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Utilization of Ground Water in the Santa Maria Valley Area, California

By G. A. MILLER *and* R. E. EVENSON

CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

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UTILIZATION OF GROUND WATER IN THE SANTA MARIA VALLEY AREA, CALIFORNIA

By G. A. MILLER and R. E. EVENSON

ABSTRACT

Overdraft in the Santa Maria Valley ground-water basin since about 1946 has resulted in a significant decline in water levels throughout the basin as ground water has been removed from storage. In 1959 approximately 2,200,000 acre-feet of ground water was in storage above sea level in the ground-water reservoir.

Estimates of storage depletion are not consistent with estimates of ground-water recharge and discharge. The natural perennial yield of the basin probably is about 50,000 acre-feet, on the basis of estimated recharge and natural discharge. The augmented perennial yield probably is about 70,000 acre-feet and includes 21,200 acre-feet of water per year released at Twitchell Dam. Storage depletion, not estimated in the seaward ends of the aquifers, will result as the fresh water–sea water interface moves landward in response to the continuing decrease in hydraulic gradient in the aquifer system.

Evidence of sea-water intrusion into the basin has not been observed, but limited sea-water encroachment may have occurred at the offshore ends of the aquifers. Additional observation wells will be necessary to provide supplemental data to insure that hydraulic heads and gradients in the deeper aquifers are properly monitored.

INTRODUCTION

This is the second interpretive report on ground-water investigations of the Santa Maria Valley area by the U.S. Geological Survey in cooperation with Santa Barbara County. The first investigation was begun in 1941 and resulted in a comprehensive report by Worts (1951, p. 1–48 and 72–169) in which the ground-water basin was described and the perennial yield of the basin was estimated. Surface-water resources of the Santa Maria Valley area were described by Thomasson (in Worts, 1951, p. 4, 48–72). In 1959 construction of Twitchell Dam and reservoir was completed by the U.S. Bureau of Reclamation on the Cuyama River just upstream from Fugler Point. Floodwater is detained by the dam and later is released for replenishment of ground-water reservoirs downstream, thereby alleviating overdraft.

Since about 1946, withdrawal of ground water from storage has caused a significant decline in water levels throughout the basin. The water users are concerned because ground water in the basin is the principal source of water supply for the area. Thus far the decline in water level has caused only an increased pumping lift. Eventually, if the water level decline continues unabated, the water level will be below sea level and the hydraulic gradient will be reversed. This will result in sea-water movement inland which will contaminate the fresh-water reservoir.

Water probably will be imported into the basin from northern California to supplement the available ground-water supply. However, the quantity of supplemental water that is required to stop the decline in water level depends on the magnitude of the overdraft in the ground-water basin.

PURPOSE AND SCOPE

The purpose of this report is to evaluate the magnitude of the overdraft in the Santa Maria Valley ground-water basin and to describe the effects of overdraft, particularly in reference to ground-water storage and sea-water encroachment. Also, the estimates of perennial yield published in Water-Supply Paper 1000 have been reappraised by an analysis of geologic and hydrologic data collected during the period 1950–59 and during the complete period of record 1918–59.

In particular, the scope of the report is to (1) summarize the geology and hydrology, as related to the occurrence of ground water, (2) give calculations of the volume of water in storage above sea level, (3) bring up to date the estimates of recharge and discharge, (4) reevaluate estimates of perennial yield, and (5) describe the sea-water-encroachment potential.

LOCATION AND GENERAL FEATURES OF THE AREA

The Santa Maria Valley (fig. 1) is a large coastal valley in northwestern Santa Barbara and southwestern San Luis Obispo Counties, Calif., at the northwest end of the San Rafael Mountains. The valley area includes the alluvial plains of the Sisquoc and Santa Maria Rivers, and upland area known as Nipomo Mesa, and an extensive upland area between Foxen Canyon and the Pacific Ocean.

The Santa Maria River is formed at the confluence of the Cuyama and Sisquoc Rivers, and its carries most of the valley's drainage to the Pacific Ocean. Twitchell Dam and reservoir control the Cuyama River by detaining the floodflow so that, later it can be released to replenish the ground-water reservoir.

Most of the water used in the Santa Maria Valley for agricultural, municipal, industrial, and domestic purposes is obtained from wells that tap the ground-water reservoir. By far the greatest quantity

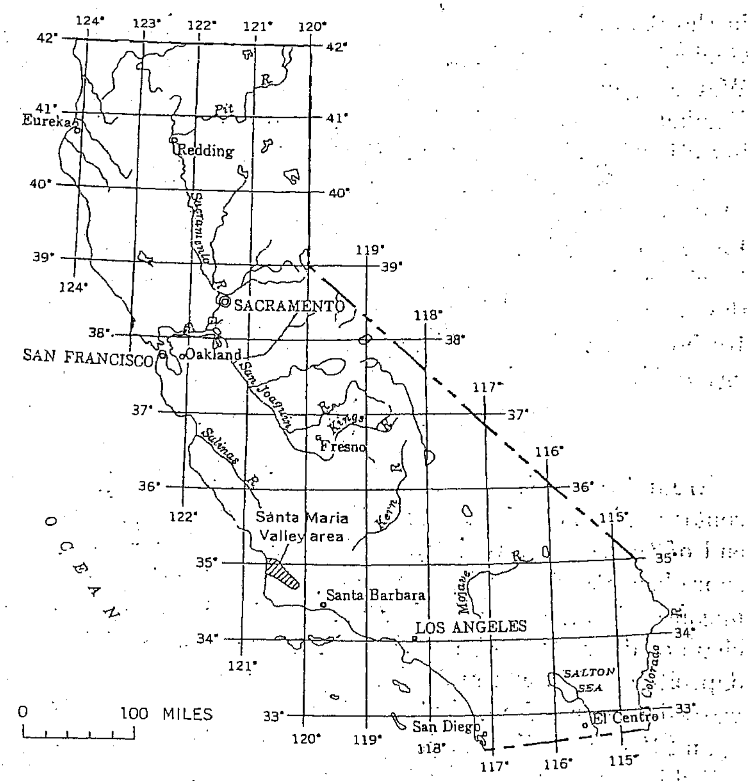

FIGURE 1.—Location of Santa Maria Valley area.

of water is used for irrigation; artichokes, broccoli, lettuce, sugarbeets, and alfalfa are among the irrigated crops that are grown on the alluvial plains. Only recently, some alfalfa has been grown on the upland area between Orcutt and Bradley Canyon. Industrial water supplies are used by a sugarbeet refinery, several oil fields and refineries, and vegetable-processing plants.

