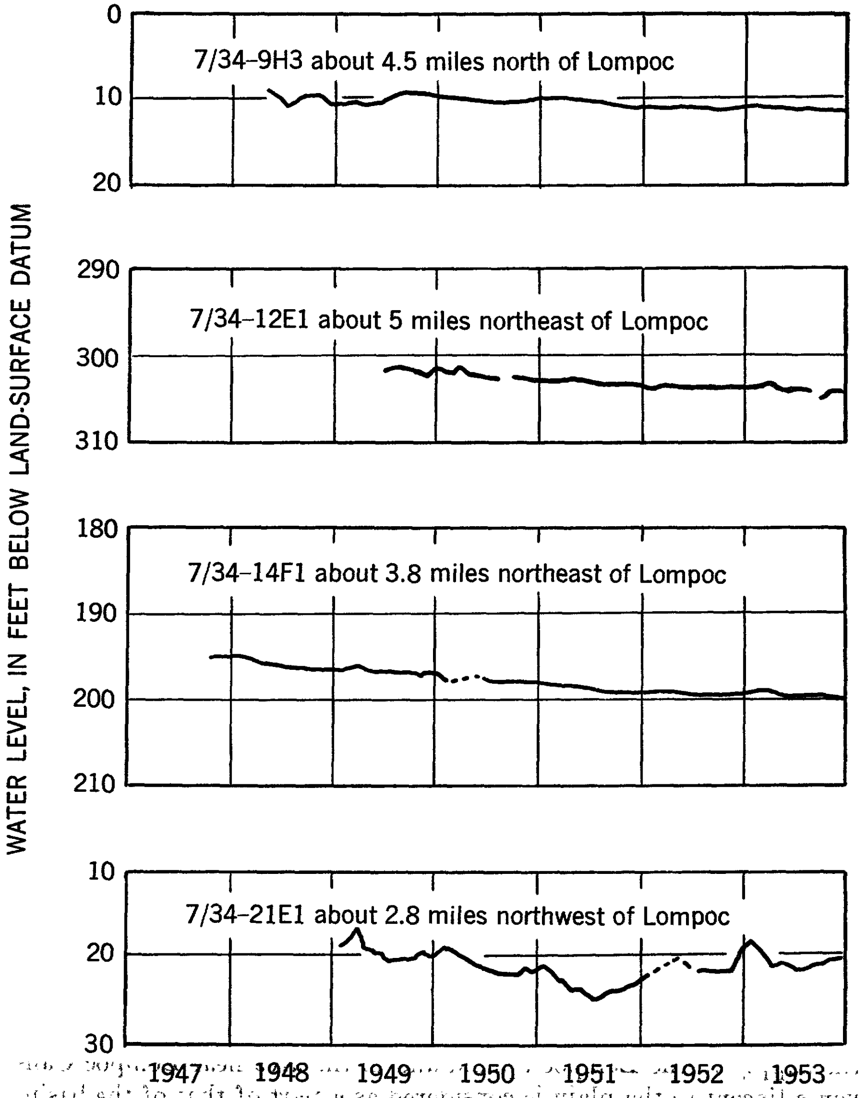

FIGURE 17.—Fluctuations of water levels in four wells northeast of the Lompoc plain.

Furthermore, (p. 88), heavy withdrawals on the Lompoc plain produced relatively little change in storage beneath the plain during the most severe drought on record (p. 63). Because precipitation and streamflow were negligible during the period, replenishment must have come from some source other than the river. The only logical source is the ground-water storage in the Orcutt sand, Paso Robles formation, and Careaga sand, which crop out in the Lompoc upland, and in the Orcutt sand and Careaga sand, which crop out south of the plain.

HYDROLOGIC EQUATION

The principal purpose of this ground-water study was to determine the sources and quantity of ground-water recharge to and discharge from the Santa Ynez River basin, and the study consisted of balancing the ground-water gains against the losses, plus or minus storage change, and determining whether the area was overdeveloped or whether additional development was possible.

In 1951 Upson (Upson and Thomasson, 1951) completed a study of the ground-water inflow-outflow equation for the Lompoc plain, for the 10-year period 1935–44. That period was essentially a wet period, and any estimate of perennial yield should include at least one complete cycle consisting of a wet period and a dry period. Upson (Upson and Thomasson, 1951, p. 3) did infer, however, that the perennial yield was at least 10,000 acre-feet for the period in question, because an average yearly withdrawal of this amount failed to produce any decline in storage. Beginning in 1945 a major drought caused a relatively small depletion of storage and made available additional data for use in revising the rough estimate of perennial yield of 10,000 acre-feet. The revised estimate still is only approximate because a complete cycle of wet and dry years is lacking. In addition, several elements of discharge and recharge cannot be properly evaluated.

Because the elements of recharge can be estimated more accurately during a dry period than during a wet period, the hydrologic equation for the Lompoc subarea has been evaluated for the 4-year period April 1947 to April 1951. From this equation it is possible to make estimates of two critical quantities: the relative magnitude of the ground-water contribution from the Orcutt sand, Paso Robles formation, and Careaga sand, and the amount of water that can be withdrawn from the basin during any similar period without exceeding the available supply.

The inflow and outflow elements in the hydrologic equation are grouped so that the equation is solved for the Lompoc subarea, and the supply in the Lompoc upland and in the area near Lompoc Canyon adjacent to the plain is considered as a part of that of the basin.

Accordingly the hydrologic equation for the Lompoc subarea is as follows:

Inflow	Outflow
Santa Ynez River by underflow	Shallow water body to the river
+	+
Santa Ynez River by seepage loss	Evaporation and transpiration
+	+
Runoff from tributary streams	Main water-bearing zone to the sea
+	+
Infiltration of rainfall on the plain	Pumpage, all uses
+	+ or −
Return of excess irrigation water	Net change in storage beneath the Lompoc plain and beneath foothill area surrounding the Lompoc plain
+	
Underground transfer from Orcutt sand, Paso Robles formation, and Careaga sand	

Most of the inflow and outflow items of the hydrologic equation have been estimated in the same manner as those in Water-Supply Paper 1107, because the available data and the lack of progress in the development of new techniques do not permit refinement of the methods used. Substantial modifications in certain elements of the equation, however, have been made in review of the reduction in recharge from the river during the period 1948–51.

Runoff from streams entering the valley on the south (runoff from streams on the north reaches the plain only during flood stages), infiltration of rain on the plain, and return of excess irrigation water are inflow elements of the inventory whose estimates are decidedly weak. On the outflow side of the equation, the weakest element of any magnitude is evapotranspiration. Selecting the dry period 1947–51 minimizes errors in estimates of runoff from streams on the south and infiltration of rain, and reduces the number of uncertain elements to two: evapotranspiration and return of excess irrigation water. Until these elements can be refined, the ground-water inventory still is considered approximate.

OUTFLOW

OUTFLOW FROM SHALLOW WATER BODY TO THE RIVER

Whenever the water table at the western end of the plain stands above the Santa Ynez River channel, ground water percolates out of the shallow zone into the stream course and passes out to sea. This quantity is measurable as the gain in streamflow between H Street Bridge and the Barrier Bridge and is available from records compiled for these two stations. The record shows that for the period April 1947 to April 1951 the total gain in flow was 400 acre-feet, or an average of 100 acre-feet yearly. Part of the gain in flow between H Street Bridge and the Barrier Bridge may be due to sewage effluent from

Camp Cooke and the city of Lompoc. The two sources combined released about 800 acre-feet per year, according to metered records during the period 1947–51, but the operators of the treatment works believe that only a small part of the release reached the Barrier Bridge—most of it was lost by evapotranspiration or by percolation to the deep water body.

EVAPOTRANSPIRATION

Upson (Upson and Thomasson, 1951, p. 133–134) estimated evapotranspiration, based on data for the bottom lands of the Santa Ana River in Riverside and Orange Counties compiled by the Division of Irrigation, United States Department of Agriculture, in part in cooperation with the Geological Survey (Muckel, written communication, 1944). He estimated that the average annual loss of water to native vegetation along the Santa Ynez River in the Lompoc subarea, an area of about 1,200 acres, was about 3,000 acre-feet and that an additional 2,100 acre-feet was transpired in an area comprising about 600 acres at the extreme western end of the Lompoc plain. But these estimates were for a period in which there was little fluctuation in water levels. During the period 1945–51 water levels declined as much as 20 feet at the eastern end of the Lompoc plain. Thus, it is reasonable to expect that consumptive use of ground water by native vegetation was considerably less than in the period 1935–44 to which a 2.5 acre-feet-per-acre factor was applied.

For the period 1947–51 evapotranspiration estimates are based on climatological data in the same manner as were the evapotranspiration estimates for the river-bottom lands upstream from Robinson Bridge (p. 49). In short, consumptive-use data for the San Luis Rey Valley were transposed to the Lompoc plain by a comparison of daylight hours and temperature in the two areas, after which the adjusted consumptive-use data were applied to the acreages of phreatophytes as outlined on aerial photos. The estimated average annual evapotranspiration determined in this manner, for the period 1947–51, was 3,000 acre-feet, which is about 2,000 acre-feet a year less than that estimated by Upson (Upson and Thomasson, 1951) for the preceding wet period.

OUTFLOW FROM MAIN WATER-BEARING BODY TO THE SEA

The average annual discharge of ground water by outflow from the main water-bearing zone to the sea for the period 1935–44 was estimated by Thomasson (Upson and Thomasson, 1951, table 18) as 460 acre-feet. For the period 1947–51 the discharge was smaller. The estimated cross-sectional area and permeability did not change, but the average seaward hydraulic gradient declined from about 5 feet per mile to an average of about 3 feet per mile in the years 1947–51. Thus, the estimated discharge for the dry years averaged about 300 acre-feet per year.

PUMPAGE

Pumpage estimates for the Lompoc plain were computed by Upson (Upson and Thomasson, 1951), based on power-consumption records supplied by the Pacific Gas and Electric Co., and energy factors in terms of kilowatt-hours per acre-foot determined from data on pump-efficiency tests also supplied by the Pacific Gas and Electric Co. The estimates covered the period 1935–44 inclusive—a period in which ground-water levels remained high and nearly constant. Since 1944 substantial water-level declines were recorded at the eastern end of the plain and, consequently, pumping lifts increased. An increase in pumping lift requires additional power to pump a given amount of water. Therefore, the use beyond 1944 of a factor for kilowatt-hours per acre-foot based on 1935–44 pump-efficiency tests is questionable. The following table shows the variation in average lifts and average energy factors, based on all available pump-efficiency tests, for the periods indicated.

Variation of energy factor and average pumping lift, 1935–51

	Pumping lift		Energy factor	
	Number of tests	Average (feet)	Number of tests	Kilowatt hours per acre-foot
1935–44	143	63.03	148	135.32
1945–51	69	92.22	73	166.02
1935–51	212	72.53	221	145.46

From the preceding table it is evident that the energy factor determined for the period 1935–44 must be revised to reflect the increase in pumping lift in the years 1945–51. One method of doing this would be to consider only the pump efficiency tests for the period 1945–51. This method is weak, unless the small number of tests available (only 73) is representative. A more accurate method was devised by determining from all available pump-efficiency tests the average number of kilowatt-hours required to lift 1 acre-foot of water 1 foot. This figure, computed to be 1.93 kilowatt-hours per acre-foot per foot of lift, when multiplied by the average lift for a particular year, results in a factor for kilowatt-hours per acre-foot that is in direct relationship to the average depth to static water level for the year. Average lifts were computed as the sum of depth to static water level, average drawdown, and discharge elevation above land surface. Depths to water were determined from the records of water-level fluctuations in observation wells, discharge elevations above land surface were determined by observation, and drawdowns were obtained from pump-efficiency tests. Of the three variables in the average lift, drawdown and discharge elevation above land surface remain nearly constant. Fluctuations of the water table, therefore, produce changes in the average lift and, consequently, changes in the average factor for kilowatt-hours per acre-foot.

Pumpage, based on this method, is listed in table 7 and the revision is extended back as far as 1935. The estimates below supersede the estimates of table 25 in Water-Supply Paper 1107, and they include estimates of additional pumpage by gas, gasoline, and diesel plants and by industry, the Lompoc Light and Power Co., domestic, stock, and dairy users, and Camp Cooke.

