COMPARISON OF TWO METHODS FOR ESTIMATING GROUND-WATER RECHARGE IN 1978-80, SANTA MARIA VALLEY, CALIFORNIA

By Paul Lipinski

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CONVERSION FACTORS

The inch-pound system is used in this report. For readers who prefer International System (SI) Units, the conversion factors for the terms used in this report are listed below:

Multiply	By	To obtain
acres	0.4047	hectares
acre-feet (acre-ft)	0.001233	cubic hectometers
acre-feet per year (acre-ft/yr)	0.001233	cubic hectometers per year
feet (ft)	0.3048	meters
square feet (ft^2)	0.09294	square meters
cubic feet (ft^3)	0.02832	cubic meters
inches (in.)	25.4	millimeters
miles (mi)	1.609	kilometers
square miles (mi^2)	2.590	square kilometers

Degrees Fahrenheit (°F) is converted to degrees Celsius (°C) by using the formula: °C = (°F-32)/1.8

COMPARISON OF TWO METHODS FOR ESTIMATING GROUND-WATER RECHARGE IN 1978-80, SANTA MARIA VALLEY, CALIFORNIA

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ABSTRACT

Infiltration from the Santa Maria River and the lower part of the Sisquoc River is the source of most of the ground-water recharge to the alluvial aquifer system of Santa Maria Valley, California. The annual recharge volumes commonly are much greater or smaller than the long-term average annual recharge. A comparison of results from two methods of estimating actual annual recharge indicates that, in Santa Maria Valley, a seepage-loss method is comparable to a water-level-change method. Both methods indicate that recharge was about 600,000 acre-feet (rounded to one significant figure) during 1978-80.

Using the seepage-loss method, annual recharges during 1978, 1979, and 1980 are estimated at 290,000, 130,000, and 190,000 acre-feet. A log-Pearson Type III probability distribution of annual flows gaged on the Sisquoc River indicates that average recurrence intervals of annual recharge volumes equal to those of 1978, 1979, and 1980 are 20, 4, and 10 years, respectively. Using the water-level-change method, annual recharges during 1978, 1979, and 1980 are estimated at 230,000, 190,000, and 160,000 acre-feet, respectively.

INTRODUCTION

The years 1978-80 were excessively wet in southern California. Annual rainfalls recorded at Cuyama (about 30 miles east of Santa Maria Valley) were 275 percent (1978), 163 percent (1979), and 182 percent (1980) of average annual precipitation for 1948-80. During the 1978-80 period, which followed 3 years of below-average rainfall, ground-water levels in some parts of Santa Maria Valley rose almost 100 feet. Because annual ground-water pumpage in the valley often exceeds annual recharge, and because quantities of annual recharge are often much greater or smaller than the long-term average for the basin, some method of estimating annual recharges and of predicting the probabilities of recurrence of annual recharge would help maximize the efficient use of ground water in the valley.

Purpose and Scope

The purpose of this study was to estimate the annual quantity of ground water recharged to the alluvial aquifer system in Santa Maria Valley during the period 1978-80, and to determine the recurrence probabilities of similar annual recharges. This report includes a comparison of two methods of estimating recharge. One method is based on water-level changes, estimates of aquifer specific yield, and estimates of pumped water consumed by evapotranspiration. The other method is based on seepage losses from streams that are the major source of recharge, and estimates of direct infiltration of precipitation. A standard probability distribution of annual flows of the Sisquoc River is used to determine the probabilities of recurrence of annual recharges equal to those of 1978-80.

Location and General Features

Santa Maria Valley is a coastal valley in northwestern Santa Barbara County and southwestern San Luis Obispo County, Calif., about 130 miles northwest of Los Angeles (fig. 1). The valley trends generally southeast-northwest and is bounded on the north by the San Rafael Mountains and the Nipomo Upland, and on the south by the Casmalia and the Solomon Hills. The valley floor, about 135 mi^2 in area, consists of the Santa Maria Plain, the Sisquoc Plain, and terraces of the Nipomo Upland and the Orcutt Upland. The Santa Maria River, formed by the convergence of the Cuyama and Sisquoc Rivers near Fugler Point, flows generally westward across the Santa Maria Plain and drains into the Pacific Ocean west of the town of Guadalupe. The effective drainage areas of the Santa Maria, Sisquoc, and Cuyama Rivers are 1,741, 471, and 1,132 mi^2, respectively.