PREVIOUS WORK AND ACKNOWLEDGMENTS

Worts (1951) prepared the first comprehensive report on the water supply of the area, and his work was referred to frequently in the preparation of this report. Woodring and Bramlette (1950) mapped the geology of the southern part of the basin and provided valuable information on the subsurface geology. Topographic maps made by the Geological Survey and by the Army Map Service were used as base maps for this report. Long-term records of streamflow and estimates of runoff from the ungaged area were provided by the U.S. Geological Survey, Surface Water Branch. Mr. Tieh-liang Hsu of the Taiwan Geological Survey compiled much useful data on ground-water storage in the Santa Maria Valley. The present report was prepared by the Geological Survey, in cooperation with the Santa Barbara County Water Agency, under the supervision of H. D. Wilson, Jr., and Fred Kunkel, successive district supervisors for Ground Water Branch investigations in California.

The Pacific Gas and Electric Co. made available data on pump-efficiency tests and agricultural-power consumption in the valley. Records of municipal water use were obtained from the city of Santa Maria, and records of water-level measurement were obtained from the Santa Maria Valley Water Conservation District. Mr. Vernon Rutherford and Mr. York Peterson provided useful data on the geology and hydrology in the Santa Maria area.

GROUND WATER

Ground water in the Santa Maria Valley is relatively fresh and is contained in a continuous aquifer system that extends from the upper end of the Sisquoc plain westward for an undetermined distance offshore beneath the Pacific Ocean. The aquifer system is composed of unconsolidated water-bearing units which include dune sand, river-channel deposits, and alluvium of Recent age and undifferentiated deposits of Pliocene and Pleistocene age. A brief summary of the water-bearing units and their hydrologic properties is given in table 1, and the areal distribution of these units is shown on plate 1. Detailed information relative to the ground-water geology is given in the comprehensive report by Worts (1951, p. 23–44).

AQUIFER SYSTEM

The aquifer system is more than 2,300 feet in saturated thickness and averages about 1,000 feet. It is composed of permeable beds of gravel and sand that locally are separated by relatively impermeable beds of silt and clay. Most of the ground water in the aquifer system is in the undifferentiated deposits of Pliocene and Pleistocene age, but the main water-bearing zone is in the lower part of the alluvium of Recent age (pl. 1).

Consolidated rocks form the bottom of the aquifer system, and the base of the fresh water, shown on plate 1, generally coincides with the contact between the consolidated rocks and the base of the undifferentiated deposits of Pliocene and Pleistocene age. The southern limit of the aquifer system approximates the topographic divide between Santa Maria and Los Alamos Valleys east of U.S. Highway 101 and the outcrop of consolidated rocks west of U.S. Highway 101. The northern limit of the aquifer system is a topographic and poorly defined ground-water divide in the vicinity of Nipomo Mesa. East of

TABLE 1.—*Water-bearing units in the Santa Maria Valley ground-water basin*

	Geologic age	Water-bearing unit	Thickness (ft)	Lithologic character	Hydrologic properties
Quaternary	Recent	Dune sand	0–200±	Medium to coarse well-sorted windblown sand; in part stabilized and in part actively drifting.	Highly porous and permeable; saturated only near the base. No wells are known to produce from this unit.
		River-channel deposits	0–25±	Boulders, gravel, sand, silt, and clay in the channels of the Cuyama, Sisquoc, and Santa Maria Rivers. Progressively finer grained downstream in Santa Maria River.	Generally above zone of water-table fluctuations, but large quantities of water infiltrate to recharge aquifers in the underlying alluvium. Worts (1951, p. 40) listed permeabilities of from 154 to 1,060 gpd per sq ft.
		Alluvium	0–200±	Gravel, sand, silt and clay. Progressively finer grained from east to west. Layer of silt and clay in upper 100 ft of alluvium acts as confining zone and extends westward from midpoint between Santa Maria and Guadalupe.	Main water-bearing zone in valley; confined in part. Most irrigation wells obtain water from the alluvium. Permeability decreases from 4,000 gpd per sq ft at the east end of the valley to 2,000 gpd per sq ft at the west end. (Worts, 1951, p. 38–39.)
	Pleistocene	Unconsolidated deposits, undifferentiated	0–2, 300	Marine and continental beds of gravel, sand, silt, and clay. Include terrace deposits, Orcutt Sand, Paso Robles Formation, and Careaga Sand.	May comprise 3 or more separate confined aquifers in western part of area, but all may be hydraulically connected in the central or the eastern part of area. Locally, permeability may be as much as 200 gpd per sq ft in the central part of area. Large quantities of water are stored in these formations.
Tertiary	Pliocene				
Jurassic		Consolidated rocks, undifferentiated	0–10, 000±	Generally impervious sandstone, shale, mudstone, and pyroclastic rocks of Pliocene and older age; also igneous and metamorphic rocks of Jurassic and Cretaceous age.	Not water bearing for the most part. Locally, fractures supply minor quantities of water to wells and springs.

Nipomo Creek and north of the Santa Maria and Sisquoc Rivers, the limit of the aquifer system is marked by the contact with the consolidated rocks.

The freedom of ground-water movement within the aquifer system decreases from east to west across the valley and also probably decreases with depth. Aquifers in the deposits of Pliocene and Pleistocene age are mostly confined, as is the main water-bearing zone, in the western part of the alluvial plain. Minor bodies of perched ground water lie above the confining beds in areas beneath the western part of the plain, beneath the Nipomo Mesa, and locally beneath the Orcutt upland. A higher head in the deeper aquifers was indicated in a well near Orcutt, where, in 1961, a flow of several hundred gallons per minute was measured passing from aquifers 1,190 feet below sea level into the upper aquifer. Water-level data are not available for aquifers below about 1,000 feet; however, electric logs of oil wells and of deep water wells indicate several continuous impermeable layers that probably would restrict hydraulic continuity in deeper parts of the basin.

The dissolved-solids content of water from various aquifers, as calculated from electric logs of oil wells and deep water wells, indicates that water of uniformly good quality is present from the top to the bottom of the saturated zone.

STORAGE CAPACITY

Ground-water storage capacity was estimated according to the method first described by Eckis and Gross (1934, p. 112) and later revised by Thomasson, Olmsted, and LeRoux (1960, p. 279–282). Although estimates of net change in ground water in storage for specific periods were listed by Worts (1951, p. 121–122), no estimate was made of the quantity of water in storage above sea level. The total volume of saturated deposits is probably about 100 million acre-feet (Worts, 1951, p. 73). However, in a coastal valley the quantity of water available for utilization is limited by the threat of sea-water intrusion if water levels are lowered to produce a landward hydraulic gradient. An effective ground-water barrier near the coast will be necessary to retard sea-water encroachment if the water level in the coastal part of the basin is to be lowered below sea level.