During the 4-year inventory period from April 1947 to April 1951, 85,500 acre-feet of ground water was pumped, or an average yearly withdrawal of 21,400 acre-feet.

NET CHANGE IN GROUND-WATER STORAGE

Water-level measurements in sufficient number to permit the preparation of a water-level contour map were not available for the spring of 1947. It was not possible, therefore, to prepare a storage-change contour map for the period April 1947 to April 1951. In lieu of such a map, the net change of ground water in storage beneath the Lompoc plain was computed from the storage-change map for the 6-year period April 1945 to April 1951, during which the total estimated storage depletion was 15,700 acre-feet (table 6).

On the basis of this change, the estimated average yearly change in storage beneath the Lompoc plain was about 2,600 acre-feet, or slightly more than 10,000 acre-feet for the 4-year period April 1947 to April 1951.

An additional decrease in storage totaling 2,700 acre-feet per year was estimated for the Lompoc upland and the outcrop area near Lompoc Canyon (p. 75).

TABLE 7.—*Annual pumpage from the main and secondary water-bearing zones of the Lompoc plain, 1935–51* [1]

[Compiled from data furnished by the Pacific Gas and Electric Co., Camp Cooke, and the city of Lompoc]

Year starting April 1	Pumpage (acre-feet)	Year starting April 1	Pumpage (acre-feet)	Year starting April 1	Pumpage (acre-feet)
1935	9,600	1941	7,300	1948	16,400
1936	13,800	1942	9,000	1949	19,400
1937	11,700	1944	14,700	1950	25,800
1938	10,300	1945	16,200	1951	18,200
1939	12,000	1946	15,700	1952	16,500
1940	12,800	1947	23,900		

[1] Figures for 1935–44 differ from those of table 25, Water-Supply Paper 1107, owing to revision of factors for kilowatt-hours per acre-foot, and the inclusion of domestic, stock, and industrial uses.

INFLOW

UNDERFLOW AND SEEPAGE LOSS FROM SANTA YNEZ RIVER

As stated by Upson (Upson and Thomasson, 1951, p. 152), the Santa Ynez River supplies water to the main water-bearing zone, partly by direct ground-water underflow through The Narrows and partly by seepage loss from the river through the shallow water body, chiefly in the area between The Narrows and H Street Bridge.

For the period 1935–44 Thomasson (Upson and Thomasson, 1951, p. 80) estimated that the underflow through The Narrows averaged about 600 acre-feet per year. This computation is based on the formula $Q=PIA$, in which P, the permeability, was estimated to be 4,000 gallons per day per square foot; I, the hydraulic gradient, was 8 feet per mile; and A, the saturated cross-sectional area, was 87,000 square feet. From 1944 through 1951 the gradient steepened steadily because of falling water levels at the eastern end of the Lompoc plain. Although the permeability remained essentially constant, the saturated cross section decreased to about 84,000 square feet in November 1951.

During 1951 the average water level in well 7/34–35F16 was 62 feet above mean sea level, and the average water level in well 6/34–2A6 (0.85 mile upstream from well 7/34–35F16) was 84 feet above mean sea level—both the lowest average levels on record. The difference in altitude is 22 feet in 0.85 mile or a gradient of 26 feet per mile. Because the hydraulic gradient increased at an almost constant yearly rate from 8 feet per mile in 1944 to an average of 26 feet per mile in 1951, the average gradient for the period April 1947 to April 1951 can be computed to be about 20 feet per mile. Similarly, the average saturated cross-sectional area can be computed to be 85,000 square feet for the same period. Thus, the estimated underflow averaged about 1,500 acre-feet per year, or totaled about 6,000 acre-feet during the 4-year period of inventory.

Seepage loss from the Santa Ynez River is estimated by the decrease in streamflow between the gages at Robinson Bridge and H Street Bridge. In addition, an unknown amount of seepage loss occurs downstream from H Street Bridge. The principal weaknesses in the estimate of seepage loss are (1) during years of large runoff the losses are commonly within the limits of error of the gaged runoff and cannot be used; thus, although the seepage losses may be large, their magnitude cannot be estimated; (2) no continuous record is available between The Narrows and Robinson Bridge, a distance of about half a mile, in which the fragmentary records show that losses have occurred; (3) the runoff from tributaries between Robinson Bridge and Surf, particularly those draining the western part of the Purisima Hills, has not been gaged and, because the runoff is not accounted for, the computed seepage loss between Robinson Bridge and the H Street Bridge may be low; also, any seepage loss downstream from the H Street Bridge has been omitted because there is no satisfactory basis for estimating it; (4) rising water in the river, which is discharge from the shallow water body starting about 4 miles downstream from H Street Bridge, masks any seepage loss for the reach between H Street Bridge and Barrier Bridge (for example, in 1948 and 1951 there was no flow at H Street, but 175 and 190 acre-feet, respectively, passed the Barrier Bridge (table 1); and (5) sewage effluent discharged into or near the river below H Street Bridge by the city of Lompoc and Camp Cooke also tends to mask any seepage loss.

For the period April 1947 to April 1951 the gaging-station records at Robinson Bridge and H Street Bridge show a total gaged difference of about 1,800 acre-feet. Assuming that the seepage-loss rate per mile between The Narrows and Robinson Bridge was the same as that between Robinson Bridge and H Street Bridge in the years April 1947 to April 1951, an additional increment of about 300 acre-feet is obtained. Thus, the inflow by seepage loss and underflow for the 4-year period of inventory is estimated to have been about 8,100 acre-feet or to have averaged about 2,000 acre-feet per year.

RUNOFF FROM STREAMS ENTERING THE VALLEY ON THE SOUTH

With regard to runoff entering the valley from the south, Upson (Upson and Thomasson, 1951, p. 126–127) stated:

> Unlike those from the north, the tributary streams from the south, chiefly San Miguelito Creek, those in San Pascual, Rodeo, and Lompoc Canyons, drain moderately extensive areas of foothill and mountainous terrain, which receive comparatively heavy rainfall. Except for the streams in Lompoc Canyon, they flow perennially almost to the canyon mouths and there lose most of their flow by percolation into the marginal parts of the upper member of the younger alluvium—and hence to the shallow water body.

Conversely, flow in the streams on the north side of the valley generally occurs only during heavy precipitation, and most of this runoff reaches the Santa Ynez River rapidly and passes out to sea. There is no low perennial flow in these streams.

Gaging stations are not maintained on the relatively small streams entering the valley on the south. Therefore, direct measurement of the total contribution from San Miguelito, San Pascual, Rodeo, and Lompoc Canyons is not possible. An approximation can be made, however, by comparing these streams with Salsipuedes Creek. During the period April 1947 to April 1951, Salsipuedes Creek, which drains the adjacent watershed to the south and east, averaged 1,000 acre-feet of runoff per year from a drainage area of 46.6 square miles, or 20 acre-feet per square mile. Assuming a runoff of 20 acre-feet per square mile for the streams on the south side of the valley with a total drainage area of 36 square miles, and assuming that all runoff seeped to the shallow and deep water bodies, the estimated contribution from this source for the period of inventory was roughly 700 acre-feet per year.

INFILTRATION OF RAINFALL ON THE PLAIN

In regard to recharge from rainfall, the same method is used here as was used by Upson (Upson and Thomasson, 1951, p. 125). The method is based on the work of Blaney (1933), in which he estimates the proportion of any one season's rain that penetrates below plant roots for a number of areas in southern California. Varying types of land cover, such as irrigated beans, miscellaneous garden, truck crops and alfalfa, brush, grass and weeds, and bare land are considered. The values of penetration, estimated by Blaney for these classes, were plotted against seasonal rainfall and smooth curves drawn. From these curves, values of penetration have been selected corresponding to the seasonal rainfall on the Lompoc plain for truck crops, miscellaneous garden crops, and alfalfa, which are considered representative of the crops grown on the Lompoc plain. Rainfall on the Lompoc plain is determined by combining rainfall at Lompoc and at Surf in the ratio of 2 to 1. The results of this study show that rainfall penetration during the period April 1947 to April 1951 probably was zero.

Blaney's method was used for the Lompoc upland and the area of outcrop near Lompoc Canyon. These areas have a cover of brush and grass in the ratio of about 2 to 1. The results of this study show that rainfall penetration on the brush areas probably was zero, and in the grass areas rainfall penetration was about 900 acre-feet per year. Total rainfall penetration, therefore, in the Lompoc subarea for the period April 1947 to April 1951 was about 900 acre-feet per year.

RETURN OF EXCESS IRRIGATION WATER

All water applied to a field during irrigation is not used by plants, but the proportion actually used and the proportion lost are very problematical. Logically, some of the applied water evaporates, some runs off the irrigated plot, and some returns to ground-water storage; but little is known concerning the magnitude of these increments on the Lompoc plain.

Perhaps the best known research concerning this problem is the work of D. C. Muckel and V. S. Aronovici (1952), who summarize an approach to the solution of this problem in the following equation:

> Water applied minus evaporation, minus transpiration, minus soil storage in root zone, minus runoff equals deep penetration.

The authors, by way of explanation, state further that:

Water applied is measured directly in the case of irrigation, and by rain gages for rain falling on the soil surface. Soil sampling is used to determine the evaporation, transpiration, and soil moisture storage within the root zone. It is assumed that water stored within the root zone will eventually be used by the plants and, therefore, becomes part of the transpiration.

Deep penetration of irrigation water is calculated in the same manner as rainfall penetration. However, since the water is applied artificially, allowances must be made for the area actually wetted when the irrigation is by furrows or rows. Also, the unevenness of the water application must be taken into account. Soil sampling is relied upon to disclose the actual conditions.

The magnitude and costliness of this approach, involving the taking of many soil samples, precluded its use in this study. Accordingly, as was done by Upson (Upson and Thomasson, 1951, p. 125), an irrigation efficiency of 85 percent is assumed for the Lompoc plain—that is, about 15 percent of the applied water returns to the water table. Thus, using these data for the 4-year period of inventory, the inflow by return irrigation water would have been on the order of 13,000 acre-feet, or an average of 3,200 acre-feet per year.

EQUATION FOR THE PERIOD 1947-51

Table 8 summarizes the estimates of ground-water inflow to and outflow from the Lompoc subarea for the 4-year period April 1947 to April 1951; also, it shows the estimated net changes in ground-water storage for the same period and compares the changes in storage with the difference between inflow and outflow. The difference between the results represents the errors in the estimates of inflow, outflow, and storage change. Also shown in table 8 for comparison are the data from the equation by Upson (Upson and Thomasson, 1951, p.

TABLE 8.—*Hydrologic equation, in acre-feet, per year, for the Lompoc subarea, 1935–44 and 1947–51*

	[1] 1935–44	1947–51		[1] 1935–44	1947–51
Inflow:			Outflow—Continued		
Seepage loss from Santa Ynez River	2,500	500	Main water-bearing zone to sea	400	300
Underflow at The Narrows	600	1,500	Pumpage, all uses	10,000	21,400
Runoff from tributary streams	5,400	700	2. Total	17,000	24,800
Rainfall penetration	4,800	900	3. Difference: (1−2)	2,200	17,200
Return irrigation water (using 15 percent of pumpage)	1,500	3,200	Ground-water storage change, net increase (+) or decrease (−):		
Return sewage effluent	(2)	800	Lompoc plain (storage units 1, 3, 4)	+1,000	17,200
1. Total	14,800	7,600	Lompoc upland (storage units 5 plus storage unit 2)	[3]−2,500	−2,700
Outflow:			4. Net loss	1,500	5,300
Shallow water body to the river	1,500	100	Difference between methods: (3−4)	700	12,000
Evapotranspiration	5,100	3,000			

[1] Upson and Thomasson (1951, p. 160).
[2] Omitted.
[3] By estimating underground transfer from adjacent deposits.

160) for the 10-year period 1935–44. The table shows that most of the inflow items estimated by Upson were considerably larger than those estimated for the drought period 1947–51. The most significant feature brought out by a comparison of the two equations is the apparent small depletion of ground water in storage under conditions of small recharge and large withdrawals during the period of drought.