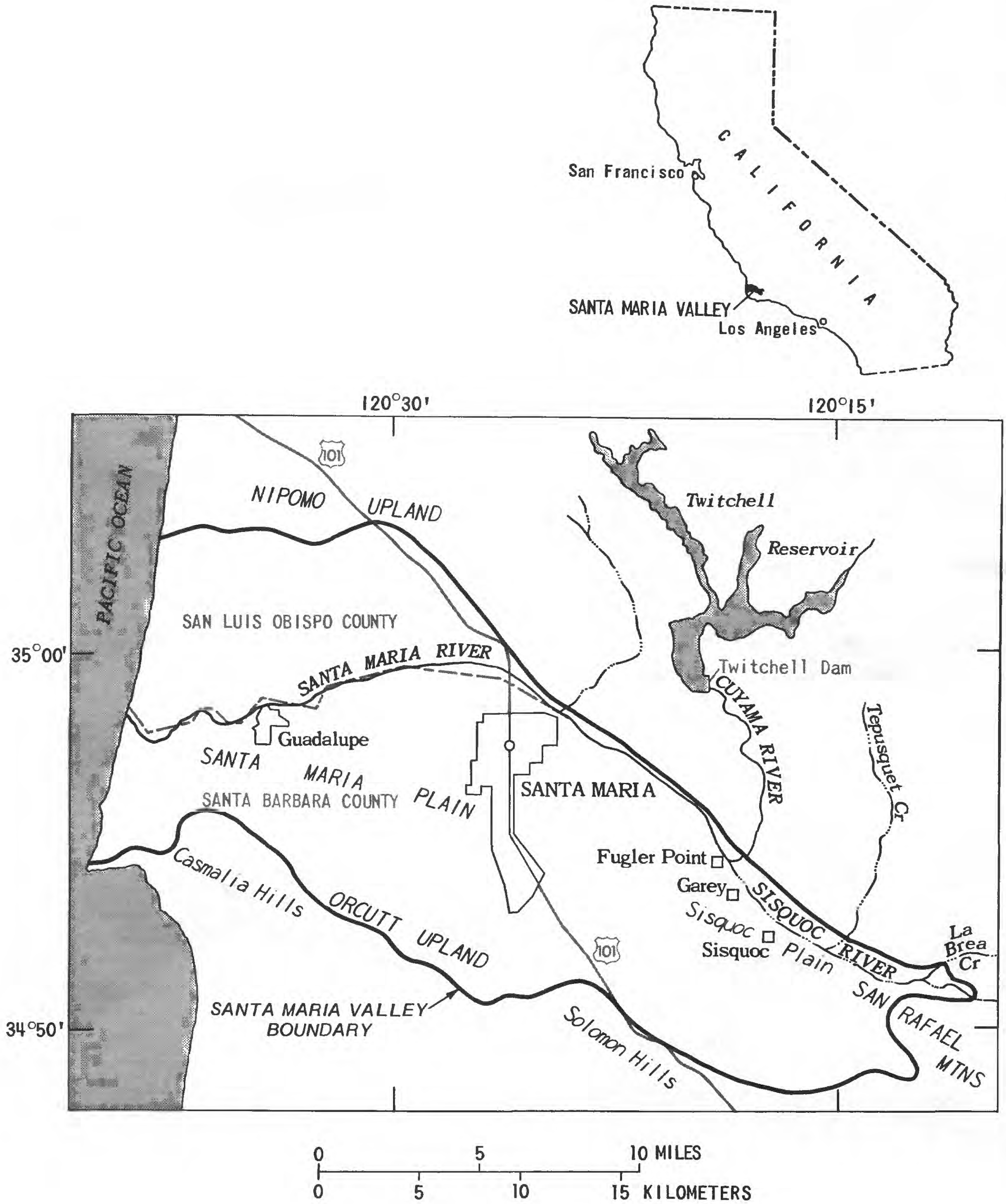

FIGURE 1.-- Location and geographic features of Santa Maria Valley.

The Sisquoc and Cuyama Rivers flow mostly over consolidated rocks, and the Santa Maria River flows over alluvial deposits that have a high potential for conveying ground-water recharge to the alluvial aquifer system in the valley. Twitchell Dam, completed in 1959, holds floodflows of the Cuyama River above Fugler Point for controlled release to the Santa Maria River to maximize ground-water replenishment. The flow of the Sisquoc River is not controlled.

The climate of Santa Maria Valley varies considerably from the valley floor to the surrounding mountains, but in general the area has cool winters and mild summers. Over most of the valley, temperatures below freezing or above 100°F are infrequent. Rainfall at Santa Maria averages about 12 inches annually, although it varies widely from year to year.

Previous Investigations

Worts (1951), in a comprehensive report on the geology and ground water of Santa Maria Valley, compiled information from several sources and conducted his own original work. His report includes a section on the surface-water resources of the valley by H. G. Thomasson, Jr., who estimated seepage losses from streams in the valley for the period 1929-45. Miller and Evenson (1966) summarized the geology and hydrology of the area, estimated average annual recharge to the ground-water basin, and described the effects and magnitude of overdraft in the valley. They estimated seepage losses from streams in the valley for the period 1919-59. Hughes (1977) discussed the distribution of ground-water quality in the basin and estimated seepage losses from 1959 to 1972.

GEOHYDROLOGY

The thickness of the alluvial aquifer system in Santa Maria Valley averages about 1,000 feet, but in places it exceeds 2,300 feet. Ground water occurs in undifferentiated alluvial deposits of Pliocene to Holocene age, and the main water-producing zone is in the lower part of the Holocene alluvium. The alluvial aquifers are unconfined in about 75 percent of the basin (see fig. 2), but in the western quarter of the basin they are confined by fine-grained deposits in the upper part of the Holocene alluvium. The eastern boundary of confinement is irregular; the western boundary is offshore. Where the aquifer system is unconfined, water is able to infiltrate from the land surface to recharge the aquifers.

Recharge to the alluvial aquifers occurs primarily as seepage losses from the major streams in the valley. The most important reaches of these streams include the Santa Maria River from Fugler Point to about 4 miles east of Guadalupe, a reach where the aquifers are unconfined, and the Sisquoc River from La Brea Creek to Fugler Point.