For the computation of the storage capacity of the ground-water basin, the area underlain by water-bearing deposits was divided into eight storage units (pl. 1). For each of the storage units, the saturated material described in the well logs was assigned a value for specific yield according to the broad classification shown in the following table. The upper limit of saturation was determined from water-level-contour maps for 1918, 1950, and 1959. These years were selected because the hydrologic equations in the following sections of the report are developed for the periods 1918–59 and 1950–59. Water-level data for 1918 are adequate for the valley floor but for the most part are interpolated for the upland areas; however, data for 1950 and 1959 are sufficient for making estimates of storage changes throughout the ground-water basin. Plate 1 shows the water-level contours for the spring of 1959.

Within each storage unit, an average specific yield was computed for each 20-foot depth increment between the top of the saturated zone and sea level (10 ft. above sea level in the Guadalupe storage unit).

Material	*Assigned specific yield (percent)* *Alluvium*	*Undifferentiated deposits of Pliocene and Pleistocene age*
Gravel (generally includes some sand)	30	25
Gravel and sand	25	20
Sand	20	20
Sand and clay	10	10
Clay	5	3

The volume of water in each 20-foot depth increment is computed by multiplying the average specific yield by the corresponding saturated volume of the increment. The summation of increment totals is the volume of water in storage above sea level in the particular storage unit. Table 2 shows the estimated ground water in storage above sea level within each storage unit for the years 1918, 1950, and 1959.

Storage estimates for the Guadalupe storage unit are based on the depth increment between the top of the saturated zone and 10 feet above sea level. The limit of 10 feet above sea level was arbitrarily chosen for this coastal storage unit as providing an adequate natural barrier against sea-water intrusion.

TABLE 2.—*Estimated ground water in storage above sea level*

Storage units (fig. 3)	Surface area (acres)	Average saturated thickness of full reservoir (in feet below 1918 water level)	Average specific yield (percent)	Number of well logs	Estimated ground water in storage (acre-ft) 1918	1950	1959
Guadalupe [1]	25,000	70	[2] 13	161	235,000	171,000	145,000
Nipomo	10,500	160	[3] 15	10	250,000	160,000	140,000
Betteravia	6,100	120	[3] 12	26	82,000	65,000	47,000
Santa Maria	17,400	160	[2] 20 [3] 15	161	540,000	292,000	265,000
Fugler Point	5,500	260	[2] 20 [3] 13	61	230,000	153,000	170,000
Orcutt	16,200	180	[3] 15	93	460,000	277,000	290,000
Bradley Canyon	22,000	340	[3] 14	41	1,020,000	992,000	900,000
Sisquoc	4,280	380	[2] 21 [3] 14	37	255,000	252,000	250,000
Totals (rounded)	107,000				3,070,000	2,360,000	2,210,000

Decrease in storage (acre-ft)	1918–59	1950–59
Net	860,000	150,000
Average annual	21,000	17,000

[1] Guadalupe storage unit estimates are from 10 ft above sea level to the top of the saturated zone; others are from about sea level to top of saturated zone.
[2] Alluvium.
[3] Deposits of Pliocene and Pleistocene age.

HYDROLOGIC EQUATION, 1918–59, 1950–59

A chief purpose of this ground-water study is to evaluate the magnitude of the overdraft and to describe its effects with particular reference to ground water in storage and sea-water encroachment. Overdraft occurs in a ground-water basin when the quantity of water withdrawn exceeds the perennial yield. The framework to evaluate the magnitude of overdraft is based on the hydrologic equation. In this equation the elements of ground-water discharge are subtracted from the elements of ground-water recharge and the difference is balanced against the observed change in ground water in storage for the periods 1918–59 and 1950–59, respectively.

Estimates of ground-water recharge, discharge, and change in storage are made by the same methods as used by Worts (1951, p. 80–123). Estimates of ground water in storage are revised for 1950 and 1959 to include new water-level data for areas that had little or no data available during earlier studies. The estimates of ground water in storage for 1918, 1950, and 1959 are based on water levels in the spring of the year at the water-level peak, usually March or April. Estimates for the elements of discharge are based on the calendar year (Jan. 1–Dec. 31) for the periods 1918–58 and 1950–58, and estimates for the elements of recharge are based on the water year (Oct. 1–Sept. 30) for the periods 1919–59 and 1951–59. Discharge estimates are based on the calendar year because most of the ground-water discharge occurs after irrigation begins in the spring. Recharge estimates are based on the water-year beginning 9 months later (Oct. 1), which is the start of the next sequence of rainstorms. The chronologic relations are, in general, hydrologically comparable for the purposes of the hydrologic equation.

RECHARGE

In the Santa Maria Valley ground-water basin, the elements of recharge in the hydrologic equation are seepage loss from streams and infiltration of rain. The return to ground water of excess irrigation water to ground water is included indirectly by calculating net pumpage as 80 percent of gross pumpage (Worts, 1951, p. 88). Underflow from streams is included in the estimates of annual seepage loss.

SEEPAGE LOSS FROM STREAMS

Recharge to the ground-water body occurs by downward and lateral percolation of water from flowing streams, principally the Sisquoc and the Santa Maria Rivers in the upper reaches of the Santa Maria plain. Measurements of streamflow in the Santa Maria Valley area have been recorded since 1929. Estimates of annual seepage loss for the period after 1943 are based on measured streamflow into and out of the valley, plus an estimated small quantity of flow contributed by ungaged streams. For the period prior to 1929, estimates of seepage loss are based on the projection of a graphic correlation of rainfall, runoff, and seepage loss for the period of record 1929–59.

Seepage loss from the gaged streams is equal to the sum of total measured flows into the valley area, plus an estimate of flow from the

ungaged streams, minus the measured outflow to the ocean. Estimates of flow from ungaged minor streams for 1946–59 are computed as 1½ times the flow in Tepusquet Creek. Gaging-station records of the flow of streams tributary to the valley area include those for the Cuyama, Huasna, and Sisquoc Rivers; Alamo, LaBrea, and Tepusquet Creeks; and, beginning in 1959, the Cuyama River below Twitchell Dam. The gaging station on the Santa Maria River near Guadalupe records streamflow discharging to the ocean.

