A WATER-RESOURCES DATA NETWORK EVALUATION FOR MONTEREY COUNTY, CALIFORNIA--PHASE 1: SOUTH COUNTY

by Patricia Showalter and Stuart H. Hoffard

U.S. GEOLOGICAL SURVEY

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Sacramento, California
July 1986

UNITED STATES DEPARTMENT OF THE INTERIOR

DONALD PAUL HODEL, Secretary

GEOLOGICAL SURVEY

Dallas L. Peck, Director

For additional information
write to:

District Chief
U.S. Geological Survey
Federal Building, Room W-2234
2800 Cottage Way
Sacramento, CA 95825

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CONVERSION FACTORS

For readers who prefer to use International System of Units (SI) rather than inch-pound units, the conversion factors for the terms used in this report are listed below:

Multiply	By	To obtain
acre-feet	0.001233	cubic hectometers
feet	0.3048	meters
feet per mile (ft/mi)	0.1894	meters per kilometers
gallons per day per foot ((gal/d)/ft)	0.01242	cubic meters per second
gallons per minute per foot ((gal/min)/ft)	0.00124	meters squared per minute
miles (mi)	1.609	kilometers
square miles (mi^2)	2.59	square kilometers

Temperature in degrees Fahrenheit (°F) can be converted to degrees Celsius (°C) as follows:

Temp °C = (temp °F-32)/1.8.

A WATER-RESOURCES DATA NETWORK EVALUATION FOR MONTEREY COUNTY, CALIFORNIA

PHASE 1: SOUTH COUNTY

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ABSTRACT

This report describes an evaluation of rainfall, surface-water, ground-water, and water-quality monitoring networks in the Salinas River basin in southern Monterey County, California, and proposes modifications to improve the networks. The general approach for the design of all monitoring networks followed these steps:

1. Collect and review all hydrologic data and water-related reports for the area.

2. Interview water authorities to determine their views on water-data needs and existing or potential water problems.

3. Develop objectives for each monitoring network.

4. Design an "ideal" or "saturation" network of monitoring sites to meet the objectives established in step 3.

5. Develop a rating system to evaluate existing and potential monitoring sites to determine which sites most effectively satisfy monitoring objectives.

6. Select a combination of monitoring sites that best meets monitoring objectives within reasonable funding limits.

The rainfall-network evaluation suggested the existing long-term network of recording rain gages be maintained as a basis for (1) extending short-term records, (2) estimating daily or hourly rainfall data for flood-damage studies, and (3) rainfall-duration and intensity studies. Installation of a recording gage on the divide above the headwaters of San Miguel Creek and one in the Jolon area would strengthen the network. Storage-type rain gages should be installed at middle altitudes of the Cholame Hills bordering the east side of the Salinas Valley and along the slopes of the hills bordering the west side of the valley. In these areas, virtually no rainfall records have been collected, and on the most recent (1974) annual rainfall map, lines of equal rainfall are poorly defined.

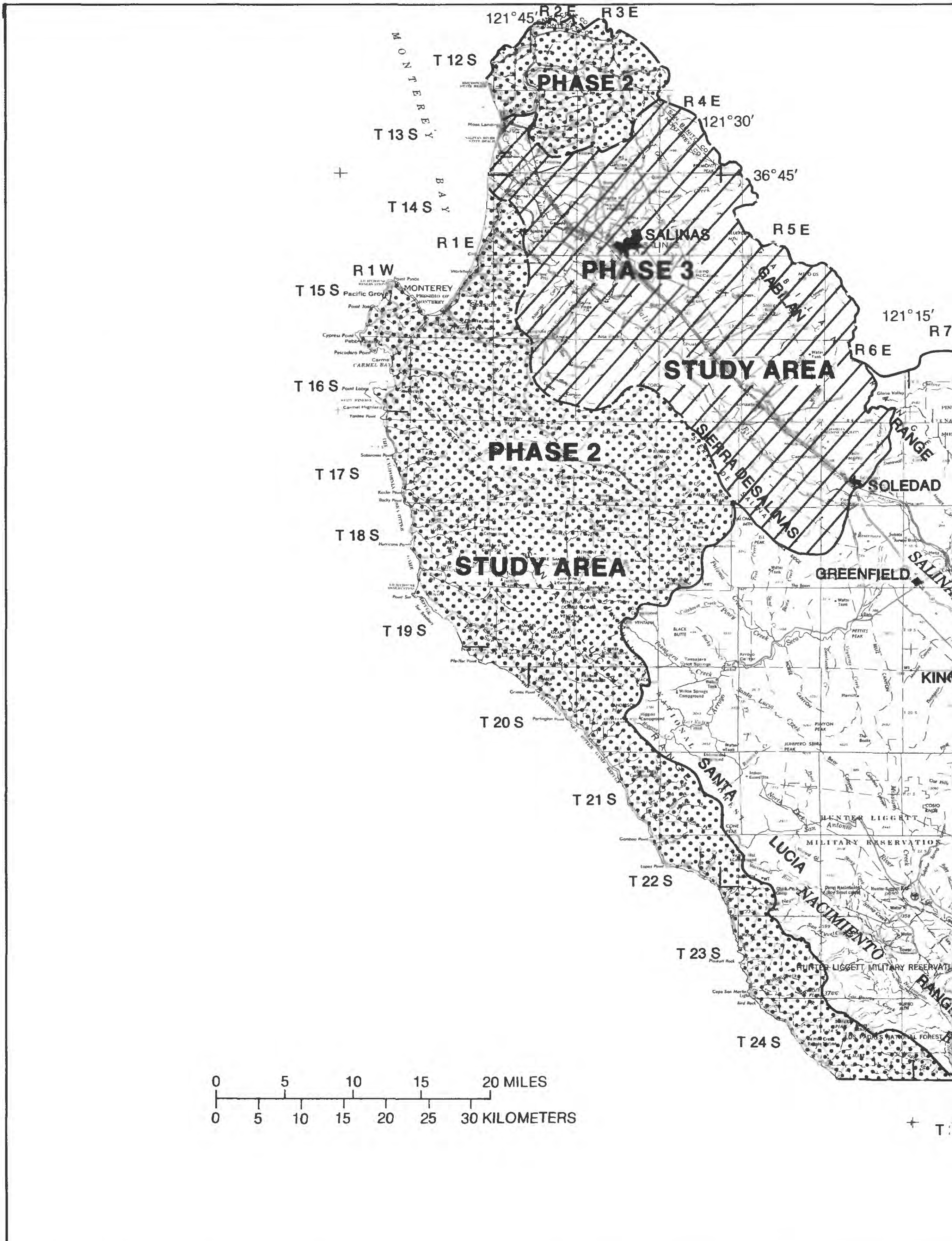
An evaluation of the surface-water network showed that some short-term gaging stations could be discontinued because regression relations were good between those stations and the long-term station Arroyo Seco near Soledad. Only a 2-percent decrease in network-information value would result if stations Arroyo Seco near Greenfield and San Antonio River near Lockwood were deleted from the existing network. Of 16 stations selected for the proposed network, 4 are new recording stations, 6 are new nonrecording streamflow and water-quality sampling sites, 5 are existing stations, and 1 is a station installed in 1969 and discontinued in 1976 due to economic considerations. The proposed network also includes three water-quality sampling stations on Lakes Nacimiento and San Antonio.

Analysis of the ground-water network did not involve development of an "ideal" network. Instead, the proposed network was developed directly from (1) information on geology, geohydrology, and ground-water quality; (2) high-priority objectives for the ground-water network; and (3) consideration for providing good areal coverage of ground-water levels and ground-water quality. Of the 145 sites selected for the proposed network, 86 are existing monitoring wells.

INTRODUCTION

Efficient water-resources development and management requires continuing data collection and analysis to provide an assessment of water-quality and quantity trends. Periodic evaluation of data-collection programs is needed to insure resource managers are provided data that adequately represent current conditions and provide a basis for detecting trends. Increases in population, intensification of land use, and different agricultural practices may bring about changes in water-resources utilization that may require expanded data collection to assess fully the effects of management practices. On the other hand, data collection at some sites may not be cost effective and should be discontinued.

This report summarizes an evaluation of rainfall, surface-water, ground-water, and water-quality monitoring networks in the Salinas River drainage basin in southern Monterey County and contains suggestions for improving the networks. Geology, rainfall and runoff regimen, land use, and other background information of the study area are briefly described. This phase 1 area report is the first of three proposed reports that will cover all of Monterey County; these reports are to be prepared in cooperation with the Monterey County Flood Control and Water Conservation District (MCFCWCD). A phase 2 area report is scheduled for coastal Monterey County areas, and a final phase 3 area report is planned for the Salinas River basin area north of Soledad. The location of the study area for phase 1 (this report) and for the other phases is shown in figure 1.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SALINAS
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Pacific Grove
SOLEDAD
GREENFIELD
GABILAN
RANGE
SIERRA DE SALINAS
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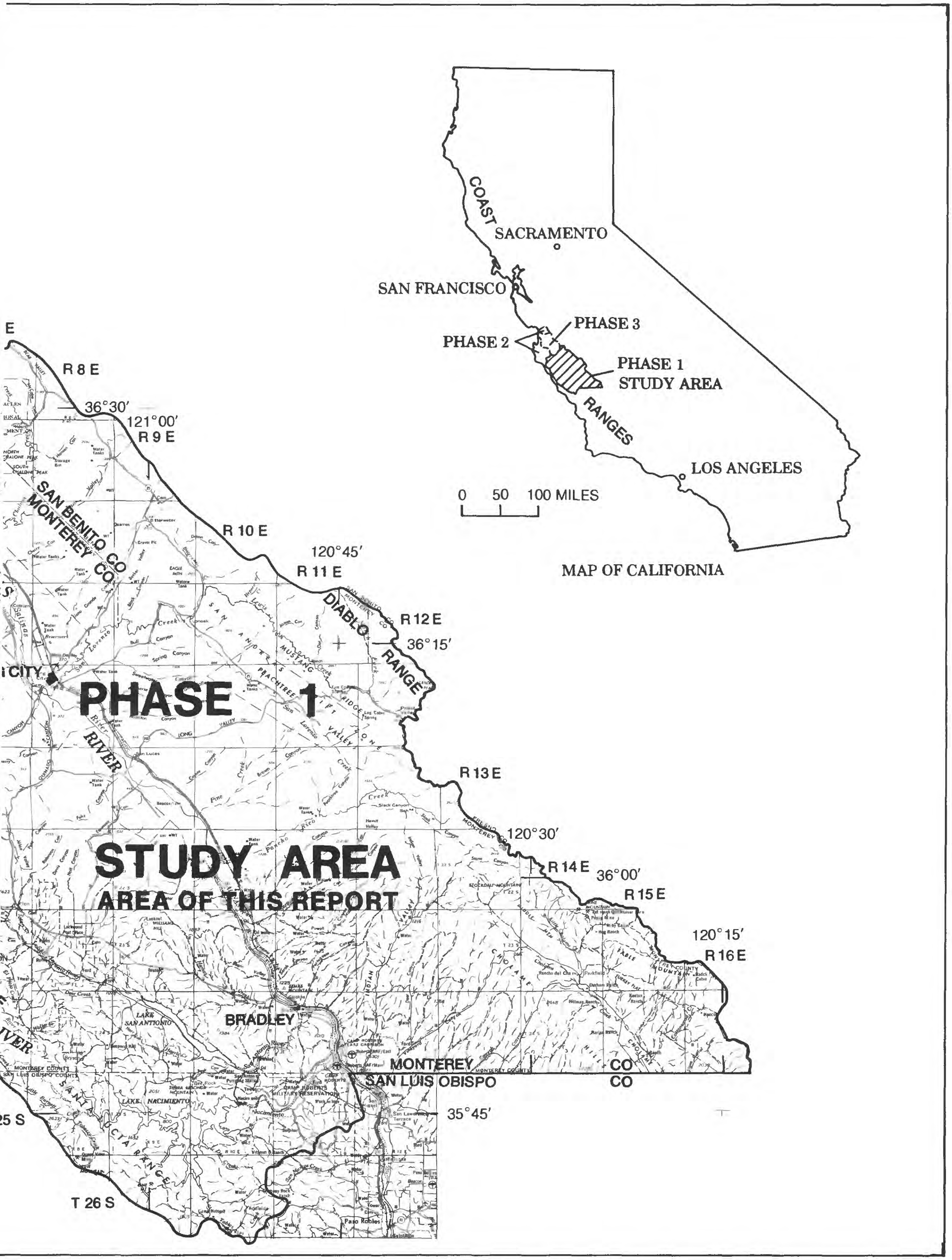

FIGURE 1. — Location of the study area.

Location and Topography

The area of this study is entirely within the Salinas River drainage basin, an intermontane valley of the central Coast Ranges of California. The Salinas River flows northward and empties into the Pacific Ocean at Monterey Bay about 125 miles south of San Francisco. The drainage basin covers an area of about 5,000 mi^2, but this study is concerned only with that part of the basin south of Soledad (fig. 1) and principally within Monterey County. Monterey County is a highly productive agricultural area that supplies fresh produce and many other farm products to areas throughout the Nation. In 1981 the gross agricultural-crop value for the county totaled nearly $893 million (Monterey County Department of Agriculture, 1981).

The study area covers 2,100 mi^2, of which 230 mi^2 is tributary drainage area within San Benito County and 210 mi^2 is in the Nacimiento River drainage basin (tributary to the Salinas River) within San Luis Obispo County. The valley floor rises from an altitude of about 200 feet at Soledad to about 540 feet at Bradley. The Sierra De Salinas and Santa Lucia Range rise abruptly along the west side of the valley to a maximum altitude of about 5,860 feet. The Gabilan and Diablo Ranges bound the east side of the valley where the highest point has an altitude of about 3,950 feet.

Agricultural, range, and forest land dominate the Salinas River drainage basin. These categories are related somewhat to land slope; agricultural land is generally flat, rangeland is rolling or steep, and forest land is steep. On agricultural land, intensity of cultivation varies considerably and generally declines to the south; south of King City most agricultural land is used for vineyards or for grain production. Much larger quantities of water are required to irrigate more intensely cultivated areas. All present water needs are being met through operation of reservoirs and ground-water recharge management; there is no imported water.

The largest community in the study area (occasionally referred to as "South County" in this report) is King City, which has a population of about 6,000, followed by Greenfield, with a population of about 4,500. The other communities have populations of less than 2,400.

Purpose and Scope

The purpose of this study was to review all hydrologic data-collection activities in the study area and to suggest revisions to improve the efficiency of data-collection activities. Objectives of the revisions are (1) to insure that the data collected meet management needs and (2) to collect the data in a cost-effective manner. Monitoring activities reviewed include collection of ground-water levels and water-quality data, surface-water discharge data, sediment-transport data, surface-water quality data, and rainfall data.

Many factors limited the scope of this study. No onsite work was budgeted except for a few brief reconnaissance-level trips; therefore, precise locations are not available for many proposed observation wells, streamflow-gaging stations, and rain gages. The evaluation of the ground-water monitoring network was particularly hampered by incomplete information on construction of existing wells (depth, perforation, and screen levels) and by the varying quality of water-level and water-quality data available for the study area.

In this study the design objectives of the rain-gage network are limited to purposes other than flood warning. The MCFCWCD, with assistance from the California Department of Water Resources (DWR) and the National Weather Service (NWS) recently installed a network of flood-warning rain gages with radio-transmitting equipment. It is beyond the scope of this study to evaluate the need for each of these flood-warning rain gages; in 1983 sufficient rainfall data had not been collected for an evaluation.

Approach

The general approach for the design of all the monitoring networks followed the steps outlined below:

1. Collect and review all hydrologic data and water-related reports for the area to determine the available data base and the documented water problems.
2. Interview water authorities to determine their views on water-data needs and existing or potential water problems.
3. Develop objectives for each monitoring network, and review and assign objective priorities with the assistance of MCFCWCD.
4. Design an "ideal" or "saturation" network of monitoring sites to meet the objectives established in step 3.
5. Develop a rating system to evaluate existing and potential monitoring sites to determine which sites most effectively satisfy monitoring objectives, which sites historically represent regional changes, and how these sites could represent historical conditions compared to representation given by the existing network.
6. Select a combination of monitoring sites that best meets monitoring objectives within reasonable funding limits.

Details on the specific approach for each network design accompany the presentation of the proposed networks under sections of this report entitled "Network Analysis." Because of the varying state-of-the-art in each field, the details of the approach vary considerably for the rainfall, surface-water, ground-water, and water-quality network evaluations. Considerably more research has been done in surface-water network evaluation; several quantitative methods have been developed.

A review of progress in designing hydrologic-data networks (Moss and Tasker, 1979) includes a bibliography of 130 technical papers, reports, and books; 37 deal with streamflow networks, 50 with surface-water quality and ground-water quality monitoring, 20 with precipitation networks, and 14 with general theory. Surprisingly, only nine papers deal with ground-water-level networks. The advanced techniques for evaluating surface-water networks have made it possible to follow a quantitative approach in this area, whereas the lack of quantitative methods in ground-water network evaluation leaves little choice other than a qualitative approach. The experience and methods used in designing effective hydrologic-data networks to supply the information needed for management of the water resources in this study area should be of widespread interest.

Climate and Hydrology

The climate in the study area is classified as dry, subhumid to semiarid (Thornthwaite, 1948); the annual precipitation is consistently deficient with respect to the annual potential evapotranspiration. The temperature range is small; at King City average monthly temperatures range from about 50°F in December and January to about 70°F in June and July. Prevailing winds are from the northwest from March through October. The foggy, moisture-laden sea air usually becomes warm and dry by the time it reaches Soledad.

Most winter storms originate in the northern Pacific Ocean and approach the coastal areas of Monterey County from the northwest. As the storms move inland, many of the frontal systems begin a counterclockwise motion, spreading rain from the southwest. Occasional, high-intensity storms originate in the tropical areas to the southwest.

Average annual precipitation ranges from about 70 inches near the crest of the Santa Lucia Range to about 10 inches on the Salinas Valley floor between Soledad and San Lucas. More than 90 percent of the rainfall occurs between October and April. Rainfall during May through September in most years totals less than 1 inch at all locations. The seasonal distribution of rainfall at King City is shown in figure 2.

Runoff is closely related to rainfall and has about the same seasonal distribution. The highest measured annual runoff occurs in the upper Arroyo Seco basin in the Santa Lucia Range; the average annual runoff for 1961-80 was 18.3 inches. The lowest measured runoff, which averages about 0.8 inch per year, occurs in the San Lorenzo Creek basin east of King City. Flow at these sites is meager during the summer, and both have been dry at times.

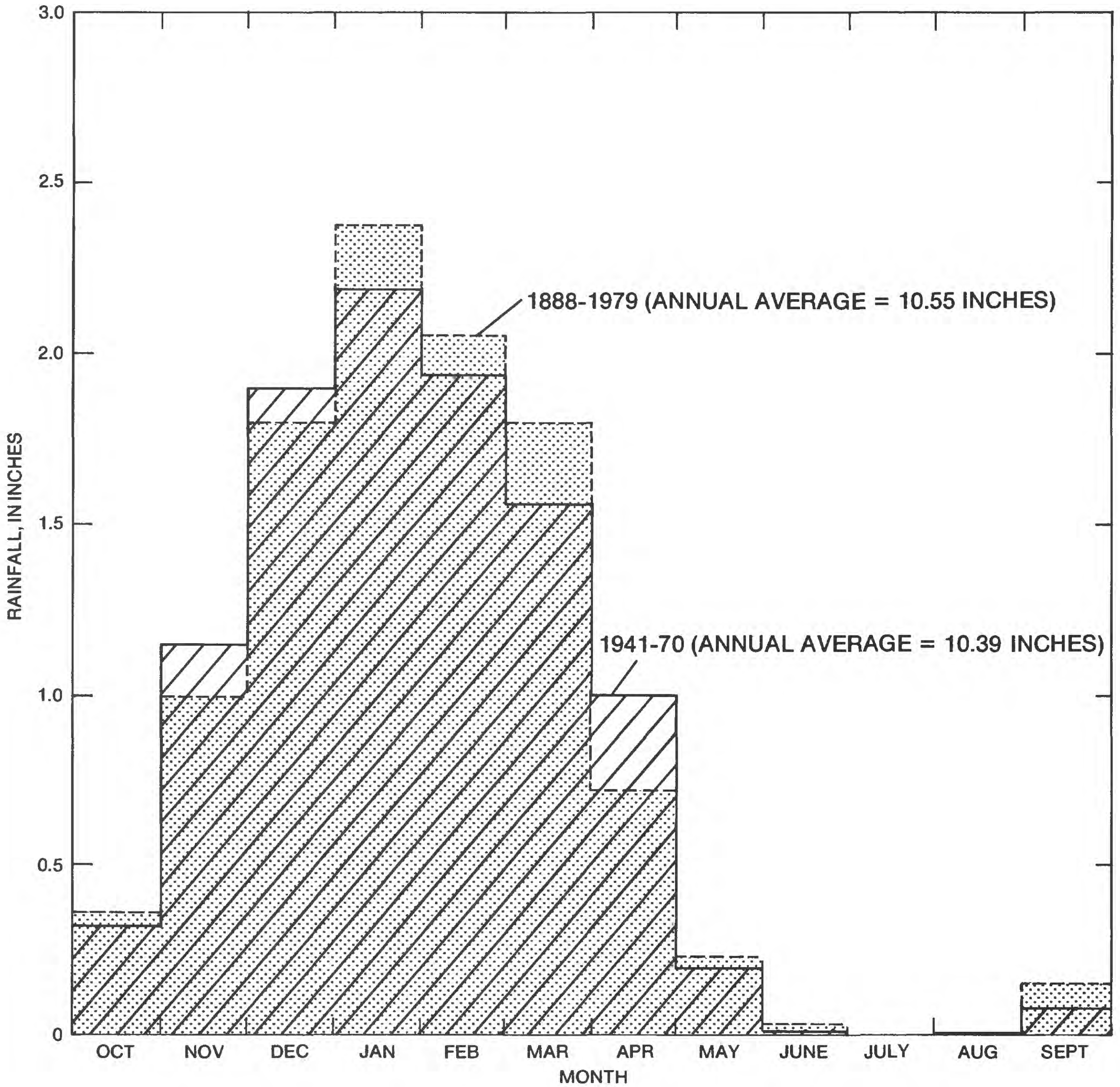

FIGURE 2. — Comparison of monthly distribution of rainfall at King City for 1888-1979 and 1941-70 (From National Weather Service records).

The mean monthly runoff distribution at the streamflow-gaging station Arroyo Seco near Soledad (fig. 3) is based on 80 years of record. On an average, almost 90 percent of the annual runoff occurs during December through April. This distribution is typical for all unregulated stream runoff in the study area. The need for storage to utilize the highly seasonal runoff led to the construction of two major reservoirs (Lake Nacimiento completed in 1957 and Lake San Antonio completed in 1965), which have a combined usable capacity of 670,000 acre-feet.

The only inflow from outside the study area comes from the upper (southern) Salinas River basin. Based on streamflow records for major upstream tributaries, the long-term annual inflow at the Monterey-San Luis Obispo County line is estimated to be 100,000 acre-feet. Runoff from the tributaries within the study area, including the Arroyo Seco, is estimated to be 380,000 acre-feet, of which 340,000 acre-feet is contributed by streams on the west side. These estimates are from gaging-station records adjusted to the 1902-81 runoff record for the station Arroyo Seco near Soledad.

Well-Numbering System

The well-numbering system used in California indicates the location of wells according to the system for the subdivision of public lands. For example, in the number 17S/6E-27E3, the number preceding the slash indicates township (T. 17 S.); the number after the slash, the range (R. 6 E.); the digits after the hyphen, the section (sec. 27); and the letter after the section number (E), the 40-acre subdivision of the section as indicated on the diagram below. Within each 40-acre tract wells are numbered (serially) as indicated by the final digit (3) of the well number. The entire study area is south and east of the Mount Diablo base line and meridian.