During periods of above-average rainfall, there is some recharge to alluvial aquifers by direct infiltration of rainfall. Using a method developed by Blaney (1934) for Ventura County, Calif., Jones and others (1977) estimated that direct infiltration of rainfall averaged about 4,800 acre-ft/yr during 1960-75. Applying the Blaney method to rainfall data for 1978-80, Jon A. Ahlroth (Santa Barbara County Water Agency, written commun., Oct. 31, 1984) estimated that direct infiltration of rainfall totaled about 70,000 acre-ft during 1978-80.

Ground water both enters and leaves the alluvial aquifers in Santa Maria Valley by subsurface flow. Subsurface inflow and outflow are probably fairly constant from year to year and average only a few thousand acre-feet per year (Jones and others, 1977).

Pumpage for irrigation, municipal, and industrial uses is the largest discharge from the alluvial aquifers in Santa Maria Valley. Jones and others (1977) estimated pumpage during 1975 at about 138,000 acre-ft, of which about 100,000 acre-ft was consumed by evapotranspiration. The remaining water was returned to the alluvial aquifers by infiltration. Available data do not allow an update of the pumpage estimate, but approximately the same quantities probably were pumped and consumed during 1978-80.

ESTIMATED RECHARGE, 1978-80

Two methods, (1) water-level change and (2) seepage loss, were used to estimate the quantity of ground water recharged to the alluvial aquifer system in Santa Maria Valley during the period 1978-80. The water-level-change method attempts to determine the quantity of water required to produce a measured water-level rise in deposits of estimated specific yield over a measured area. In this context, 10,000 ft^3 of water would be required to produce a 5-foot rise in water level over a 10,000 ft^2 area in deposits of 20-percent specific yield (5 ft X 10,000 ft^2 X 0.20 = 10,000 ft^3).

The seepage-loss method assumes that any decrease in the amount of streamflow between two adjacent stream gages infiltrates to the water table. By this method, if in a given period 5,000 acre-ft of flow is gaged upstream and 3,800 is gaged downstream, 1,200 acre-ft is the presumed recharge.

Water-Level-Change Method

Water-level data for the period 1977-80 were used to construct annual water-level-change maps (figs. 2, 3, and 4). Water-level-change contours were drawn using 10-foot increments, and the volume of sediment in each 10-foot increment was calculated. Multiplying the volume in unconfined areas of sediment by the aquifer specific yield gives the volume of water needed to saturate the sediment. This volume of water represents the change in ground-water storage due to the difference between all sources of recharge and discharge.

It should be noted that during 1978 the largest water-level rises in the alluvial aquifer occurred beneath the Santa Maria River. (See fig. 2). As the aquifer beneath the river filled, ground water moved south and caused large water-level rises south of the river during 1979-80. (See figs. 3 and 4).

Specific yields of various lithologies in the alluvial aquifers in Santa Maria Valley, as estimated by Miller and Evenson (1966), are shown in table 1. In nearby Cuyama and Santa Ynez Valleys, Miller (1976, p. 37) and Singer and Swarzenski (1970, p. 19) estimated that the specific yield of the alluvial aquifers averages about 15 percent, and this is probably a fairly accurate estimate of the average specific yield of unconfined alluvial aquifers in Santa Maria Valley.

TABLE 1.--Estimated specific yield of different lithologies in alluvial aquifers in Santa Maria Valley

[After Miller and Evenson (1966)]

Material	Assigned specific yield (percent)	
	Holocene alluvium	Pliocene and Pleistocene deposits
Gravel	30	25
Gravel and sand	25	20
Sand	20	20
Sand and clay	10	10
Clay	5	3