Table 3 shows that seepage loss from streams ranged from slightly more than 4,000 acre-feet in the 1948 water year (Oct. 1, 1947–Sept. 30, 1948) to about 150,000 acre-feet in the 1941 water year. The total seepage loss for the 41-year period (water years 1919–59) was about 1,600,000 acre-feet, or an annual average loss of about 39,000 acre-feet. The seepage loss for the 9-year period (water years 1951–59) was about 370,000 acre-feet, or annual average of about 41,000 acre-feet.

TABLE 3.—*Estimated seepage loss from streams, 1919–59*

[All values are rounded]

Water year ending (Sept. 30)	*Inflow (acre-ft)*	*Outflow (acre-ft)*	*Seepage[1] loss (acre-ft)*	*Water year ending (Sept. 30)*	*Inflow (acre-ft)*	*Outflow (acre-ft)*	*Seepage[1] loss (acre-ft)*
1919	28,000	3,000	25,000	1941	333,000	183,000	150,000
1920	6,000	0	6,000	1942	52,600	1,090	51,500
				1943	178,000	71,900	106,000
1921	10,000	0	10,000	1944	83,000	13,560	69,400
1922	114,000	40,000	74,000	1945	49,250	4,990	44,300
1923	30,000	4,000	26,000				
1924	9,000	0	9,000	1946	29,500	4,880	24,600
1925	36,000	7,000	29,000	1947	15,800	2,530	13,300
				1948	4,000	0	4,000
1926	12,000	0	12,000	1949	7,000	0	7,000
1927	30,000	4,000	26,000	1950	13,100	2,460	10,600
1928	24,000	1,000	23,000				
1929	15,000	0	15,000	1951	6,300	0	6,300
1930	7,200	0	7,200	1952	210,800	104,700	106,000
				1953	27,200	360	26,800
1931	4,800	0	4,800	1954	29,900	1,270	28,600
1932	114,000	42,000	72,000	1955	11,100	0	11,100
1933	26,200	3,700	22,500				
1934	17,700	0	17,700	1956	36,500	4,200	32,300
1935	43,200	3,600	39,600	1957	6,200	0	6,200
				1958	270,300	133,500	137,000
1936	55,500	19,300	36,200	1959	14,500	0	14,500
1937	190,000	88,000	102,000	*Seepage loss*		*1919–59*	*1951–59*
1938	262,000	135,000	127,000	Total		1,600,000	370,000
1939	24,600	0	24,600	Annual			
1940	27,700	0	27,700	average		39,000	41,000

[1] Estimated, 1919–29; in small part estimated, 1930–59.

Twitchell Dam, completed in 1959 near the mouth of the Cuyama River, has a reservoir capacity of 239,000 acre-feet. It was designed to conserve most of the river flow by storing water during periods of high flow and, later, releasing the water at rates which would allow percolation into the channel of the Santa Maria River. Schedules are planned to release a total maximum flow of 300 cfs (cubic feet per second), which is considered the optimum rate for maximum seepage in the Santa Maria River channel. The U.S. Bureau of Reclamation (1958, p. 12) estimated that Twitchell Dam reservoir will yield an additional 21,200 acre-feet of water annually for recharge to the ground-water basin.

INFILTRATION OF RAIN

Most of the precipitation on the watershed occurs as rain. Infiltration of rain as recharge to the ground-water reservoir occurs throughout most of the basin. Worts (1951, p. 80–81) divided the basin into three areas having different rain-infiltration characteristics on the basis of surface soil, vegetation, and underlying formations. The first area, which includes about 20,000 acres of irrigated land, contains relatively permeable soils underlain by permeable unconsolidated deposits. Much of this area has a high percentage of rain infiltration because it lies fallow during the rainy season, and throughout the year the soil moisture content normally is high owing to irrigation. The second area of rain infiltration includes about 60,000 acres of grassland and is similar in permeability to the first area. It has a low percentage of rain infiltration because of dense vegetative cover. The third area, which includes about 60,000 acres of scrub oak, brush, and some grassland, is underlain principally by thin soils and relatively impermeable consolidated rock and has a low percentage of rain infiltration.

Estimates of rain infiltration by Worts (1951, p. 80), which were based on data from Ventura County (Blaney, 1933, p. 82–91), assume no infiltration on irrigated land if annual rainfall is less than 12 inches, grassland if annual rainfall is less than 15 inches, and brush land if annual rainfall is less than 18 inches. Worts (1951, p. 81) estimated that for the brushland underlain principally by consolidated rocks, about 10 percent of the rainfall in excess of 18 inches would be added to the ground-water body as recharge.

Table 4 lists the precipitation at Santa Maria and the estimated annual recharge to the ground-water body by infiltration of rain for the water years 1919–59. Estimates for 1944–1959 are adjusted to account for the change in irrigated acreage. Recent studies of rain infiltration in comparable land areas in the Santa Ynez River basin indicate that the estimated recharge may be low for the irrigated land (Blaney and others, 1963, p. 9).

TABLE 4.—*Precipitation at Santa Maria and estimated infiltration of rain, 1919–59*

[Precipitation data from U.S. Weather Bureau. Infiltration values are rounded]

Water year ending Sept. 30	*Precipitation (in.)*	*Infiltration (acre-ft)*
1919	11.40	0
1920	9.19	0
1921	11.48	0
1922	16.44	8,400
1923	12.66	400
1924	6.11	0
1925	15.04	2,900
1926	10.08	0
1927	15.59	6,000
1928	15.34	4,900
1929	10.70	0
1930	9.33	0
1931	8.97	0
1932	16.48	9,000
1933	11.35	0
1934	7.68	0
1935	19.55	25 000
1936	13.48	1,000
1937	20.82	35,000
1938	22.18	40,000
1939	11.51	0
1940	14.61	2,000
1941	30.75	80,000
1942	16.95	12,000
1943	17.22	13,000
1944	14.56	2,000
1945	11.31	0
1946	11.08	0
1947	9.42	0
1948	8.20	0
1949	9.17	0
1950	10.47	0
1951	8.66	0
1952	18.57	23,000
1953	10.87	0
1954	12.12	300
1955	13.17	1,900
1956	14.56	4,300
1957	9.01	0
1958	25.86	66,000
1959	7.62	0

	1919–59	*1951–59*
Precipitation (in.):		
Total	549.56	120.44
Annual average	13.40	13.38
Infiltration (acre-ft):		
Total	340,000	95,000
Annual average	8,200	11,000

Estimates of rain infiltration listed in table 4 indicate a range from 0 during several years to 80,000 acre-feet in 1941. Average annual recharge by infiltration of rain for the 41-year period 1919–59 is about 8,200 acre-feet, and for the 9-year period 1951–59, nearly 11,000 acre-feet.