D	C	B	A
E	F	G	H
M	L	K	J
N	P	Q	R

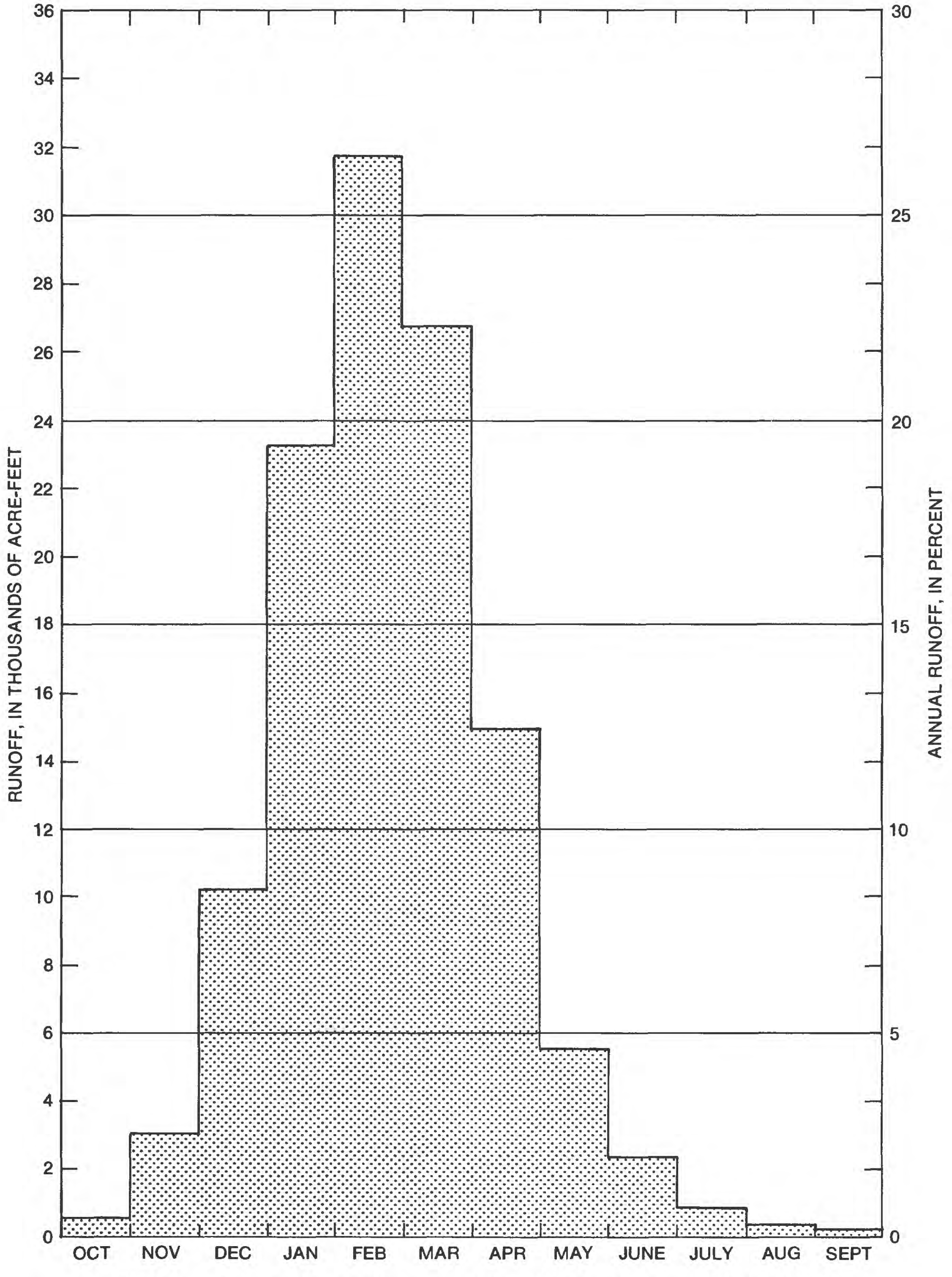

FIGURE 3. — Mean monthly runoff at station 11152000, Arroyo Seco near Soledad, 1902-81.

Acknowledgments

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We also want to thank Donald H. Neudeck and William Mancebo, California Department of Water Resources, for their help in locating rain gages and David Ririe, the Monterey County Agriculture Extension Agent, for contributing his widespread knowledge of land-use and irrigation practices in the Salinas Valley.

PRECIPITATION-NETWORK ANALYSIS

Method of Analysis

Definition of Objectives

The first step in evaluating the adequacy of a precipitation-monitoring network is to define the objectives of the data-collection program. Rainfall data may be collected for land-use planning with the objective of determining long-term monthly and annual rainfall averages and the variability of rainfall. Rainfall data also are needed on a real-time basis for flood warning and for runoff predictions. Current rainfall data are of value in making irrigation- and range-management decisions.

Precipitation-monitoring evaluation objectives are to design a network suitable for defining the areal variability of long-term average monthly and annual rainfall and to supply information on areal distribution of rainfall for specific periods that may be required in future hydrologic studies. As stated previously, an evaluation of flood-warning rain gages is beyond the scope of this report.

Definition of Data Accuracy

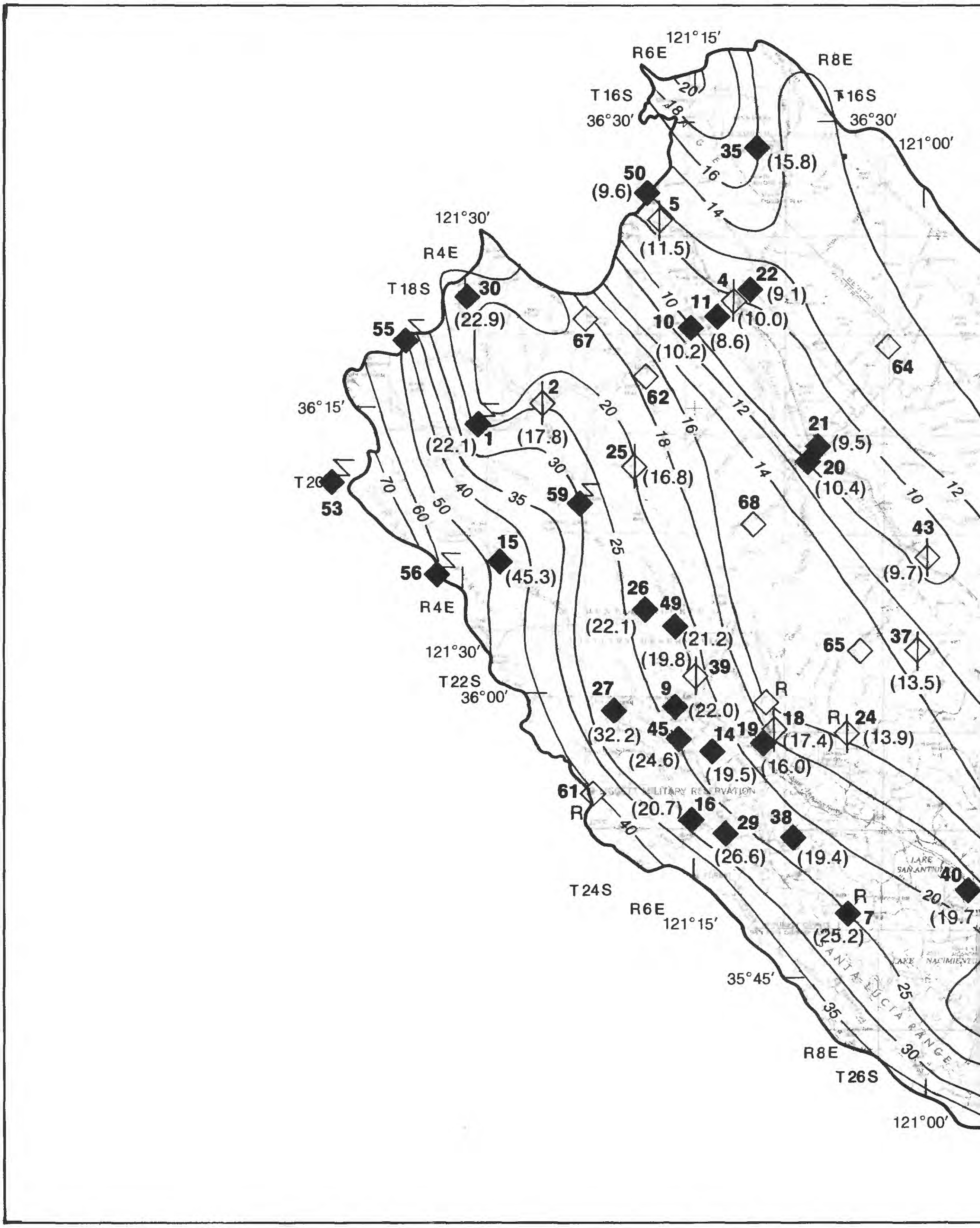
A major limiting factor in establishing accuracy goals for a precipitation-monitoring network is the accuracy of equipment used to measure rainfall. In an analysis of rain-gage accuracy, the California Department of Water Resources (1981, p. 8) pointed out that rain gages probably have a 5- to 10-percent average deficiency which ranges from zero when there is no air movement to 72 percent when the wind speed is 35 miles per hour. Nordenson (1968) stated that scientists in the Soviet Union have suggested average corrections of 14 to 17 percent to increase measured rainfall to true rainfall.

Rain gages should be located where there is some shelter from wind, but should not be located in the shadow of vegetation or structures that intercept some rainfall. Obviously, every rain gage in a network has a unique exposure and is subject to differing wind effects. Variation in size, shape, and height of rain gages also creates discrepancies in measured rainfall because of differing air turbulence associated with each type of gage. Considering the variability in measured rainfall resulting from nonuniform exposure conditions and instrumentation, an accuracy of 10 percent in determining areal rainfall would seem about as good as could be expected.

Compilation of Available Rainfall Records

Rain gages in the study area have been operated by several agencies, private companies, ranches, and individuals. An effort was made to collect all local rainfall information indexed in meteorologic and data catalogs and to normalize the data to the 1941-70 period. The 1941-70 rainfall average appears to be nearly the same as the average for the longest records available, and the 1941-70 averages are readily available for many National Weather Service (NWS) stations. The 1888-1979 average rainfall for King City is 10.55 inches, and the 1941-70 average is 10.39 inches. The gage locations are shown in figure 4. The records located, the operators of the gages, period of record available, and the normalized 1941-70 annual rainfall are listed in table 1. A total of 52 rainfall records was used. Several other records were located but were too short or intermittent to normalize reliably. Some records were considered redundant and have not been listed. For example, records exist for four rain gages within a 2-mile radius of King City. Only the NWS and the Monterey County Road Department records for King City have been used.

Much rainfall information was obtained from a California Department of Water Resources (1981) report containing data and microfiche records from 97 agencies for more than 4,000 stations representing 106,000 station-years of record. This publication lists monthly and annual rainfall totals for water years beginning October 1. Common practice in many county agencies, including those in Monterey and San Luis Obispo Counties, is to tabulate annual rainfall for the climatic year beginning July 1. Annual totals for the climatic and water years are nearly identical in the study area because rainfall in the July-September period is usually insignificant as shown in figure 2.



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SANTA LUCIA RANGE
LAKE SAN ANTONIO
LAKE NACIMIENTO
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5 (11.5)
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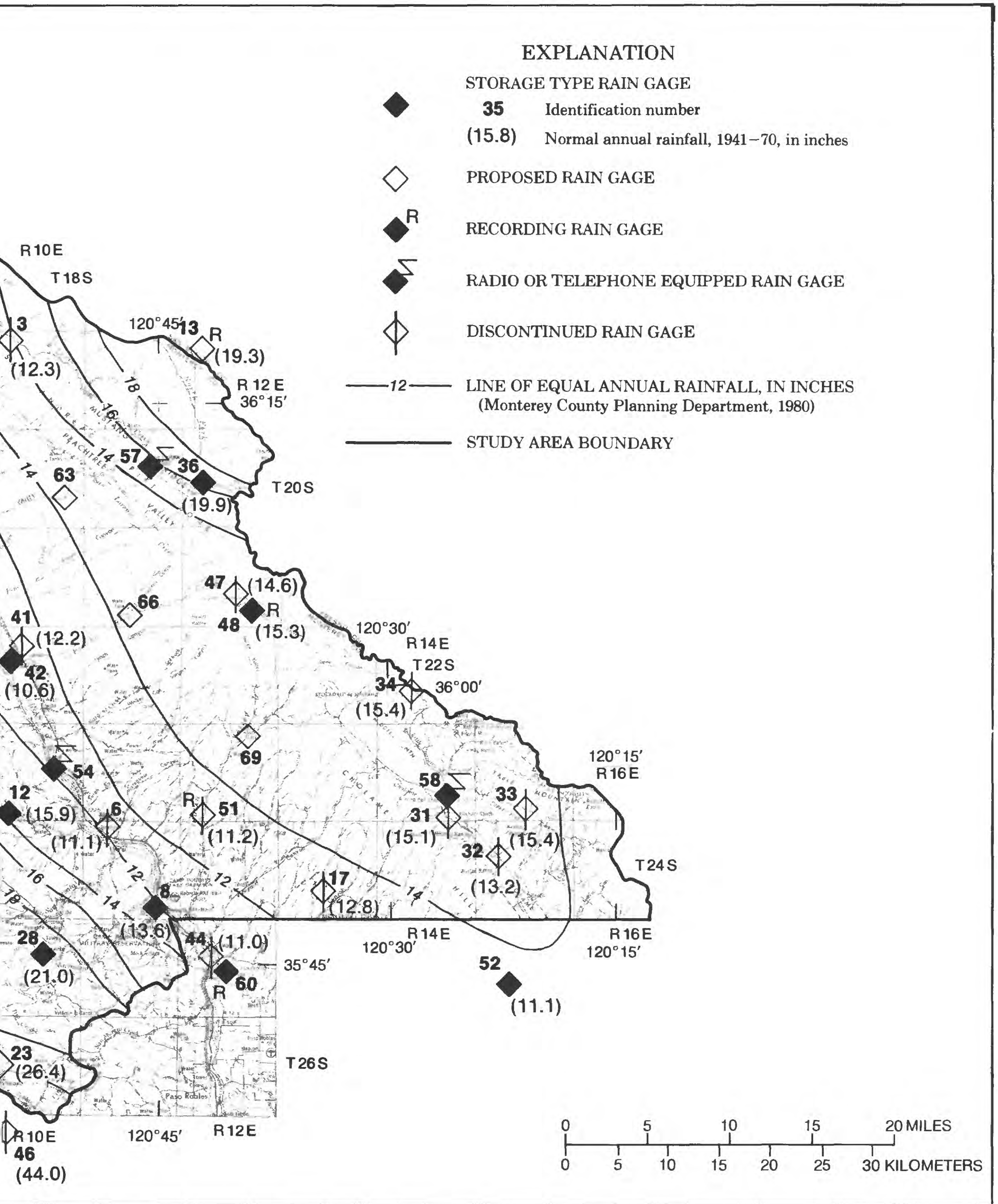


FIGURE 4. — Location of rain gages and average annual rainfall distribution.

TABLE 1. - Selected rainfall stations in and adjacent to southern Monterey County study area

[Agency: NWS, National Weather Service; P, Private individual or company; USA, United States Army; C of E, U.S. Army Corps of Engineers; MCRD, Monterey County Road Department; USFS, U.S. Forest Service; and SLO, San Luis Obispo County. Period of record: hyphen following water years indicates active station]

Station No. (fig. 4)	Station Name	Township	Range	Agency	Period of record	Normalized 1941-70 annual rainfall (inches)
1	Arroyo Seco	19	4	NWS	1950-	22.1
2	Arroyo Seco Millers 1G	19	5	NWS	1950-52	17.8
3	Associated Oil 4H	19	10	P	1924-29	12.3
4	Associated Oil 5H	18	7	P	1924-29	10.0
5	Associated Oil 6	17	6	P	1924-35	11.5
6	Bradley	24	11	NWS	1947-71	11.1
7	Bryson	24	8	NWS	1947-	25.2
8	Camp Roberts	24	11	USA	1952-	13.6
9	Central Stoney	22	6	USA	1965-	22.0
10	Greenfield Baker	18	7	C of E	1959-	10.2
11	Greenfield (Road Dept.)	18	7	MCRD	1964-	8.6
12	Hames Valley	23	10	P	1964-	15.9
13	Hernandez 7SE	12	12	NWS	1940-	19.3
14	High Point	23	7	USA	1968-	19.5
15	Indians Guard Station	21	5	USFS	1962-	45.3
16	Irus	23	7	USA	1971-	20.7
17	Jackson-Reinhert	24	13	SLO	1940-67	12.8
18	Jolon	23	7	NWS	1893-1925	17.4
19	Jolon (Hunter-Liggett)	23	7	USA	1971-	16.0
20	King City	20	8	NWS	1888-	10.4
21	King City (Road Dept.)	20	8	MCRD	1964-	9.5
22	L. E. Ranch	18	7	MCRD	1961-	9.1
23	Las Tablas	26	10	SLO	1966-77	26.4
24	Lockwood 2N	22	8	NWS	1941-78	13.9
25	Los Vaqueros	20	6	NWS	1903-10	16.8
26	Milpitas	21	6	USA	1964-	22.1
27	Nacimiento	22	6	USA	1971-	32.2
28	Nacimiento Dam	25	10	NWS	1957-	21.0
29	Palisades	24	7	USA	1971-	26.6
30	Paloma	18	4	NWS	1941-	22.9

TABLE 1. - Selected rainfall stations in and adjacent to southern Monterey County study area - Continued

Station No. (fig. 4)	Station Name	Town-ship	Range	Agency	Period of record	Normalized 1941-70 annual rainfall (inches)
31	Parkfield----------------	23	14	NWS	1939-75	15.1
32	Parkfield Wilson---------	24	15	SLO	1971-77	13.2
33	Parkfield 6SE------------	23	15	NWS	1908-75	15.4
34	Parkfield 7NNW-----------	22	14	NWS	1953-68	15.4
35	Pinnacles----------------	17	7	NWS	1937-	15.8
36	Priest Valley------------	20	12	NWS	1899-	19.9
37	Rancho San Lucas---------	22	9	P	1883-1961	13.5
38	Sam Jones----------------	24	8	USA	1965-	19.4
39	San Antonio Mission------	22	7	NWS	1960-71	19.8
40	San Antonio Dam----------	24	9	NWS	1960-	19.7
41	San Ardo-----------------	22	10	NWS	1896-1978	12.2
42	San Ardo (Road Dept.)----	22	10	MCRD	1964-	10.6
43	San Lucas----------------	21	9	P	1923-48	9.7
44	San Miguel---------------	25	12	SLO	1950-77	11.0
45	San Miguelito------------	23	6	USA	1973-	24.6
46	Seven X Ranch------------	27	10	SLO	1930-76	44.0
47	Slack Canyon-------------	21	12	NWS	1956-76	14.6
48	Slack Creek--------------	21	12	NWS	1944-45, 1977-	15.3
49	Site Alpha---------------	21	6	USA	1965-	21.2
50	Soledad------------------	17	6	NWS	1874-	9.6
51	Valleton-----------------	23	12	NWS	1944-71	11.2
52	White Ranch--------------	25	15	SLO	1932-	11.1

Normalizing Short-Term Rain-Gage Records

Rain gages that have been operated only a few years may be a useful part of a network. If good correlations with long-term stations are developed, long-term annual statistics can be synthesized from short-term records.

Short-term records in the study area were normalized to the 1941-70 period by correlating with concurrent long-term records. An example computation of the 1941-70 normal rainfall at the Monterey County Road Department "Greenfield" gage is shown below:

Greenfield average precipitation 1964-79 = 9.38 inches
King City NWS average precipitation 1964-79 = 11.18 inches
King City NWS average precipitation 1941-70 = 10.39 inches

$$\frac{\text{Greenfield 1964-79}}{\text{King City 1964-79}} = \frac{\text{Greenfield 1941-70}}{\text{King City 1941-70}}$$

$$\frac{9.38}{11.18} = \frac{\text{Greenfield 1941-70}}{10.39}$$

Greenfield 1941-70 = 8.72 inches.

This method of normalizing short-term records is simpler than using regression analysis and yields nearly identical results. A linear-regression model was developed for the Greenfield and King City 1964-79 records. The model is:

Greenfield = 0.96 + 0.752 King City (inches).

This equation yields a normalized rainfall of 8.77 inches for Greenfield. In some cases, more than one long-term record was used to normalize short records. For instance, using the Soledad record to normalize the Greenfield record, the 1941-70 Greenfield normal rainfall is 8.45 inches; therefore, an average of 8.6 inches was used in table 1.

The accuracy with which the short-term record can be normalized depends on proximity of a long-term station and the number of years of concurrent record; the more concurrent record, the better the accuracy. Relative accuracy to be expected using varying lengths of concurrent record is indicated by regression curves shown in figures 5 to 7. Forty years of concurrent record for King City and San Ardo were divided into 5-, 10-, and 20-year periods and separate linear regressions were developed for each period. This base period differs from the other periods used because the longer period makes a better example. The 1941-80 period has not been used or referred to as a normal base.

Errors were ±16 percent for 5-year regressions, +9 to -4 percent for 10-year regressions, and about ±3 percent for 20-year regressions. If these accuracies are assumed to be typical for concurrent records at any close pair of stations in the study area, 10 years of record at any new station would be sufficient to compute a long-term normal rainfall figure within 10 percent for that location, excluding other sources of error.

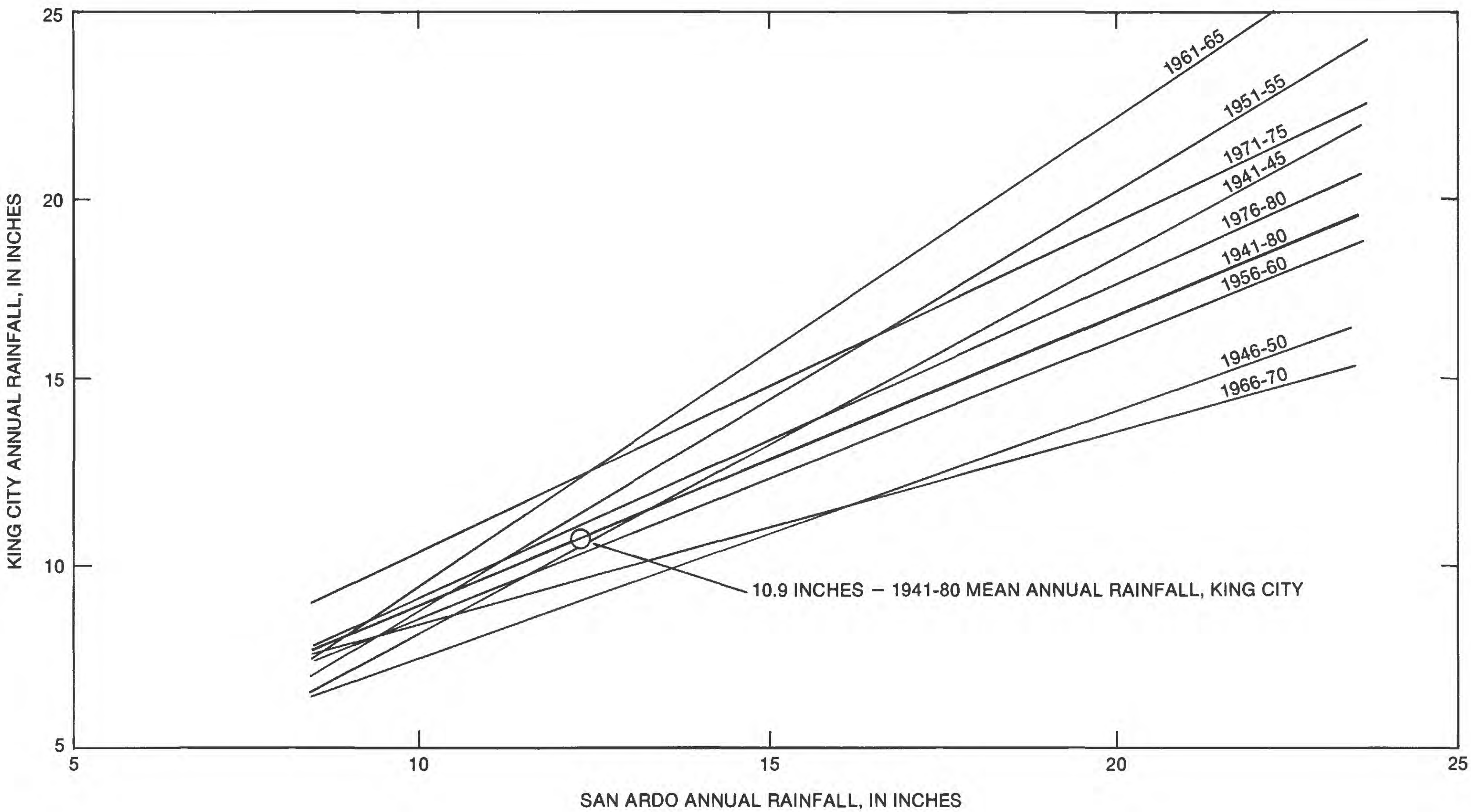


FIGURE 5. — Annual rainfall at King City and San Ardo for 5-year periods from 1941 to 1980.