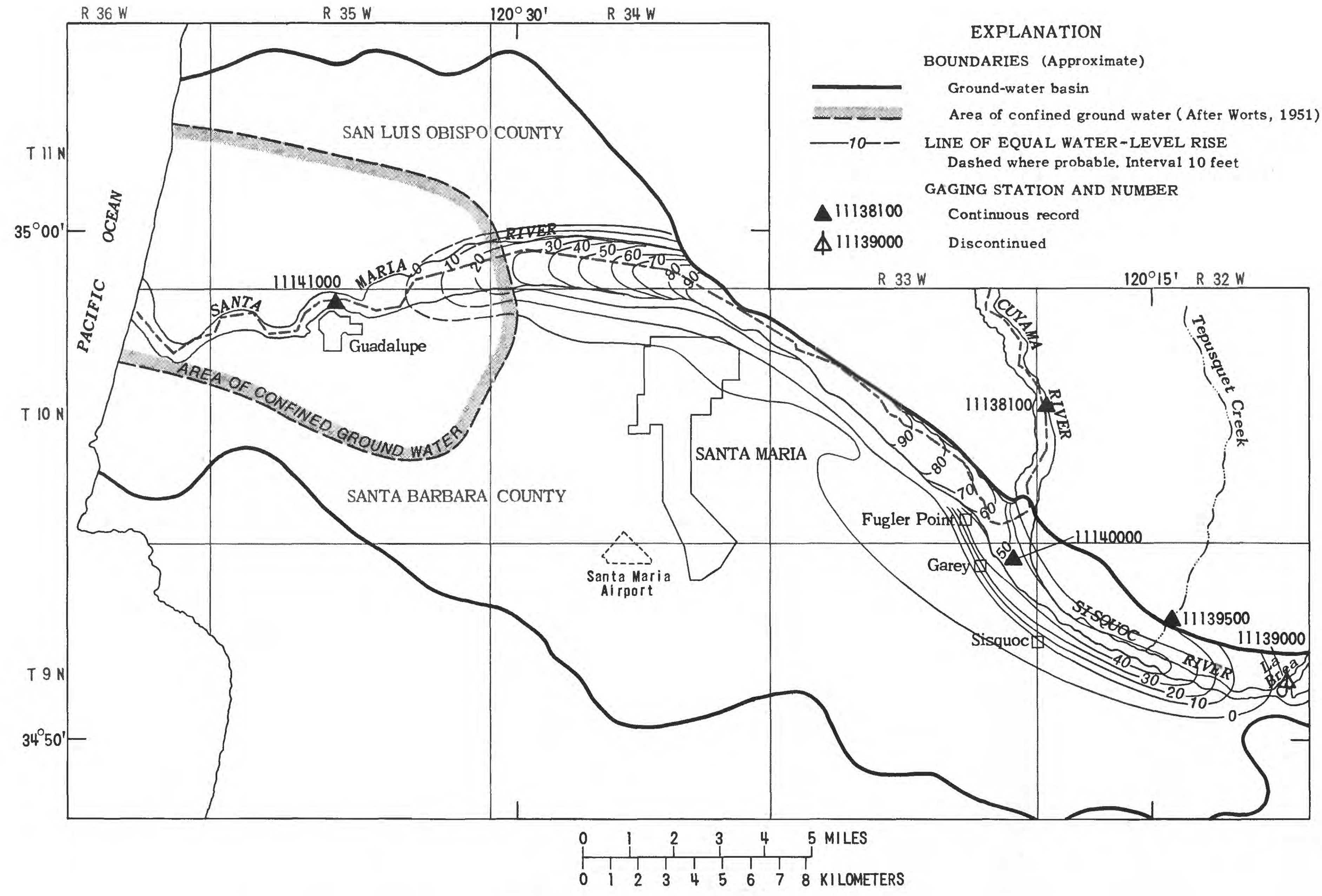

FIGURE 2.-- Water-level change, 1978, and location of gaging stations.