The percentage of rain that reaches the ground-water body probably will increase in the future because urbanization in the valley will concentrate the runoff, decrease evapotranspiration, and cause grassland to be converted to irrigated land.

DISCHARGE

Discharge of ground water from the Santa Maria basin has occurred in four ways:

1. Underflow to the ocean.
2. Evapotranspiration by vegetation.
3. Overflow of the ground-water basin resulting in streamflow to the ocean.
4. Withdrawals from wells.

Before the turn of the century, practically all discharge from the basin was by natural means, in about 1898, however, irrigation by water from wells was begun in the valley, and since the early 1920's most of the discharge of ground water has been from wells (Worts, 1951, p. 84). Thus, irrigation, much of it from formerly flowing wells in the confined area, has resulted in a decline of water level near the west end of the valley. It has also affected the natural discharge by:

1. Decreasing the seaward gradient and reducing the underflow to the ocean.
2. Lowering the water level below the root zone of phreatophytes (the natural vegetation) and causing them to die.
3. Lowering the water level at the landward end of the confined area, thereby stopping natural ground-water overflow, which formerly discharged as streamflow to the ocean.

UNDERFLOW TO THE OCEAN

Under natural conditions, ground-water underflow discharges to the ocean in an undetermined area offshore, as is indicated by the seaward hydraulic gradient at the west end of the ground-water basin. The quantity of discharge can be estimated according to Darcy's Law expressed in the equation $Q=P_fIA$, where Q is the discharge, in gallons per day; P_f is the field coefficient of permeability, in gallons per day per square foot of aquifer at field temperature (64°F); I is the hydraulic gradient, in feet per foot; and A is the cross-sectional area, in square feet, through which discharge occurs. Worts (1951, p. 95) determined the values of coefficient of permeability, the cross-sectional area, and the hydraulic gradient for the coastal end of the Santa Maria Valley ground-water basin as follows:

Geologic unit	*Cross-sectional area (sq ft)*	*Field coefficient of permeability (gpd per sq ft)*
Alluvium (lower member)	2, 238, 000	2, 000
Undifferentiated deposits of Pliocene and Pleistocene age:		
Paso Robles and Orcutt Formations	29, 200, 000	65
Careaga Sand	11, 800, 000	75

Year	*Hydraulic gradient (ft per mile)*
1918	10
1936	6
1944	8

No new data are available on the permeability of the aquifers, but recent data from oil wells drilled near the coast generally substantiate the cross-sectional areas shown in the previous table. Hydraulic gradients of ground water are indicated by water levels, and, in 1961, a gradient of 5 feet per mile in the alluvium was computed from water levels in wells near the coast. The ground-water gradient in the alluvium thus determined in 1961 is considered representative of gradients of water in the deeper aquifers.

On the basis of amounts of underflow computed for 1918, 1936, 1944, and 1959 and correlated with hydrographs shown in figure 2, annual underflow to the ocean is estimated for the 41-year period (calendar years 1918–58) and is shown in table 5. Additional water-level data will be necessary to substantiate the assumed hydraulic gradient of ground water in the deep aquifers.

Table 5 shows a maximum annual underflow to the ocean of 16,000 acre-feet in 1918 and 1919, when the ground-water basin was nearly full and the hydraulic gradient was 10 feet per mile. By 1958, underflow had decreased to about 8,000 acre-feet per year and the gradient

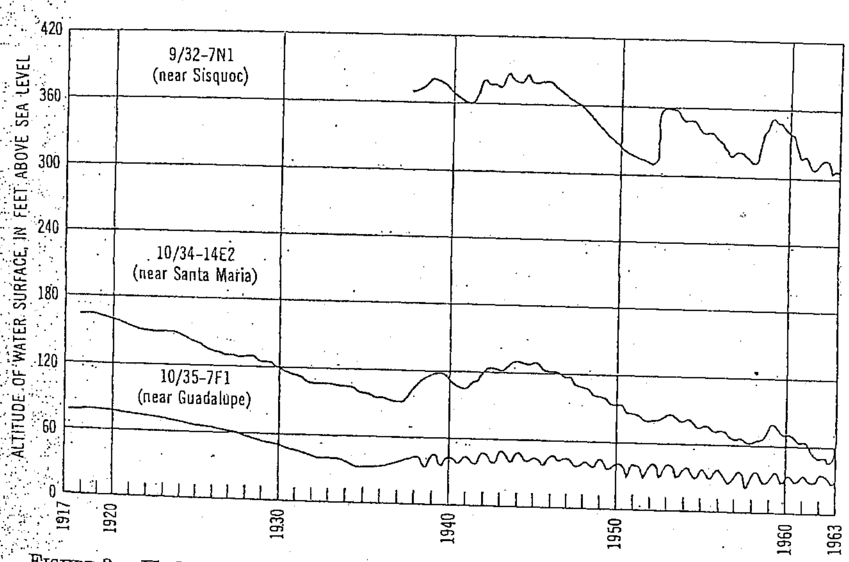

FIGURE 2.—Hydrographs of wells near Sisquoc, Santa Maria, and Guadalupe.

was approximately 5 feet per mile. The estimated average annual discharge by underflow into the ocean was about 11,000 acre-feet for the 41-year period 1918–58, and was about 8,000 acre-feet for the 9-year period 1950–58.

TABLE 5.—*Estimated underflow to the ocean from the ground-water basin, 1918–58*

[All values are rounded]

Calendar year	*Underflow to ocean (acre-ft)*	*Calendar year*	*Underflow to ocean (acre-ft)*	*Calendar year*	*Underflow to ocean (acre-ft)*
1918	[1] 16,000	1932	11,000	1946	12,000
1919	16,000	1933	10,000	1947	12,000
1920	16,000	1934	10,000	1948	9,300
		1935	10,000	1949	9,300
1921	16,000			1950	8,500
1922	15,000	1936	[1] 9,500		
1923	15,000	1937	9,500	1951	8,400
1924	15,000	1938	10,000	1952	8,300
1925	14,000	1939	12,000	1953	8,300
		1940	11,000	1954	8,200
1926	14,000			1955	8,200
1927	14,000	1941	11,000		
1928	13,000	1942	12,000	1956	8,100
1929	12,000	1943	12,000	1957	8,100
1930	12,000	1944	[1] 12,800	1958	8,000
1931	11,000	1945	13,000		

Underflow to ocean (acre-ft)	*1918–58*	*1950–58*
Total	470,000	74,000
Annual average	11,000	8,000

[1] Estimate by Worts (1951, p. 95, table 11).