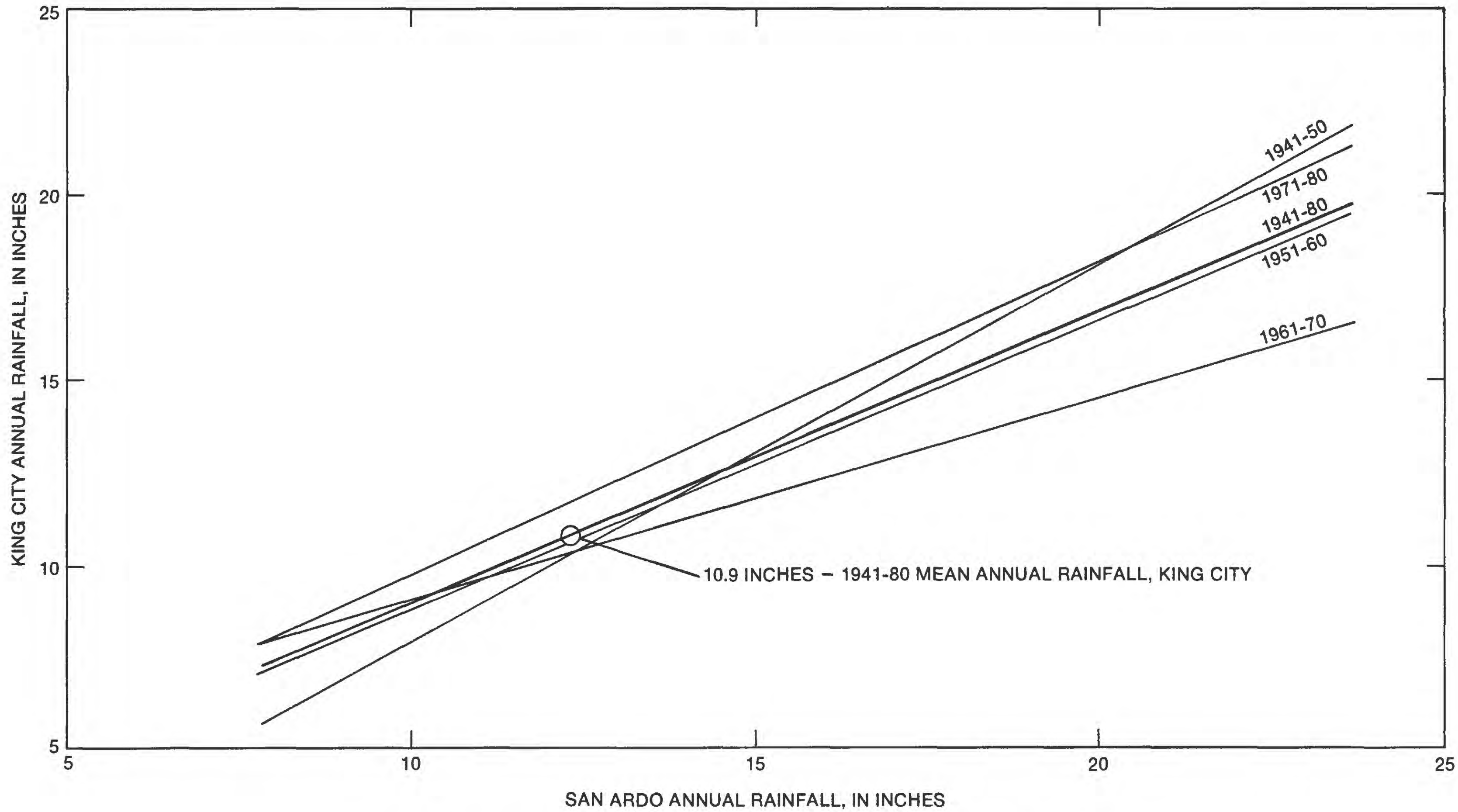


FIGURE 6. – Annual rainfall at King City and San Ardo for 10-year periods from 1941 to 1980.

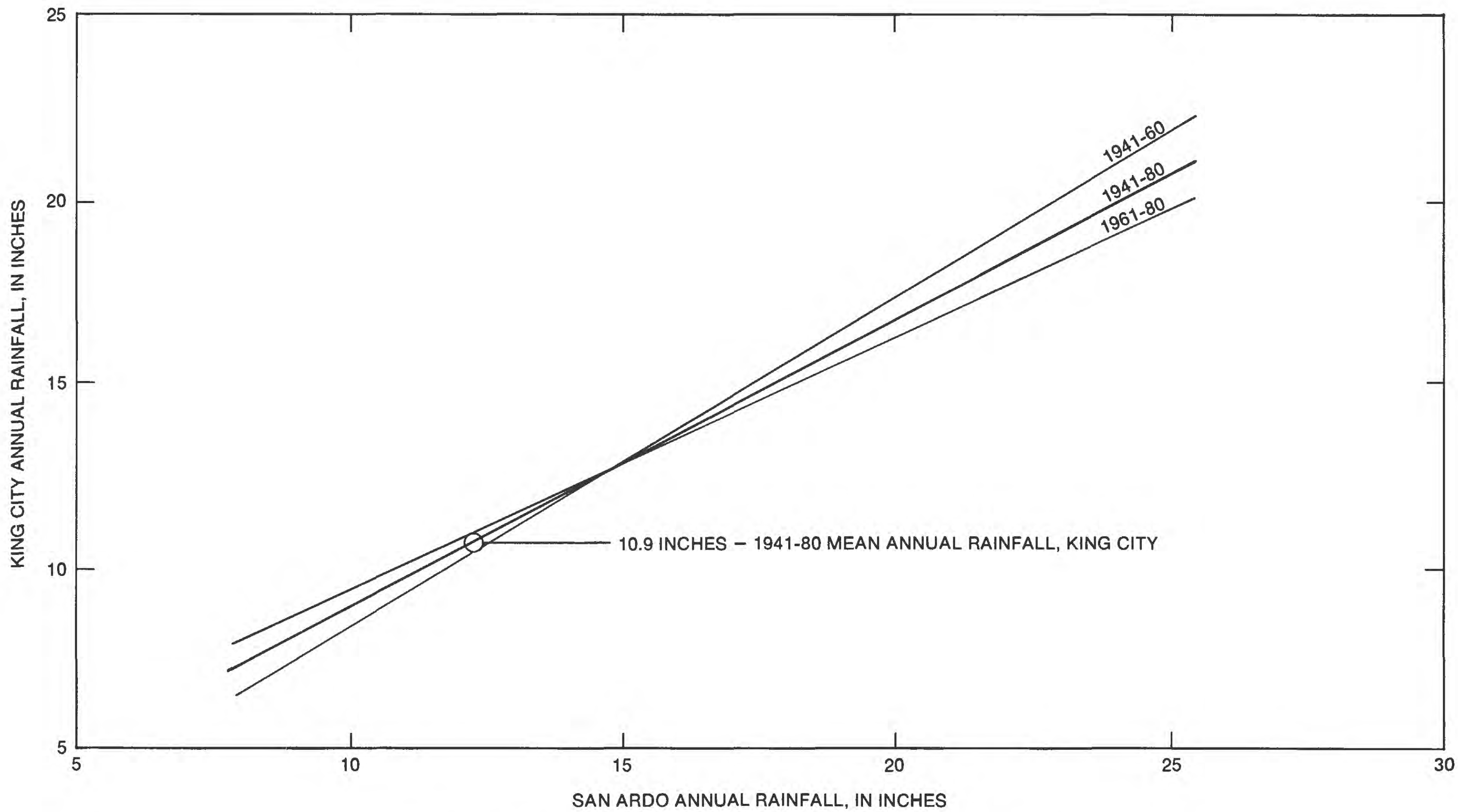


FIGURE 7. – Annual rainfall at King City and San Ardo for 20-year periods from 1941 to 1980.

The method used for evaluating rain gages for the proposed network was the comparison of normalized annual rainfall for each rain-gage record with annual rainfalls as defined by existing mean annual rainfall maps. A fairly detailed rainfall map believed to have been prepared by the U.S. Soil Conservation Service in 1974 has been published (Monterey County Planning Department, 1980); lines of equal annual rainfall from this map have been duplicated in figure 4. Lines of equal annual rainfall for the study area south of Monterey County are from Rantz (1969). The map in figure 4 is considered the best basis for measuring the adequacy of the rainfall network. The degree to which normalized annual rainfall for the 52 rain gages (table 1) fits this mean annual rainfall model is the basis for evaluating adequacy of the rainfall information. For instance, 10- and 12-inch lines of equal rainfall along the Salinas Valley seem to be confirmed by the existing record. Rainfall records at higher altitudes of Pancho Rico southeast to Parkfield indicate the 14-inch line of equal rainfall should be drawn farther east, at a higher altitude. Rainfall records between the valley floor and the tops of the Cholame Hills are insufficient to define mean annual rainfall satisfactorily in this area.

The mean annual rainfall map is admittedly a biased measure of the network adequacy inasmuch as it was developed using much of the same network data. At least 6 additional years of record are now available at many of the stations used to develop the map, however, and some new independent station data also are available.

Ideal and Proposed Precipitation Networks

The "ideal" network design concept used in other parts of this report was not followed in developing a precipitation network. There are no widely accepted standards for establishing the density of rain gages in an ideal network. The California Department of Water Resources (1981) suggested that one rain gage per township would seem to be a reasonable minimal network density for reconnaissance-level evaluations of water supply. On this basis, about 60 rain gages would be required in the study area. An "ideal" or "saturation" network of 600 rain gages could be defined, but would be of little practical value in developing an operational network.

In order to evaluate the effectiveness of each station in the ideal network and to determine which stations to keep in the proposed operating network, we first should know the rainfall variation at each site. This, of course, is not known and is, after all, the reason for collecting rainfall data. Moss and Tasker (1979) stated, "It is a paradox of network design that the statistical parameters controlling the optimality of a network are frequently the unknowns that the network is being designed to estimate."

More appropriate methods of network design developed in recent years were considered by the authors. Chang (1977) evaluated precipitation-gage density in topographically complex West Virginia by relating topographic properties of distance, elevation difference, and land slope to correlation coefficients for pairs of rain-gage records. The method appears applicable to a large area like West Virginia (24,000 mi^2), but has diminished applicability to the relatively small area of this study. Work by Bras and Rodrigues-Iturbe (1976) on network design relates density to cost and accuracy criteria, but the methodology is overpowering and costly for use in this network design.

Evaluation and Selection of Rain Gages for the Proposed Network

In this evaluation, discontinued rain gages as well as presently operated gages have been considered, including 36 stations operated for or by Federal agencies, 10 stations operated by county agencies, and 6 stations operated by private companies or individuals. Discontinued stations with significant periods of record that correlate well with long-term records still compose a viable portion of the network and can be used for estimating rainfall in presently ungaged areas. Availability of data from these older discontinued sites is extremely important in the selection of locations for the long-term gages.

Primary factors that determine optimum density of long-term rain gages in the network for the study area are topography, correlation of rainfall between points in the network, accuracy goals, and available funding. The orographic uplift of airmasses over mountainous areas produces rainfall variations that require a higher density of rain gages for definition than is necessary on a flat valley floor.

Rain-Gage Correlation

If correlation between rainfall records is good, rainfall can be estimated with fewer long-term records. In order to assess the degree of correlation, a correlation matrix of annual rainfall was constructed using all possible pairings of 31 selected rain gages in southern Monterey County. Sixty-one percent of 465 correlation coefficients equaled or exceeded 0.90 and 20 percent equaled or exceeded 0.95. Only 37 correlation coefficients fell below 0.80; these low correlations were nearly all related to two stations whose records, therefore, are suspect. No attempt was made to be selective by choosing adjacent stations to improve correlations. Stations as far apart as Arroyo Seco (station No. 1) and Parkfield (station No. 31) were correlated. The matrix showed a high degree of correlation between South County rain gages on an annual basis. There is no apparent need to increase the existing network density on the basis of lack of correlation or nontransferability of data.

Recording Rain-Gage Network

A basic long-term network of recording rain gages should be maintained as a basis for extending short-term records, for estimating daily or hourly rainfall data for flood-damage studies, and for rainfall duration and intensity studies. A good network of recording and polling (remote reporting) rain gages in and adjacent to the study area was in operation in 1983. These gages and the operating agencies are shown in table 2; the location is shown in figure 4.

Donald Neudeck (California Department of Water Resources, oral commun., December 15, 1981) indicated that DWR plans to install a transmitting device at the U.S. Forest Service gage located at Las Tablas (station No. 23, fig. 4). This gage will furnish data for the southern part of the Nacimiento River drainage basin.

The areal distribution of recording stations, except for a few significant gaps, is fairly good. In the Santa Lucia Range, there is a 32-mile gap between the Mining Ridge and Bryson recorders. A recording gage on the divide above the headwaters of San Miguel Creek (station No. 61, fig. 4) would strengthen the network in this area. A recording gage in the Jolon area (station No. 18, fig. 4) would fill a gap in the network interior. Although there are many storage gages in the Fort Hunter-Liggett area, there are no recorders.

TABLE 2. - Network of recording and polling (remote reporting) rain gages in and adjacent to the study area in 1983

Map No. (fig. 4)	Station name	Township	Range	Operator
1	Arroyo Seco----------------	19	4	National Weather Service
7	Bryson--------------------	24	8	National Weather Service
20	King City-----------------	20	8	National Weather Service
50	Soledad-------------------	17	6	National Weather Service
53	Anderson Peak No. 77------	20	3	Monterey County FC & WCD
54	Bradley-------------------	23	10	California Department of Water Resources
55	Chews Ridge No. 44--------	19	4	Monterey County FC & WCD
56	Mining Ridge No. 22-------	21	4	Monterey County FC & WCD
57	Mustang Ridge No. 16------	20	11	Monterey County FC & WCD
58	Parkfield-----------------	23	14	California Department of Water Resources
59	Pinyon Peak No. 66--------	20	5	Monterey County FC & WCD
60	San Miguel (Wolf Ranch)---	25	12	National Weather Service

Nonrecording Rain-Gage Network

The annual rainfall map (fig. 4) shows a number of areas where lines of equal rainfall are poorly defined. Practically no rainfall records have been collected at the middle altitudes of the Cholame Hills bordering the east side of the Salinas Valley or along the slopes of the hills bordering the west side of the valley. This does not necessarily mean no records were available for these areas; an inventory should be made of these areas to determine if any ranchers, farmers, or other residents have collected any rainfall data of significant duration. If no records are discovered, storage-type rain gages might be installed near the locations shown in table 3.

Preferably, standard 8-inch diameter nonrecording rain gages could be located near dwellings in these areas to reduce vandalism. Local observers would be desirable if available, but monthend visits by U.S. Geological Survey or county personnel would be adequate. A light oil should be added to the rain gages to reduce evaporation losses between monthly visits. In most years, visits from May through September would be unnecessary unless rain occurred. These gages should be operated for about 5 to 10 years depending on the quality of the record and the degree of correlation with nearby long-term stations. Once a reliable correlation was established, the short-term record could be normalized to the desired base period, and the station could be discontinued.

When normalized record has been developed for these new sites, a revised annual rainfall map could be prepared. Several revisions in the lines of equal rainfall could be made on the basis of records presently available. Five to 10 years from now, an improved rainfall map could be developed using the data from the suggested new stations and the relatively new flood-warning stations installed since 1978. For ease in reviewing, editing, and analyzing rainfall data, it is suggested that the monthly totals be placed in computer storage on a current basis.

TABLE 3. - Location of suggested storage-type rain gages

Map No. (fig. 4)	Location	Town-ship	Range
63	Highway 198 and Pine Valley Road	20	10
64	Highway G13 (Bitterwater Road) at county line	17	9
65	Lockwood-San Lucas Road, about altitude 1,000 feet	22	8
66	Pancho Rico Road at Peach Tree Canyon	21	11
67	Paraiso Springs, about altitude 1,000 feet	18	5
68	Pine Canyon Road, about altitude 800 feet	20	7
69	Big Sandy Creek (Indian Valley Road), about altitude 1,400 feet	23	12

SURFACE-WATER NETWORK ANALYSIS

Surface-Water Quantity

Systematic collection of streamflow data in the study area began in 1902 with the establishment of a stream-gaging station on the Arroyo Seco near Soledad. Since then, 22 other area stations (fig. 8) have been operated for varying periods; periods of operation and type of data collected are listed in table 4. Two stations outside the study area, Salinas River at Paso Robles and Estrella River near Estrella, are included because of their importance in monitoring Salinas River inflow to Monterey County. Nine active stations listed in table 4 are operated by the U.S. Geological Survey in cooperation with other agencies.

TABLE 4. - Surface-water records available for the study area

[Period of record: Hyphen following water years indicates active station]

Station No.	Station Name	Drainage area (mi^2)	Records available, complete water years	Daily figures	Annual peaks only
11147500	Salinas River at Paso Robles	389	1940-65,		
			1970-	X	--
11148500	Estrella River near Estrella	924	1956-	X	--
11148550	Indian Valley Creek tributary	.13	1961-73	--	X
11148800	Nacimiento River near Bryson	140	1956-71	X	--
11148820	Sapaque Creek tributary at Bryson	.76	1969-73	--	X
11148900	Nacimiento River below Sapaque Creek, near Bryson.	156	1972-	X	--
11149400	Nacimiento River below Nacimento Dam, near Bradley.	322	1958-	X	--
11149500	Nacimiento River near San Miguel	343	1940-57	X	--
11149650	Sulphur Spring Canyon near Jolon	5.16	1961-67,	--	X
			1968-73	X	--
11149700	San Antonio River at Sam Jones Bridge, near Lockwood.	211	1959,	X	--
			1962-65		
11149900	San Antonio River near Lockwood	223	1966-	X	--
11150000	San Antonio River at Pleyto	284	1930-65	X	--
11150002	San Antonio River tributary near Pleyto	.50	1961-65	--	X
11150500	Salinas River near Bradley	2,536	1949-	X	--
11150700	Feliz Canyon tributary near San Lucas	3.00	1961-66		
			1967-71	X	--
11150800	Cow Creek near San Ardo	4.80	1961-64,	X	--
			1965-73	--	X
11150950	San Lorenzo Creek tributary near Bitterwater	3.24	1961-73	--	X
11151000	San Lorenzo Creek near King City	215	1941-42	X	--
11151300	San Lorenzo Creek below Bitterwater Creek, near King City.	233	1959-	X	--
11151500	San Lorenzo Creek at King City	259	1943-45	X	--
11151600	Little Rabbit Valley Creek near San Benito	4.25	1961-73	--	X
11151700	Salinas River at Soledad	3,563	1969-78	X	--
11151870	Arroyo Seco near Greenfield	113	1962-	X	--
11151950	Sand Creek near Paraiso Spring	14.8	1962-73	--	X
11152000	Arroyo Seco near Soledad	244	1902-	X	--

The 25 active and discontinued gaging stations compose a multipurpose streamflow network. In order to evaluate the effectiveness of the network, it is necessary to divide it into subnetworks based on defined objectives. The Geological Survey's Office of Water Data Coordination classifies water data into the following three levels:

Level 1. A data base for broad, nationwide planning and background information, and to hedge against development of unanticipated needs for data.

Level 2. Data for general water-resources planning.

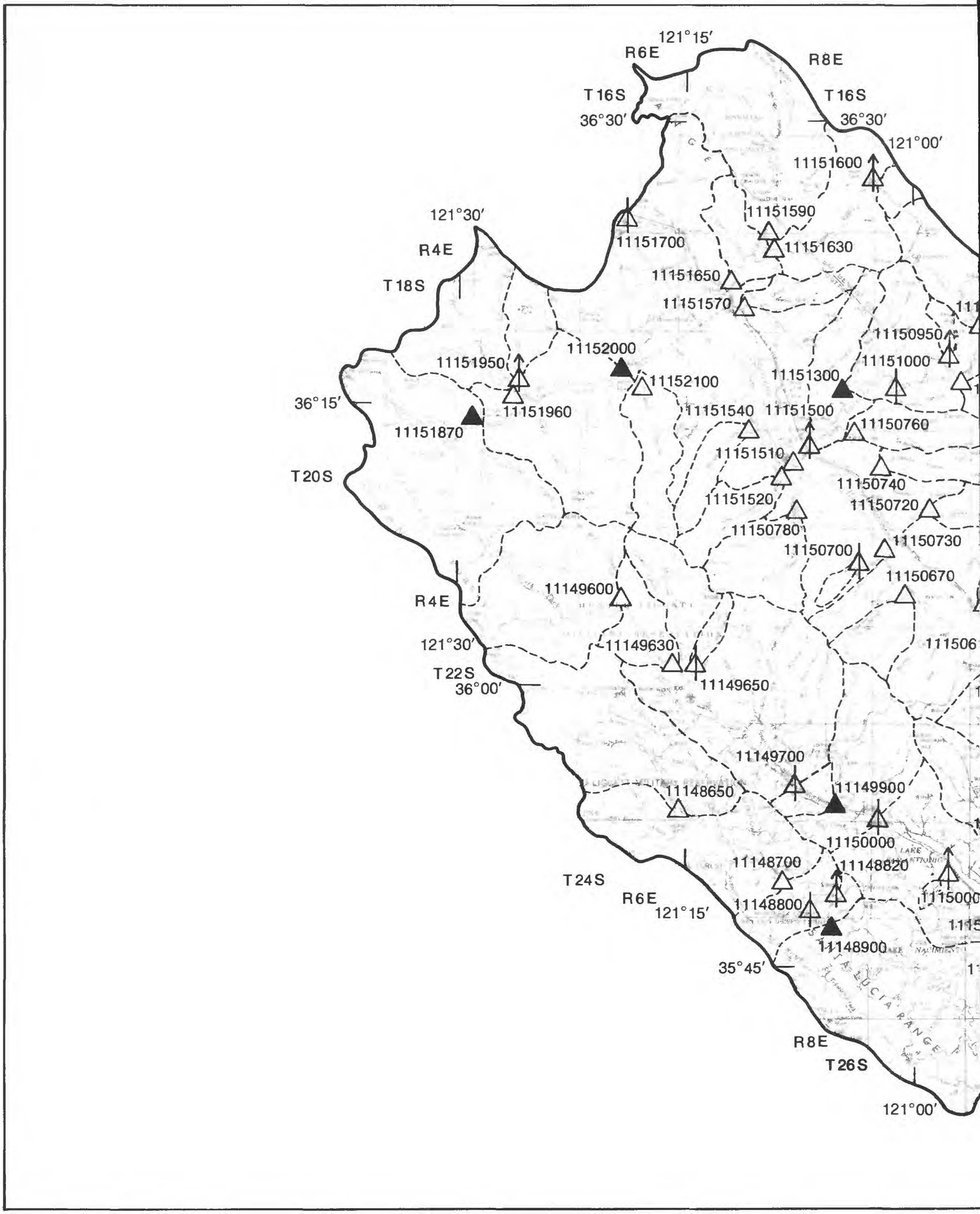
Level 3. Data and information for specific planning, management, and forecasting activities.

Level 1 and 2 data are of a contingency nature. Experience has shown needs, often unforeseen, develop for this information; there is no reliable way to generate years of streamflow data after the need becomes acute. Level 3 data needed for project design or to operate established water projects and analyze operations usually are funded as part of the project cost. Four of the nine currently operating stations shown in table 4 considered to be level 3 stations are shown in table 5.

These stations also may serve other uses; only the level 3 purpose most clearly related to MCFCWCD operations is shown. Level 3 stations are considered essential to management.

TABLE 5. - Level 3 gaging stations

Station No.	Station Name	Cooperator	Use of record
11147500	Salinas River at Paso Robles.	U.S. Army Corps of Engineers	Managing flood releases from Lakes Nacimiento and San Antonio.
11148500	Estrella River near Estrella.	California Department of Water Resources	Managing flood releases from Lakes Nacimiento and San Antonio.
11149400	Nacimiento River below Nacimiento Dam, near Bradley.	Monterey County	Monitoring releases from Lake Nacimiento and water-rights adjudication.
11150500	Salinas River near Bradley.	California Department of Water Resources	Managing releases from Lakes Nacimiento and San Antonio.



121°15′
R6E
R8E
T16S
36°30′
T16S
36°30′
121°00′
11151600
11151590
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T18S
11151650
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11150950
11152000
11151950
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11151300
11152100
36°15′
11151960
11151540
11151500
11151870
11150760
11151510
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11151520
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11150780
11150700
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11149600
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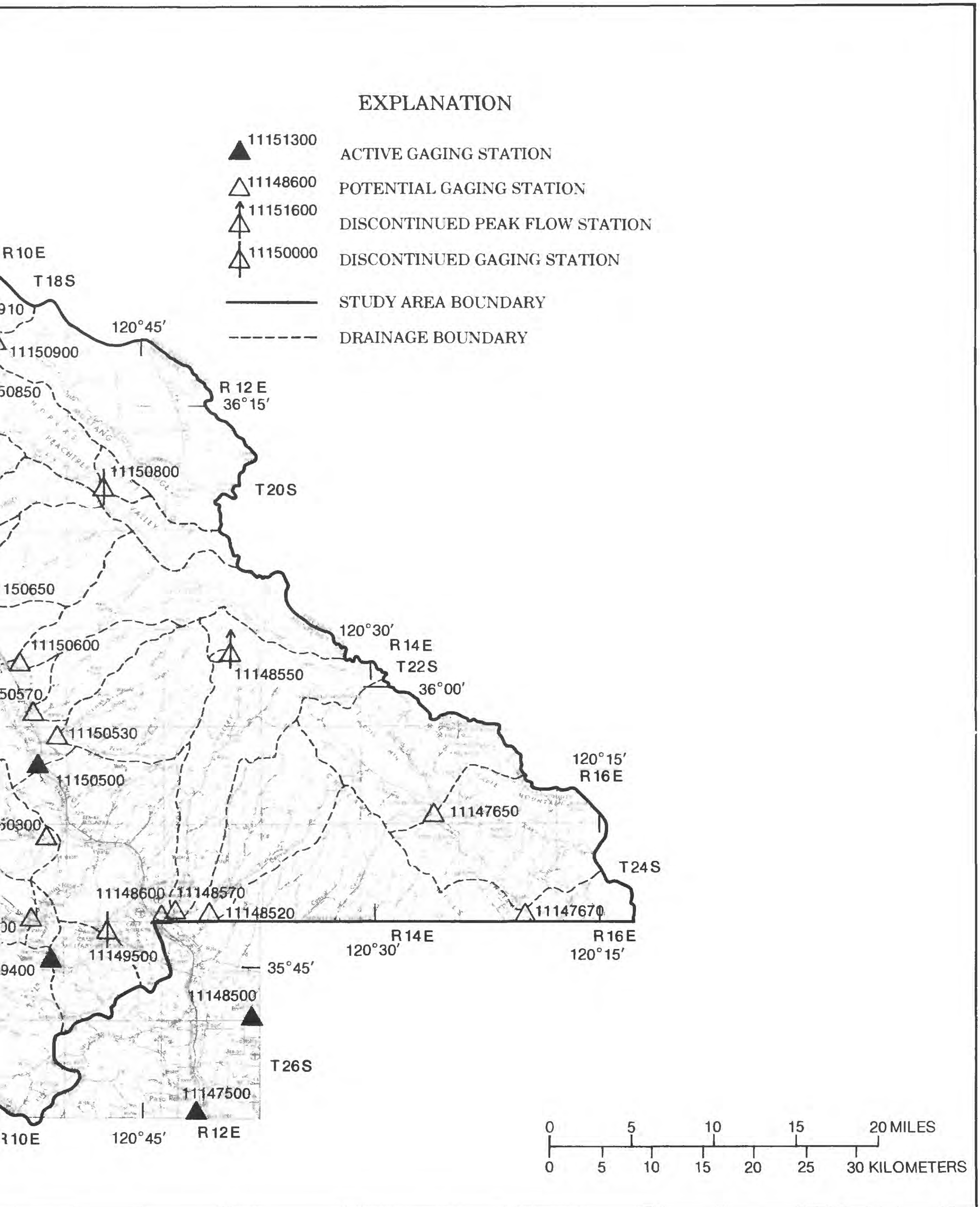


FIGURE 8. — Location and status of streamflow-gaging stations in the study area.