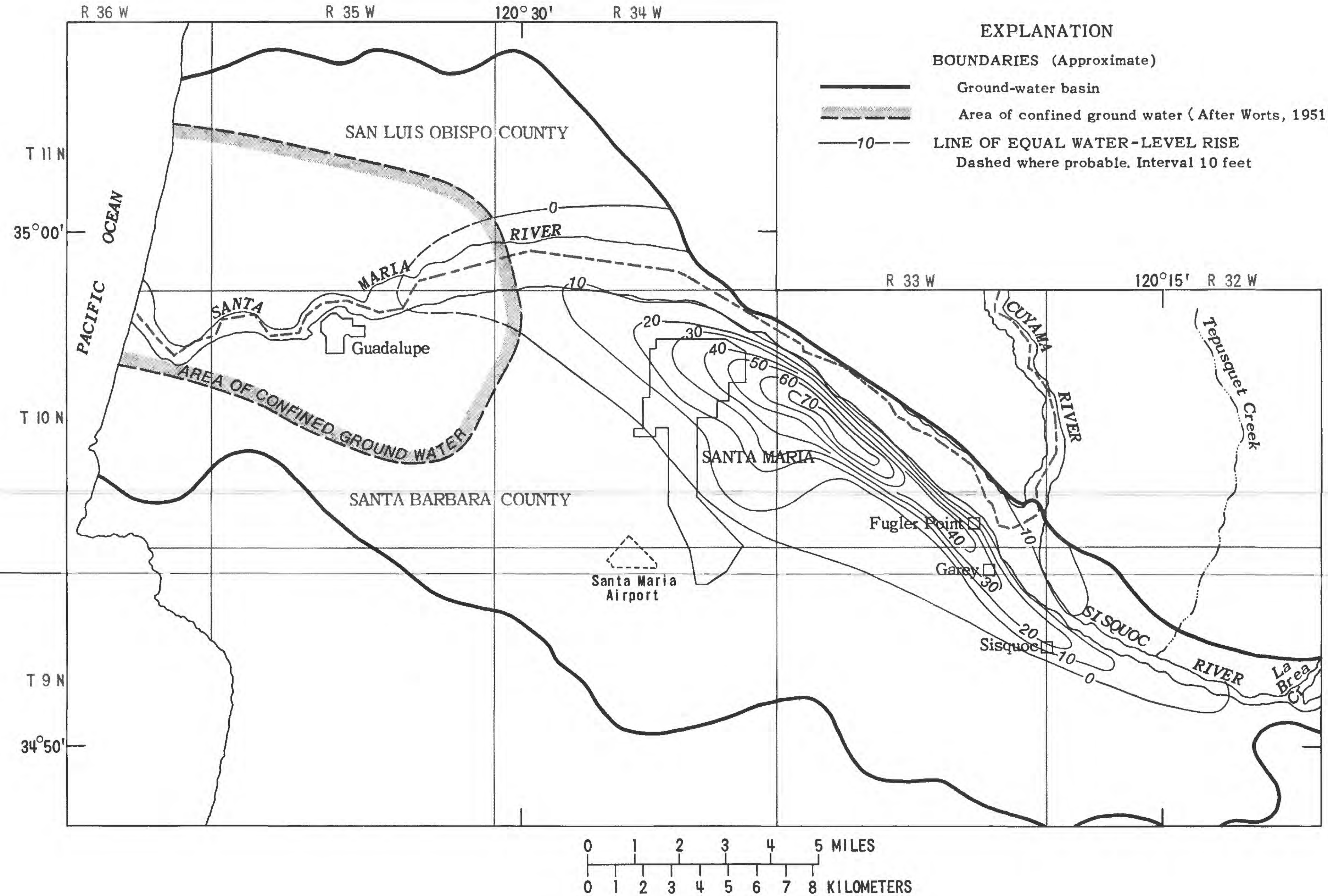

FIGURE 3.– Water-level change, 1979.

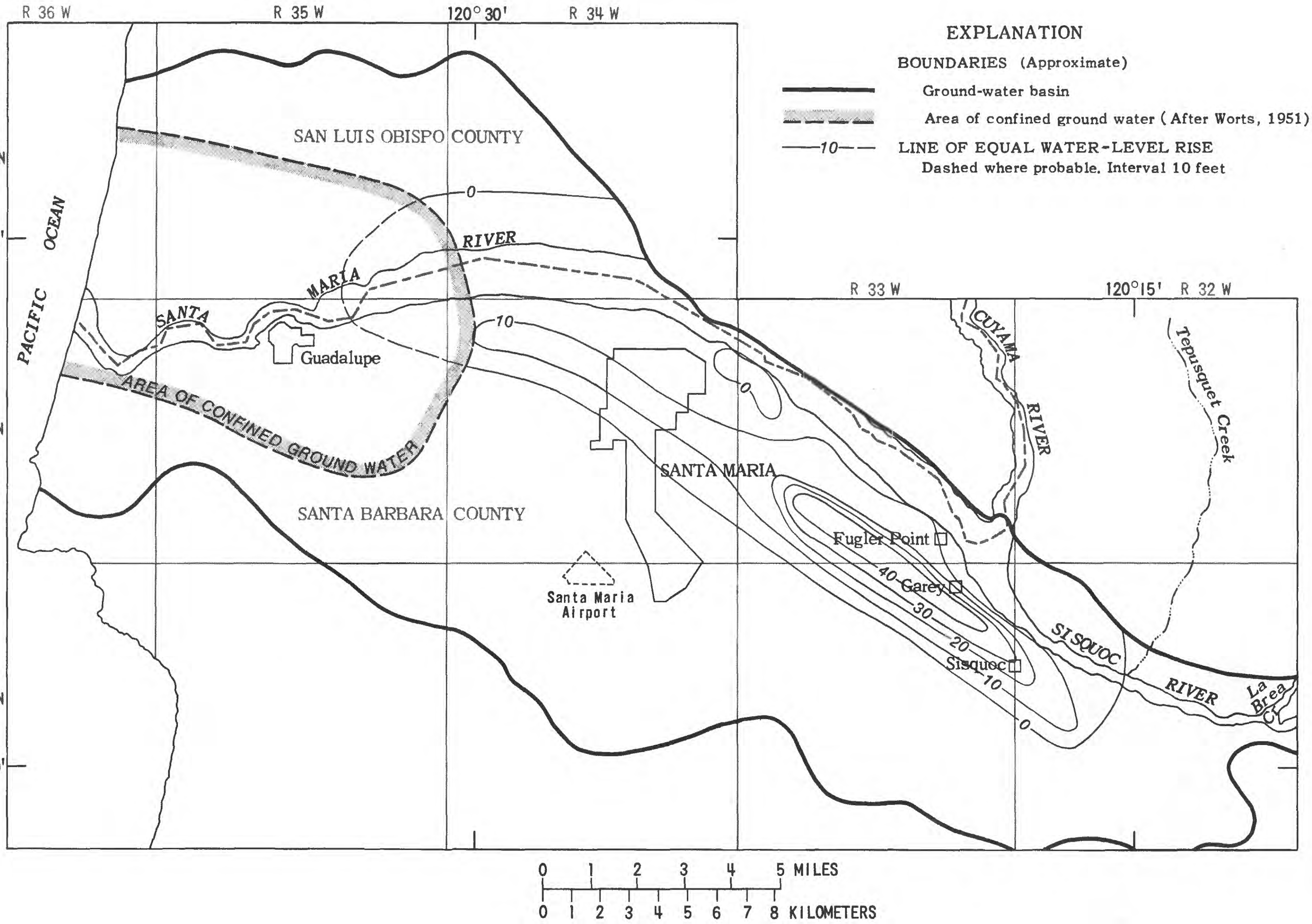

FIGURE 4.-- Water-level change, 1980.

In areas where the alluvial aquifers are confined, the specific storage probably averages about 1 X 10^{-6} per foot. Very small quantities of recharge water will cause water-level rises of a few tens of feet. Figures 2, 3, and 4 show that the maximum water-level rise in the confined area of the aquifer system was about 28 feet during 1978; during 1979 and 1980, the water-level rises were less than 10 feet. Because these water-level rises in the area of confined ground water represent negligible quantities of recharge, they were not included in the estimate of recharge.