WITHDRAWALS BY WELLS

Most of the ground-water discharge is by pumping from wells, and the water is used for agriculture, public supply, and industry. By far the largest quantity of pumped water is for irrigation of agricultural lands. A few irrigation wells are pumped by diesel or natural-gas engines, and the others are pumped by electric powerplants. The quantity of water pumped for public supply is determined by metered flow, and the quantity of water pumped for agriculture and industry is estimated.

Estimates of the quantity of water pumped for irrigation from 1932 to 1958 are based on electric-power data obtained from the power company. Estimates for years prior to 1932 are based on irrigated acreage and duty of water as described by Worts (1951, p. 85 and 88).

For the period 1945–58, estimates of the pumpage for irrigation are computed by dividing the electric power consumed (kilowatthours (kwhr)) during the base year of 1950 by the appropriate energy factor (kwhr per acre-ft) for each of 15 power areas. These areas were selected on the basis of pumping lift. Average energy factors for each power area were determined from pump-efficiency data for the years 1947–53. Energy factors were adjusted each year to account for increases in pumping lift in those power areas where water levels had changed since 1950. Pump efficiencies ranged from 30 to 80 percent and averaged 55 percent. The unit-power factor averaged 1.6 kwhr per acre-ft. per foot of lift.

Table 6 lists the net pumpage for irrigation for the 41-year period, calendar years 1918–58. Data for the years 1929–44 are from Worts (1951, p. 89). Net pumpage for irrigation is computed as 80 percent of the gross; use of this percentage leaves 20 percent of the gross for return to the ground-water body.

TABLE 6.—*Net pumpage for irrigation, 1918–58*

[All values are rounded. Pumpage for 1918–28 estimated by author from irrigated acreage and duty of water; that for 1929–44 estimated by Worts (1951, p. 89); that for 1945–58 estimated by author from electric power consumption]

Calendar year	*Net pumpage (acre-ft)*	*Calendar year*	*Net pumpage (acre-ft)*	*Calendar year*	*Net pumpage (acre-ft)*
1918	5,000	1932	41,000	1946	88,000
1919	5,000	1933	36,000	1947	96,000
1920	6,000	1934	38,000	1948	83,000
		1935	41,000	1949	88,000
1921	11,000			1950	90,000
1922	16,000	1936	48,000		
1923	22,000	1937	47,000	1951	74,000
1924	26,000	1938	47,000	1952	87,000
1925	28,000	1939	52,000	1953	77,000
		1940	60,000	1954	83,000
1926	31,000			1955	88,000
1927	34,000	1941	48,000		
1928	36,000	1942	49,000	1956	87,000
1929	40,000	1943	54,000	1957	86,000
1930	42,000	1944	57,000	1958	111,000
1931	43,000	1945	82,000		

Net pumpage (acre-ft)	*1918–58*	*1950–58*
Total	2,180,000	780,000
Annual average	53,000	87,000

In addition to pumpage for irrigation, a comparatively small amount of water is pumped each year for industrial, public-supply, domestic, and livestock uses. This pumpage is shown in table 7.

Estimates of pumpage for industrial use are based on pump capacity, operating time, and product or process requirements.

For the period 1952–58, records of public water-supply pumpage were furnished by the city of Santa Maria; and, for the period prior to 1952, estimates of pumpage were made from per-capita-use data derived for the years during which pumpage was metered. Both excess water applied to lawns and sewage effluent return an unknown quantity of water to the ground-water body. However, the amount probably is small and, therefore, has been disregarded. Estimates of pumpage for the city of Guadalupe were obtained from the Campodonico Water Works. Estimates of public water-supply pumpage used by other communities and rural areas in the valley are based on a per capita use of 150 gallons per day.

The Santa Barbara County Farm Advisor reported (Ray Gieberger, oral commun., 1962) that in recent years about 6,500 head of dairy cattle and about 15,000 head of beef cattle in the Santa Maria Valley have required more than 1 million gallons of water a day, or approximately 1,100 acre-feet per year.

Prior to 1946 a considerable quantity of water was discharged by flowing wells in the western part of the confined area. However, by 1949 these wells had stopped flowing. Estimates of the quantity of water discharged from these wells are based on a probable maximum flow of 2,000 acre-feet in 1918, a minimum flow of 500 acre-feet in 1936 (table 7), and an average flow of about 1,200 acre-feet a year for the period 1942–45 (Worts, 1951, p. 91). Estimates for the periods 1918–36 and 1945–51 are apportioned in accordance with a probable flow of 2,000 acre-feet in 1918 and no flow since 1948.

Estimates of withdrawal of water by pumping for purposes other than irrigation are shown in table 7.

CHANGE IN AMOUNT OF GROUND WATER IN STORAGE

The final element of the hydrologic equation, the change in amount of ground water in storage, is the difference between the quantity of water in storage at the beginning of a selected period and that in storage at the end of the same period. Water-level data were used to compute the volume of water in storage above sea level in 1918, 1950, and 1959, as shown in table 2. However, only data for 1950 and 1959 are adequate for making estimates of storage changes throughout the complete basin, and these show a depletion in storage of about 6 percent for the period 1950–59. Water-level data for 1918 are adequate for the valley floor but are largely extrapolated for the upland areas and are subject to error.

As is shown in table 2, the amount of ground water in storage decreased about 860,000 acre-feet in the period 1918–59, an average annual decrease of about 21,000 acre-feet. The amount of ground water in storage decreased about 150,000 acre-feet in the period 1950–59, an average annual decrease of about 17,000 acre-feet. No estimate of

storage change has been made for the probable landward displacement of the fresh water–sea water interface in the offshore extension of the aquifer.