The remaining five stations currently in operation are level 1 and 2 stations shown in table 6.

Data from stations Nacimiento River below Sapaque Creek, near Bryson and San Antonio River near Lockwood are used for reservoir inflow-outflow computations, but do not supply real-time information for managing releases. Stations at Arroyo Seco near Greenfield and near Soledad could be classified as level 3, in view of recent renewed interest in constructing a reservoir on the stream. Both stations also are used for flood warning, another level 3 function. The uses of these stations are evaluated later in this report to determine if both are needed in the network.

Nine stations shown in table 4 were operated for varying periods of time from 1961 to 1973 to collect annual peak-flow data for small drainage areas for a regional flood study (Waananen and Crippen, 1977). Consideration has been given to reactivating a few of these stations, but the cost effectiveness of doing so is doubtful. An additional 10 years of peak-flow information is required to substantially reduce the standard error of estimate for flood frequencies at these stations. Revising the regional peak-regression formulas in order to apply the new information to other sites would be expensive.

If a potential exists for major urban growth in the study area with attendant need for more roads, bridges, culverts, and drainage facilities, the expense might be justified. It appears, however, that the major land use in the study area will remain oriented toward agriculture and grazing. Except for King City, most communities in the area have declined in population. Because of the small likelihood of urban growth in this area, renewed collection of flood data at the discontinued sites is considered unwarranted.

TABLE 6. - Level 1 and 2 gaging stations

Station		Cooperator	Use of record
No.	Name		
11148900	Nacimiento River below Sapaque Creek, near Bryson.	California Department of Water Resources	For general water-resources planning and sediment-transport computations.
11149900	San Antonio River near Lockwood.	Monterey County	For general water-resources planning and sediment-transport computations.
11151300	San Lorenzo Creek below Bitterwater Creek, near King City.	California Department of Water Resources	For general water-resources planning.
11151870	Arroyo Seco near Greenfield.	Monterey County	For general water-resources planning.
11152000	Arroyo Seco near Soledad.	California Department of Water Resources	A base level of information for broad planning and background information.

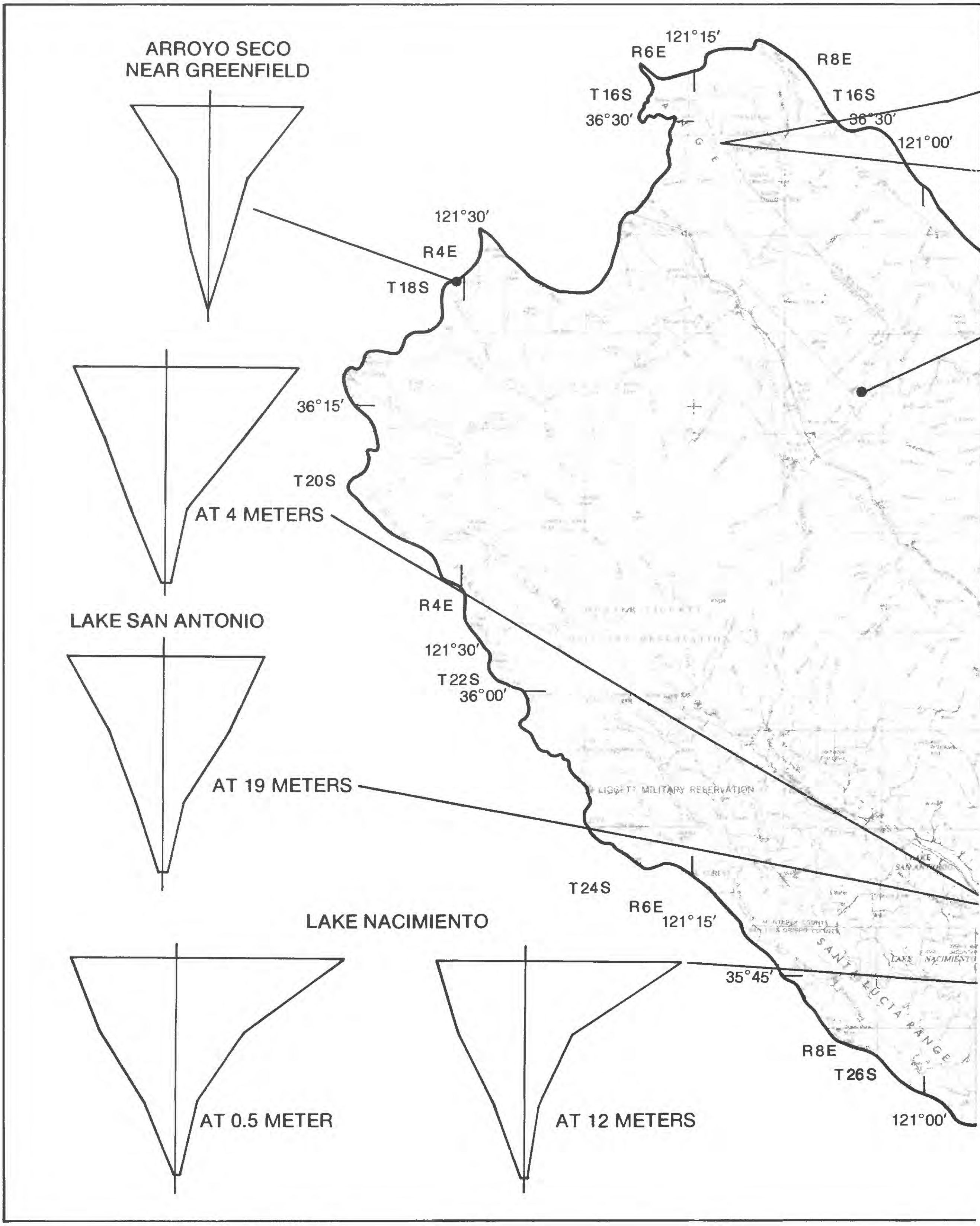
Surface-Water Quality

The marked surface-water quality differences from one side of the valley to the other are caused largely by precipitation patterns and geology. Because precipitation is greater on the west side of the basin than on the east side (fig. 4), runoff per square mile is greater, and the mineral concentration of surface water on the west side of the basin is generally lesser than that of surface water on the east side. More important, geologic differences between east and west sides affect water quality. Granite in the Sierra de Salinas on the west side is relatively insoluble compared to the metamorphic and faulted "basement complex" rocks in the Gabilan Range on the east side. Gypsum beds in the Gabilan Range are particularly soluble.

Water quality for some study-area streams is shown diagrammatically in figure 9. Because surface-water quality data have not been collected routinely throughout the study area, the data shown in the diagrams were collected at different times. These water-quality diagrams are intended to illustrate only different water-quality types in the study area--not the variation in water quality at any particular time. Where possible, multiple chemical analyses were averaged to construct water-quality diagrams. The number of analyses averaged to produce each Stiff diagram in figure 9 is indicated in table 7. The shape of the diagrams was similar for individual analyses at each station, except for Salinas River near Bradley where the diagrams indicate two distinct water types depending on which flow dominates--from the upper basin (particularly from Estrella River drainage) or from Lakes Nacimiento and San Antonio. Diagrams for Lake Nacimiento and San Lorenzo Creek illustrate differences between water types of the east and west sides.

Average surface-water quality for the Salinas River basin as a whole, as well as for the study area, is a mixed type in which calcium and bicarbonate ions dominate. Water from the west side of the study area is a mixed type dominated by calcium and bicarbonate. Water from Arroyo Seco is the prime example of calcium bicarbonate water in the study area and represents the quality typical of west-side streams. Water analyzed from the Salinas River near Bradley, more typical of the average type throughout the study area, represents a composite of water from upstream and water released from reservoirs. Although calcium and bicarbonate are dominant ions near Bradley, they do not constitute one-half of the total ionic concentration as they do in Arroyo Seco. Sulfate and magnesium make up a significant part of the total ionic concentration near Bradley.

Water from the east side of the study area, such as from San Lorenzo Creek drainage, is a mixed cation type dominated by sodium and sulfate ions with high concentrations of magnesium and chloride. Salt deposits have precipitated from the water from place to place along these east-side stream channels. This highly mineralized water has a specific conductance of more than 2,500 µS/cm. Gypsum deposits in the Gabilan Hills are probably the source of high sulfate concentrations. Fortunately, the flow from streams on the east side is low and affects only slightly the overall water quality in the basin. East-side streams flow intermittently during winter and are dry during summer. The sporadic flow probably causes considerable differences in the quality of ground water near King City.


ARROYO SECO
NEAR GREENFIELD
LAKE SAN ANTONIO
AT 4 METERS
AT 19 METERS
LAKE NACIMIENTO
AT 0.5 METER
AT 12 METERS
121°15′
R6E
R8E
T16S
36°30′
121°00′
121°30′
R4E
T18S
36°15′
T20S
T22S
36°00′
LIGGETT MILITARY RESERVATION
T24S
35°45′
T26S
SANTA LUCIA RANGE

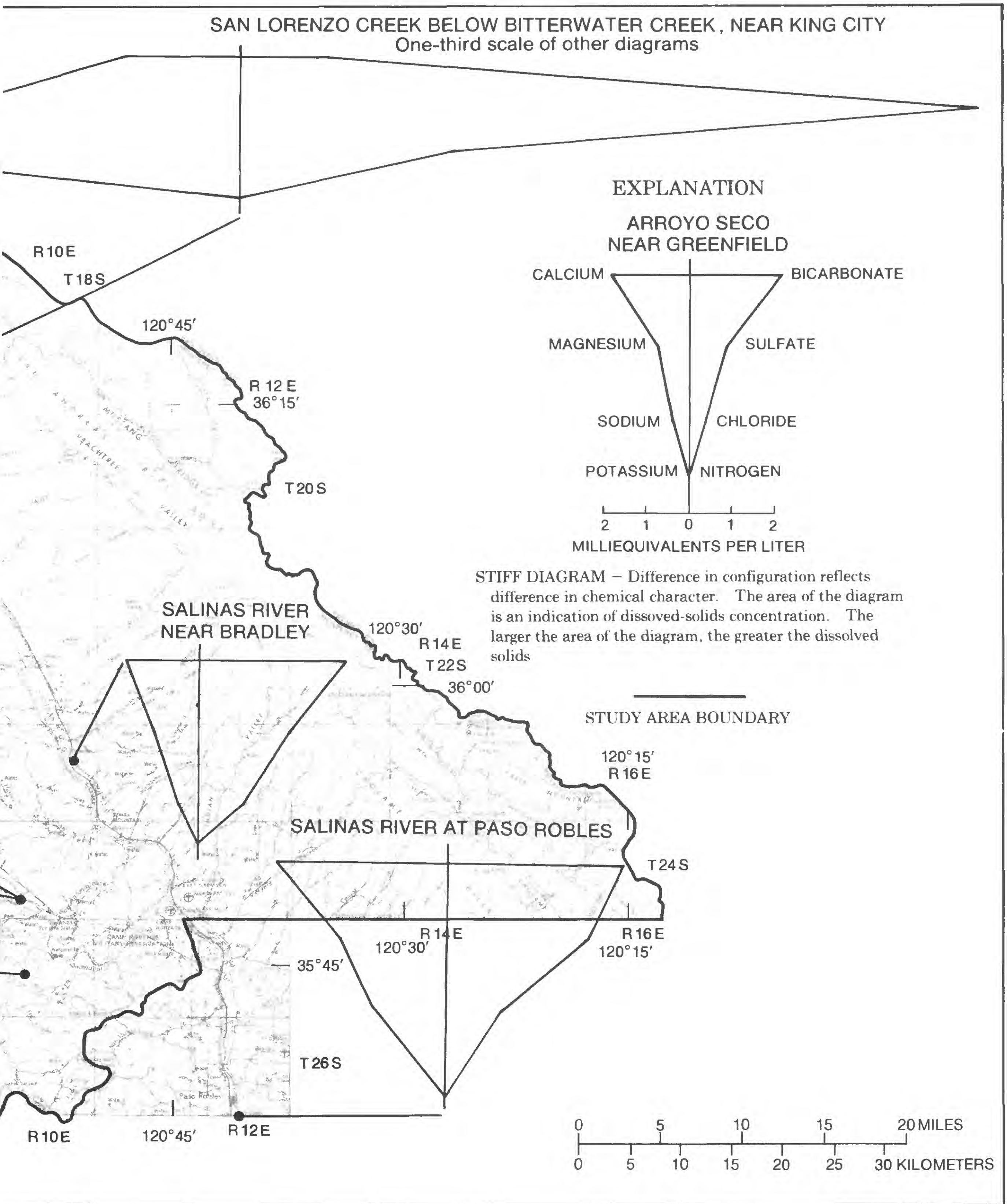


FIGURE 9. — Stiff diagrams of surface-water quality at selected stations.

TABLE 7. - Description of Stiff diagrams shown in figure 9

Station No. and name	Date	Number of analyses averaged	Daily flow rate (ft^3/s)	Dominant ions	Characteristics
11147500 Salinas River at Paso Robles.	Water year 1980	2	13-105	Calcium and bicarbonate dominate, but magnesium, dissolved sulfate, sodium, and chlorine also important.	Of samples analyzed along the Salinas River, sample from Paso Robles has highest mineral content. General shape of Stiff diagram is similiar to the other stations' diagrams, however.
11150500 Salinas River near Bradley.	Water year 1980	12	30-2,500 (Instantaneous flow rate)	Calcium, bicarbonate with magnesium, sodium, and dissolved sulfate also important.	Shape of Stiff diagram varies depending on whether flow is dominated by reservoir release water, upper Salinas River runoff, or Estrella River. During most of year release water dominates, so diagram depicts quality of the release water. When Estrella River runoff is significant, dissolved sulfate and sodium components are much greater. Diagram of runoff from upper Salinas River has a similar shape to diagram of release water but has a higher mineral content.
Lake San Antonio at 4 meters.	08-25-77	1		Calcium and bicarbonate dominate, but dissolved sulfate and magnesium also important.	Shape of Stiff diagram is similar to shape of diagrams at Bradley and at Arroyo Seco.

Lake San Antonio at 19 meters.	08-25-77	1		Calcium and bicarbonate dominate, but dissolved sulfate and magnesium also important.	Stiff diagrams at both depths very similar.
Lake Nacimiento at 0.5 meters.	08-24-77	1		Calcium and bicarbonate dominate, but dissolved sulfate and magnesium also important.	Stiff diagram similar to shape of diagram at Bradley, but bicarbonate more prominent.
Lake Nacimiento at 12 meters.	08-24-77	1		Calcium and bicarbonate.	Similar to water near surface. Similar to water in Lake San Antonio and the Salinas River.
11151300 San Lorenzo Creek below Bitter-water Creek, near King City.	11-08-77	1	0.15	Sodium and dissolved sulfate.	Sample collected at a low flow, so water probably has higher mineral content than normal. San Lorenzo Creek water probably has worst quality of entire basin and is distinct from water from stations along the Salinas River. Although mineral content is much higher than water from the Estrella River drainage, chemical makeup is similar.
11151870 Arroyo Seco near Greenfield.	Water year 1980	3	18-2,800	Calcium and bicarbonate.	Lowest dissolved-solids concentration in Salinas River drainage basin. Concentration decreases with increased flow.
11152300 Salinas River near Chualar.	Water year 1980	12	13-5,560 (Instantaneous flow rate)	Calcium and bicarbonate.	Shape of Stiff diagram varies with flow rate. Average is similar to water from station at Paso Robles, but has lower mineral content. Quality of high flows very similar to quality of Arroyo Seco.

Reservoir water-quality data shown in the diagrams (fig. 9) were collected in August 1977 at the end of a severe drought, so they may indicate higher-than-normal chemical concentrations. In any case, the quality of water from the reservoirs and that of water from near Bradley is similar, but the 1977 samples of reservoir water contained a greater percentage of bicarbonate than the 1980 samples of river water from near Bradley.

Surface-water quality of the study area reflects the influence of three sources: (1) The release-water from reservoirs which dominates flow on the main stem Salinas River from just above Bradley to King City; (2) the small east-side streams, particularly San Lorenzo Creek, which discharge small quantities of water containing high dissolved-solids concentrations, and (3) the Arroyo Seco which enters the Salinas River at the downstream end of the study area and contains water of low mineral content similar to the reservoir release-water.

Method of Analysis

A multipurpose network was developed in two steps. The first step was the development of an "ideal" or conceptual network that would monitor the flow of practically every significant stream in the study area. This step is a rather subjective procedure concerned primarily with developing a high-density network to supply all the streamflow and water-quality data that rationally would be expected to have some planning or operational value. No consideration was given to cost.

The second step was the evaluation of the stations in the ideal network to determine their relative value with regard to defined objectives. Twelve objectives for quantifying streamflow and eight objectives for monitoring streamflow quality were defined in collaboration with MCFCWCD personnel; these objectives and assigned priority points are shown in table 8. The ranked objectives were key factors in assessing relative value of currently operating stations and several new potential monitoring sites.

In addition to ranked objectives, streamflow and gaging-station characteristics were developed to aid in evaluating current and potential monitoring sites. These characteristics, with the range of points assigned to each, are shown in table 9.

TABLE 8. - Surface-water network objectives as of 1982

Priority points	Monitoring objectives
	Streamflow
10	1. Determine ground-water recharge by water-balance computation.
9	2. Improve long-term estimates of water available for irrigation, domestic, and industrial use.
8	3. Provide early flood warning.
7	4. Monitor for water rights.
7	5. Determine sediment-transport rates downstream from dam site.
7	6. Provide specific site data for designing dams, levees, flood channels, bridges, and culverts.
6	7. Manage irrigation diversions and recharge.
5	8. Provide data for hydropower design.
4	9. Plan or manage instream uses.
3	10. Determine streamflow characteristics to develop regional relations applicable to ungaged sites.
2	11. Determine sediment-transport rates upstream from dam sites.
1	12. Manage municipal and industrial use.
	Surface-water quality
10	13. Evaluate suitability of water for irrigation and domestic use.
10	14. Assess quality of reservoir-release water for irrigation and domestic use and determine influence of percolated water on ground-water quality.
9	15. Develop a water-quality baseline.
8	16. Determine the surface-water outflow and quality from a. San Lorenzo Creek, b. Pancho Rico Creek, and c. Chalone Creek.
6	17. Develop a baseline of trace elements, particularly in the Arroyo Seco.
5	18. Determine the quality and quantity of flow across the Monterey-San Luis Obispo County line.
4	19. Determine water-quality trends for water impounded at reservoirs.
3	20. Evaluate water-quality impacts on instream use.

TABLE 9. - Rating characteristics for gaging stations

Mean annual flow points.--$(Q_{maf})^{\frac{1}{2}}$, rounded to nearest whole number, where Q_{maf} is in cubic feet per second. Q_{maf} was estimated for ungaged sites using Q_{maf}/mi^2 for nearby gaged streams. If a gage was already operating on the same stream, Q_{maf} was computed using the difference in drainage areas, or the drainage area of the ungaged site if it is less than the difference.

Areal significance.--Points for the relative ranking of the stream in the flow network were assigned as follows: Station on Salinas River, 4 points; station farthest downstream on a major tributary, 3 points; station above a downstream station on a major tributary, 2 points; and station on a minor tributary, 1 point.

Data accuracy.--Some gaging sites are inherently superior to others with regard to potential accuracy because of channel configuration and bed material. Gaging conditions were estimated for each site, and points were assigned as follows: Good site, 3 points; fair site, 2 points; and poor site, 1 point.

Ability to measure unimpaired flow.--A desirable quality in any collection site is the ability to use the data collected to estimate similar characteristics for other sites. If the flow is unimpaired (not affected by upstream storage or diversions), the data can be used to estimate flow characteristics for similar nearby streams. Points were assigned for the ability to measure or compute unimpaired flow as follows: Good, 4 points; poor, 0 or 1 point.

Cost of operation and maintenance of gaging station.--Points were assigned for the estimated operation and maintenance of gages based on accessibility and probable frequency of measurements as follows: Low cost, 4 points; average cost, 2 points; high cost, 0 or 1 point.

Cost of gage construction.--Points were assigned for the probable relative cost of installing a gaging station as follows: Gage already installed (no cost), 4 points; average installation cost, 2 points; high installation cost, 0 point.

Ideal Network

Nine currently operating gages, eight discontinued gages, and twenty-eight potential new sites were selected for the ideal network. All ungaged streams in the study area directly tributary to the Salinas River and greater than 10 mi^2 in drainage area were included, as were several major branches of large tributaries such as San Lorenzo Creek. Sites on the San Antonio and Nacimiento Rivers considered in the past for dam sites (Monterey County Flood Control and Water Conservation District, 1957) and four new sites and one discontinued site on the Salinas River also have been included. Ideal network sites are listed in table 10.

It is not financially feasible to monitor streamflow at all sites suggested for the ideal network. This list is intended to be a starting point from which an affordable network of stations can be selected. It should be stressed the list is only an aid to be used for selecting network sites. The point system is an attempt at objectivity; it is not an infallible decision tool. The main purpose of assigning priority points was to establish a consistent approach. Professional judgment was the basis for final site selections.

Proposed Network

Methods for Selecting Stations

In selecting stations for the actual network, two basic assumptions were made regarding funding and the number of years data-collection activity would be funded. The first assumption was that level 3 water-management stations proposed for the network are justifiable as a prudent operating expense in the same manner that inventory and accounting expenses are accepted as part of the fiscal-management process. If a gaging station below a dam can improve the accuracy of measurement of an annual release of approximately 100,000 acre-feet by just 1 percent, or 1,000 acre-feet, the value of that increment of water is several times the cost of operating the gage.

Justifying level 1 and 2 stations is hampered by an inability to measure directly the information value of collected data; the data value are contingent on future needs. Because no benefits/cost ratio can be established for the data, the decision on how much to budget for data collection becomes political and is commonly based on former budgets for data-collection programs.

The second assumption was that the proposed network would be operated indefinitely. Level 3 stations would be operated indefinitely for management purposes; some level 2 stations would be discontinued when flow characteristics have been defined adequately and replaced with new stations. Eventually, enough data will have been collected so that conceivably only one or two permanent level 1 stations would be needed to monitor trends and document hydrologic events. The objectives for this network are listed in table 8.