Where the alluvial aquifers are unconfined, the areas between lines of equal water-level rise in figures 2, 3, and 4 are:

Range in water-level rise (feet)	Area between lines of equal water-level rise (acres)		
	1978	1979	1980
0-10	9,710	20,600	21,900
10-20	3,080	6,700	11,200
20-30	4,250	3,060	1,220
30-40	2,230	2,280	1,000
40-50	1,770	1,900	920
50-60	670	2,180	--
60-70	410	680	--
70-80	260	320	--
80-90	1,540	--	--
>90	3,360	--	--

The total change in volume of saturated sediment was then calculated for each year. This was done assuming that the average water-level rise was 5 feet in the area between the 0- and 10-foot lines of equal water-level rise; the average rise was 15 feet between the 10- and 20-foot lines; and so forth. The estimated yearly changes in volume of saturated sediment are 890,000 acre-ft during 1978, 630,000 acre-ft during 1979, and 380,000 acre-ft during 1980.

The volumes of recharge water in excess of the volume pumped and lost to evapotranspiration were estimated by multiplying the above volumes of sediment by the aquifer specific yield of 15 percent. These volumes are 130,000 acre-ft during 1978, 94,000 acre-ft during 1979, and 57,000 acre-ft during 1980.

The volume of pumped water lost from the system due to evapotranspiration probably averaged about 100,000 acre-ft/yr; therefore, recharge during 1978, 1979, and 1980 is estimated at 230,000, 190,000, and 160,000 acre-ft, respectively. Total recharge during 1978-80 using the water-level-change method is estimated at about 580,000 acre-ft.

Seepage-Loss Method

Streamflow records from six gaging stations in the Santa Maria Valley were used to estimate seepage losses from 1978-80 (table 2). The location of the gaging stations is shown in figure 2, except for station 11138500, Sisquoc River near Sisquoc, which is about 2 miles east of the map area. Because the station on La Brea Creek near Sisquoc (11139000) has not been operated since 1973, and because previous records show that this stream contributes as much as 25 percent of the flow at the station on the Sisquoc River near Garey (11140000), some estimate of the flow of La Brea Creek during 1978-80 was needed. Least-squares regression of 30 years of previous records showed that annual flows measured at station 11138500 on the Sisquoc River near Sisquoc (range 774 to 135,100 acre-ft/yr) were closely correlated with those measured at station 11139000 on La Brea Creek near Sisquoc (range 0 to 48,620 acre-ft/yr), with a correlation coefficient greater than 0.98 (1.00 = perfect correlation). Thus, data from the station on the Sisquoc River near Sisquoc were used in a regression equation to estimate flow at the discontinued station on La Brea Creek near Sisquoc for the period of interest. These estimates are shown in table 2.

The quantity of surface water lost to infiltration was estimated for (1) the Santa Maria River between Fugler Point and Guadalupe, and (2) the Sisquoc River between Sisquoc and Garey, using the following equations:

$$\begin{array}{c}\text{Santa Maria River}\\ \text{seepage loss}\end{array} = \begin{array}{c}\text{11140000,}\\ \text{Sisquoc River}\\ \text{near Garey}\end{array} + \begin{array}{c}\text{11138100,}\\ \text{Cuyama River}\\ \text{below Twitchell}\\ \text{Dam}\end{array} - \begin{array}{c}\text{11141000,}\\ \text{Santa Maria River}\\ \text{at Guadalupe}\end{array} \qquad (1)$$

$$\begin{array}{c}\text{Sisquoc River}\\ \text{seepage loss}\end{array} = \begin{array}{c}\text{11138500,}\\ \text{Sisquoc River}\\ \text{near Sisquoc}\\ \text{(2 miles east}\\ \text{of study area)}\end{array} + \begin{array}{c}\text{11139000,}\\ \text{La Brea}\\ \text{Creek}\\ \text{near}\\ \text{Sisquoc}\end{array} + \begin{array}{c}\text{11139500,}\\ \text{Tepusquet}\\ \text{Creek}\\ \text{near}\\ \text{Sisquoc}\end{array} - \begin{array}{c}\text{11140000,}\\ \text{Sisquoc River}\\ \text{near Garey}\end{array} \qquad (2)$$

By the seepage-loss method, addition of equations 1 and 2 gives total seepage losses, the major sources of ground-water recharge, for the valley. The results of the calculations are shown in table 3. To provide continuity with Hughes' (1977) report, in which seepage losses were tabulated for the period 1959-72, table 3 includes losses from 1973-80.

Thus, total estimated seepage losses during 1978-80 are 540,000 acre-ft (rounded). Considering the additional 70,000 acre-ft that is estimated to have recharged alluvial aquifers by direct infiltration of precipitation, ground-water recharge in Santa Maria Valley during 1978-80 is estimated to have totaled about 610,000 acre-ft.