SIGNIFICANCE OF THE HYDROLOGIC EQUATION

For the period 1935–44 table 8 shows a discrepancy between methods of only 700 acre-feet per year, whereas for the period 1947–51 it shows a difference of about 12,000 acre-feet per year. For the latter period this difference indicates one or more of the following conditions: the estimates of inflow are low, the estimates of outflow are high, the estimated net changes in storage, particularly in the Lompoc upland, are too small, and (or) there are other possible sources of inflow. With regard to the elements of inflow, the estimated return irrigation water and possibly rainfall infiltration are most subject to error. The only significant estimate of outflow subject to question is evapotranspiration.

The estimated net change in storage in the Lompoc upland, where few well data or water-level records are available, may be considerably in error. The estimated depletion shown in table 8 for the foothill area is only slightly more than the inflow of 2,500 acre-feet estimated by Upson (Upson and Thomasson, 1951, p. 160), even though the hydraulic gradient from the area was steepened during the drought period 1947–51. Therefore, the estimated storage depletion of 2,700 acre-feet for the foothill area probably is low.

Other possible sources of inflow for the Santa Ynez and Santa Rita subareas might be fractures in the consolidated rocks. The equations on page 52 and in tables 4, and 8 consistently suggest other sources of inflow, or else the estimated elements of inflow, outflow, and(or) net storage change consistently are in error in the same direction. Although some water might be supplied from the consolidated rocks around the Lompoc plain, it is unreasonable to assume that the full 12,000 acre-feet was supplied from this source.

During the period 1947–51 the average yearly total discharge from the Lompoc plain was about 25,000 acre-feet, of which 2,600 acre-feet was supplied from storage beneath the plain. The remaining 22,400 acre-feet per year must have been supplied by the inflow items and from storage in the foothill area as listed in the hydrologic equation, because they are the only known sources of principal recharge. Proportioning the recharge by inflow items is a difficult task, but the selection of the dry 1947–51 inventory period, by its very nature, reduces the magnitude of the estimates—for such items as recharge from the river, runoff from streams on the south, and infiltration of rainfall—to quantities that are nearly negligible. It is logical to assume, therefore, that the bulk of replenishment came from outside the perimeter of the plain, and that a lesser amount came from the return of excess irrigation water and from the discharge of sewage by Camp Cooke and the city of Lompoc. The river, although supplying much of the recharge whenever flow is available, certainly did not supply it during the inventory period in question, because underflow and seepage loss between The Narrows and H Street Bridge averaged only 2,000 acre-feet per year.

The small decline of water levels in relation to withdrawals in the Lompoc plain, commencing about 1945, proves that there is considerable recharge to the plain from local sources other than the river, particularly from the Orcutt sand, Paso Robles formation, and Careaga sand. Although the hydrologic equation for the period 1935–44 demonstrated that the average pumpage of 10,000 acre-feet produced little or no change in ground-water storage, the equation for the dry period 1947–51 indicates that an average yearly withdrawal of 21,400 acre-feet produced a decrease in storage beneath the Lompoc plain of only 2,600 acre-feet per year.

Additional proof that the ground-water bodies beneath the plain are recharged from local sources other than the river is available in a comparison of hydrographs for the Santa Maria Valley and hydrographs for the Lompoc plain. In the Santa Maria Valley it is known that for the period 1929–50 the recharge was entirely dependent on infiltration of precipitation and the flow of the Sisquoc and Santa Maria Rivers (Worts, 1951), and the hydrographs of wells reflect this dependence. Falling water levels in the Santa Maria Valley during dry periods have been the result of almost the entire draft of the valley being supplied from storage, whereas in the Lompoc plain only minor depletions of storage beneath the plain have been required to meet withdrawals, despite the fact that there was little or no flow in the river.

Therefore, owing to the poor correlation of the estimates in table 8, it would be desirable to collect more water-level records in the areas around the Lompoc plain. Additional field work in the Lompoc subarea would be necessary in order to refine estimates of return irrigation water and rainfall penetration.

CONSIDERATION OF PERENNIAL SUPPLY

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

Upson (Upson and Thomasson, 1951, p. 3) stated that the pumpage in the wet period 1935–44 caused no apparent overall decline of water levels in the Lompoc subarea, and therefore they concluded that the perennial yield was at least equal to the average yearly withdrawals for the period, or was at least 10,000 acre-feet a year. Because water levels were not depressed, the maximum recharge opportunity by seepage loss from the river was not realized and natural water losses were high. Hence, the estimated yield of 10,000 acre-feet a year was a minimum figure.

The data collected during the 6-year dry period April 1945–April 1951 show that, with an average yearly pumpage of nearly 20,000 acre-feet (table 7), there was an estimated 6-year net depletion in storage of 15,700 acre-feet (table 6) beneath the Lompoc plain and crudely 16,000 acre-feet beneath the Lompoc upland and the area near Lompoc Canyon, or a total of 32,000 acre-feet. This total depletion of storage was only about 14 percent of the estimated gross storage capacity of 230,000 acre-feet (table 5 and fig. 15). Accordingly, the data show that for the period 1945–51 there was an ample supply available to sustain the pumpage of 20,000 acre-feet a year.

Although pumpage and storage depletion comprise useful elements in estimating short-term yield during a dry period, the perennial yield must be considered over the long term and must include an equal number of both wet and dry periods. Figure 3 shows that since 1868 the wet and dry periods have averaged about 14 and 11 years in length, respectively. For a long period in which the wet and dry periods are of these average durations, the perennial yield may be expressed as (1) the total recharge less total unrecoverable water losses (which include evapotranspiration from uncultivated lands and outflow to the Pacific Ocean) plus that part of the gross storage capacity that is rechargeable from local sources, all divided by 11 (for the dry period part of the equation), plus (2) the total recharge less total unrecoverable water losses less that part of the gross storage capacity that is rechargeable from local sources, all divided by 14 (for the wet period part of the equation); and the sum of (1) and (2) divided by two.

However, the following quantitative analysis of total inflow, which is the total recharge plus return irrigation water, is used in place of total recharge, because no accurate estimates are available for return irrigation water in the Lompoc subarea. Perennial yield cannot be derived directly from an equation containing an estimate of total inflow. Accordingly, the term "perennial pumpage", which has been suggested by J. F. Poland of the Geological Survey (oral communication, 1956) is introduced to express the quantity of water that can be pumped perennially from a basin—it is a measure of the pumpage rather than of the net draft. The perennial pumpage can be evaluated in terms of the following equation:

$$\text{Perennial pumpage} = \left[\frac{\text{Total inflow} - \text{Total unrecoverable water losses} + \text{Rechargeable storage capacity}}{11\ \text{(average length of dry period in years)}} + \frac{\text{Total inflow} - \text{Total unrecoverable water losses} - \text{Rechargeable storage capacity}}{14\ \text{(average length of wet period in years)}}\right] \div 2$$

Because ground water in storage never has been depleted substantially during a prolonged dry period, there is no accurate means to estimate the maximum total recharge during a wet period or the maximum rechargeable storage capacity, both essential to the solution of the above equation. Nevertheless, the estimates obtained for the 7 years 1945–52 can be extrapolated to estimate the order of magnitude of the quantity of water that can be pumped perennially from the Lompoc subarea.

The estimates of total inflow and total unrecoverable water losses for the 4-year dry period 1947–51 (table 8) and an estimate of the rechargeable storage capacity can be used to obtain a rough approximation of the first part of the above equation for perennial pumpage. First, it is assumed that the average 11-year dry period would be as severe as the 4-year dry period 1947–51, during which total inflow was relatively small. Table 8 shows that estimated inflow totaled 7,600 acre-feet a year and that there could have been an additional yearly inflow of as much as 12,000 acre-feet, if the difference between the two methods is attributable to unduly low estimates of inflow. Thus, the total inflow may have been as little as 7,600 or as much as about 20,000 acre-feet a year.

Second, it is probable that the unrecoverable water losses would be large when water levels were high at the end of a wet period and small when the levels were low at the end of a dry period. Evapotranspiration losses plus shallow-water discharge to the river plus ground-water outflow to the sea might range from 2,000 to 4,000 acre-feet a year, the average of which (3,000) is only 400 acre-feet a year less than the amounts shown in table 8 for the period 1947–51.

Third, the rechargeable storage capacity can be estimated crudely by using the magnitude of the net increase in storage of 8,500 acre-feet (10,800 less 2,300 acre-feet in table 6) in the one wet year, spring 1951 to spring 1952, which immediately followed the 6-year period of storage depletion.

If a 14-year wet period supplied sufficient inflow, on the average, to produce a net increase in storage of about 8,000 acre-feet a year, which is slightly less than that in 1951–52, then the rechargeable storage capacity would be about 110,000 acre-feet, about 50 percent of the estimated gross storage capacity of the Lompoc subarea and about 80 percent of the estimated gross storage capacity beneath the Lompoc plain (table 5 and fig. 15).

Thus, for an 11-year dry period as severe as the 4 years 1947–51, the above estimates can be placed in the first part of the equation to obtain "partial" perennial pumpage, on a per year basis, as follows:

"Partial" perennial pumpage = 7,600 to 20,000 − 3,000 + 10,000
= 15,000 to 27,000

The range in the amounts, between 15,000 and 27,000 acre-feet, is the result of the difference between the estimated inflow of 7,600 acre-feet a year and the sum of this inflow and the difference between methods of 12,000 acre-feet a year (table 8), which assumes that all the difference of 12,000 acre-feet would be attributable to underestimates in the elements of inflow and that there are no errors in the elements of outflow and ground-water storage change. Although the above limits for the first part of the equation show the probable order of magnitude of the "partial" perennial pumpage, the range is large and the result is not of much practical use.

Another approach to the solution of the perennial pumpage during an 11-year dry period similar to the 6-year period 1945–51 is to utilize the estimates of pumpage, storage depletion, and rechargeable storage capacity. The pumpage of about 20,000 acre-feet a year caused a total net depletion in storage of about 32,000 acre-feet, or about 5,000 acre-feet a year. As was mentioned, the estimated rechargeable ground-water storage capacity may be on the order of 110,000 acre-feet. Starting with full capacity at the beginning of an 11-year dry period, the water in storage could be depleted at an estimated rate of about 10,000 acre-feet a year. This rate of depletion is 5,000 acre-feet a year more than the estimated average rate of depletion during the 6 years 1945–51, which, in turn, suggests that the pumpage for the period could have been at least 5,000 acre-feet a year more. Because some of the pumpage returns to storage as excess irrigation water, the increase of 5,000 acre-feet would be more nearly equal to the net draft (ground water permanently removed from the supply). Accordingly, this analysis suggests that, for an 11-year dry period, based on estimates for the 6 dry years 1945–51, the "partial" perennial pumpage would be the sum of the pumpage of 20,000 acre-feet a year plus the additional pumpage that would be sufficient to increase the net

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storage depletion from 5,000 to 10,000 acre-feet a year, or somewhat more than 25,000 acre-feet. If the basin could sustain this draft, then the conditions for the first part of the equation are satisfied and the "partial" perennial pumpage for the 11-year dry period also would be at least 25,000 acre-feet a year.

Although there are several assumptions involved in arriving at the above two estimates for the first part of the equation for perennial pumpage of the Lompoc subarea, the results, in part, seem to agree reasonably well. The first analysis suggests a range between 15,000 and 27,000 acre-feet and the second an amount of at least 25,000 acre-feet a year. Because the average pumpage of about 20,000 acre-feet a year in the 6 dry years 1945–51 caused a net depletion in storage of about 32,000 acre-feet, or less than one-third of the estimated rechargeable storage capacity, in about one-half of an 11-year dry period, the amount involved in the first part of the perennial-pumpage equation probably would be more nearly 25,000 to 27,000 than 15,000 acre-feet a year. Accordingly, 25,000 acre-feet a year is considered to be the order of magnitude of the first part of the equation.