TABLE 10. - Ideal network operating and potential gaging stations

[Listed in downstream order]

Town-ship/range	Map No. (fig. 8)	Site name	Drainage area (mi^2)	Points: Stream-flow	Points: Character-istics	Points: Quality	Points: Total priority
26S/12E	11147500[1]	Salinas River at Paso Robles-------	390	38	23	14	75
23S/14E	11147650	Cholame Creek below Little Cholame Creek, near Parkfield----	69	22	12	20	54
24S/15E	11147670	Cholame Creek below Cottonwood Creek, near Parkfield------------	140	22	13	15	50
25S/12E	11148500[1]	Estrella River near Estrella-------	922	28	19	9	56
24S/12E	11148520	Vineyard Canyon near Camp Roberts--	51	22	13	0	35
24S/12E	11148570	Big Sandy Creek near Camp Roberts--	83	22	12	15	49
24S/11E	11148600	Salinas River at county line-------	1,679	48	15	33	96
23S/7E	11148650	Nacimiento River at San Miguelito dam site------------------------	99	28	20	9	57
24S/8E	11148700	Nacimiento River at Jarret Shut-in-	132	28	17	18	63
25S/8E	11148900[1]	Nacimiento River below Sapaque Creek, near Bryson--------------	162	30	28	22	80
25S/10E	11149400[1]	Nacimiento River below Nacimiento Dam------------------------------	322	43	24	42	109
21S/6E	11149600	San Antonio River at Milpitas dam site------------------------	66	28	13	28	69
22S/6E	11149630	San Antonio River at Milpitas B reservoir site-------------------	85	28	13	28	69
23S/8E	11149900[1]	San Antonio River near Lockwood----	223	23	27	32	82
24S/10E	11150200	San Antonio River below San Antonio Dam---------------------	331	48	13	42	103
24S/10E	11150300	Hames Creek near Bradley-----------	42	22	15	25	62
23S/10E	11150500[1]	Salinas River near Bradley---------	2,535	44	16	43	103
23S/10E	11150530	Sargent Creek near San Ardo--------	50	29	14	25	68
22S/10E	11150570	Lynch Canyon near San Ardo---------	21	22	12	9	43
22S/10E	11150600	Pancho Rico Creek at San Ardo------	65	29	16	33	78

TABLE 10. - Ideal network operating and potential gaging stations - Continued

Township/range	Map No. (fig. 8)	Site name	Drainage area (mi^2)	Points: Streamflow	Points: Characteristics	Points: Quality	Points: Total priority
22S/10E	11150610	Salinas River at San Ardo----------	2,706	45	10	36	91
21S/10E	11150650	Pine Creek near San Ardo-----------	41	22	12	25	59
21S/9E	11150670	Espinosa Canyon near San Lucas-----	14	22	14	9	45
20S/9E	11150720	Long Valley Creek near San Lucas---	22	22	12	15	49
21S/9E	11150730	Salinas River at San Lucas---------	2,845	45	11	22	78
20S/9E	11150740	Wildhorse Canyon near King City----	18	22	12	25	59
20S/8E	11150760	Sweetwater Canyon near King City---	20	22	12	17	51
20S/8E	11150780	Quinado Canyon near King City------	27	22	14	25	61
19S/9E	11150850	San Lorenzo Creek at Lonoak--------	56	12	13	23	48
19S/10E	11150900	Lewis Creek near Lonoak------------	98	12	14	23	49
18S/10E	11150910	Bitterwater Creek near Lonoak------	32	12	13	27	52
19S/8E	11151300[1]	San Lorenzo Creek below Bitterwater Creek, near King City------	233	33	19	27	79
20S/8E	11151500	San Lorenzo Creek at King City-----	259	29	14	36	79
20S/8E	11151510	Salinas River at King City---------	3,243	45	13	33	91
20S/8E	11151520	Pine Canyon near King City---------	17	22	14	19	55
20S/7E	11151540	Thompson Canyon near King City-----	14	22	14	9	45
18S/7E	11151570	Cherry Canyon near Greenfield------	11	22	12	9	43
18S/7E	11151590	Chalone Creek above Topo Creek-----	79	12	12	25	49
18S/7E	11151630	Topo Creek near Greenfield---------	49	12	12	9	33
18S/7E	11151650	Chalone Creek near Greenfield------	142	22	14	33	69
17S/6E	11151700	Salinas River at Soledad-----------	3,563	45	18	28	91
19S/4E	11151870[1]	Arroyo Seco near Greenfield--------	113	38	26	28	92
19S/5E	11151960	Paloma Creek near Greenfield-------	64	12	14	25	51
19S/6E	11152000[1]	Arroyo Seco near Soledad-----------	244	52	19	28	99
19S/6E	11152100	Reliz Canyon near Greenfield-------	25	22	14	18	54

[1]Gaging stations operating as of January 1986.

Evaluation of existing level 1 and 2 stations.--The first step in selecting stations for the proposed network was to evaluate active level 1 and 2 stations to determine if the record was sufficient to define streamflow characteristics within an acceptable degree of accuracy. Moss and Tasker (1979) stated, "Hydrologic information, which is predominantly derived from hydrologic data, exhibits a classical decreasing marginal utility." Restated, this means every succeeding year of record increases the information value of the record less than did the preceding year of record.

Using an equation adapted from Hardison (1969) for computing standard error, the reduction in standard error with time for selected streamflow characteristics at the Arroyo Seco near Greenfield station is shown in figure 10. The curve for standard error of estimate of mean annual flow at the Arroyo Seco near Soledad station (fig. 11) indicates the standard error has been reduced by only 3 percent between 1945 and 1980, as compared to a reduction of 16 percent between 1910 and 1945. After 80 years of operation, another 20 years of record will be required to reduce the standard error by approximately 1 percent. This does not necessarily mean the continued operation of a station with 80 years of record cannot be justified. Dawdy and others (1970) used the record for Arroyo Seco near Soledad station to illustrate that the station could be operated for well over 100 years before the cost of data collection exceeded the data value for designing a high-yield reservoir.

In a 1970 internal review of the State cooperative gaging-station network between U.S. Geological Survey and California Department of Water Resources, regression relations between long- and short-term streamflow stations were used as a guide in deciding if short-term stations should be discontinued. For the Central Coastal area, which includes Monterey County, a regression of annual streamflows with an average standard error of 48 percent or less was considered accurate enough to propose discontinuance. In figures 12 through 15, mean annual flow at Arroyo Seco near Soledad is regressed against mean annual flows for Arroyo Seco near Greenfield, Nacimiento River below Sapaque Creek, San Antonio River near Lockwood, and San Lorenzo Creek below Bitterwater Creek, near King City, respectively. Standard errors of regressions range from 8.5 percent for Arroyo Seco near Greenfield to 87.3 percent for San Lorenzo Creek. Standard errors of estimate for regressions between west-side Salinas River tributaries are very good, ranging from 8.5 to 26.4 percent.

On the basis of these strong regressions, it would seem that most stations could be discontinued for level 1 and 2 purposes. A method devised by Maddock (1974) for measuring the effects on the information value of a network caused by discontinuing various stations has been applied by Carrigan and Golden (1975) in Montana, Illinois, and Georgia. This method of network optimization has been applied to the five level 1 and level 2 stations in the study area.

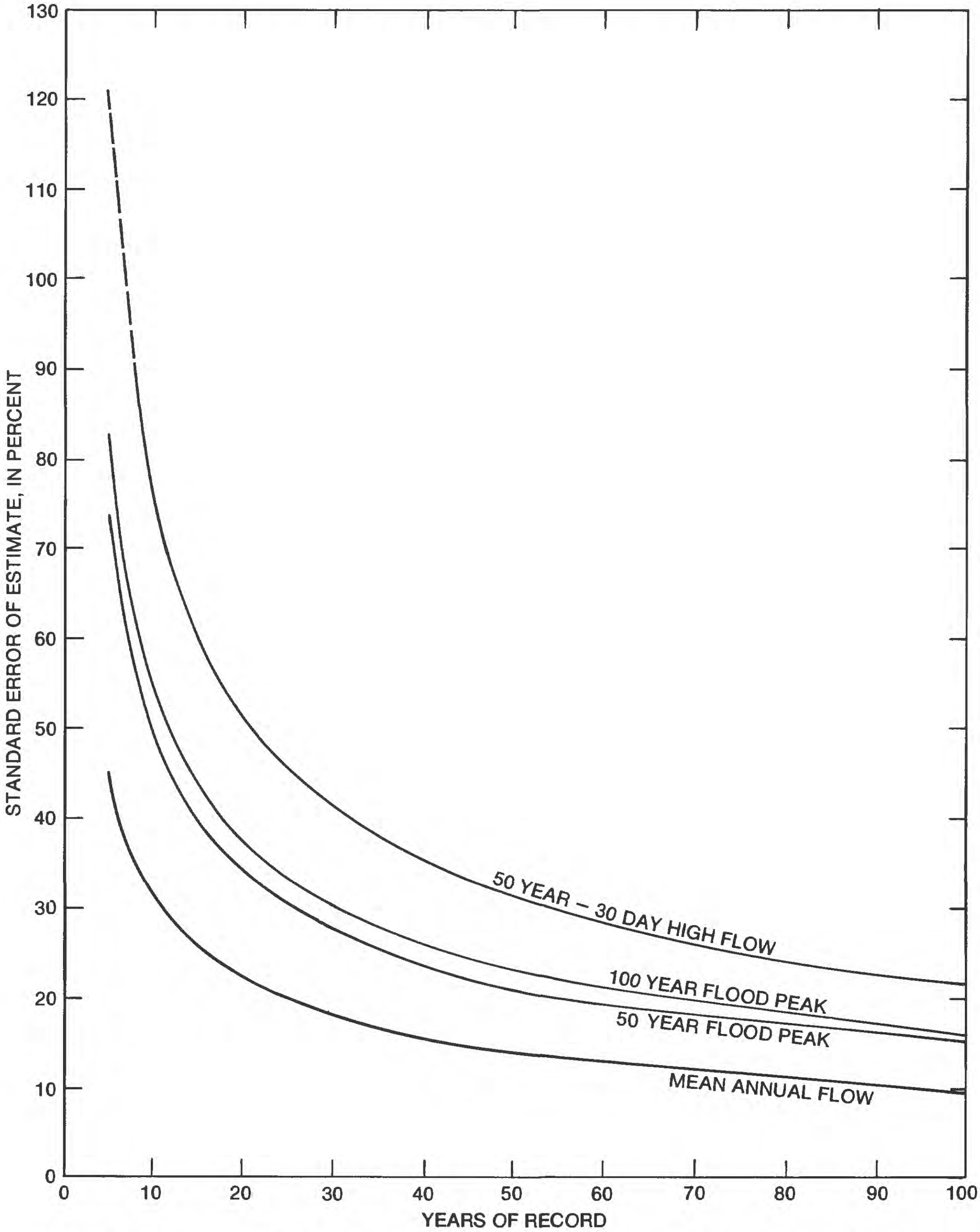


FIGURE 10. — Curves for selected streamflow characteristics showing decrease in standard error of estimate with increasing years of record for Arroyo Seco near Greenfield.

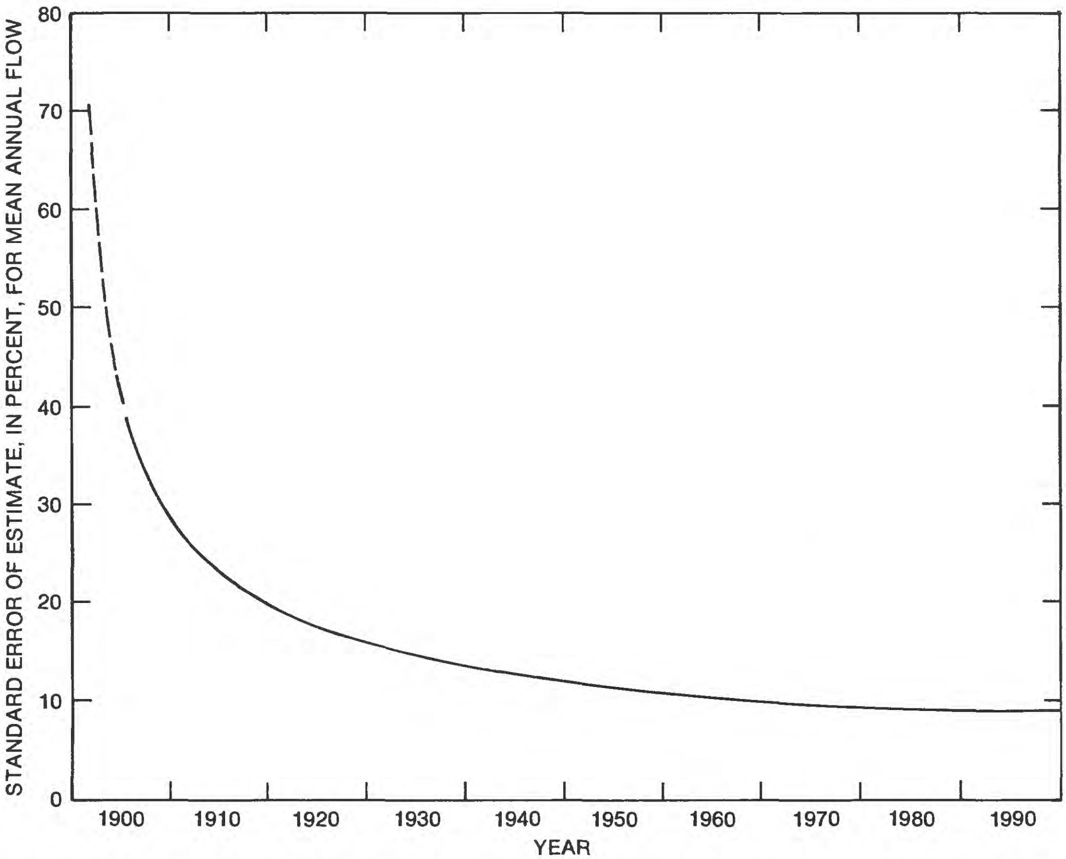


FIGURE 11. — Curve showing reduction in standard error of estimate of mean annual flow with increasing years of record for Arroyo Seco near Soledad.

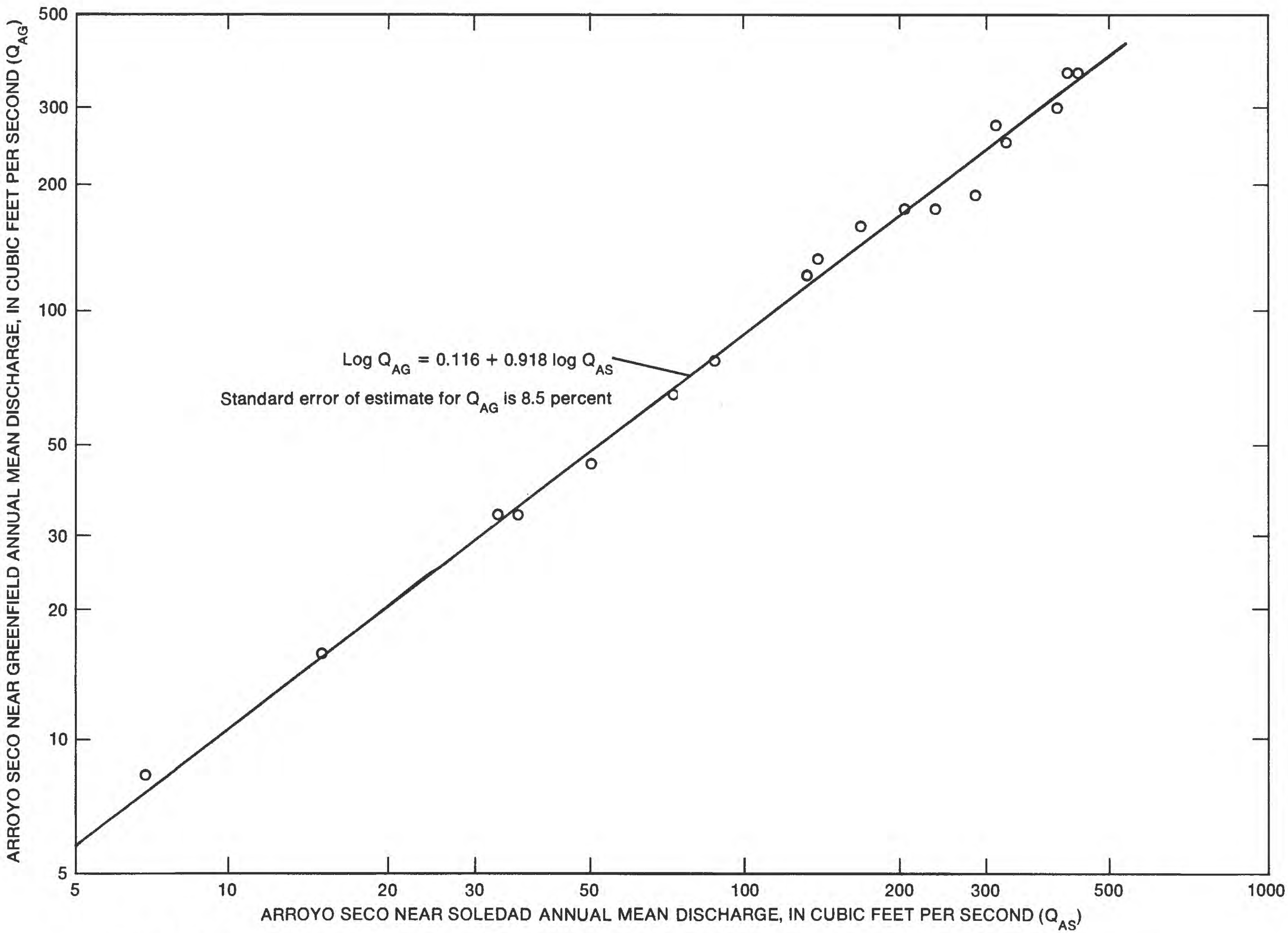


FIGURE 12. — Linear regression plot of annual mean discharges, water years 1968 through 1980, for gaging stations Arroyo Seco near Greenfield versus Arroyo Seco near Soledad.

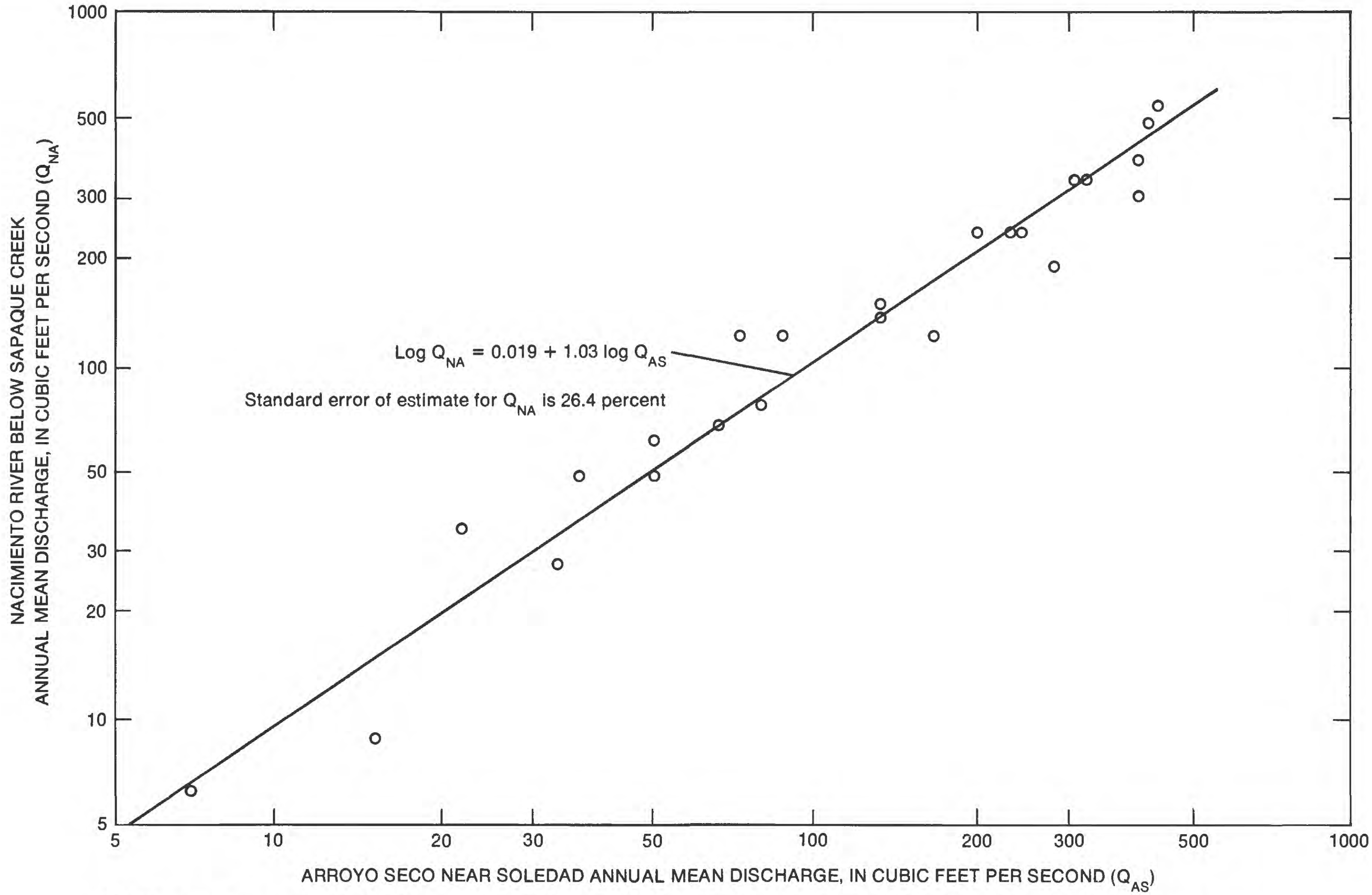


FIGURE 13. — Linear regression plot of annual mean discharge, water years 1956 through 1980, for gaging stations Arroyo Seco near Soledad versus Nacimiento River below Sapaque Creek.

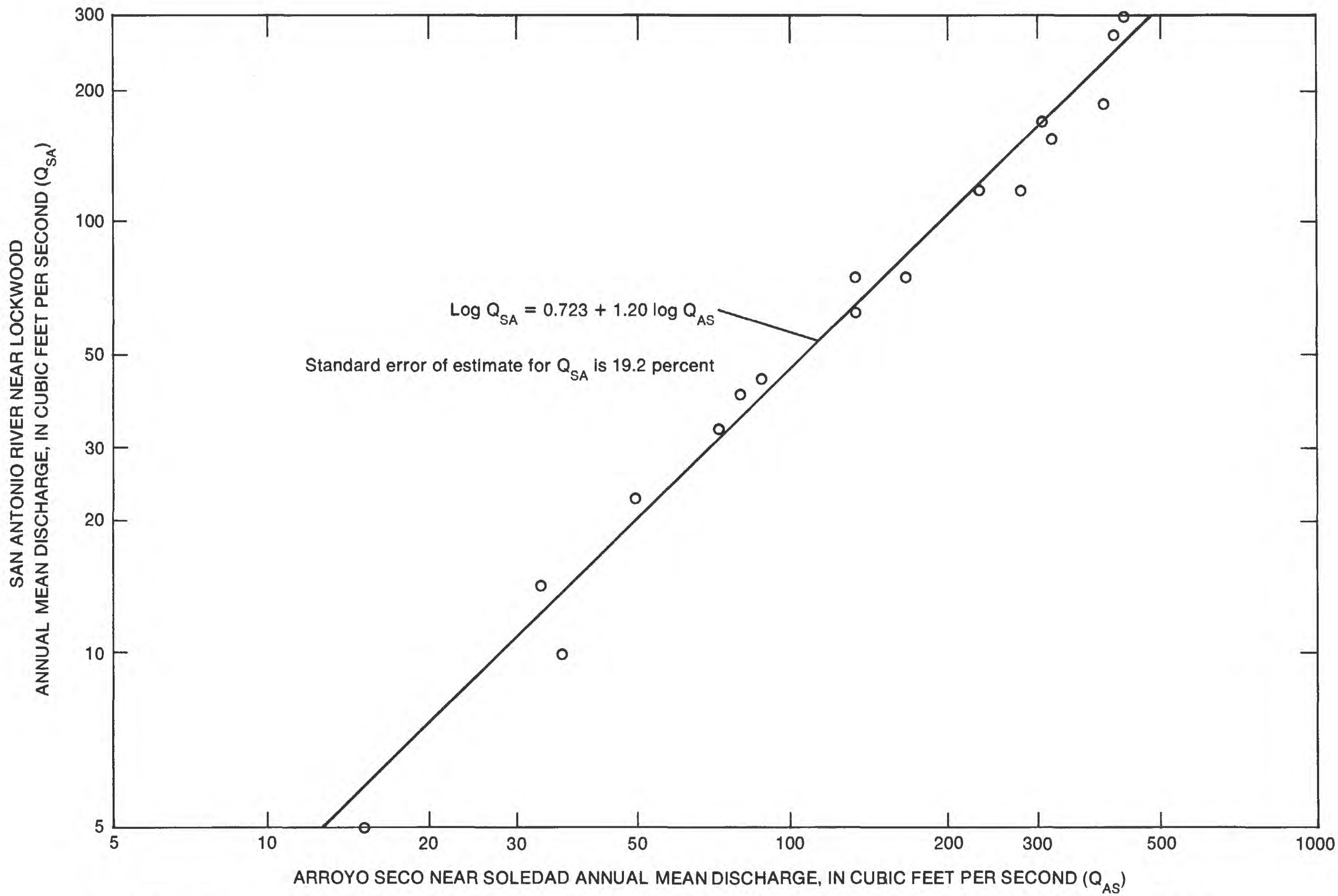


FIGURE 14. — Linear regression plot of annual mean discharges, water years 1959,1962 through 1980, for gaging stations Arroyo Seco near Soledad versus San Antonio River near Lockwood.