TABLE 7.—*Estimated withdrawal of water by wells for uses other than irrigation, 1918–58*

[All values rounded]

Calendar year	Industrial use (acre-ft)	Public-supply and domestic use (acre-ft)		Livestock use (acre-ft)	Flowing wells (acre-ft)	Total (acre-ft)
		Santa Maria	Other			
1918	200	500	500	250	2,000	3,400
1919	500	500	500	250	2,000	3,800
1920	800	550	500	250	2,000	4,100
1921	1,000	600	500	250	1,900	4,200
1922	1,100	600	500	250	1,900	4,400
1923	1,300	600	600	250	1,800	4,600
1924	1,400	700	600	250	1,800	4,800
1925	1,600	700	600	250	1,700	4,800
1926	1,600	700	600	250	1,600	4,800
1927	1,800	800	600	250	1,500	5,000
1928	1,900	800	600	250	1,400	5,000
1929	2,000	800	600	250	1,300	5,000
1930	2,100	900	700	250	1,200	5,200
1931	2,200	1,000	700	250	1,100	5,200
1932	2,400	1,000	700	250	900	5,200
1933	2,400	1,000	700	250	700	5,000
1934	2,600	1,100	700	250	600	5,200
1935	2,500	1,200	700	250	600	5,200
1936	2,700	1,200	700	250	500	5,400
1937	2,800	1,300	700	250	600	5,600
1938	2,900	1,300	700	250	700	5,800
1939	3,000	1,400	700	250	800	6,200
1940	3,100	1,400	800	250	900	6,400
1941	3,200	1,400	800	250	1,000	6,600
1942	3,500	1,600	800	250	1,100	7,200
1943	4,000	1,800	800	250	1,200	8,000
1944	4,200	1,700	800	250	1,300	8,200
1945	3,800	1,800	800	500	1,000	7,900
1946	3,700	1,800	800	750	500	7,600
1947	3,800	2,000	900	750	200	7,600
1948	3,800	2,000	900	750	100	7,600
1949	3,800	2,100	900	900	0	7,700
1950	3,800	2,200	1,000	1,200	0	8,200
1951	3,800	2,200	1,000	1,200	0	8,200
1952	3,900	2,300	1,000	1,200	0	8,400
1953	4,000	2,600	1,000	1,200	0	8,800
1954	4,000	2,600	1,100	1,200	0	8,900
1955	4,000	2,600	1,100	1,300	0	9,000
1956	4,100	2,800	1,100	1,300	0	9,300
1957	4,100	2,800	1,100	1,300	0	9,300
1958	4,200	2,800	1,200	1,300	0	9,500
Total	110,000	60,000	32,000	22,000	36,000	260,000

Withdrawal of water (acre-ft)	1918–58	1950–58
Total	260,000	80,000
Annual average	6,400	8,900

SUMMARY AND SIGNIFICANCE OF THE HYDROLOGIC EQUATION

Table 8 summarizes the hydrologic equation for the periods 1918–59 and 1950–59. Estimates of recharge, discharge, and change in storage are based on the same methods as those by Worts (1951, p. 72–123). However, estimates of storage change have been revised by the availability of extensive water-level data for the springs of 1950 and 1959. The most significant feature brought out by an analysis of the two periods of comparable recharge is that the equation is almost in balance for the period 1918–59. On the other hand, large withdrawals of ground water during the period 1950–58 have caused only a small depletion of ground water in storage; the result has been a relatively large imbalance or discrepancy in the hydrologic equation.

TABLE 8.—*Hydrologic equation for the Santa Maria Valley ground-water basin*

[All values rounded]

Average annual recharge (acre-ft)	*1919–59*	*1951–59*	
Seepage loss from streams (table 3)	39, 000	41, 000	
Infiltration of rain (table 4)	8, 200	11, 000	
Total	47, 000	52, 000	(1)
Average annual discharge (acre-ft)	*1918–58*	*1950–58*	
Underflow to ocean (table 5)	11, 000	8, 000	
Net pumpage:			
Irrigation (table 6)	53, 000	87, 000	
Other uses (table 7)	6, 000	8, 900	
Total	70, 000	104, 000	(2)
Equation balance (acre-ft)	*1918–59*	*1950–59*	
Recharge (1) minus discharge (2)	−23, 000	−52, 000	(3)
Average annual change in amount of ground water in storage (table 2)	−21, 000	−17, 000	(4)
Average annual discrepancy in hydrologic equation, (3) minus (4)	2, 000	35, 000	

The hydrologic equation shown in table 8 indicates an average annual discrepancy of about 35,000 acre-feet for the period 1950–59, compared to a near-balance for the period 1918–59, even though the annual average precipitation (table 4) was approximately the same for both periods. Because water-level data for 1950 and 1959 are more reliable than those for 1918, the estimate of storage change (table 2) for the period 1950–59 probably is more accurate even though the imbalance is significantly greater. Also, the discrepancy in the equation for the period 1950–59 is of a magnitude that indicates a situation similar to that in other basins in Santa Barbara County; that is, the difference between recharge and discharge is considerably more than the change in storage indicates (Wilson, 1959, p. 86–88, and Evenson and others, 1962, p. 61–101). The difference between recharge and

discharge for the period 1950–1959 is about three times the estimated change in storage.

All estimates for the various elements of the hydrologic equation are subject to errors which are expressed as the discrepancy in the hydrologic equation (table 8). Errors in the estimated recharge may be due to low estimates of penetration of rain and additional unknown sources of recharge. One source of additional recharge may be subsurface inflow from fractured or weathered zones in the consolidated rocks that border and underlie the basin. Errors in estimated net pumpage may be due to inaccurate estimates of return irrigation water.

Estimates of storage change may be low because estimates of specific yield are low or because some water is being mined from the submarine extension of the ground-water reservoir. As ground-water outflow to the ocean has gradually decreased during the past years, the fresh water-salt water interface presumably has moved landward and thereby has displaced a corresponding amount of ground water in storage in the offshore extension of the aquifer. This amount would be in addition to the previously calculated storage. Supplemental hydrologic data will be necessary before estimates can be made of the magnitude of the displaced amount of storage.

PERENNIAL YIELD AND OVERDRAFT

Perennial yield of a ground-water basin generally is the maximum amount of water than man may use from the basin annually and still maintain the ground water in the basin as a permanently renewable resource. Overdraft is the quantity of water pumped from the basin in excess of the perennial yield. Worts (1951, p. 123) stated, "The perennial yield of the water-bearing deposits in a coastal area is the rate at which water can be pumped from wells year after year without decreasing the storage to the point where the rate becomes economically infeasible, the rate becomes physically impossible to maintain, or the rate causes the landward migration of sea water into the deposits and thus renders the water chemically unfit for use."

The detainment of floodflow by Twitchell Dam and reservoir, on the Cuyama River, will result in an estimated increase of 21,200 acre-feet per year to the yield of the ground-water basin (U.S. Bureau of Reclamation, 1958, p. 12).

Estimates of perennial yield are based on the hydrologic equation for the 1950–59 period and may be determined by two methods: perennial yield may be equal to the average annual recharge minus the unrecoverable water, or it may be equal to the average annual pumping draft plus or minus the change in amount of ground water in storage.