Another feature brought out by this analysis of the relation between the pumpage and the net depletion in storage during the 6 dry years 1945–51 is that more ground water must have been available either as inflow or as water from storage than is shown in the hydrologic equation (table 8). Because there is little possibility of significant overestimates in the elements of outflow, it seems that most of the difference (12,000 acre-feet a year) between the two methods (table 8) was supplied by inflow and(or) by storage depletion. This would suggest either an increase in total inflow of nearly 150 percent or an increase in storage depletion of about 300 percent. The latter possibility appears most unlikely, but there could be substantial increases in the estimates of return irrigation water, rainfall penetration, and runoff from tributary streams that could account for a substantial part of the "missing" water.

In the second part of the perennial-pumpage equation for a 14-year wet period, total inflow must be sufficient not only to provide the estimated average 3,000 acre-feet a year of natural water losses and to replenish the rechargeable storage space at an estimated rate of 8,000 acre-feet a year, but also to supply a substantial excess for the average yearly pumpage.

The wet year 1951–52 is the only one of record that followed a series of dry years during which a moderate depletion of storage occurred and, therefore, is the only wet year on which any estimates of the second part of the perennial-pumpage equation can be based. Rainfall and runoff in 1951–52 were above the average for past wet periods and, hence, storage space being available, recharge also was above average. During an exceptionally wet year the availability of water for ground-water recharge, is great; but, if the ground-water reservoir is nearly full, then relatively little recharge will occur. For example, during the wet years 1935–44 precipitation was great, but the ground-water reservoir remained essentially full and the bulk of the runoff in the Santa Ynez River wasted to the Pacific Ocean. In 1952 precipitation was great, but even after 6 dry years the water levels were drawn down only a maximum of about 20 feet beneath the river channel. Hence, the recharge, although substantial, probably would have been considerably more had the water levels been drawn down near or to sea level, thereby providing a large reservoir space for the available recharge. Even so, from fall 1951 to spring 1952 there was an increase in storage of about 11,000 acre-feet (table 6).

The elements for the second part of the perennial-pumpage equation, based on the 1 year, spring 1951 to spring 1952, are estimated as follows: Pumpage was 18,200 acre-feet (table 7), natural water losses about 3,400 acre-feet (table 8), and net increase in storage 8,500 acre-feet (computed from table 6). The total inflow was sufficient not only to supply the pumpage and natural water losses but also to produce the net increase in storage. Therefore, the estimated total inflow for the year was the sum of these three, or about 30,000 acre-feet.

Thus, for a 14-year wet period, based solely on the wet year 1951–52, the above estimates can be placed in the second part of the equation to estimate crudely a "partial" perennial pumpage, on a per-year basis, as follows:

$$\text{``Partial'' perennial pumpage} = 30{,}000 - 3{,}000 - 8{,}000 = 19{,}000 \text{ acre-feet}$$

Both this estimate and the estimate of 25,000 acre-feet for the first part of the equation are based on the pumpage rather than the net draft. Thus, based on the extrapolated estimates for 11 dry years and 14 wet years, the overall equation for perennial pumpage of the Lompoc subarea is the average of the estimates for the first and second parts of the equation, or is approximately:

$$\text{Perennial pumpage} = \frac{25{,}000 + 19{,}000}{2} = 22{,}000 \text{ acre-feet}$$

The best evidence that the perennial pumpage is in excess of 20,000 acre-feet is the estimated total net storage depletion of only 32,000 acre-feet with a pumpage of 20,000 acre-feet a year during the 6 dry years 1945–51. Of course, if the rechargeable storage capacity is considerably less than the estimated 110,000 acre-feet, then the estimated perennial pumpage also will be less. However, the ratio of decrease in rechargeable storage capacity to decrease in perennial pumpage is about 12 to 1; that is, for every decrease of 12,000 acre-feet in storage capacity there would be a decrease of only 1,000 acre-feet a year in the perennial pumpage. Obviously, if the rechargeable storage capacity has been underestimated, then the converse will be true.

The least accurate estimate in the overall equation is the estimated total inflow of 30,000 acre-feet a year during a 14-year wet period, which is based on the data for only the 1 wet year 1951–52. The Santa Ynez River, which affords a large recharge opportunity during wet periods had a median discharge of about 105,000 acre-feet for the period of record 1908–44, according to Thomasson (Upson and Thomasson, 1951, table 8). Thus, ample water has been available for recharge from this source alone, but the unknown element is the amount of the surface flow that would be lost from the stream to ground water if water levels were drawn down far below the low levels in 1951. This element of the total inflow is most critical to the determination of the rechargeable storage capacity of the Lompoc subarea and, hence, to the estimate of perennial pumpage.

Finally, the estimate of perennial pumpage of the Lompoc subarea was based on information obtained prior to the closure of Cachuma Dam in 1953. The estimates probably were affected somewhat by the operations of Gibraltar and Juncal Dams, which are relatively small structures. The future regimen of the Santa Ynez River downstream from Cachuma Dam, which has a reservoir capacity of 210,000 acre-feet, will be controlled in large part by the operations of the dam and reservoir. It is probable that with reduced runoff the seepage loss from the river will be less, which, in turn, would reduce not only the total inflow but also the rechargeable storage capacity. The collection of basic data by the Geological Survey in cooperation with the Santa Barbara County Water Agency and the Bureau of Reclamation, will provide part of the necessary information for revising and refining the elements of the hydrologic equation as they may be affected by the operation of Cachuma Dam.

CHEMICAL CHARACTER OF GROUND WATER

GENERAL NATURE OF THE CHEMICAL PROBLEM

By chemical analysis it is possible to identify the more important substances in water and to determine their absolute mineral concentrations. With this knowledge, water can be classified as to its suitability for any of a variety of uses. For irrigation waters some substances, such as calcium, magnesium, potassium, sulfate, and nitrate, are beneficial to plant growth, whereas others, such as sodium and boron, may be essential in small quantities but in large quantities may have an adverse effect on the soil or vegetation. It is essential, therefore, to know the proportions in which the various constituents occur in water.

Native waters are usually of good chemical quality, unless they are in contact with a highly mineralized soil. Contamination of the native fresh water can take place progressively by mixing with waters that are high in dissolved solid. Mixing of fresh water with ocean water, industrial wastes, or oil-field brines is an example of this type of contamination. Contamination can take place also whenever the establishment of unfavorable gradients permits the percolation of inferior water from adjacent permeable aquifers or from the ocean. It is not always easy to identify contaminants because, coincident with or subsequent to the blending of the fresh and inferior waters, certain chemical reactions may completely mask the nature of the contaminant. Base exchange and sulfate reduction (discussed later) are two such processes.

In the Lompoc subarea the problems with regard to chemical quality are: To classify the ground waters as to their suitability for irrigation purposes, to type the waters as to their chemical composition, to review the status of possible contaminants, and to determine whether any change over the years has taken place by chemical reaction or by the mixing of fresh waters with exterior contaminants.

In 1941 analyses of the waters from wells were assembled from various sources. These analyses included some detailed partial analyses and many brief partial analyses. The detailed partial analyses included a quantitative determination of specific conductance (electrical conductivity), hardness, calcium, magnesium, sodium plus potassium, bicarbonate, and sulfate, whereas the brief partial analyses included only specific conductance, chloride, and hardness.

Until recent years there has been no orderly program for sampling the waters of the Lompoc plain, and as a result the coverage has been spotty and at times inadequate. The University of California, College of Agriculture, in 1935 sampled the waters of many wells for detailed partial analyses, and in the period 1941–43 the Geological Survey did some additional sampling. Between the years 1943–48 samples were not collected. As a result of the drought, commencing about 1945 and accompanied by falling water levels, a program of sampling at the west end of the plain was begun in the spring of 1950 and has continued to the present time. The purpose of this program was to collect representative samples twice yearly for brief partial analyses that might give some indication as to whether sea-water intrusion was occurring. In addition, 25 detailed partial analyses have been made. A complete tabulation of all available analyses is contained in table 8 (at end of report) which contains analyses made by the University of California, College of Agriculture, for which samples were supplied by the Farm Advisor in Santa Barbara; by the Bureau of Standards (samples supplied by the Bureau of Reclamation); by Camp Cooke; and by the U. S. Geological Survey.

SUITABILITY OF WATER FOR IRRIGATION

The method of interpretation here considered is that proposed by Wilcox (1948). The method is based on the presumption that the water will be used under average conditions as related to quantity, soil permeability, drainage, climate, and crops. It is not applicable under unusual conditions. Three elements—percent sodium, dissolved solids expressed as electrical conductivity, and boron—are considered in the analysis of irrigation water.

The quantity and kind of dissolved salts contained in water determine the amount of electric current that the water may conduct. The specific conductance (expressed as micromhos at 25° C) indicates in a general way the concentration of dissolved solids and is useful also as an indication of other approximate relations. Specific conductance when divided by 100 is approximately equal to the sum of the anions or cations present in the water, expressed in equivalents per million, and when multiplied by 0.7 is approximately equal to dissolved solids, expressed in parts per million (ppm).

Percent sodium is determined by dividing sodium, expressed in equivalents per million, by the total cations, also expressed in equivalents, times 100. The percent sodium is critical in irrigation water because water having a high percent sodium reacts with the soil or accumulates in the soil so as to produce alkali conditions or alkali soils.

Figure 18 is a plot of percent sodium versus dissolved solids expressed as electrical conductivity for 79 analyses of well-water samples collected as shown in the explanation. The samples were selected so as to provide representative geographic coverage of the Lompoc plain. Indicated on this plot are the ranges of suitability of water for irrigation purposes. Figure 18 shows that the ground waters of the Lompoc plain have ranged between the limits "good to permissible" and "doubtful to unsuitable" since at least 1935. No single analysis indicates a water wholly unsuitable for irrigation, but only two analyses fall in the classification "excellent to good".

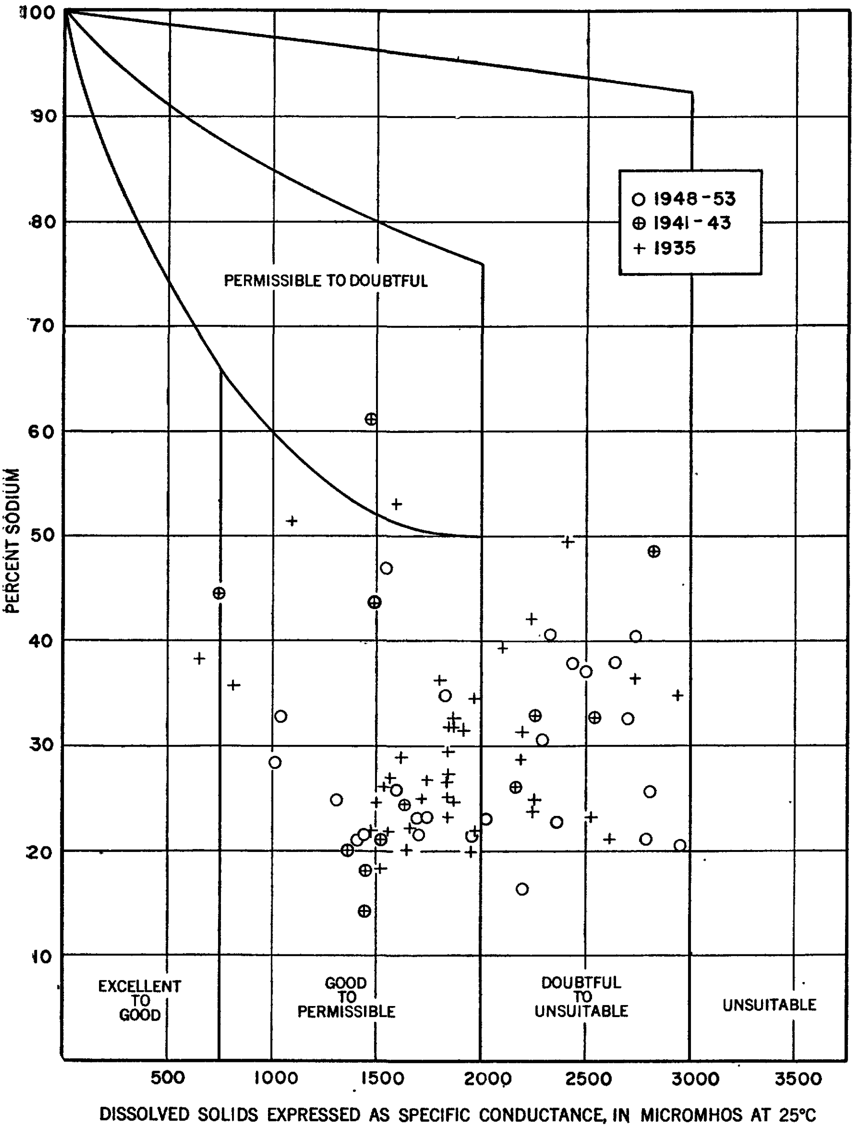


FIGURE 18.—Suitability of ground waters of the Lompoc subarea for irrigation.