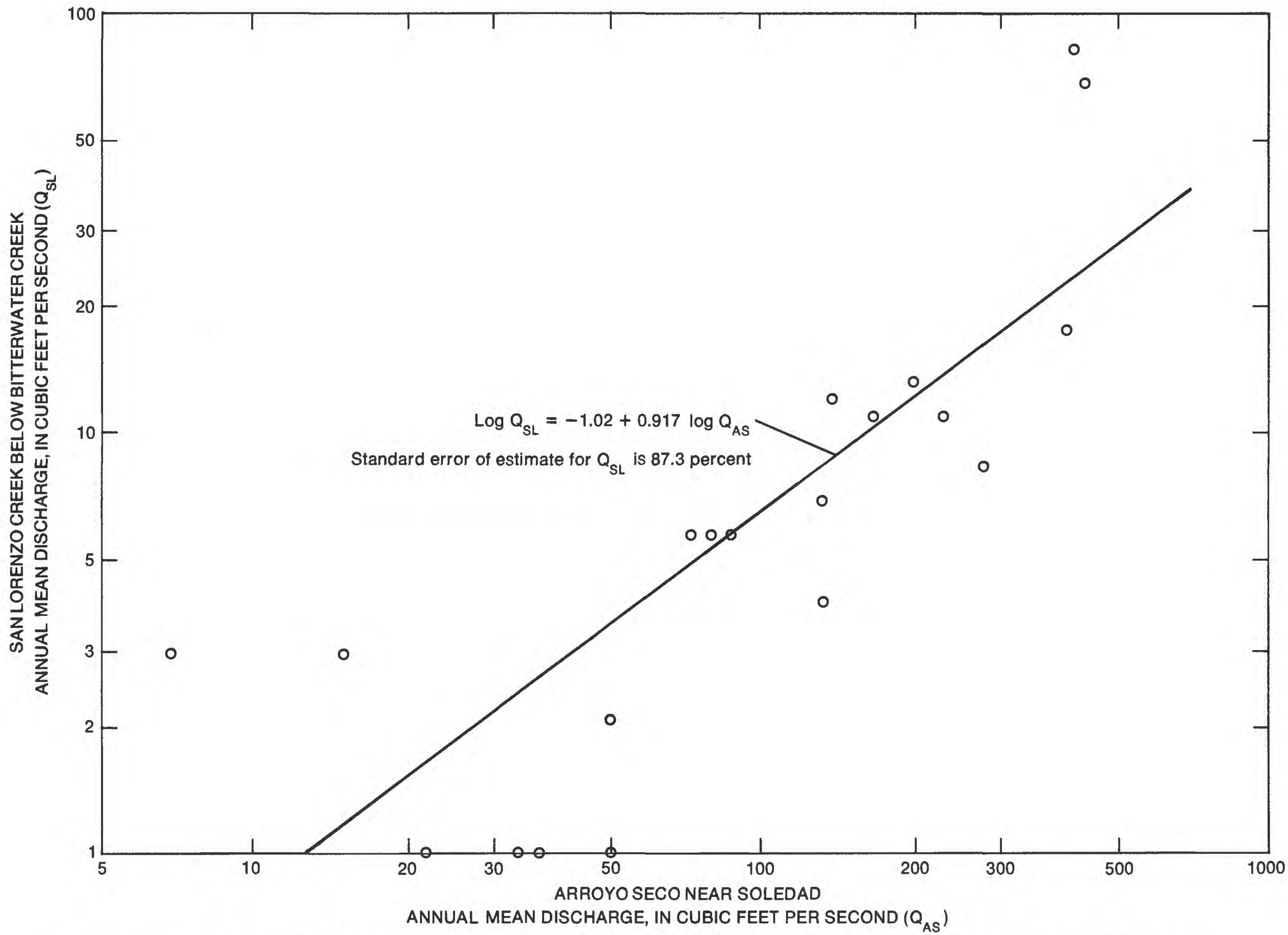


FIGURE 15. — Linear regression plot of annual mean discharges, water years 1959 through 1980, for gaging stations Arroyo Seco near Soledad versus San Lorenzo Creek below Bitterwater Creek, near King City.

A basic technique premise is that if a station is dropped from a network, information for the site can continue to be developed by correlation with data collected at retained sites. Maddock (1974) derived an equation to compute the information obtained by retaining a station or by transferring information from a retained station to a discontinued station. The Maddock equation was used to determine the total information value for every combination of retained gaging stations, pairing each retained station with every deleted station to find the greatest combined information-transfer value. Results of this analysis and the annual operating costs are summarized in table 11.

TABLE 11. - Calculated total information value and annual operating costs for all theoretical combinations of gaging stations

[Stations: 1, Arroyo Seco near Soledad; 2, Arroyo Seco near Greenfield; 3, San Antonio River near Lockwood; 4, Nacimiento River below Sapaque Creek; and 5, San Lorenzo River below Bitterwater Creek]

	Retained station combination	Best transfer pairs	Total information[1]	Annual operating costs
		One station discontinued		
	1, 2, 3, 4	3-5	4.822	$5,800
	1, 2, 3, 5	3-4	4.967	5,800
	1, 2, 3, 5	4-3	4.967	2,900
Best	1, 3, 4, 5	1-2	4.976	5,800
		Two stations discontinued		
	1, 2, 3	3-4, 3-5	4.79	5,800
	1, 2, 4	4-3, 5-4	4.79	2,900
	1, 2, 5	2-3, 1-4	4.89	2,900
	1, 3, 4	1-2, 3-5	4.80	2,900
	1, 3, 5	1-2, 3-4	4.94	2,900
Best	1, 4, 5	1-2, 4-3	4.94	0
	2, 3, 4	2-1, 3-5	4.80	5,800
	2, 3, 5	2-1, 3-4	4.94	5,800
	2, 4, 5	2-1, 4-3	4.94	2,900
	3, 4, 5	4-1, 3-2	4.89	2,900
		Three stations discontinued		
	1, 2	2-3, 1-4, 1-5	4.64	2,900
	1, 3	1-2, 3-4, 3-5	4.76	2,900
	1, 4	1-2, 3-4, 4-5	4.76	0
Best	1, 5	1-2, 1-3, 1-4	4.91	0
	2, 3	2-1, 3-4, 3-5	4.76	5,800
	2, 4	2-1, 4-3, 4-5	4.76	2,900
	2, 5	2-1, 2-3, 2-4	4.86	2,900
	3, 4	4-1, 3-2, 3-5	4.72	2,900
	3, 5	3-1, 3-2, 3-4	4.86	2,900
	4, 5	4-1, 4-2, 4-3	4.84	0
		Four stations discontinued		
	1	1-2, 1-3, 1-4, 1-5	4.59	0
	2	2-1, 2-3, 2-4, 2-5	4.60	2,900
	3	3-1, 3-2, 3-4, 3-5	4.68	2,900
Best	4	4-1, 4-2, 4-3, 4-5	4.66	0
	5	5-1, 5-2, 5-3, 5-4	4.12	0

[1]Numbers are relative and useful for comparison only.

In the column of annual operating costs, only the Monterey County share is shown. The costs represent one-half the annual funding (1983 fiscal-year level) for the Arroyo Seco near Greenfield (station No. 2 in table 11) and the San Antonio River near Lockwood (station No. 3). In 1983, the remaining three stations were financed jointly by the U.S. Geological Survey and the California Department of Water Resources.

Because all the stations have high correlation coefficients, the spread in information values (table 11) for various combinations is small. Also, the effect on the information value of dropping stations is relatively small. If the stations Arroyo Seco near Greenfield and San Antonio River near Lockwood were discontinued, the decrease in network information value would be only about 2 percent. The total information figures shown in table 11 are relative numbers and are useful only for comparison.

Data-collection activities proposed for deletion or change in the existing network.--In view of the information-optimization results shown in table 11 for the existing level 1 and 2 stations, the following changes are suggested:

11149900 San Antonio River near Lockwood

This station has an excellent correlation with the stations Nacimiento River below Sapaque Creek and Arroyo Seco near Soledad. Improvement in long-term estimates of flow by continued operation is negligible.

Sediment records have been collected at this station since 1966. Daily records were computed for 1966-73. Since 1974, periodic sediment samples (approximately eight per year) have been collected with the expectation they could be used to improve estimates of monthly and annual sediment discharge using methods proposed by Colby (1956). Unfortunately, periodic samples have not covered a wide enough range in discharge during most years to significantly improve sediment-discharge estimates that can be made using the 1966-73 daily sediment-record data.

Estimates of annual suspended-sediment discharge computed for water years 1974-81 from periodic sample data were supplemented by sediment data collected prior to the 1974 water year, using the sediment-transport curve method. Total sediment yield for 1974-82 was computed at 1,155,000 tons. The sediment yield for this period was 1,386,000 tons, or 21 percent more, when recomputed by the sediment-transport method, using only 1966-73 daily water and sediment data. This difference is probably less than probable measurement- and computational-process errors for a record based on periodic samples. Results indicate little information regarding sediment transport will be lost by discontinuing this gaging station and the periodic sediment sampling.

This station could be used in management of releases from Lake San Antonio, but at present the streamflow record is not used for this purpose on a current or real-time basis. If eventually a hydroelectric-generation plant is installed below San Antonio Dam and water is diverted from the Nacimiento River into the San Antonio River basin (CH2M Hill, 1982), the Lockwood station could be useful for managing the reservoir and meeting potential Federal Energy Regulatory Commission licensing requirements. This station could be discontinued unless there is a plan to use the gage for real-time data acquisition and for managing the reservoir.

11151870 Arroyo Seco near Greenfield

The operation of this station for a continuous-discharge record does little to improve the long-term estimate of flow at this site. The 22-year record can be extended to 80 years using the excellent correlation with the record for Arroyo Seco near Soledad.

The value of the station for collecting sediment data also is considered marginal. Significant improvement in estimates of long-term sediment yield would require several more years of data collection. Sediment records collected since the Marble Cone fire in 1977 document the dramatic increase in sediment production immediately following the fire and the steady decrease toward pre-burn sediment yields as shown by the sediment-transport curves in figure 16. At the gage site, the channel cross section (fig. 17) has degraded nearly to its preburn elevations. Provisional sediment data for the 1982 water year indicate the sediment-discharge/water-discharge relation at that time was comparable to that of the preburn period. When construction starts at the proposed dam upstream from this station, sediment records no longer will reflect the natural sediment yield. Assuming construction begins by 1990 or earlier, time is insufficient to collect enough data to significantly change present estimates of long-term sediment-transport rates.

Principal use of this station is for flood-warning purposes. The discharge record has been used to calibrate a rainfall-runoff model developed by NWS, which in turn is used with telemetered rainfall data to predict flood peaks. For model-calibration purposes, a partial-discharge record would be sufficient. It is therefore suggested that continuous discharge no longer be computed at this station and that the station be operated for flood-stage information only from November through April. Discharge measurements could be made during flood season to maintain a current stage-discharge rating curve.

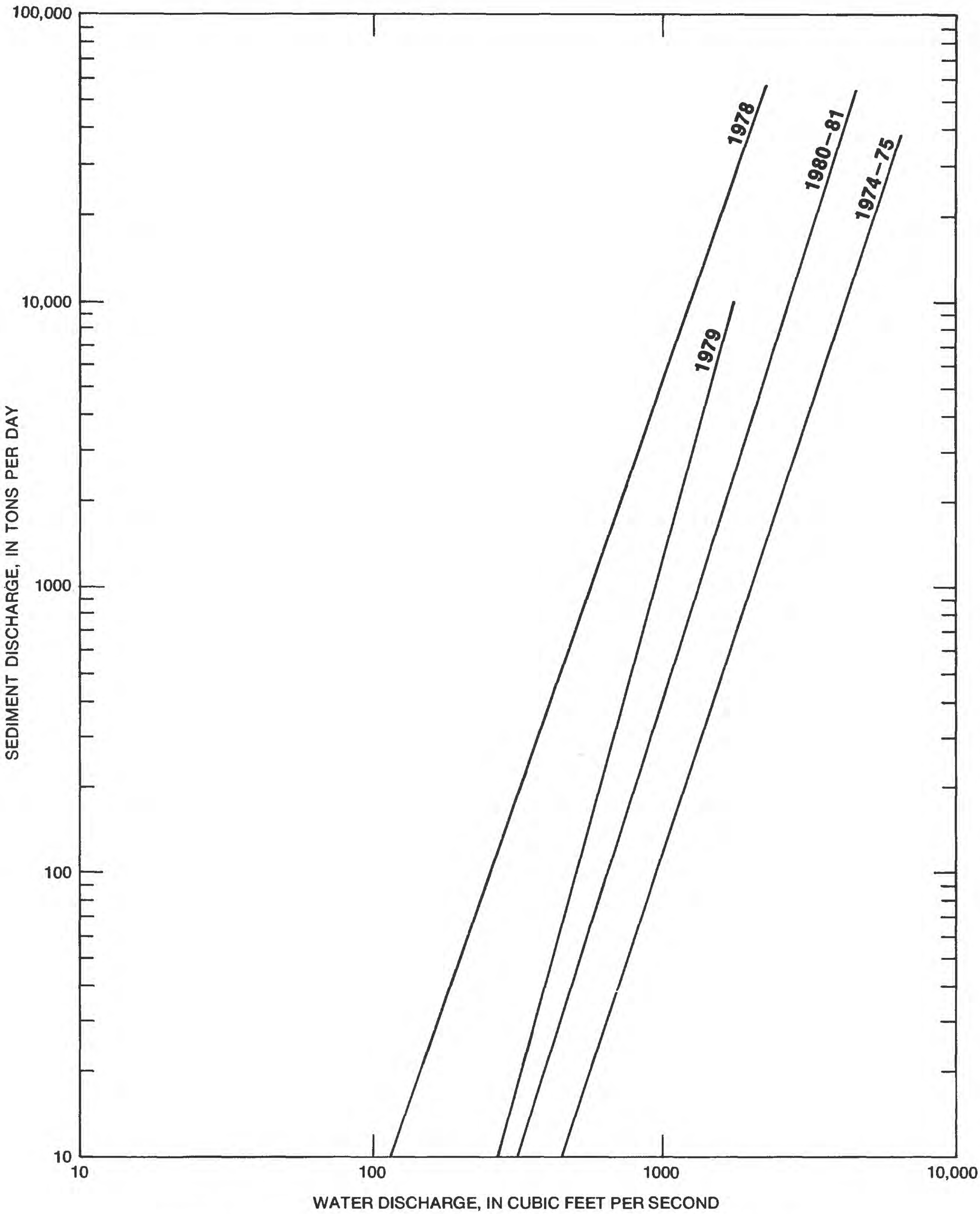


FIGURE 16. — Average sediment transport curves for 1974-75, 1978, 1979, and 1980-81, for the Arroyo Seco near Greenfield gaging station.

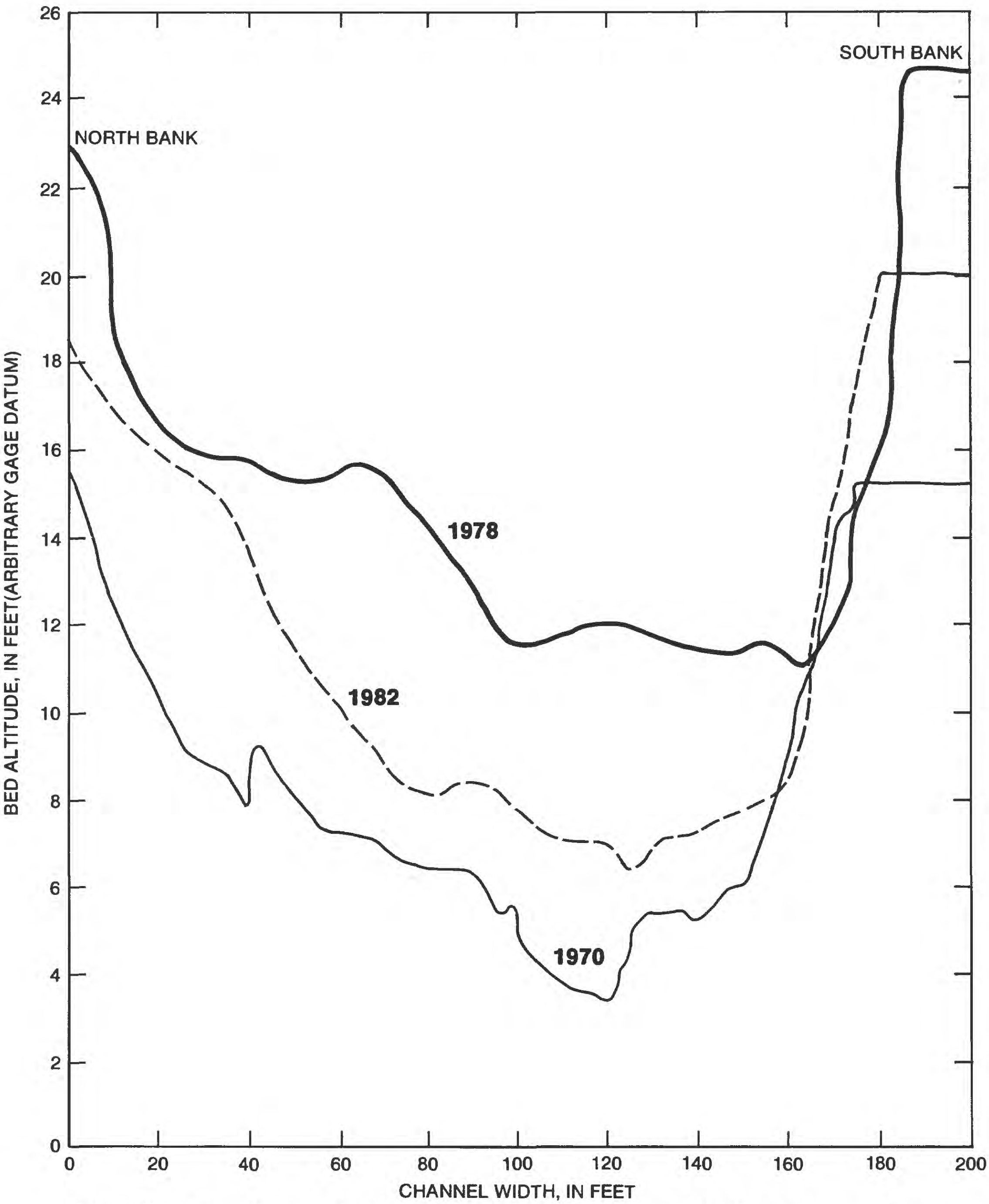


FIGURE 17. — Channel cross section 585 feet above Arroyo Seco near Greenfield gaging station, surveyed after peaks of January 16, 1970; February 7, 1978; and December 22, 1982.

Description of Proposed Surface-Water Network

Suggested dissolved constituents and physical qualities for water-quality sampling are shown in table 12. Onsite tests could be made every time a gaging station is visited; samples for constituents requiring laboratory analysis could be collected at the proposed frequency. The stations suggested to be continued and new stations to be added to the streamflow network are presented in table 13. The stations are listed in the decreasing order of importance with regard to monitoring objectives.

TABLE 12. - Sampling categories for surface-water sampling

Field tests:	
Specific conductance	
pH	
Temperature	
Dissolved oxygen (only below dams and at Arroyo Seco)	
General minerals, dissolved:	
Calcium	Carbonate, Bicarbonate
Magnesium	Dissolved sulfate
Sodium	Chlorine
Potassium	Nitrate
Iron	Boron
Trace elements and organics, dissolved	
Nutrients, dissolved	
Kjeldahl nitrogen	
Ammonia	
Phosphorus	

TABLE 13. - Proposed gaging-station network, southern Monterey County (Phase 1)

[Type of flow data: LCR, long-term continuous record; MDM, monthly discharge measurement; Stage, stage and high-flow discharge measurement; SCR, short-term continuous record; and SDM, seasonal discharge measurement. Field tests: A, performed each visit]

Station No.	Station Name	Activity level	Priority points[1]	Type of flow data	General mineral	Nutrients	Trace elements	Field tests
11149400	Nacimiento River below Nacimiento Dam	3	109	LCR	2	2	2	A
11150500	Salinas River at Bradley	3	103	LCR	--	--	--	A
11150200	San Antonio River below San Antonio Dam	3	103	MDM	2	2	2	A
11152000	Arroyo Seco near Soledad	1	99	LCR	10	10	10	A
11148600	Salinas River at county line	3	96	LCR	10	10	10	A
11151870	Arroyo Seco near Greenfield	3	92	Stage	--	--	--	--
11151700	Salinas River at Soledad	3	91	LCR	2	2	2	A
11148900	Nacimiento River below Sapaque Creek, near Bryson	2	80	LCR	--	--	--	A
11151300	San Lorenzo Creek below Bitterwater Creek	1	79	LCR	10	10	10	A
11150600	Pancho Rico Creek at San Ardo	2	78	SCR	2	2	2	A
11151650	Chalone Creek near Greenfield	2	69	SCR	2	2	2	A
11148650	Nacimiento River at San Miguelito damsite	2	57	SCR	--	--	--	A
11150530	Sargent Creek near San Ardo	2	68	SDM	4	2	1	A
11150300	Hames Creek near Bradley	2	62	SDM	4	--	1	A
11151510	Salinas River at King City	2	91	SDM	--	--	--	--
11150730	Salinas River at San Lucas	2	78	SDM	--	--	--	--
11150610	Salinas River at San Ardo	2	91	SDM	--	--	--	--

[1]Tabulated in table 10.

Justification for each station and the data-collection activity follows:

11149400 Nacimiento River below Nacimiento Dam, near Bradley (level 3 station)

This station has the highest total priority points (table 13) because it monitors ground-water recharge and flood-control releases from the county's largest reservoir, provides data relevant to water rights, and is a potential site for water-quality sampling. In addition to the present collection of a continuous-flow record at this site, water-quality sampling is suggested twice annually; one sample could be collected at high flow and one at low flow. Dissolved oxygen should be determined each time the gaging station is visited because this reach of stream is fish habitat.

11150500 Salinas River near Bradley (level 3 station)

Flow at this long-established accounting and flood-warning station represents the combined releases from Lakes San Antonio and Nacimiento and runoff from 1,885 mi^2 of additional drainage area. The record is used in computing ground-water recharge, and river stages are telemetered to the DWR Flood-Forecasting Center. DWR collects samples monthly here for general mineral and nutrient analyses; samples for trace elements are collected less frequently. Sampling would be continued. In addition, a continuous recorder is suggested to monitor temperature, pH, and specific conductance for a 3-year period. The continuous record would define daily as well as seasonal variations in water quality.

11150200 San Antonio River below San Antonio Dam (potential level 3 station)

This site rates high for monitoring releases of recharge water to Salinas Valley and for sampling water quality. Present releases from Lake San Antonio are determined from calibrated settings for the hollow-cone release valve in the dam. Because releases are generally small and fairly constant, this method of measuring outflow should be adequate if monthly streamflow measurements are made to verify the valve calibration. A gaging station here is not necessary at this time; however, if a hydroelectric-generation plant is constructed below San Antonio Dam, a gaging station would be needed. Generation releases would be much larger and more varied than the present releases.

Onsite tests suggested for this station include testing of dissolved oxygen each time the site is visited and at least two sample collections per year for other sampling categories--one at high flow and one at low flow.

11152000 Arroyo Seco near Soledad (level 1 station)

This station has been operated continuously since 1902. Its principal value is that of an index station for documenting long-term flow trends and extending short-term records for other stations in the area using correlation and regression techniques. If a dam is built upstream, this station will lose some of its value for trend detection and estimating flows at other sites. Consequently, need for this station could be reevaluated if the dam is built.

Water-quality sampling is proposed here in addition to continuing flow measurements. Because Arroyo Seco flow is a major source of both surface- and ground-water inflow to the Salinas Valley, its quality is important. An initial intensive program is needed to develop a water-quality baseline. Onsite tests should be made at each visit. In addition, water-quality samples for other categories would be collected at least ten times annually for 3 years. Samples collected at different flow levels would determine water-quality variations between high and low flows. After 3 years of data collection, results could be evaluated and the monitoring program amended as needed.

11148600 Salinas River at county line (potential level 3 station)

A station at this site would furnish key data for computing the water balance for the Salinas River basin in Monterey County, as well as furnishing information useful in managing releases from Lakes Nacimiento and San Antonio. At present, Salinas River at Paso Robles flow record is combined with the Estrella River record to approximate Salinas River flow above the mouth of the Nacimiento River. A gage at the county line would measure runoff from an additional 366 mi^2 of ungaged drainage area downstream from the Paso Robles and Estrella stations; this also could be a strategic location for sampling the quality of water entering the county. If financial support was withdrawn for either the Estrella or Paso Robles stations, a station at the county line would be even more important. In view of increasing the accuracy in measuring the Salinas River inflow to the county, the value of the station for water-quality sampling, and the assurance of continuity of record, a gaging station is advisable near the county line. Water-quality monitoring at this site would define background quality of the river before Lake Nacimiento water was admixed. The sampling pattern suggested for the Arroyo Seco near Soledad is also suggested for this station.

11151700 Salinas River at Soledad (potential level 3 station)

A gage installed here in 1969 was discontinued in 1976 due to economic pressures. This station furnished data to quantify river recharge to the ground-water system in the reach between the San Antonio River and Arroyo Seco and also furnished stage and discharge data useful in tracking flood peaks along the Salinas River. Should a dam be built on the Arroyo Seco, this would be a critical station for managing releases. Reestablishment of this station is important. Onsite water-quality tests would be made each time the gage is visited. Twice per year, once at high flow and once at low flow, samples would be collected for general mineral, nutrient, and trace-metal analysis.