TABLE 2.--Streamflow at surface-water gaging stations, 1973-80

[In acre-feet per year]

Calendar year	11138500, Sisquoc River near Sisquoc	11139000, La Brea Creek near Sisquoc (estimated)	11139500, Tepusquet Creek near Sisquoc	11140000, Sisquoc River near Garey	11138100, Cuyama River below Twitchell Dam	11141000, Santa Maria River at Guadalupe
1980	75,434	14,056	3,275	6,472	109,709	21,187
1979	33,862	6,048	774	28,367	80,079	2,223
1978	135,300	25,588	2,450	107,800	125,900	49,850
1977	2,500	7	87	541	0	24
1976	4,260	346	182	400	0	6
1975	17,550	2,906	437	7,850	5,710	307
1974	20,100	3,397	1,510	5,940	27,150	209
1973	46,370	8,457	2,920	36,300	48,470	9,990

TABLE 3.--Seepage losses, 1973-80

[In acre-feet]

Calendar year	Sisquoc River	Santa Maria River	Total (rounded)
1980	86,293	94,994	180,000
1979	12,317	106,223	120,000
1978	55,538	183,850	240,000
1977	2,053	517	2,600
1976	4,388	394	4,800
1975	13,043	13,253	26,000
1974	19,067	32,881	52,000
1973	21,447	74,780	96,000

COMPARISON OF METHODS

Because the actual quantities of ground water recharged to the basin are not known, there can be no comparison of the recharge estimates to the "correct" value. It should be noted, however, that recharge estimates from both methods are comparable. Using the water-level-change method, recharge during 1978-80 is estimated at 580,000 acre-ft; using the seepage-loss method, recharge during the same period is estimated at 610,000 acre-ft (table 4). Both methods are probably accurate to one significant figure, and thus both methods yield the same estimate of 600,000 acre-ft.

The water-level-change method indicates that annual recharges for 1978, 1979, and 1980 represented 119 percent, 98 percent, and 83 percent, respectively, of the average annual recharge for the 3-year period; the seepage-loss method indicates that annual recharges were 143 percent, 64 percent, and 94 percent of the 3-year average (table 4). Both methods show agreement that 1978 produced the most recharge, but disagree as to the relative magnitude of recharge during 1979 and 1980. Table 4 shows that the quantity of rainfall recorded at both Santa Maria and Cuyama was highest in 1978, lowest in 1979, and intermediate in 1980; these numbers agree with the magnitude of annual recharges estimated using the seepage-loss method.

TABLE 4.--Comparison of yearly distributions of precipitation and estimated recharge

	Precipitation				Estimated recharge			
	Santa Maria		Cuyama		Seepage-loss method		Water-level-change method	
Calendar year	Inches	Percent of 3-year average	Inches	Percent of 3-year average	Acre-feet	Percent of 3-year average	Acre-feet	Percent of 3-year average
1980	13.47	77	10.44	88	190,000	94	160,000	83
1979	13.28	76	9.35	79	130,000	64	190,000	98
1978	25.75	147	15.80	133	290,000	143	230,000	119
Total-----------------------------					610,000		580,000	

Both methods of estimating recharge make use of simplifying assumptions, the validity of which directly affect the reliability of the estimates. The simplifying assumptions of both methods are discussed in detail below.

Three assumptions limit the accuracy of the water-level-change method of estimating ground-water recharge. It is assumed that: (1) the lines of equal water-level rise are accurate representations of area water-level rises, (2) the estimate of the average specific yield is reasonably accurate, and (3) the median value of adjacent lines of equal water-level rise is representative of the average rise in the area between the lines.

The accuracy of the lines of equal water-level rise is a source of some error in the estimate of recharge in Santa Maria Valley. The wells in the monitoring network are rather spread out, resulting in poor resolution when small areas of the network are considered. Not only is the coverage by the network marginal in this respect, but the wells were measured only annually. If for any reason a well was not measured during the annual well run, that data point was lost. Also, some wells seem to respond more slowly to recharge than others, and water-level data from some of the slow-response wells were considered unusable.

The estimate of specific yield for alluvial aquifers of 15 percent is probably fairly accurate for this system, as a whole. Definition of variations in specific yield both areally and vertically would improve the recharge estimate, but the error introduced by assuming an average specific yield is probably not greater than a few percent.

Similarly, by using the median value of adjacent lines of equal water-level rise as the average rise in the area between the lines, errors of perhaps as much as 50 percent could occur in small areas. But valleywide, this assumption probably does not introduce errors of more than a few percent.

In addition to limiting assumptions, the accuracy of the water-level-change method is directly dependent on the accuracy of estimating that part of the pumpage lost from the system due to evapotranspiration. Evapotranspiration of pumped water is estimated at 300,000 acre-ft during 1978-80, about one-half of the volume of water estimated to have recharged the ground-water system during the same period. Thus, a 20-percent error in estimating the volume of pumped water lost by evapotranspiration would translate into a 10-percent error in the recharge estimate when using the water-level-change method for 1978-80. During periods of less recharge, a 20-percent error in the estimate of pumped water lost to evapotranspiration would translate into an even larger error in the recharge estimate.

The seepage-loss method of estimating ground-water recharge assumes that (1) ungaged contributions to streamflow are unimportant, (2) evaporation from the stream channel is insignificant, and (3) streamflow records are sufficiently reliable to allow accurate calculations of streamflow losses.

Miller and Evenson (1966) estimated that ungaged seepage losses in the valley were equal to 1½ times the flow gaged at station 11139500, Tepusquet Creek near Sisquoc, and they included that estimate in their calculations of seepage losses. For this study, 1½ times the flow at the station on Tepusquet Creek averaged less than 1 percent of the total seepage losses, so the ungaged seepage losses were considered insignificant and were not used in the recharge estimate. The recharge estimate would increase only slightly if ungaged seepage losses were considered.