Boron is the third item to be considered in evaluating water for fitness for use in irrigation. In small quantities it is beneficial to plant life, but in higher concentrations it may have a definite injurious effect depending on the type of plant life. The permissible limits for boron of the several classes of irrigation water are shown by Wilcox (1948) in the following table.

Permissible limits of boron concentration for several classes of irrigation water

Classes of water	Crop groups		
	Sensitive (ppm)	Semitolerant (ppm)	Tolerant (ppm)
Excellent	<0.33	<0.67	<1.00
Good	0.33 to 0.67	0.67 to 1.33	1.00 to 2.00
Permissible	.67 to 1.00	1.33 to 2.00	2.00 to 3.00
Doubtful	1.00 to 1.25	2.00 to 2.50	3.00 to 3.75
Unsuitable	>1.25	>2.50	>3.75

Unfortunately most of the water samples collected over the years have not been analyzed for boron concentration. Based on a total of 3, 22, and 9 analyses in the years 1941–43, 1945, and 1948–53, respectively, the average boron concentration is about 0.4 part per million, the maximum observed concentration being about 1.1 parts per million. According to the preceding table, a concentration of 0.4 part per million of boron would indicate a water of good quality for even the most sensitive crops. The only crop grown on the Lompoc plain that is sensitive to boron is walnuts, and therefore for all other crops the waters may be classified as "excellent to good" so far as boron is concerned.

CHEMICAL QUALITY

The 25 water samples for which detailed partial analyses were made during the period 1948–53 show various predominant ions, apparently having in common only a high mineral content. This is in contrast to the type of water most widely used for public and private supplies—a calcium bicarbonate water in which calcium, magnesium, and bicarbonate make up the greater part of the dissolved mineral matter. For the most part, calcium and sulfate are the predominant cation and anion, respectively, in the ground waters of the Lompoc plain, and to a lesser extent, sodium and chloride.

In the 70 individual samples tested for chloride content during the period 1948–53, the average concentration was about 246 ppm. Only about 20 percent of the analyses showed concentrations in excess of 300 ppm, and these were evenly distributed throughout the plain. As pointed out by Upson (Upson and Thomasson, 1951, p. 163), the variation appears to be governed by the different formations that contain the deep water body in different parts of the area. The highest concentration, as much as 8,830 ppm in well 7/35–18J1, is in the shallow water body near Surf, whereas the lowest concentrations are at the eastern end of the plain. The average chloride content in test wells 7/34–9H3, 12E1, and 21E1 in the Lompoc upland is less than 100 ppm.

The specific conductance of 33 samples collected during the period 1948–53 averaged about 2,200 micromhos, and the hardness of 70 samples averaged about 735 ppm. The percent sodium is low, averaging about 30 percent. However, in water from one well near Surf the percent sodium was more than 80. Several of the samples analyzed for silica had a concentration of 20 to 55 ppm. In view of the extensive deposits of diatomaceous earth in the foothill areas south of Lompoc and of the fairly high concentration of silica noted in the ground water, perhaps this constituent warrants more detailed investigation in the future, especially if the water is ever considered for industrial uses.

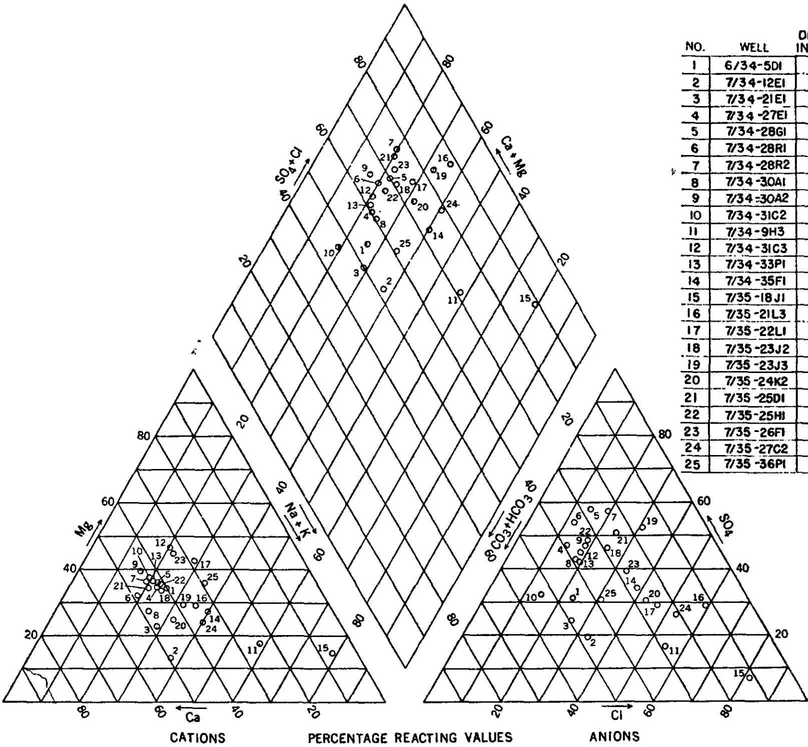
TYPES OF WATER

Most native waters contain relatively few dissolved constituents, the cations (metals or bases) and anions (acid radicals) being in chemical equilibrium with one another (Piper, 1944, p. 915). Usually the most abundant cations are calcium, magnesium, and sodium. Other cations usually occur in lesser quantities, unless the water is highly concentrated or of unusual composition. The major anions are bicarbonate, sulfate, and chloride, and, as in the cation group, there are a number of anions that occur in lesser quantities. For the purpose of study by use of trilinear diagrams, however, the water samples are treated as though they contained only the three major cations and three major anions.

If one of the principal cations (calcium, magnesium, or sodium) in a water sample occurs in excess of 50 percent of the total cation group, all ions expressed in equivalents per million, the water may be typed according to the predominant cation as a calcium, magnesium, or sodium water (Piper, Garrett, and others, 1953, p. 26). If the predominant ion is less than 50 percent, the water is typed according to the first two predominant cations—for example, calcium-magnesium or sodium-calcium water. This same process of water typing applies also to the anions, so that a specific water sample may be typed as a sulfate, bicarbonate, or chloride water, or as a combination type.

In figure 19, for samples collected during the period 1948–53, the cation triangle shows a calcium-magnesium water to be the principal water type in the cation group; the analyses show that calcium is the predominant cation. However, the concentration of the other cations suggests three possible occurrences: Leaching of salts by irrigation waters, base-exchange activity, and salt-water intrusion. The occurrence and the extent of any one of these possible waters is not easily proved, because all variations of cation combinations occur in about the same proportions.

In the anion triangle (fig. 19) the sulfate ion appears to predominate, although here also the concentration of the other anions, as in the cation group, is sufficient to suggest one of three possibilities:



NO.	WELL	DEPTH, IN FEET
1	6/34-5D1	137
2	7/34-12E1	385
3	7/34-21E1	145
4	7/34-27E1	170
5	7/34-28G1	180
6	7/34-28R1	146
7	7/34-28R2	20
8	7/34-30A1	198
9	7/34-30A2	181
10	7/34-31C2	—
11	7/34-9H3	88
12	7/34-31C3	28
13	7/34-33P1	100
14	7/34-35F1	148
15	7/35-18J1	111
16	7/35-21L3	—
17	7/35-22L1	219
18	7/35-23J2	158
19	7/35-23J3	32
20	7/35-24K2	180
21	7/35-25D1	200
22	7/35-25H1	180
23	7/35-26F1	186
24	7/35-27C2	118
25	7/35-36P1	122

FIGURE 19.—Chemical character of ground waters from the Lompoc plain.

Leaching of salts by irrigation waters, salt-water intrusion, or sulfate reduction.

The trilinear plot of figure 19 shows the chemical character of water according to the relative concentration of its constituents, but it does not show the absolute concentrations. By expressing the concentrations of the constituents in equivalents per million (milligram equivalents per kilogram) the absolute concentrations of the various constituents are obtained. The Collins (1927) bar diagram (fig. 20) shows the absolute concentrations for 15 samples collected from selected wells from 1948 to 1952.

Upson (Upson and Thomasson, 1951, p. 163) mentions the leaching of salts, as irrigation water percolates from the shallow water body to the deep water body, as a possible cause for high chloride content, locally between 500 and 1,500 ppm, in the shallow zone. However, these local high chlorides are more likely the result of concentration of salts caused by evaporation of irrigation waters applied to clayey soils and their subsequent downward percolation to the shallow water body.

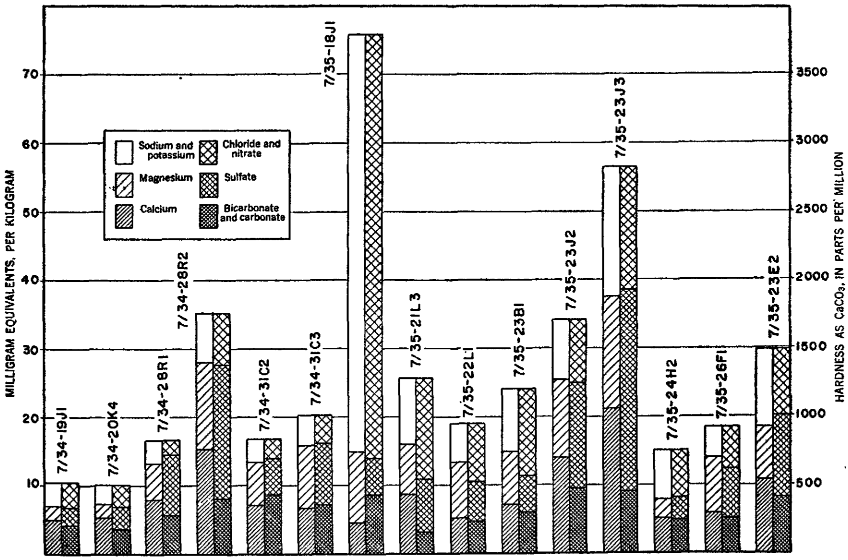


FIGURE 20.—Composition of water from selected wells in the Lompoc subarea, 1948–52.

Base-exchange reaction, or replacement of an ion in the water by a different ion from the soil, usually of calcium by sodium, plays an important role in the alteration of ground water, especially in zones of low permeability, and the most common result is a natural softening of the water. Only the proportions of the positively charged ions (cations) are affected by natural softening, usually without any substantial change in concentration. Briefly, in certain clay-forming minerals the bases (calcium, magnesium, sodium, and potassium) are held loosely in varying proportions. As pointed out by Piper, Garrett, and others (1953, p. 85–90) in reviewing the literature, if these minerals are in contact with a natural water and if they are not in equilibrium as to the water's chemical composition, they will adsorb from the water ions for which they have a relatively strong bond, releasing an equal number of ions for which they have a weaker affinity. The water will show an increase in one or more of the bases and a decrease in one or more of the remaining bases, usually according to the decreasing rank of the common bases (sodium, potassium, magnesium, and calcium, in that order).

Available information is too meager to establish definitely whether base exchange occurs in the ground waters of the Lompoc subarea, but the data in table 9 suggest that a natural softening process might possibly have been operative since at least 1935, with a resultant average decrease of about 100 ppm in hardness. Base exchange is offered by Foster (1942) as the explanation of the softening of salty ground waters in coastal areas.

Sulfate reduction, common in waters that are in contact with organic matter in the sediments that contain the water, is a molecule-for-molecule substitution of bicarbonate for sulfate (Piper, Garrett, and others, 1953, p. 90). The process itself and the extent of its importance to the waters of the Lompoc plain are not fully understood.