11148900 Nacimiento River below Sapaque Creek, near Bryson (level 2 station)

Principal value of this station is determining long-term characteristics of unregulated streamflow and measuring inflow to Lake Nacimiento. The data also are useful for long-range planning operations for the reservoir and could give real-time flow information for day-to-day management, if telemetry equipment were installed.

Data from this station correlate well with those from the Arroyo Seco and the San Antonio River stations. Should the Arroyo Seco dam be constructed, this station would be a better index station for the study area than the Arroyo Seco near Soledad station. Onsite tests only, to evaluate water quality, are suggested at this station.

Periodic sediment sampling could be discontinued at this station for the same reasons given for discontinuing sampling at the San Antonio River near Lockwood station. Annual sediment yields computed with and without periodic samples collected at this station during 1974-81 differed by a maximum of only 9 percent.

If at some future date there is reason to suspect that land-use changes or natural events have altered sediment production, resumption of daily sediment sampling would be the best way to document the change. Should concern develop about the rate of sediment deposition in Lake Nacimiento, a survey of the reservoir would be appropriate to establish reduction in storage volume.

11151300 San Lorenzo Creek below Bitterwater Creek, near King City (level 1 station)

This is the only tributary gaging station in operation in the study area on the east side of the Salinas Valley. Presumably, it is an index of flow from other east-side tributaries. Correlation with runoff from the west-side tributaries is poor, as witnessed by regression with Arroyo Seco (fig. 15). Discharge is significant from a water-quality standpoint because dissolved-solids concentration usually is related to discharge. The impact of the poor quality water on recharge water quality has not been fully assessed. For this reason, the continued measurement of streamflow is advisable with the addition of water-quality sampling.

For the first 3 years of water-quality monitoring, the intensive sampling pattern suggested for Arroyo Seco near Soledad is suggested. In addition, a continuous temperature, pH, and specific-conductance recorder could be installed. These records would provide insight into daily, storm-related, and seasonal variations in water quality.

11150600 Pancho Rico Creek at San Ardo (potential level 2 station)

A gaging station is needed here to expand information on east-side runoff characteristics. San Lorenzo Creek is the only east-side stream that has been gaged in the study area. A short-term record of flow (up to 10 years) should substantially increase our knowledge of the runoff characteristics of drainage basins in the Gabilan Hills. If streamflow data for Pancho Rico and San Lorenzo Creeks correlate well, the long-term San Lorenzo record could be used with more confidence in estimating runoff from ungaged tributaries on the east side of the Salinas Valley.

A streamflow record for Pancho Rico Creek also would be an important aid in evaluating the magnitude of suspected water-quality problems. Based on a few historic records and a plume of poor-quality ground water originating where Pancho Rico Creek enters the Salinas Valley, the quality of water from Pancho Rico Creek probably is almost as poor as that from San Lorenzo Creek. Gypsum beds, probably an important water-quality factor in San Lorenzo Creek, also are found in the Pancho Rico Creek drainage basin. The sampling pattern suggested at Nacimiento River below Nacimiento Dam should be followed for the station at Pancho Rico Creek.

11151650 Chalone Creek near Greenfield (potential level 2 station)

A water-quality sampling program is suggested for this station for the reasons given for establishing a station on Pancho Rico Creek. Chalone Creek, the largest east-side tributary below San Lorenzo Creek, drains a terrane of diverse geology including Mesozoic granite, Miocene and Pleistocene marine and nonmarine deposits, and Miocene volcanic rocks of Pinnacles National Monument. A short-term recording station is suggested, principally to correlate flow with San Lorenzo Creek and to characterize the water quality.

11150530 Sargent Creek at San Ardo (potential level 2 site)

This site is suggested for seasonal discharge measurement and water-quality sampling to aid in characterizing runoff-water quality from the Cholame Hills area. Because runoff is infrequent in this semiarid area, no more than two to four samples a year are likely to be obtained. Probably 5 years of sampling would supply adequate information to evaluate baseline water quality. Samples would be analyzed for general mineral constituents, and the first samples of every season also would be analyzed for trace elements. This site was chosen over Vineyard Canyon and Big Sandy Creek because it has better measuring and sampling sites.

11150300 Hames Creek near Bradley (potential level 2 site)

Seasonal discharge measurements and water-quality samples are needed at this site to characterize water quality to runoff from hills bordering the west side of Salinas Valley. The hills from the San Antonio River mouth north to Arroyo Seco are nearly all the same geologic formation (middle Miocene non-marine sedimentary rocks). About four samples per year for 5 years could be collected throughout the range of flow; general mineral analyses could be made on all samples, and trace-element analysis could be made annually at the first sampling of the season. Also, analysis for nutrients could be made once a year late in the season. Onsite tests could be made each time the site is visited.

11148650 Nacimiento River at San Miguelito damsite (potential level 2 station)

Except for the Arroyo Seco damsite mentioned earlier, the Nacimiento River has the best undeveloped damsite, from the standpoint of unit runoff per square mile, in the study area. Average rainfall over the basin above this site is greater than 30 inches per year, and runoff probably averages 85,000 acre-feet or more per year, based on downstream flow records collected since 1956. Annual flow at this damsite was estimated by Harding and Bunte (Monterey County Flood Control and Water Conservation District, 1957) to be about 20 percent of the total runoff of the Nacimiento River basin, or only 42,000 acre-feet. Although the Jarret Shut-in damsite has a slightly higher priority rating, no gage is suggested for that site because of the proximity of the existing station, Nacimiento River below Sapaque Creek. The drainage area of the existing gage is only 24 percent larger than at the Jarret Shut-in site; a discharge record for the upstream site could be estimated with fair accuracy.

A gaging station is suggested in the vicinity of the San Miguelito damsite. Correlation of flows at this site with those at the Nacimiento River below Sapaque Creek station should be excellent. Ten years of record should be sufficient to establish a base for good, long-term estimates of flow at this site. No water-quality sampling is suggested here.

11151510 Salinas River at King City (potential level 2 station)

Priority points for this site were based on recharge, flood-warning, and water-quality objectives. The high score shown in table 10 is misleading because a station at King City would not add significantly to the information collected at the Bradley and Soledad stations. Although a recording station is not suggested here, seasonal discharge measurements made during periods of steady flow could help define areal and temporal ground-water recharge distribution. No water-quality sampling is suggested.

11150730 Salinas River at San Lucas (potential level 2 site)

Justification is the same as for the King City station. Only seasonal discharge measurements are suggested at this time.

11150610 Salinas River at San Ardo (potential level 2 site)

Justification and suggestions are the same as for the King City and San Lucas stations.

Sampling Program for Reservoirs

Lakes in moderate climates, like those in the Salinas River basin, are classified as warm-monomictic, which means they are generally stratified during the warm months of the year and mixed during the cold months.

To develop a water-quality baseline, three samplings of Lakes Nacimiento and San Antonio would be made in each of 2 years during (1) summer stratification, (2) overturn to winter mixed, and (3) winter mixed. The timing of sampling for overturn is crucial and will vary from year to year, depending on weather patterns. Each sampling would include at least three profiles in each reservoir--one in the deepest part near the dam, a second in the middle, and a third near the inlet. In Lake Nacimiento, an additional profile may be necessary in the arm of the reservoir formed by Las Tablas Creek. The most important profile is in the deepest part of the reservoir because greater stratification occurs in deeper water.

During summer, the lakes stratify when warm water near the surface traps cooler water underneath. Particulate nutrients collect near the bottom during this phase. Stratification was observed in Lake Nacimiento on August 24, 1977, when the temperature ranged from 24.5°C near the surface to 9.5°C at 27 meters (U.S. Geological Survey, 1978). Sampling would be done in August or September to define the summer stratification.

Temperatures near the surface and near the bottom would be measured daily from mid-November until overturn, which occurs when water at the surface cools to approximately the temperature of water at the bottom. As water at different levels mixes during overturn, the nutrient particles also mix throughout the water column. Samples would be collected during the overturn.

During most of the winter the lake is mixed, and the water temperature is fairly uniform throughout the water column. Nutrient particles are suspended throughout the water column except during quiet periods when they tend to settle. Winter sampling would be done between January and March.

In spring, warm weather heats the water at the surface, and the water column starts to stratify. As the temperature difference increases between the surface and deep water, particulate nutrients settle to the bottom. The summer stratification is established at different times each year depending on the seasonal weather pattern.

Depth profiles of temperature, pH, specific conductance, light penetration and transmission, and dissolved oxygen could be measured during each of the three yearly samplings (table 14). Secchi disk depth measurements also could be made and samples collected for nutrient and trace-element analysis. During overturn and winter, a depth-composite sample could be collected for nutrient and trace-element analysis. During summer stratification, samples would be collected from near the surface and near the bottom.

TABLE 14. - Yearly frequency of reservoir sampling

Sampling location	Sampling constituents						
	Profile						
	pH	Temperature	Specific conductance	Dissolved oxygen	Light penetration and transmission	Nutrients*	Trace elements*
Lake Nacimiento near dam------------	3	3	3	3	3	5	5
Lake Nacimiento at middle-----------	3	3	3	3	3	5	5
Lake Nacimiento near inlet----------	3	3	3	3	3	5	5
Lake Nacimiento in Las Tablas Creek Arm----	3	3	3	3	3	5	5
Lake San Antonio near dam------------	3	3	3	3	3	5	5
Lake San Antonio at middle-----------	3	3	3	3	3	5	5
Lake San Antonio near inlet----------	3	3	3	3	3	5	5

Note: Each lake should be sampled during (1) summer stratification, (2) overturn to winter mixed, and (3) winter mixed.

*When lake is stratified, a sample will be collected near the surface and near the bottom. When mixed, one composite sample will be collected.

GROUND-WATER NETWORK ANALYSIS

Geologic Setting

The Salinas River drainage basin is part of the Salinian block, a northwest-aligned structural-depositional basin that ranges from 10,000 to 15,000 feet in depth (Burch and Durham, 1970), bounded on the northeast by the San Andreas fault zone and on the southwest by the Jolon fault zone (fig. 18). The block is characterized by a basement complex of granitic and metamorphic rock overlain by a thick sequence of marine and nonmarine sedimentary rock. Much of the block is covered by Holocene alluvium. The Paso Robles Formation of alluvial and colluvial origin overlies the Pancho Rico Formation of marine origin. This sedimentary sequence functions as a productive aquifer. Virtually all of the study area's ground water is pumped from the top 400 feet of this aquifer, which is composed of the Paso Robles Formation and alluvium.

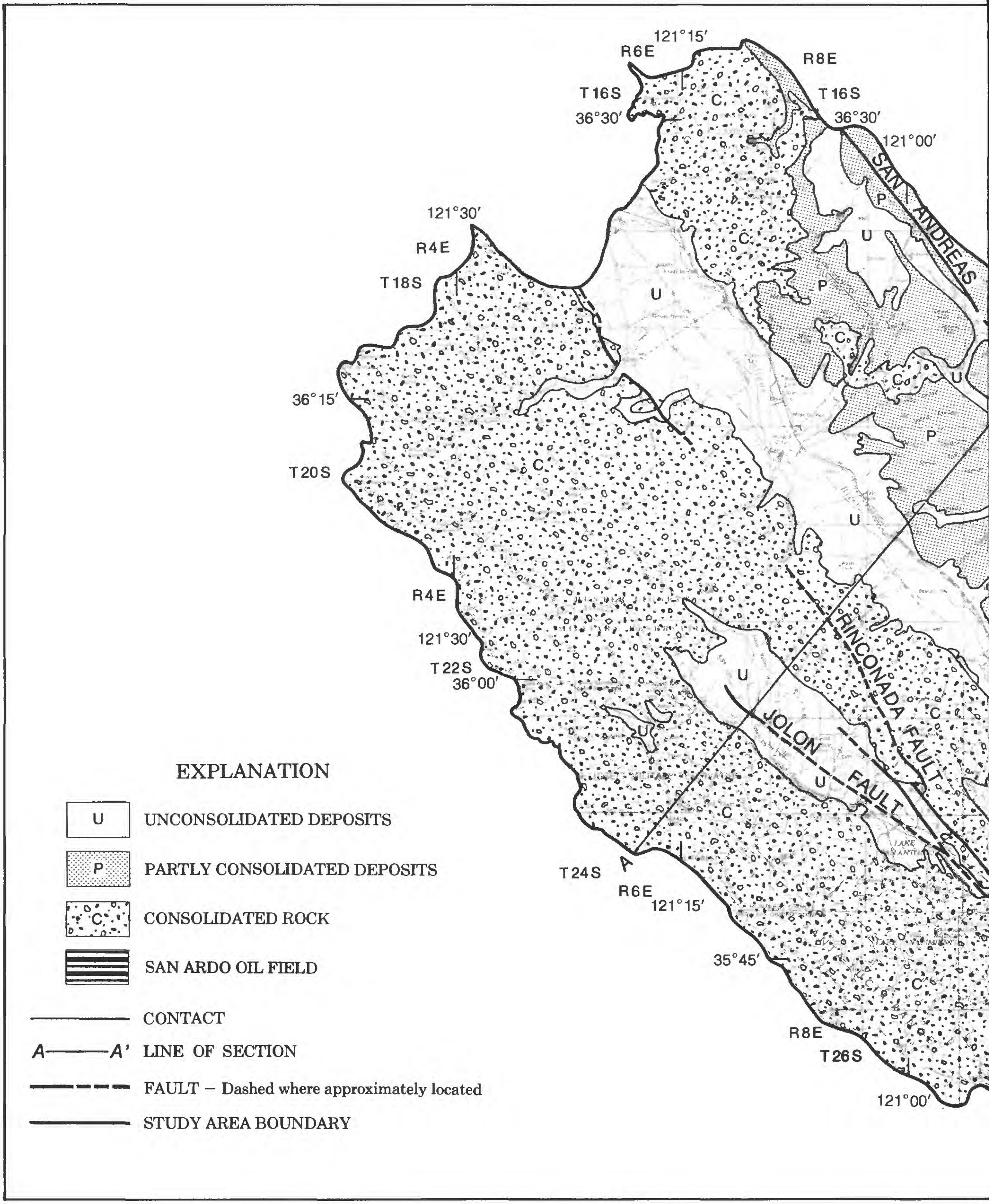
Geologic Formations

Geologic formations are grouped into three general units on the basis of their capacity to yield ground water, as was done by Durbin and others (1978). The units are (1) consolidated rocks that yield only a small quantity of water, at some locations insufficient to sustain even domestic and stock wells; (2) partly consolidated deposits that yield small to appreciable quantities of water to wells; and (3) unconsolidated deposits that generally are prolific aquifers. Areal distribution of the units and their stratigraphic relations are shown in figure 18.

Consolidated rocks.--The consolidated rocks include the basement complex and older marine rocks. The rocks, where sufficiently fractured or weathered, supply small quantities of water to domestic and stock wells. As shown in figure 18, the consolidated rocks are exposed mostly in the mountainous areas on the southwest side of the basin. These rocks are relatively insoluble, so runoff in this region generally contains high-quality water.

Partly consolidated deposits.--Partly consolidated deposits consist of interbedded units of sandstone, conglomerate, and mudstone of the Pancho Rico Formation of Miocene age (Durham, 1974) exposed on the northeastern side of the Salinas Valley. The rocks are relatively soluble, so water quality in this area is poor compared to that from the southwest side of the valley. Wells in the Pancho Rico Formation yield small to moderate quantities of water depending on texture and saturated thickness of the sandstone and conglomerate penetrated.

Unconsolidated deposits.--The unconsolidated deposits include the nonmarine Paso Robles Formation of Pliocene and Pleistocene age and alluvium of Holocene age, which consist of lenticular interbeds of sand, gravel, silt, and clay. A few lenticular beds of gypsum found in the Paso Robles Formation in the upper reaches of the Pancho Rico and San Lorenzo Creek drainages affect water quality because they dissolve into calcium and dissolved sulfate.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STUDY AREA BOUNDARY

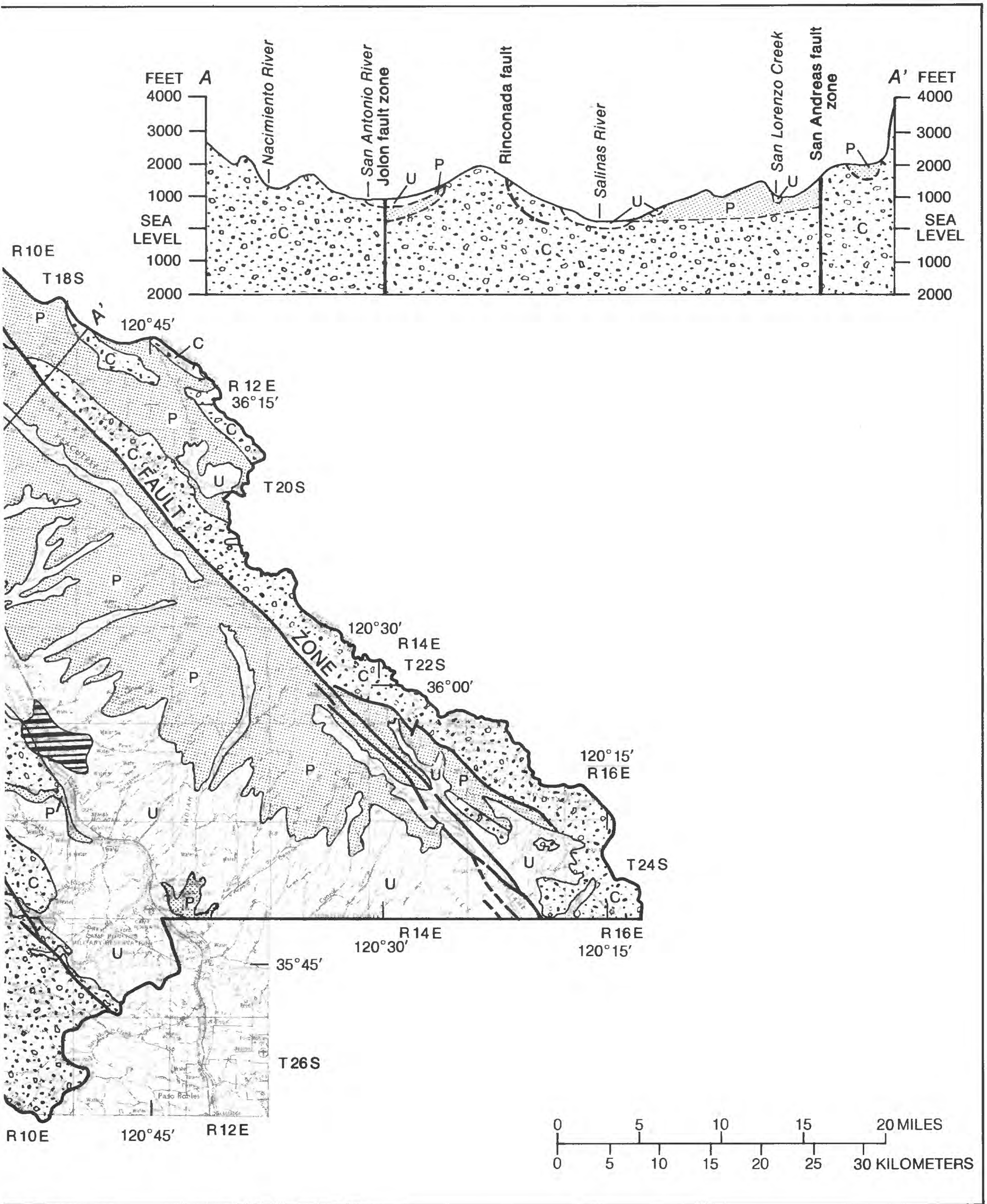


FIGURE 18. — Geology of the study area (Modified from Showalter and others, 1984).

Wells in the Paso Robles Formation, the most important aquifer in the study area, generally yield from 200 to 4,000 gal/min. The Paso Robles Formation, widely exposed at the southern end of the study area where it probably is at least 1,000 feet thick, also is exposed in the upper drainage area of the San Antonio River. It underlies alluvium and is as much as 1,500 feet thick near Greenfield. Along the Salinas River channel and channels of the tributaries, the Paso Robles Formation underlies alluvium.

Alluvium as defined herein includes river deposits, alluvial fan deposits, and windblown sand deposits. It consists of lenticular, interconnected beds of sand, gravel, silt, and clay with a cumulative thickness of as much as 300 feet.

The alluvial-fan deposits on both sides of the valley are composed of materials eroded and washed down from the mountains. The fan deposits by Arroyo Seco, the largest fan in the study area, serve as an important recharge zone. Higher parts of the fans commonly consist of cobbles and gravel in a matrix of sand, silt, and clay; the broader, lower parts of the fans commonly are composed of finer grained and better sorted materials. The maximum thickness of the fan deposits is probably about 500 feet. In general, alluvial-fan deposits on the southwest side of the valley (such as the Arroyo Seco fan) are more permeable than those on the northeast side. Wells in these deposits on the southwest side commonly yield from 2,000 to 3,000 gal/min; those on the northeast commonly yield from 10 to 40 gal/min, although some yield as much as 2,000 gal/min.

Geohydrology

Over geologic time the Salinas River and its tributaries have deposited lenses of clay, silt, sand, and gravel to form a porous aquifer down the length of the Salinian block. Generally, the ground-water basin is thicker near the mouth of the river and thinner toward the south. In the study area, the basin averages about 1,000 feet in thickness (Durbin and others, 1978). The remainder of this section concentrates on that part of the ground-water basin composed of the unconsolidated sediments.

Occurrence of Ground Water

To facilitate discussion, the California Department of Public Works, Division of Water Resources (1946) divided the Salinas River ground-water basin at the San Ardo oil fields into the upper and lower basins. They subdivided the lower basin into four areas: Upper Valley, Forebay, East Side, and Pressure Area. Showalter and others (1983) subdivided the upper basin of the Salinas River drainage basin into the Upper Narrows and subbasins. The area of this report encompasses the four subareas from the 1946 report as well as the Upper Narrows subarea. Several small bodies of alluvium along tributaries that serve as local water supplies, such as in the Lockwood area, are included in the study area, although they are not part of the subareas. The geohydrologic characteristics of each subarea are summarized in table 15. This information was compiled primarily by California Department of Public Works, Division of Water Resources (1946), by Durbin and others (1978), and from hydrologic data collected largely by MCFCWCD.

The main source of recharge to the Upper Valley, Forebay, and Upper Narrows subareas is infiltration from the Salinas River and its tributaries. Dry-season Salinas-River flow is sustained largely by releases from Lakes Nacimiento and San Antonio. Recharge also occurs through streambeds of unregulated streams. MCFCWCD calculates the amount of annual releases conserved and recharge, based on surface-water flow records. Recharge computed from reservoir releases for 1965-81 is shown in table 16.

Direction of Ground-Water Flow

In unconsolidated alluvial deposits of the Salinas Valley and in valleys tributary to the Salinas River, ground-water flow generally follows the direction of the surface-water flow. Locally, pumping troughs may change flow directions from time to time.

Contours of ground-water levels measured in the study area during autumn 1980 (fig. 19) show that ground-water flow is generally to the north and in the direction of surface-water flow. The similarity of the ground- and surface-water flow directions indicates the interdependence of surface and ground water.

No water-level data were available for the area 3 to 4 miles north of the county line in Tps. 23 and 24 S. From a recharge point of view, this is a crucial area. Water released from Lakes Nacimiento and San Antonio enters the valley just south of Bradley about 8 river miles north of the county line and is a major source of recharge in the basin. Water-level data are necessary to determine the velocity and quantity of ground-water flow in this reach. This high-quality release water ultimately will upgrade ground-water quality of the entire lower basin. Water-level information in this area is needed to calculate how quickly the benefits from the recharging activities will reach pumping zones downstream.