Because most streams in the valley are ephemeral and most streamflow usually occurs during the wet season when evaporation rates are at a minimum, evaporation from stream channels is probably insignificant. The recharge estimate would decrease slightly if evaporation from stream channels were considered in the method.

Streamflow records from gaging stations in Santa Maria Valley for the period 1978-80 are described as "fair" to "good," except for records from station 11141000, Santa Maria River at Guadalupe, which are "poor" (U.S. Geological Survey, 1982). As defined by the Geological Survey, "good" means that about 95 percent of the daily discharges are accurate within 10 percent; "fair," within 15 percent; and "poor," records have less than "fair" accuracy. It is probably reasonable, solely on the basis of accuracy of record, to conclude that seepage losses estimated using data from these stream gages are accurate to within 20 percent.

FREQUENCY OF OCCURRENCE OF SIMILAR ANNUAL RECHARGE

To determine the frequency of occurrence of annual recharges equal to those of 1978, 1979, and 1980, annual-flow data from the station on the Sisquoc River near Sisquoc (11138500) were ranked and plotted on logarithmic-probability paper, and a log-Pearson Type III distribution was fit to the data (fig. 5). The Sisquoc station was chosen to determine frequency of occurrence because no controls on flow occur above the gaging station, and flows there should be representative of natural cycles. Precipitation was not used for the probability distribution because no quantitative relation between rainfall and streamflow was apparent, whereas flow measured at the station on the Sisquoc River near Sisquoc correlated very well (greater than 93 percent) with seepage losses calculated for the basin.

The graph shows the exceedence probability, in precent, for annual flows. For 1978, 1979, and 1980 annual flows, the probabilities are 5 percent, 25 percent and 10 percent, respectively. Because recurrence interval is the reciprocal of exceedence probability, the streamflow and recharge conditions of 1978 could be expected to be exceeded about 1 year in 20; the 1979 conditions, about 1 year in 4; and the 1980 conditions, about 1 year in 10.

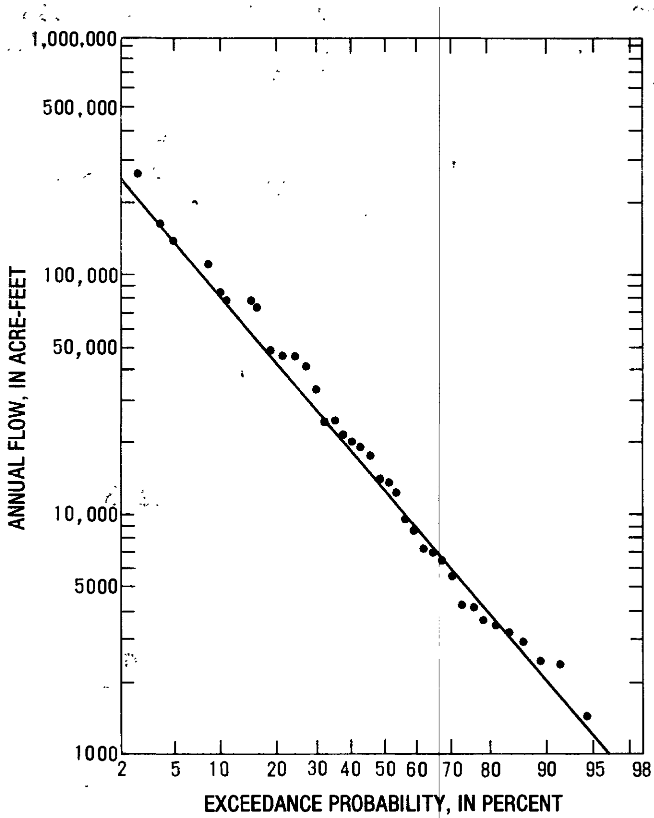

FIGURE 5.-- Log-Pearson Type III distribution of annual flows gaged at station 11138500, Sisquoc River near Sisquoc, 1944-80.

The graph was constructed using calendar-year discharges for 37 years of record from 1944 to 1980. The probability distribution may change slightly as more years of record become available and the ranking of discharges changes. The curve should be replotted about every 5 years.

SUMMARY AND CONCLUSIONS

Recharge to the alluvial aquifer system of Santa Maria Valley occurs primarily as infiltration from major streams. The reach of the Sisquoc River from Sisquoc to Garey and the reach of the Santa Maria River from Fugler Point to near Guadalupe contribute most of the ground-water recharge to the valley. Two methods of estimating annual recharges during the excessively wet period 1978-80 were applied in this study with comparable results. Both methods indicated that recharge was about 600,000 acre-ft (rounded) during the 3-year period.

Annual recharges estimated using the seepage-loss method are 290,000 acre-ft for 1978, 130,000 acre-ft for 1979, and 190,000 acre-ft for 1980. Based on yearly flows measured at the gaging station on the Sisquoc River near Sisquoc, the long-term average recurrence intervals of similar annual recharges are estimated at 20 years for 1978, 4 years for 1979, and 10 years for 1980. Using the water-level-change method, estimates of annual recharges are 230,000 acre-ft for 1978, 190,000 acre-ft for 1979, and 160,000 acre-ft for 1980.

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