INTRUSION OF SEA WATER

In discussing sea-water intrusion in the Lompoc subarea, Upson (Upson and Thomasson, 1951, p. 164) mentioned the possible occurrence of a small wedge of sea water within the coastal end of the main water-bearing zone. He suggested the possibility that, if pumping increased or continued at the 1947 rate, the fresh-water head might be reduced sufficiently in the main water body to allow sea water to penetrate farther inland within the main water-bearing zone. The landward movement of the sea-water wedge would be in conformance with the theory advanced by W. Badon Ghyben (1889, p. 21) and Alexander Herzberg (1901), who independently worked out the general relationship between sea water and fresh water in contact within permeable deposits. The plane of contact, which is rather sharply defined if no appreciable fluctuations in head occur, is dependent on the differential densities of the sea water and fresh water, roughly 1.025 to 1, so that for every foot of elevation above sea level of the fresh water, the interface of the fresh water and sea water will be 40 feet below sea level.

However, in recent years it has been pointed out (Todd, 1953, p. 749–754) that the application of the density ratio directly to determine the depth to the interface is strictly applicable only under static conditions of no movement of ground water, a condition that does not exist in nature. Under conditions of ground-water flow, the interface will be displaced in the direction of flow, usually by a substantial amount where steep hydraulic gradients exist. However, the degree of displacement from that indicated by the 40:1 ratio ordinarily is not great where the hydraulic gradient is low, as in the coastal segment of the main water-bearing zone beneath the Lompoc plain.

In 1941 the water level in the main water-bearing zone was estimated to be 3 feet above sea level at Surf, and the conclusion was drawn that the interface of the salt water and fresh water was about 120 feet below sea level. Cross sections showed that the water-bearing zone extended below this depth, so that the possibility of sea water invading the water-bearing aquifer was real, should any extensive pumping lower that 3-foot head. The contour map for the fall of 1951 shows that the head at Surf has declined only slightly and, apparently, the position of the interface of the fresh water and sea water remained nearly the same. Although sea-water encroachment has not yet become a critical factor, the danger still exists. Should extensive pumping draw down the piezometric surface and cause an inland hydraulic gradient to develop, a landward advance of the interface of the fresh water and sea water would result.

CHANGES IN QUALITY OF GROUND WATER

For the past 10 to 15 years too few analyses of ground waters in the Lompoc subarea are available to permit any definite conclusions with regard to changes of quality. Average concentrations of selected constituents are presented in the following table, but they should not be taken too literally as indicators of specific changes because, in most cases, the averages are based on completely independent analyses for ground waters sampled from individual wells, only a few analyses being given for any one well in each of the sampling periods. The changes indicated for the three sampling periods, therefore, may or may not represent a change in quality of the water bodies. In each of the three sampling periods samples were collected so as to provide geographical coverage on the entire plain.

Average concentrations of chemical constituents for ground waters of the Lompoc subarea, 1935–53

Constituent	1935		1941–43		1948–53	
	Number of analyses	Average concentration (ppm)	Number of analyses	Average concentration (ppm)	Number of analyses	Average concentration (ppm)
Chloride (Cl)	37	180	61	230	70	246
Hardness as $CaCO_3$	37	817	61	722	70	735
Calcium (Ca)	38	139	13	198	29	171
Bicarbonate (HCO_3)	38	453	13	468	29	402
Sulfate (SO_4)	38	292	13	620	29	417
Percent sodium	39	30	13	32	27	30
Specific conductance..micromhos at 25°C	39	[1] 1,800	13	2,000	27	2,300
Boron (B)	22	0.34	3	0.37	9	0.54

[1] Approximate estimate based on total dissolved solids divided by 0.7.

In 1953, after a review of the adequacy of the sampling program, 12 samples for detailed partial analysis were obtained from wells that previously had been sampled in either 1935 or 1941–43. The sampling pattern provided full coverage of the plain, but significant changes in quality were observed in only one area—the central western part of the Lompoc plain just south of the mouth of Pine Canyon. In this area several analyses show an increase in chloride concentration of more than 100 percent. Because sea-water intrusion has not occurred (p. 102), the increase in chloride concentration must be due to the leaching and concentration of salts from irrigation water and (or) the mixing of the ground waters with some exterior contaminant.

The investigation of that area is to be continued by the collection of more samples for brief partial analyses in an effort to define the vertical and horizontal limits of contamination. When the limits have been defined, additional detailed partial or complete analyses of ground waters within the area will be obtained and used in an effort to determine the source of the contamination.

SUMMARY AND CONCLUSIONS

1. During the drought years 1945–51 ground water stored in the alluvial deposits of the Santa Ynez River valley between Cachuma Dam site and Robinson Bridge was depleted only a little—full recovery being effected with the winter rains of 1951–52. The largest depletion occurred in the Santa Ynez subarea, where water levels declined as much as 9 feet between April 1945 and April 1951. Lesser declines were observed in the Buellton and Santa Rita subareas.

2. Although the 1945–51 depletion of ground water stored in the Santa Ynez subarea amounted to 50 percent of the total water stored, the depletions in the Buellton and Santa Rita subareas were only about 12 and 16 percent, respectively.

3. Little is known regarding the maximum seepage-loss rates of the Santa Ynez River, but an imposing example of how fast large quantities of water can be recharged to the younger alluvium and river-channel deposits was obtained from daily water-level measurements made in observation wells in the winter of 1951–52. In the relatively short period January 7 to 18 a total gain in storage of 8,800 acre-feet occurred in the ground-water reservoirs of the Santa Ynez, Buellton, and Santa Rita subareas. More precise data concerning maximum percolation rates may be obtained during the release of regulated flows from Cachuma reservoir down a dry channel with lowered water levels. The first of many such releases planned by the Bureau of Reclamation indicated a maximum seepage loss of about 18-second-feet, but the rate probably would have been greater had the release been greater.

4. Data collected during the contemplated controlled releases from Cachuma reservoir will assist the Bureau of Reclamation in determining an equitable operating program for the Cachuma project. As presently constituted, the interim contract between the U. S. Government and the Santa Ynez Valley Water Conservation District guarantees the rights of the downstream users to the natural flow of the river, but to permit at least that rate of flow at all times might result in some loss of water. For example, if the ground-water storage in the alluvial deposits of the river is at or near full capacity, the re-

lease of water under the terms of the interim contract might well be wasted by flow to the ocean, surface evaporation, or consumptive use by native vegetation. Possibly the criterion in the final contract should not be the release of water merely to hold water levels at a maximum elevation, but rather some plan by which an inventory could be kept of water "owed" to downstream users—the water to be released at the most opportune time. Releases made at times during the season of least evaporation and transpiration, when storage space was available, would be the most efficient.

5. Although hydrographs of wells in the alluvial deposits adjacent to the Santa Ynez River show that water levels recovered fully as a result of the 1951–52 above-average rainfall, only a slight recovery was observed in the Santa Ynez upland. Water-level data in this area show that withdrawals for irrigation during the period 1945–51 exceeded replenishment, but whether the long-term yield is being exceeded cannot be determined until water-level fluctuations are observed during the next wet period.

6. Ground-water depletions in the Lompoc plain in the period 1945–51 were somewhat greater than those observed in the alluvial valley upstream from Robinson Bridge. At the eastern end of the plain, in an area of concentrated pumping, water levels declined as much as 20 feet, to the lowest levels on record, but elsewhere on the plain depletions were relatively minor. Recovery of water levels during the winter rains of 1951–52 were substantial, but not complete, in the areas of concentrated pumping.

7. Ground-water inventories in the Santa Ynez, Buellton, Santa Rita, and Lompoc subareas show that estimated storage depletions are inconsistent with ground-water withdrawals and estimates of the known sources of recharge. Quantitatively they indicate that additional sources of recharge exist or that sizable errors are involved in one or more items of the inventory. The most likely sources of error in the computations are the estimates of evapotranspiration, deep penetration of rainfall, and return irrigation water, because they are based on data from other areas. Soil sampling and the use of direct measurements of soil moisture would confirm or correct these estimates. Should this reexamination of the basin still fail to bring into balance recharge, withdrawals, and change in ground-water storage, the obvious conclusion would be that the consolidated rocks bordering most of the perimeter of the river valley are sufficiently fractured and adsorptive to store and transmit water to the alluvial deposits along the river. If this is true, then the rate of recharge to the fractured rock and the rate of transmission as underflow be-

come critical elements in the determination of perennial yield. If average yearly recharge to the consolidated rocks is meager—and there are indications that this is so—then most of the apparent unbalance between withdrawals and recharge is being sustained by the depletion of a supply that was accumulated over the ages and which, eventually, might cease to be of benefit. A study of soil moisture and runoff in the mountain area might reveal the rate of recharge to the consolidated rocks, but the critical element involving the rate of transmission to the basin would remain unknown.

8. On the basis of the 1947–51 inventory and an assumed value for rechargeable ground-water storage capacity, it would appear that, during a drought of as much as 11-years' duration, the Lompoc basin might be able to support an average yearly pumpage of about 25,000 acre-feet. At the end of that period recoverable water would have been depleted and the rate of recharge during the ensuing wet years would be critical. The 1947–51 inventory shows that during above-average rainfall seasons the storage volume beneath the Lompoc plain undoubtedly would be filled rapidly, but information concerning the rates of replenishment to the adjacent older deposits is almost completely lacking. Unanswered, then, is the question of whether the long-term average annual recharge is sufficient to meet a perennial pumping demand of 25,000 acre-feet a year.

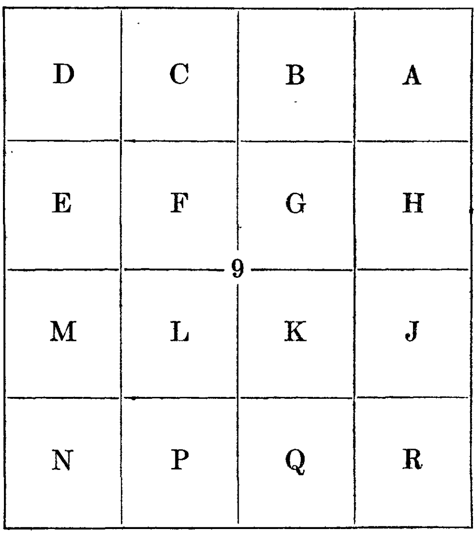
9. Throughout the drought years water levels at the west end of the Lompoc plain remained above sea level, thereby preventing the encroachment of sea water into the ground-water basin. The present pattern and rate of ground-water withdrawal suggest that there is no immediate danger of sea-water intrusion.

10. This report points out some rather sharp inconsistencies in the hydrologic data collected to date and focuses attention on several elements that will require reexamination before the perennial yield of the Santa Ynez basins can be estimated with accuracy. Because the full development of the water resources of the Santa Ynez River basin will not be possible until the hydrology and geology of the area are fully understood, it is essential that a continuing inventory be made of the water resources. Special emphasis should be placed on a re-evaluation of evapotranspiration by phreatophytes, return of irrigation water, and the deep penetration of rainfall. The latter two elements could be estimated simultaneously by means of soil-moisture studies for over a period of 2 or 3 seasons. A refined estimate of use of water by phreatophytes would require the operation of several climatological stations and a classification of the phreatophytes by type and area.

WELL-NUMBERING SYSTEM

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

The wells are assigned numbers according to their location in the rectangular system for the subdivision of public land. For example, in the number 6/32-9A2 the part of the symbol that precedes the hyphen indicates the township and range (T. 6 N., R. 32 W.). The one or two digits following the hyphen indicate the section (sec. 9), and the letter indicates the 40-acre subdivision of the section as shown in the accompanying diagram.



Within each 40-acre tract the wells are numbered serially as indicated by the final digit of the symbol. This well 6/32-9A2 is the second well to be listed in the NE¼NE¼ of sec. 9. As virtually all of the Santa Barbara County is in the northwest quadrant of the San Bernardino base and meridian lines, the foregoing abbreviation is sufficient for the County. Some parts of the County have never been public land; for these the rectangular system of subdivision has been projected.

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REFERENCES

Badon Ghyben, W., 1889, Nota in verband met de voorgenomen put boring nabij Amsterdam (Notes of the probable results of the proposed well drilling near Amsterdam): Inst. Ing. Tijdschr., The Hague.