Recharge for the period 1951–59 averaged 52,000 acre-feet per year (table 8), and unrecoverable water (underflow to the ocean) for the same period averaged 8,000 acre-feet per year (table 5). The indicated perennial yield is the difference between the two estimates, or about 44,000 acre-feet. With continuing overdraft, underflow to the ocean will decrease as the hydraulic gradient is reduced. If the gradient is reduced from 5 to 2 feet per mile, underflow to the ocean will decrease from about 8,000 to 3,000 acre-feet per year and the natural perennial yield will increase proportionately to about 49,000 acre-feet, which closely agrees with the estimate of 53,000 acre-feet made by Worts (1951, p. 128). The additional yield of 21,200 acre-feet from Twitchell Dam augments the perennial yield of the basin to about 70,000 acre-feet per year.

Estimated pumping draft for the period 1950–58 averaged 96,000 acre-feet per year (table 8), and the average change in storage was 17,000 acre-feet per year (table 8). Thus, the indicated natural perennial yield is about 80,000 acre-feet. An additional 5,000 acre-feet increment, obtained as a result of reducing the hydraulic gradient to 2 feet per mile, and a 21,200 acre-feet increment from Twitchell Dam result in an augmented perennial yield of about 106,000 acre-feet.

The large discrepancy of closure of the hydrologic equation (table 8) for the period 1950–59 indicates that use of the elements-of-recharge method is preferable to the use of the elements-of-discharge method to determine perennial yield. The discrepancy represents the sum of all the errors in the hydrologic equation plus the unknown quantity of water mined as a result of the landward migration of the fresh water–sea water interface. However, 70,000 acre-feet probably is both a realistic and a conservative estimate of the augmented perennial yield of the Santa Maria Valley ground-water basin.

Overdraft occurs whenever average annual discharge exceeds 70,000 acre-feet per year, and during years of overdraft, water levels will probably decline. If water levels decline enough to establish a landward hydraulic gradient, then protective steps must be taken to prevent extensive sea–water encroachment and consequent contamination of the fresh-water aquifers.

SEA-WATER ENCROACHMENT

Seaward hydraulic gradients and consistently low chloride concentrations in water from wells near the west end of the valley are indications that sea-water encroachment has not been an obvious problem. However, as water levels have been lowered, the seaward hydraulic gradient has decreased and an unknown amount of sea-water encroachment probably has occurred at the offshore ends of the aquifers. If the seaward gradient continues to decrease and reverses to a landward gradient, sea water will move inland in the aquifers.

The coastal segment of the Santa Maria Valley ground-water basin (pl. 1) consists of several permeable aquifers of sand and gravel confined and separated by relatively impermeable zones of silt and clay. Data are not available to determine whether ground-water gradients are the same in each of the aquifers in the coastal segment of the basin. However, if one assumes that the gradient is the same in each aquifer, comparison of the relative position and shape of the intruded wedge of sea water for ground-water gradients of 10, 5, and 2 feet per mile is significant.

A mathematical equation used to determine the length of the sea-water wedge in coastal aquifers was discussed by Brooks (1960, p. 1–13) and can be expressed for confined aquifers as

$$L=\frac{P(S-1)m^2}{2q} \qquad (1)$$

where

q=seaward rate of flow of fresh water per unit aquifer width (gpd per ft)
L=length of intruded sea-water wedge (ft)
m=thickness of pressure aquifer (ft)
$S=\frac{w_s}{w}=\frac{1.025}{1}$=ratio of unit weight of sea water to fresh water (w_s is density of sea water; w is density of fresh water)
P=field coefficient of permeability (gpd per sq ft)

In equation 1

$q=PmI$
I=hydraulic gradient (in ft per ft).

Substituting PmI for q in equation 1

$$L=\frac{(S-1)m}{2I} \qquad (2)$$

Thus, equation 2 indicates that the length of the intruded sea-water wedge (L) is dependent only on the thickness of the aquifer (m) and the hydraulic gradient of ground-water discharge (I); the length of the wedge is directly proportional to the aquifer thickness and inversely proportional to the hydraulic gradient.

In the coastal segment of the basin, the length of the intruded sea-water wedge for the lower alluvial aquifer is computed as follows:

$$L=\frac{(S-1)m}{2I}$$

where

m=100 feet
I=10 feet per mile, or 10/5,280.

Then, substituting values, equation 2 becomes

$$L=\frac{0.025\times 100}{2(10/5,280)}=660 \text{ feet}$$

Electric-log data show that below the base of the alluvium, several of the aquifers are about 50 feet thick. The length of the intruded sea-water wedge will vary, depending on the hydraulic gradient and the thickness of the aquifer, as is shown in the following table.

I=hydraulic gradient (ft per mile)	m=thickness of pressure aquifer (ft)	
	100	50
	Length of intruded sea-water wedge (ft)	
10	660	330
5	1,320	660
2	3,300	1,650

Although a seaward gradient of about 5 feet per mile existed in 1961, the chloride concentration in water from a well within a few hundred feet of the coast was only about 60 parts per million. Therefore, the submarine outlet of the aquifer in the lower member of the alluvium probably was farther than 1,320 feet offshore.

The submarine outcrop of aquifers below the alluvium may extend even farther seaward, but no data are available to show either hydraulic gradients or hydraulic pressures, both of which are necessary to understand the hydraulic system in the coastal segment of the basin. At least two observation wells having piezometers that tap at least three aquifers (table 1) will be necessary to evaluate this hydraulic system in relation to sea-water encroachment.

SUMMARY AND CONCLUSIONS

Overdraft since about 1946 has resulted in a significant decline in water level throughout the basin as ground water has been removed from storage.

In 1959 approximately 2,200,000 acre-feet of ground water was in storage above sea level in the ground-water basin—a depletion of about 6 percent for the period 1950–59.

Estimates of ground-water storage depletion are not consistent with estimates of ground-water discharge and known sources of recharge. Errors may exist in one or more items of the ground-water inventory, but they are most likely to be in the estimates of discharge and in the estimates of change in ground water in storage.

The best estimates of perennial yield, therefore, are based on the elements of ground-water recharge. A conservative estimate of the natural perennial yield is nearly 50,000 acre-feet; the augmented perennial yield, which includes the 21,200 acre-feet of water released at Twitchell Dam, is about 70,000 acre-feet per year.

Intrusion of sea water has not been observed in landward parts of the basin, but limited sea-water encroachment probably has occurred in the offshore extension of the aquifers. Although electric logs of oil wells drilled near the coast indicate the presence of several fresh-water aquifers of different thicknesses, data are not available to show hydraulic pressures and hydraulic gradients in each of the aquifers. Adequate evaluation of the potential sea-water encroachment into the ground-water basin will necessitate the construction and maintenance of at least two observation wells that penetrate the entire sequence of aquifers. These wells should provide the data necessary to determine hydraulic pressures and gradients in at least three of the major aquifers.

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