Blaney, H. F., 1930, Rainfall penetration and consumptive use of water in Santa Ana River valley and coastal plain: California Dept. Public Works, Water Res. Div. Bull. 33.

——— 1933, Rainfall penetration *in* Ventura County investigation: California Dept. Public Works, Water Res. Div. Bull. 46, p. 82–90.

——— 1946, Salinas basin investigation: California Dept. Public Works, Water Res. Div. Bull. 52, p. 211–226.

——— 1952, Determining evapotranspiration by phreatophytes from climatological data: Am. Geophys. Union Trans., v. 33, p. 61–66.

Collins, W. D., 1927, Notes on practical water analysis: U. S. Geol. Survey Water-Supply Paper 596–H., p. 235–261.

Eckis, Rollin, 1934, South coastal basin investigation; Geology and groundwater storage capacity of valley fill: California Dept. Public Works, Water Res. Div. Bull. 45.

Foster, M. D., 1942, Base exchange and sulfate reduction in salty ground waters along Atlantic and Gulf Coast: Am. Assoc. Petroleum Geologist Bull., v. 26, no. 5, p. 838–851.

Herzberg, Alexander, 1901, Die Wasserversorgung einiger Nordseebäder (The water supply on parts of the North Sea Coast): Jour. Gasbelerichtung und Wasserversorgung, Jahrg. 44, Munich.

Gatewood, J. S., Robinson, T. W., Colby, B. R., Hem, J. D., and Halpenny, L. C., 1950, Use of water by bottom-land vegetation in lower Safford Valley, Ariz.: U. S. Geol. Survey Water-Supply Paper 1103.

Meinzer, O. E., 1923a, Outline of ground-water hydrology with definitions: U. S. Geol. Survey Water-Supply Paper 494.

——— 1923b, Occurrence of ground water in the United States, with a discussion of principles: U. S. Geol. Survey Water-Supply Paper 780.

Meinzer, O. E. (editor), 1942, Hydrology: Natl. Research Council, Physics of the Earth Series, Part 9, 712 p., McGraw-Hill Book Co., Inc.

Muckel, D. C., and Aronovici, V. S., 1952, Rainfall and irrigation water penetration in the upper Santa Ana River valley, San Bernardino County, Calif.: U. S. Dept. Agr. mimeographed rept., 97 p.

Piper, A. M., 1944, A graphic procedure in the geochemical interpretation of water analyses: Am. Geophys. Union Trans., Part 6, p. 914–923.

Piper, A. M., Gale, H. S., Thomas, H. C., and Robinson, T. W., 1939, Geology and ground-water hydrology of the Mokelumne area, Calif.: U. S. Geol. Survey Water-Supply Paper 780.

Piper, A. M., Garrett, A. A., and others, 1953, Native and contaminated ground waters in the Long Beach-Santa Ana area, Calif.: U. S. Geol. Survey Water-Supply Paper 1136.

Theis, C. V., 1935, The relation between the lowering of the piezometric surface and the rate and duration of discharge of a well using ground-water storage: Am. Geophys. Union Trans., pt. 2, p. 519–524.

——— 1938, The significance and nature of the cone of depression in groundwater bodies: Econ. Geology, v. 33, no. 8, p. 889–902.

Todd, D. K., 1953, Sea-water intrusion in coastal aquifers: Am. Geophys. Union Trans., v. 34, no. 5, p. 749–754.

Troxell, H. C., 1933, Ground-water supply and natural losses in the valley of Santa Ana River between Riverside Narrows and the Orange County line, pt. 2 *of* Water losses under natural conditions from wet areas in southern California: California Dept. Public Works, Water Res. Div. Bull. 44, pt. 2, p. 147–172.

Upson, J. E., and Thomasson, H. G., Jr., 1951, Geology and water resources of the Santa Ynez River basin, Santa Barbara County, Calif.: U. S. Geol. Survey Water-Supply Paper 1107.

Veihmeyer, F. J., and Brooks, F. A., 1954, Measurements of cumulative evaporation from bare soil: Am. Geophys. Union Trans., v. 35, p. 601–606.

Wilcox, L. V., 1948, Explanation and interpretation of analyses of irrigation waters: U. S. Dept. Agr. Circ. 784.

Worts, G. F., Jr., 1951, Geology and ground-water resources of the Santa Maria Valley area, Calif.: U. S. Geol. Survey Water-Supply Paper 1000.

TABLE 9.—*Chemical analyses of well waters in the Lompoc subarea*

Well or location	Owner	Date of collection	Temperature (° F.)	Dissolved solids (DS)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Boron (B)	Fluoride (F)	Nitrate (NO_3)	Hardness as $CaCO_3$	Specific conductance (micromhos at 25° C.)
			Parts per million																
6/34-4R1	City of Lompoc	4-12-42	68.5											111				690	1,410
5A1	Bodger Seeds Ltd	4-14-42	59.0		40	0.36	126	87	63	6.8	506		205	114			36	672	1,450
		4-14-42	68.5											112				675	1,430
		1-20-43		1,050			140	78	72	1.1	480	0	220	120			20		
5D1	McClure estate	1935		424			61	25	66		186		31	148				255	
		9-25-53	67.0	1,060	49	.01	142	74	106	2.0	482	0	261	148	0.25		8.7	659	1,570
5H1	John Bodger & Sons	1935		833			104	74	92		442		218	124				564	
5K2	do	6-2-41	75.0											930				1,225	4,260
		10-2-41	70.0											901				1,190	4,340
		10-11-41	70.5											886				1,000	3,640
6C1	A. R. Leege	5-26-41	75.0											191				1,075	2,080
6C2	Bank of America	2-12-52												205				704	
7F1	do	9-18-41	71.0											128				825	1,780
9A2	City of Lompoc	4-14-42	62.0	982	45	.13	152	76	45	7.2	498		228	111			6	692	1,440
11H1	Hollister estate	10-30-41	70.5											199				975	2,130
7/34-9H3	USGS on Union Oil Co. property.	3-31-48	61.0	278	43	.01	19	8.5	55	2.9	70	0	32	80			2.5	82	356
12E1	do	6-18-49	72.0											129				275	1,020
		6-18-49												129				270	986
		1-7-50												125				350	
		1-9-50		598	27	.32	102	16	88	3.2	296		95	120			.2	320	
19J1	Camp Cooke, well 3	1948					112				262		137	180				353	
		1949											141	138					
		1950					108				242		107	169				358	
		1951					101				290		110	156				334	
		2-20-52		626			98	25			248		121	134				346	
20K4	Camp Cooke, well 5	1948					111				225		145	185				393	
		1949					103				208		144	125				334	
		1950					96				232		106	128				326	
		1951					108				273		132	108				364	
		2-20-52		608			106	23			220		152	118				364	
20M2	Camp Cooke, well 4	1948					124				279		152	190				433	
		1949					103				263			144				396	
		1951					118				324		132	170				393	
		2-20-52		672							269		131	192				388	

21E1	USGS on Camp Cooke property	1- 9-50												86				288	883
		1-10-50												99				288	1,050
		1-10-50		503	43	0.15	91	26	64	2.4	282		109	88			0.1	334	
21J1	Union Oil Co	2- 2-45												163				225	938
22F1	Earl Calvert	8-11-41												273				475	1,530
		2- 5-52												180				348	
22H1	H. E. Harris	8-11-41	77.0											158				230	820
		10-23-41	67.0	450	43	.12	52	18	74	2.2	161	0	27	147			.77	204	
		2- 5-52												152				206	
22H4	Frank Onstott	2- 5-52												142				160	
22J2	Mrs. Elizabeth Rucker	9-15-41	71.5											169				258	931
23L1	do	2-20-52												200				464	
23M1	Mrs. Lothelle Hall	9-19-41	71.0											145				235	946
		2- 5-52												180				280	
23M2	Charles Davis	2- 5-52												200				360	
24N1	State of California	9-16-41	71.0											203				340	1,060
25D2	G. Kitaguchi	2- 5-52												410				664	
25F1	William Dutra	9-15-41	71.0											160				390	1,330
		10- 2-41	70.0											868				3,750	6,570
25G1	Mrs. Josephine Hayes	9-16-41	71.0											161				190	783
25K1	Mrs. William Dutra	8-11-41	77.0											186				500	1,590
25P2	W. T. McHenry	2-12-52												165				576	
26A1	G. Kitaguchi	8-11-41	77.0											198				250	1,040
26C1	Union Sugar Co	8-11-41	77.0											239				1,000	2,240
26H1	R. C. Lilly	2- 5-52												136				468	
26Q2	Guy Hibbits	4-14-42	63.0	1,156	36	0.98	156	83	81	8.0	397		458	80			0.2	731	1,550
		4-14-42	68.5											79				725	1,520
26Q3	R. and M. Hibbits	2- 5-52												110				626	
26R1	Guy Hibbits	9-19-41	71.0											174				525	1,760
26R2	W. T. McHenry	8-11-41	77.0											343				650	1,650
		2- 5-52												205				600	
26R3	A. Mattias	2- 5-52												123				530	
27E1	A. Chiodi	1935					117	67	86		342		338	87	0.05			568	
		9-15-41	71.0											81				625	1,400
		10- 2-53		1,250	34	.06	167	86	106	5.5	473	0	442	100	.70	0.5	.90	770	1,690
27F2	M. and W. G. Moore	2- 5-52												110				612	
27F4	J. M. Wilson	2- 5-52												105				592	
27K1	M. Lester Schuyler	8-11-41	77.0											77				500	1,270
28B1	S. B. Westrope	2- 5-52												220				1,432	
28E1	T. M. Parks	1935		1,266			168	86	146		464		485	149				773	
		6- 2-41	76.0											197				1,050	2,120
28F1	F. Guerra	7- 8-41	73.0											839				3,425	6,070
		9-11-41	70.0											841				3,500	5,620
		2- 5-52												285				1,312	
28F2	do	1935		1,007			146	75	112		456		380	106	.80			673	
28G1	G. H. Summers	1935		1,037			148	77	105		445		370	115	.60			686	
		9-29-53	67.0	1,890	30	.03	237	126	150	5.5	479	0	808	155	.78	.4	3	1,110	2,340
28H1	T. M. Parks	1-20-43		1,020			130	71	89	2	420		350	86	.50		0		
		2- 5-52												295				850	
28J1	R. D. Rennie	2- 5-52												220				924	
28L1	Dell Danils and A. Lehman	7- 8-41	73.0											98				600	1,470
		7- 7-42	75.0											94				725	1,460

TABLE 9.—*Chemical analyses of well waters in the Lompoc subarea*—Continued

Well or location	Owner	Date of collection	Temperature (° F.)	Dissolved solids (DS)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Boron (B)	Fluoride (F)	Nitrate (NO_3)	Hardness as $CaCO_3$	Specific conductance (micromhos at 25° C.)
			Parts per million																
7/34–28R1	W. A. Burpee	6- 8-48		1,010	31	0.02	158	64	75	8	336		430	73	0.4	0.8	6.1	657	1,430
28R2	USGS, A. C. Zvolanek property	6- 8-48		2,100	19	.02	305	154	156	16	491		942	242	1	.5	24	1,390	2,790
29E1	W. H. Sanor	1935		935			146	68	86		420		315	110				644	
30A1	G. F. Sanor	1939		1,317			168	81	158		384		612	124			0	752	
		9-29-53		923	42	.03	140	49	83	5.4	345	0	293	100	.35	.1	.2	551	1,300
30A2	W. H. Sanor	2-12-52												240				1,244	
30E1	Arthur Rudolph	5-26-41	76.0											105				700	1,530
30F1	H. S. Buckman	1935		979			136	72	105		424		332	122				636	
30G1	J. E. Sauor	1935		877			132	60	73		366		323	106	.20			576	
30L1	Union Sugar Co.	1935		1,073			163	90	90		576		338	104	.40			777	
30L2	do	1935		1,035			140	78	115		530		330	105	.04			670	
30M1	do	1935		1,030			157	56	135		580		303	89				623	
30R2	Mrs. Elizabeth Manfrina	1935		1,100			164	88	98		561		370	100				772	
31A1	Maple School District	7- 8-41	73.0											102				675	1,480
31A2	Burpee Ranch	4-11-11		3,526	28		413	420	519	12.9	202		1,041	615				821	
		6-28-11		1,433	16	10	238	160	148	7.9	214		270	172					
		5-15-24		1,095	55		156	78	80		10		188	88				812	
		4-16-41		1,085			132	50	190		543		336	105				535	1,790
		5- 2-41	76.0											93				750	1,520
		9-25-53	67.0	1,690	42	.05	235	130	100	3.5	558	0	606	180	.68	.2	2	1,120	2,190
31A3	Burpee Seed Co.	5-15-24			37	17.2	143	74	80		653		260	92				660	
		4-12-41		7,725			618	206	1,730		762		3,330	1,460				2,389	11,600
		6- 2-41												98					
		9-11-41	70.0											131				850	1,810
		10-12-41	70.0											123				625	1,760
		5-25-42	72.0											100				775	1,470
31B2	do	2-12-52												110				688	
31C1	Union Sugar Co.	7- 8-41	73.0											92				650	1,500
31C2	do	6- 8-48		943	42	.03	142	75	75	6.4	534		254	85	.50		.4	633	1,410
31C3	do	6- 8-48		1,140	10	.02	134	113	95	6.4	444		430	134	.50	.4	.6	799	1,700
31P1	D. T. Wood	1935		1,239			158	112	123		555		352	216	.10			855	
31R2	J. F. De Costa	2-12-52												220				932	
32C1	E. C. Bailey	7- 8-41	73.0											120				825	1,710

32C2	do	7-8-41	72.5	1,019										113				825	1,619
32P1	W. C. Bissinger	1935					143	70	125		500		284	147				645	
33C4	G. E. Learned	2-5-52												120				260	
33L1	Mrs. Meecham	7-8-41	73.0											164				1,100	2,160
33L2	E. Allen	1935		1,349			204	111	135		662		353	215				966	
33M1	Puritan Ice Co	6-16-30		1,404			193	98	130		580		402	295				8,875	
		2-5-52												225				1,188	
33P1	D. Douglas	1935		1,565			183	94	129		549		413	172	0.7			843	
		2-5-52												180				880	
		9-30-53		1,430	47	0	197	103	114	3.5	532	0	462	160	.72	0.3	15	915	1,960
34A1	Mrs. Mary Skaarup	8-11-41	77.0											80				650	1,410
34A2	do	2-5-52												100				508	
34Q1	Buckman, Denholm, and Holden.	8-11-41	77.0											172				800	1,900
		3-14-52												340				898	
35C5	Valla Bros.	2-5-52												330				912	
35F1	Antone Mattias	1935		1,581			184	99	230		452		543	302				866	
		8-11-41	77.0											283				900	2,260
		4-14-42	65.0	1,612			195	107	152		434		489	293				926	2,290
		4-14-42	68.5											267				1,000	2,140
		9-29-53	66.0	1,870	46	.03	195	100	281	11	494	0	502	420	1.1	.3	1.5	898	2,730
35J1	Chris Madsen	9-16-41	71.0											105				800	1,780
35K1	Mrs. M. McDonald	9-16-41	71.0											138				900	2,060
35K4	Chris Madsen	8-11-41	77.0											150				1,100	2,360
35L1	Eugene Schuyler	8-11-41	77.0											117				650	1,640
35N1	do	9-18-41	71.0											152				790	1,860
		2-5-52												155				714	
35P2	Robinson and Lane	9-18-41	71.0											114				600	1,570
36D1	C. J. Hayes	9-16-41	71.0											183				575	1,670
7/35-13N1	Camp Cooke property	6-2-41	75.0											175				300	1,090
16G1	do	6-2-41	75.5											488				600	2,280
17B1	do	5-2-41	76.0											477				415	2,060
18J1	do	8-26-48												4,170				1,200	12,800
		12-15-48												8,830				3,750	23,400
		8-21-51												2,095				682	7,970
		4-25-52					90	128	1,350	48	514	16	252	2,280				751	7,830
		9-10-52	76.0								582	0		2,350					8,350
		4-23-53												2,290				625	7,220
20J1	do	5-26-41	76.0											375				825	3,370
		7-8-41	73.0											1,689				1,700	6,000
		8-11-41	77.0											1,499				1,583	5,490
		9-11-41	70.5											2,036				2,250	5,990
20J1	do	9-30-41	70.0											1,528				1,625	5,710
		10-27-41	70.0											2,059				2,125	6,860
		12-11-41	68.5											1,873				2,000	6,240
		5-25-42	72.0											1,630				625	5,160
21L1	do	1935		1,350			128	70	274		420		256	412	0.2			608	
21L3	do	5-14-51	72.8											535				783	2,520
		8-21-51	73.5											512				780	2,560
		4-25-52					176	90	210	9.5	196	0	372	565				809	2,590
		9-10-52	75.0								188	0		540					2,530
		4-23-53												540				750	2,500

TABLE 9.—*Chemical analyses of well waters in the Lompoc subarea*—Continued

Well or location	Owner	Date of collection	Temperature (° F.)	Parts per million															Specific conductance (micromhos at 25° C.)
				Dissolved solids (DS)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Boron (B)	Fluoride (F)	Nitrate (NO_3)	Hardness as $CaCO_3$	
7/35-21R1	B. Huyck	5-26-41	76.0											663				850	2,980
		7-8-41	72.0											622				700	2,910
		8-11-41	77.0											609				800	2,910
		9-11-41	70.5											629				750	2,760
21R1	do	9-30-41	70.0											640				750	3,040
		10-11-41	62.0	1,920	29	7.8	183	80	356	3.8	355		356	635			3.2	786	
		10-27-41	70.0											633				500	2,820
		5-25-42	72.0											603				550	2,510
22E1	Camp Cooke property	1935		1,044			90	35	193		326		116	284	0.20			368	
22F1	do	1935		837			135	65	78		451		173	160	.10			604	
22J1	Union Sugar Co.	1935		988			108	73	150		482		246	170	.50			570	
		7-8-41	73.0											159				625	1,570
		8-26-48												233				1,825	1,920
		5-14-51	72.8											245				828	1,970
22K1	do	8-26-48												272				513	1,730
22L1	Camp Cooke property	5-14-51	72.8											345				997	2,350
		8-21-51												337				918	2,390
		4-25-52					107	96	125	9.5	292	0	281	328				662	1,900
		4-23-53												365				910	2,280
22P1	do	7-10-41	73.0											272				450	1,600
23B1	Camp Cooke property	10-17-41	65.0	1,530	38	.9	187	95	185	5.3	551		399	282			.83	857	
		1948					114						180	178				435	
		1951					204						431	376				924	
		1-15-52		1,490			148	94					252	456				754	
		2-14-52												390				908	
23E2	Union Sugar Co.	5-26-41	76.0											377				1,025	2,600
		5-16-51												357	.30			936	2,670
		8-21-51												346				882	2,670
		4-23-53					217	94	250	13	512	0		345			5	928	2,630
23J1	Union Sugar Co.	6-14-44												202					
		11-4-49												233				900	2,330
23J2	do	6-4-48		2,000	40	.02	285	138	193	11	590		744	298	.60	0	.80	795	2,800
23J3	do	6-4-48		3,410	20	.02	424	200	421	18	561		1,410	635	1.12	.2	2.4	1,880	4,530

23L1	do	7-8-41	73.0											177				550	1,640
24H2	Camp Cooke property	1948					109				295		140	169				407	
		1949					112				309			220				428	
		1950					106				304		164	226				360	
		1951					136				368		161	192				475	
		2-20-52		910			106	34.1			306		156	247				404	
24J1	Tom Parks	1935		1,261			148	67	216		464		292	306				644	
24K2	A. B. Henning	1935		1,196			154	61	192		515		329	202				636	
		1-20-43					180	75	170		520		440	180	0.50				
		5-16-51	72.8											296	.20			882	2,430
		9-25-53	67.0	1,870	47	0.05	252	90	221	14	479	0	425	450	.72	0.1	14	998	2,710
24M1	W. R. Beattie	1935		1,103			134	75	156		500		325	163	.40			643	
24P1	H. E. Beattie	6-17-44												198					
		5-16-51	72.8											229				1,260	2,620
24P2	do	1935		1,085			146	71	140		475		330	160	.40			656	
24R2	Tom Parks	1935		1,041			141	67	137		450		290	181	.80			627	
		6-2-41	75.0											164				650	1,590
25D1	H. E. Beattie	1935		970			142	71	99		436		312	128	.60			646	
		1935		1,146			166	71	141		520		352	156	.40			706	
		10-2-53		2,360	42	.02	324	153	170	8.5	548	0	884	320	.46	.3	1.5	1,440	2,940
25F1	Union Sugar Co	1935		900			148	69	76		515		253	96	.10			653	
		1935		968			111	71	146		530		218	157	.10			569	
25H1	Arthur Rudolph	1935		1,139			157	77	100		494		345	113	.50			708	
		9-25-53	67.0	1,510	27	.02	201	104	127	5.5	482	0	561	160	.61	.2	4.1	929	2,020
25K1	Mrs. Harvey Hilburn	2-12-52												180				836	
25K2	do	1935		852			123	64	97		512		216	96	.20			570	
25L2	Mrs. Kate McConnel	1935		828			137	68	65		495		205	105	.10			622	
25P2	Sudden estate	7-8-41	73.0											110				675	1,398
26A2	Charles Bondietti	7-8-41	73.0											92				550	1,310
		5-16-51	73.0											91				500	1,250
26F1	Union Sugar Co	1935		884			117	70	109		488		198	146	0.30			580	
		6-23-44												180					
		8-20-51												161				763	1,710
		4-25-52					121	100	94	6.6	318	0	351	225				713	1,730
26F2	do	7-10-41	73.0											173				700	1.620
26J1	Artesia School	1-20-43		3,640			320	290	260		500		1,230	660	.10		0.4		
26J2	Union Sugar Co	4-14-42	64.0	894	38	1.4	130	75	65	8.4	466		199	121			.1	633	1,370
		4-14-42	68.5											122				690	1.330
26J4	County of Santa Barbara	5-16-51	73.0											130				663	1.500
		2-12-52												160				684	
		2-12-52												160				708	
27C2	Southern Pacific Railroad	1935		1,619			244	84	238		384		289	572	.10			954	
		5-14-51	72.8											470	.20			791	2,580
		9-25-53	65.0	1,530	44	0	169	69	221	7	302	0	302	450	.32	0	5.1	705	2,320
28H1	Perrozzi Bros	1935		605			66	25	128		164		48	256	0			268	
35C2	S. Colli	5-26-41	76.0											135				255	793
36B1	Union Sugar Co	7-8-41	73.0											423				1.400	3,150
36E1	Sudden Estate	1935		1,022			130	93	105		418		258	227				707	
36J3	Fred Huyck	1935		1,446			174	144	128		513		444	300				1,026	
36P1	Bertha Carr	1935		363			33	29	58		97		76	119					
		10-2-53		1,180	32	.02	117	87	160	4	461	0	285	215	.39	.3	21	650	1,820

TABLE 9.—*Chemical analyses of well waters in the Lompoc subarea*—Continued

Well or location	Owner	Date of collection	Parts per million															
			Temperature (° F.)	Dissolved solids (DS)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Boron (B)	Fluoride (F)	Nitrate (NO_3)	Hardness as $CaCO_3$	Specific conductance (micromhos at 25° C.)
7/35-36Q2	Turri Bros	5-26-41	76.5	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	321	-----	-----	-----	975	2,290
		7-8-41	72.5	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	173	-----	-----	-----	400	1,330
		8-11-41	77.0	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	445	-----	-----	-----	825	2,560
		9-11-41	70.5	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	317	-----	-----	-----	800	2,160
		9-30-41	70.0	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	369	-----	-----	-----	875	2,410
36Q2	do	10-27-41	70.0	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	307	-----	-----	-----	850	2,240
		12-11-41	69.0	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	389	-----	-----	-----	700	2,320
		5-25-42	72.0	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	318	-----	-----	-----	950	2,220

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