TABLE 15. - Geohydrologic characteristics of each subarea

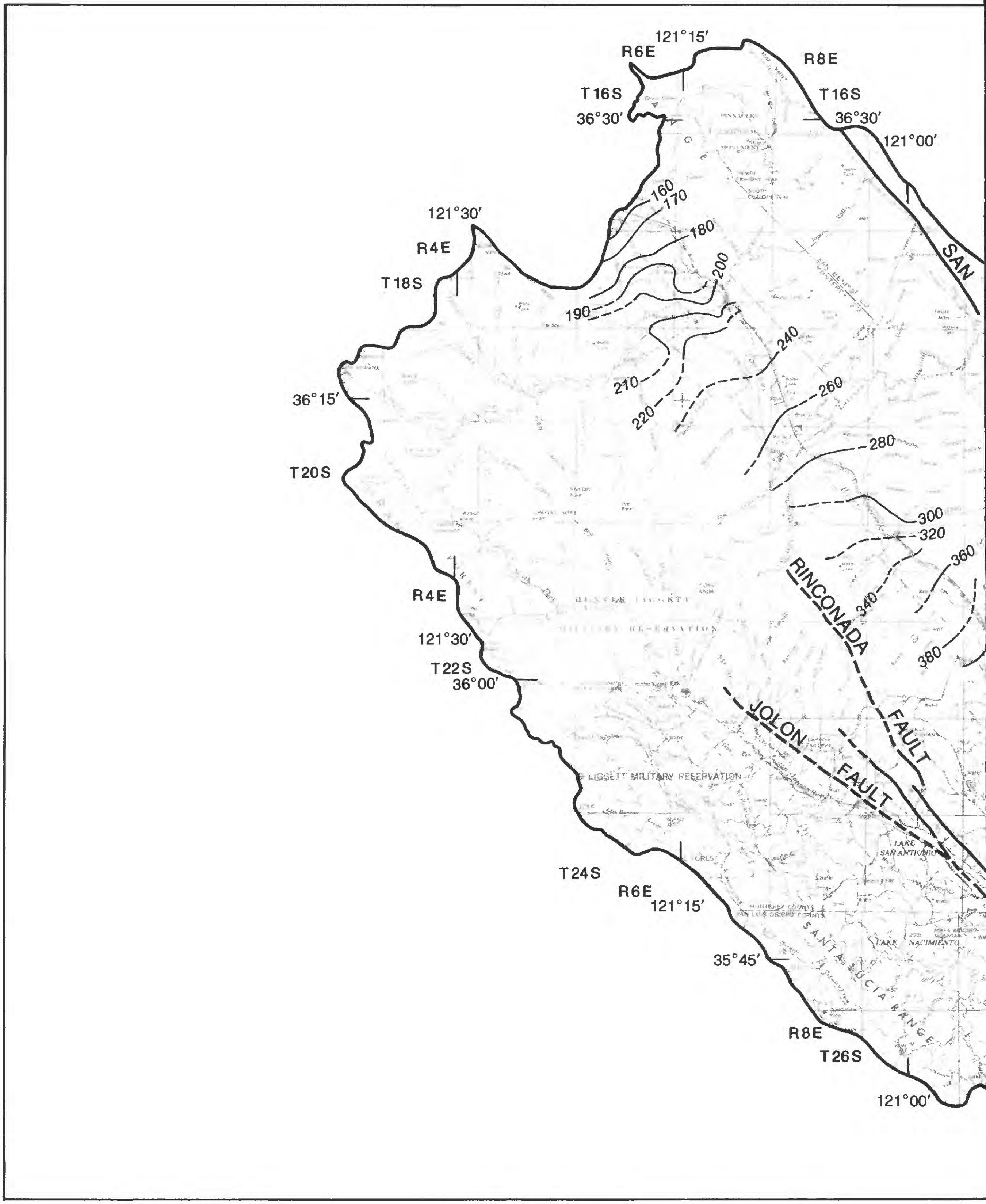
Subarea	Confinement	Aquifer thickness (feet)	Depth to water (feet)	Annual water-table fluctuation (feet)	Average specific capacity [(gal/min)/ft of drawdown]	Recharge source	Transmissivity [(gal/d)/ft]	Remarks
Forebay	Unconfined	[1]200-2,500 (most <400)	12-285	20	109	Percolation from Salinas River and Arroyo Seco; underflow from Upper Valley.	8.1×10^5	This is an area permeability, so recharge is high. Even with heavy irrigation pumping, water tables have remained high.
Upper Valley	Unconfined	[1]400-1,400	10-285	7	192	Percolation from Salinas River and tributaries; releases from Lakes Nacimiento and San Antonio.	Not available	Pumpage is much lower in this subarea than in subareas to north. Valley narrows and steepens in this area.
Upper Narrows	Partial	[2]<600	[2]10-200	10	Not available	Percolation from Salinas River; inflow from Lakes Nacimiento and San Antonio.	Not available	Ground water flows through this zone from upper to lower basin. From time to time hump in water table may form at south end of area, restricting flow from upper basin.

[1]Durbin and others (1978).
[2]Estimate based on wells outside of area.

TABLE 16. - Annual reservoir (Lakes Nacimiento and San Antonio) releases conserved

[Computed by Monterey County Flood Control and Water Conservation District from U.S. Geological Survey streamflow records]

Water year		Releases conserved, in acre-feet
1965-66		169,500
1966-67		107,000
1967-68		187,200
1968-69		111,300
1969-70		149,500
1970-71		166,000
1971-72		221,000
1972-73		116,300
1973-74		125,700
1974-75		125,900
	10-year average	147,900
1975-76		216,300
1976-77		231,900
1977-78		141,200
1978-79		151,400
1979-80		120,600
1980-81		173,800
	Total period average	157,200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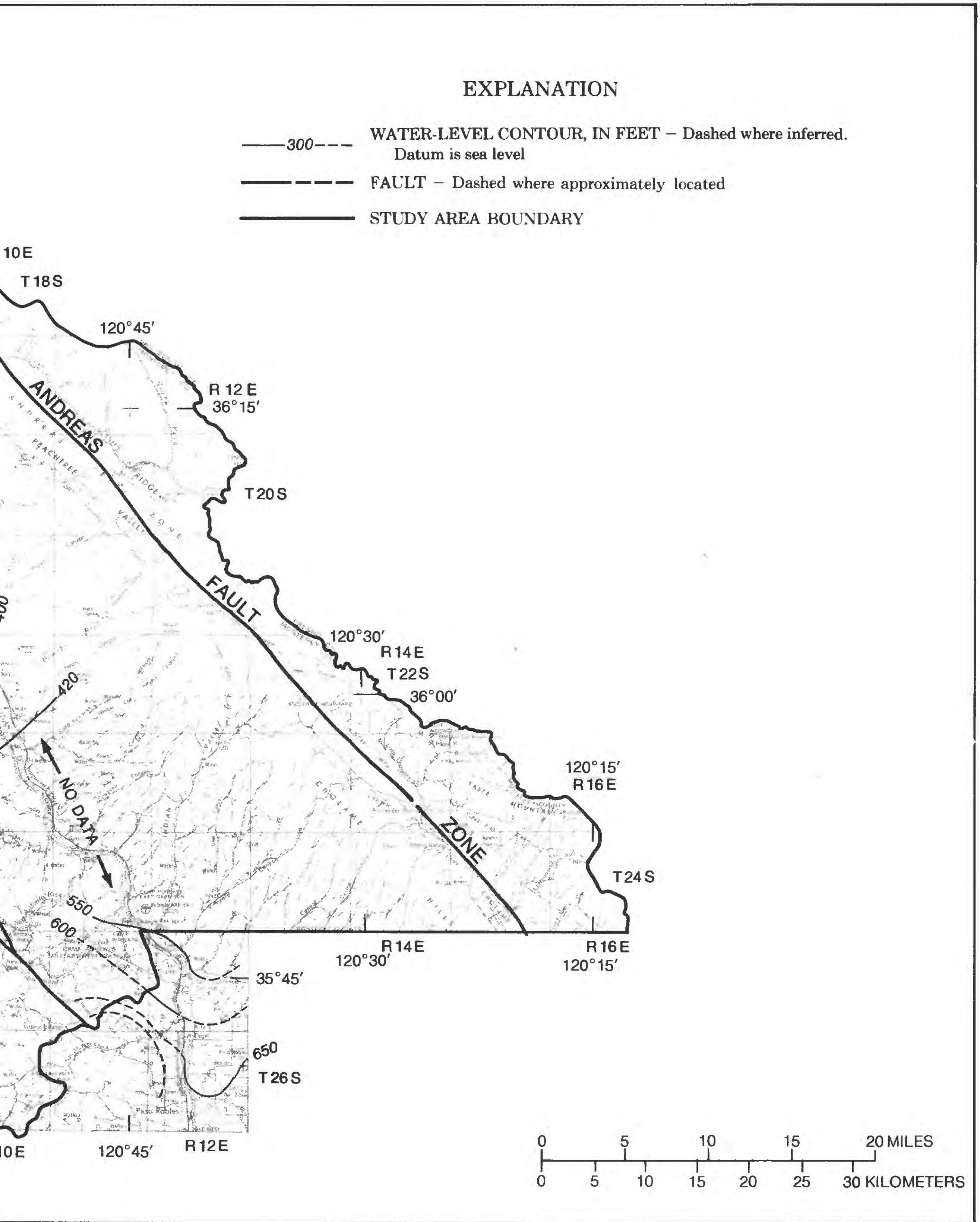


FIGURE 19. — Ground-water levels in autumn 1980.

The Upper Narrows area between Bradley and San Miguel (fig. 18) may restrict ground-water flow because the alluvium is particularly narrow and thin. Without water-level information, the amount of water flowing through this neck, which separates the upper basin from the lower basin, cannot be directly calculated. Quality differences between the ground water of the upper and lower basins are distinct (Showalter and others, 1984), which suggests the quantity of ground water flowing from the upper basin to the lower basin may be small.

Ground-Water Flow Barriers

The constriction in the alluvial valley between Bradley and San Miguel functions as a ground-water flow restraint. The alluvium is much more permeable than the underlying Paso Robles Formation. Although ground water probably flows continually from the upper basin to the lower basin through the Paso Robles Formation, it may not always flow through the alluvium. The Paso Robles Formation forms a virtual weir in this reach, and ground water may not always be high enough to reach the weir notch--that is, the base of the alluvium.

Faults commonly function as ground-water flow restraints. In the study area, major faults parallel the direction of ground-water flow and are outside of the water-bearing sediments; consequently, they do not restrict ground-water flow. Some tributaries, such as the Arroyo Seco and the Nacimiento and the San Antonio Rivers, cross faults that could restrict flow, but water-table offsets indicating restricted flow have not been observed.

Slope of the Water Table and the River Channel

The autumn 1980 water-table elevation along the Salinas River and altitude of the lowest point (thalweg) across the river channel at selected locations are plotted in figure 20. The channel slope indicates the topography of the river-valley changes. From the tidal zone to King City, the channel slope averages approximately 4 ft/mi. In this reach the Salinas River has formed a broad flat valley where the Salinas agricultural industry is centered. From King City where San Lorenzo Creek joins the Salinas River to the confluence of the Salinas and the Estrella Rivers, the channel slope averages about 7 ft/mi. The alluvial valley narrows in this reach and is less than a mile wide at Bradley.

Where the water table is above the channel bottom, the stream is gaining--that is, ground water is flowing into the stream channel. Where the water table is below the channel bottom, the stream is losing; that is, surface water is percolating through the channel to the water table. This rule does not apply north of Chualar (outside of this study area) because a series of clay layers separates the river from the aquifer.

It is important to understand where the stream is gaining or losing in order to manage ground-water recharge and to track the movement of dissolved constituents. Throughout most of the study area the channel of the Salinas River and the water table are at approximately the same altitude (fig. 20), which indicates the Salinas River shifts from a losing stream to a gaining stream from time to time, depending on fluctuations in water-table altitude. Streamflow records indicate a net loss as the river flows northward, so the river is normally losing in this reach.

Historic Water-Level Changes

Ground-water levels for each subarea of the Salinas basin in Monterey County have been monitored since 1931. DWR monitored ground-water levels from 1931 to 1951; since 1951, monitoring has been done by MCFCWCD. The average water-level change has been calculated by averaging water-level measurements made in each subarea. The decline from 1944 to 1980 has been only 2 feet in the Forebay and 1 foot in the Upper Valley; no records are available for the Upper Narrows subarea. These declines are not large enough to be significant. Water-level variations of this magnitude can result from annual weather, pumping, or time-of-measurement variations. Recharge water from the reservoirs (Lakes Nacimiento and San Antonio) which began operation in 1957 helps stabilize the water levels in this area.

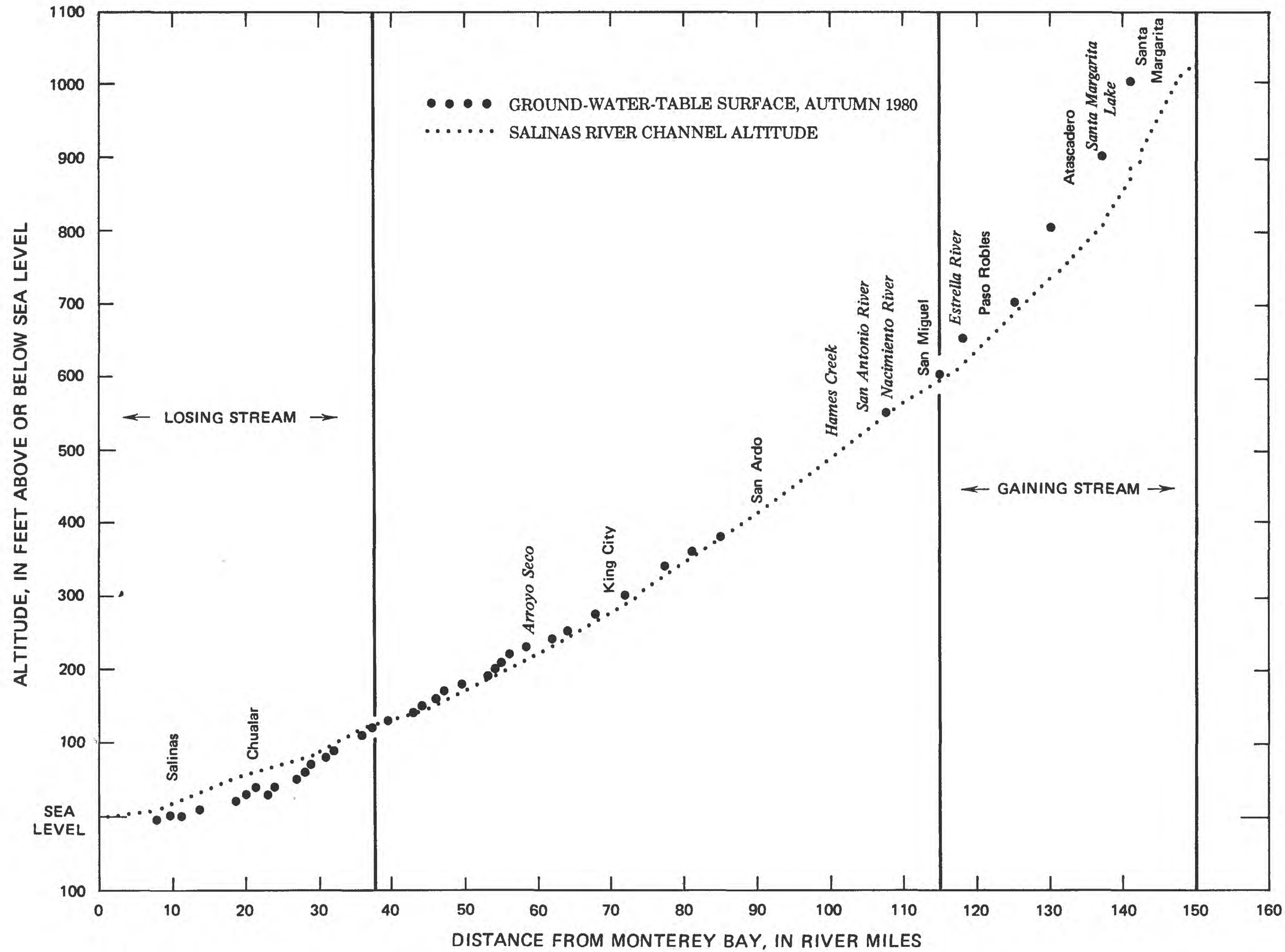


FIGURE 20. — Slope of the autumn 1980 water table and the Salinas River channel (From Showalter and others, 1984).

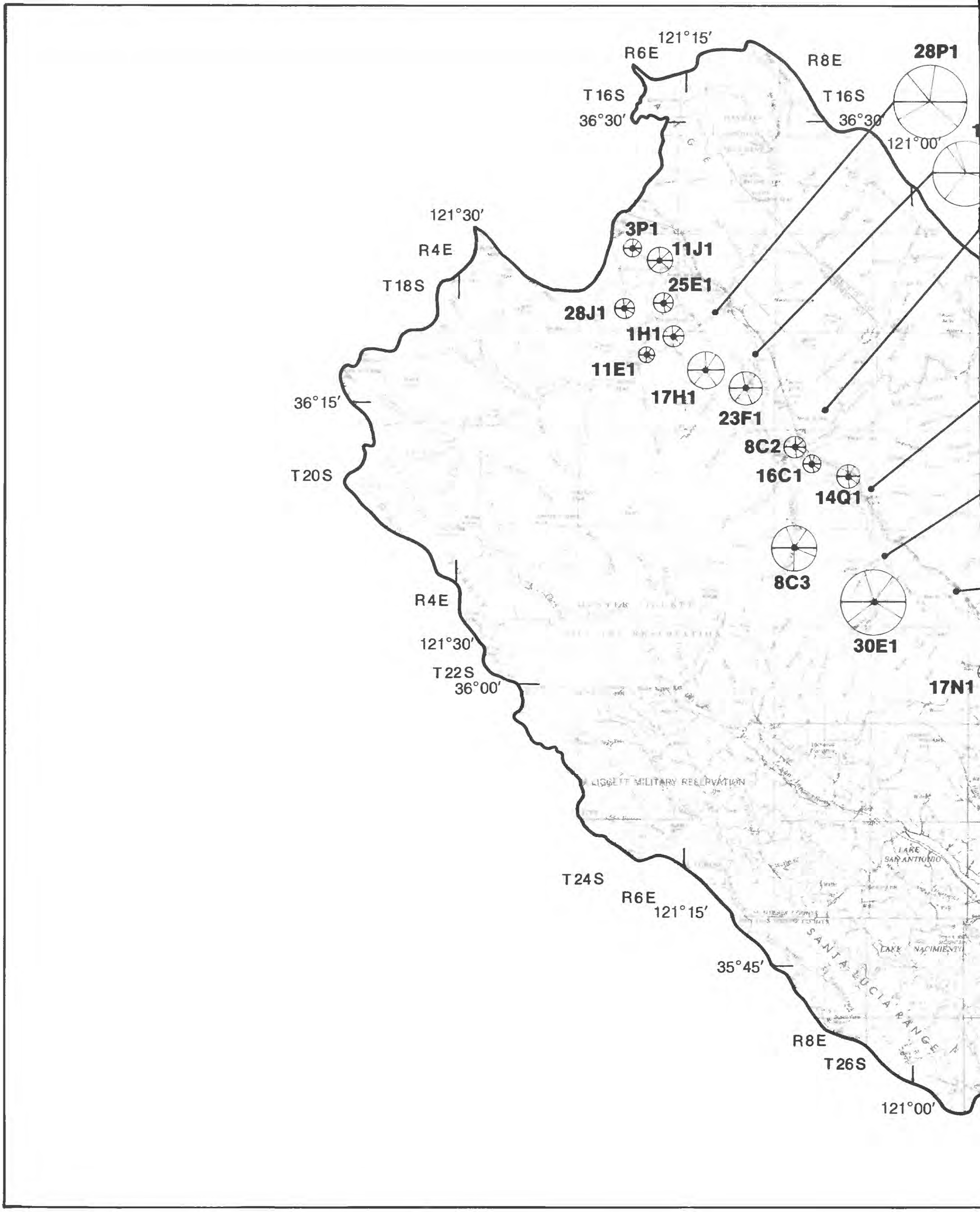
Ground-Water Quality

Variations in the type and quality of ground water in the study area are shown in figure 21. The pie diagrams in this figure represent the percentages of the major cations (calcium, magnesium, and sodium) and anions (bicarbonate, sulfate, and chloride) in the ground water. The analyses used to draw the pie diagrams were made from samples collected during the early 1970's. Results of individual samples, not the average of several samples, were used to draw these pie diagrams. Although the overall ground-water-quality type may still be the same as during the 1970's, values at any specific point probably have changed. As with the surface water, the poorest quality ground water came from the San Lorenzo Creek drainage, and the highest quality came from the Arroyo Seco drainage.

Water quality may be distinguished by the dominant ions expressed as a percentage of the total anions or cations. For example, a calcium bicarbonate water is one in which calcium amounts to more than 50 percent of the anions, in milliequivalents per liter, and a mixed water is one in which no anion or cation amounts to more than 50 percent of the total anions or cations.

Dissolved-solids concentrations range from approximately 300 to 3,000 mg/L in the study area (fig. 21), which is much greater than the range in the Paso Robles basin upstream from the study area (Showalter and others, 1984). This difference between the ground-water quality of the study area and that of the Paso Robles basin probably results primarily from the poor-quality ground water from the San Lorenzo and Pancho Rico Creek drainages. Heavier agricultural development in the study area also may contribute to the differences.

Although general mineral analyses have not been made routinely throughout the study area, specific-conductance and chloride data have been collected by MCFCWCD for more than 20 years. The location of the MCFCWCD monitoring-network wells is shown on plate 1. MCFCWCD also has collected nitrate data routinely from this network since 1978. Most of the monitoring wells are concentrated in the northern part of the study area downstream from King City. Few wells are located in the area from King City to San Ardo. The existing monitoring network does not cover the area between Lynch Canyon (just south of San Ardo) and the southern boundary of the county.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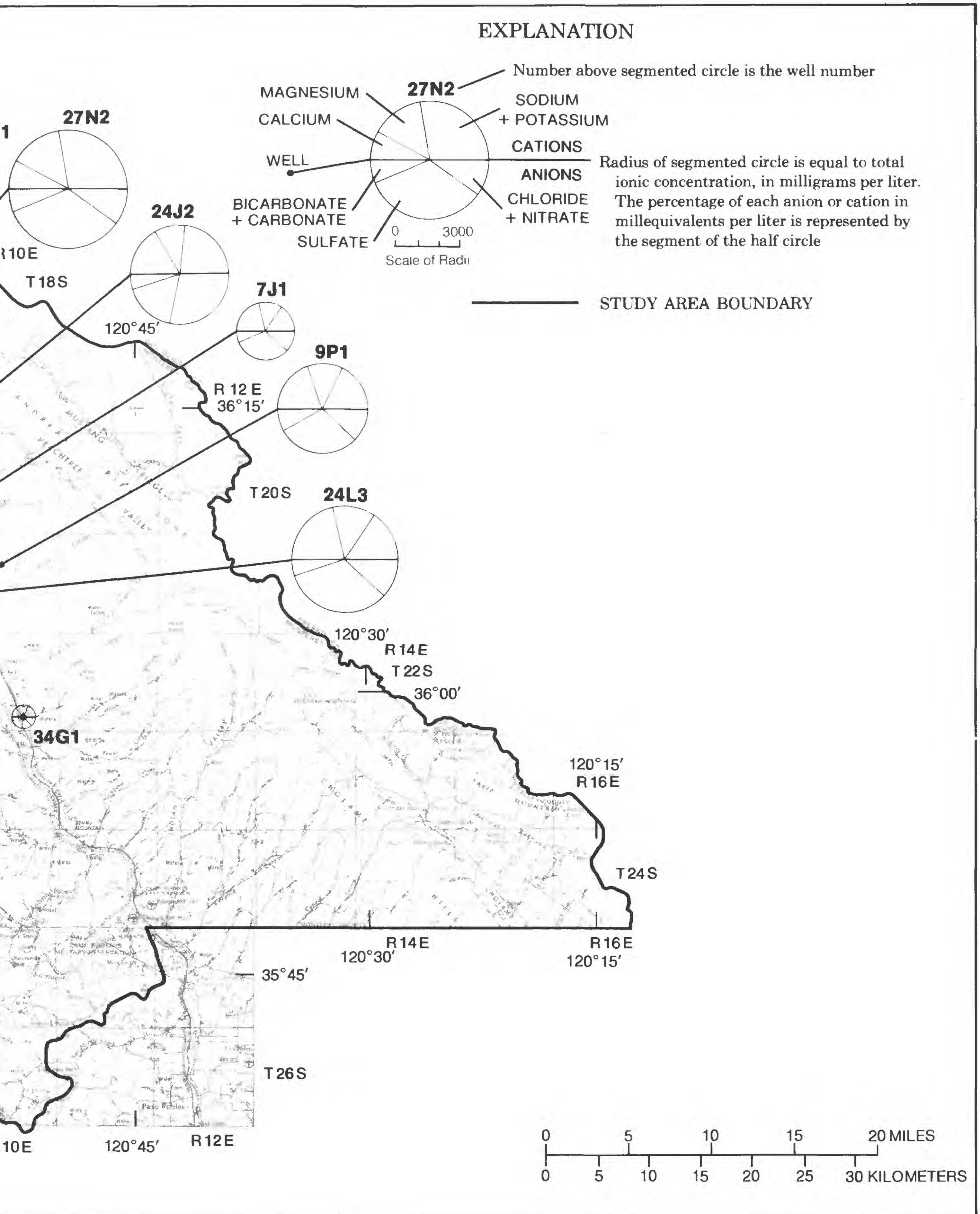


FIGURE 21. — Ground-water quality in the study area (Modified from Showalter and others, 1984).

Specific Conductance

Because only specific conductance and chloride were tested, the improvement in water quality relates only to those two. Specific conductance indicates the mineralization level of water and serves as a general water-quality indicator. Data summarized in table 17 for specific conductance identify significant water-quality changes. Generally, the data indicate that an improvement in water quality has taken place in the study area in the last decade. This statement is based on applying Student's T-test to two periods, 1963-71 and 1972-81. Data from 1963 to 1981 were chosen because they could be transferred easily to computer storage. Tests indicate significance at the 95-percent confidence interval.

A significant improvement (lowering) in specific conductance (at the 95-percent confidence level) did not occur in most townships, but was noted in 4 of the 15 townships. On the other hand, a significant decline in water quality (rise in specific conductance) was not observed in any townships; in all but two townships the mean specific-conductance value for 1972-81 was lower or better than that for the earlier period. In T. 18 S., R. 7 E., an area of intense agricultural development located far downstream from the reservoirs and just upstream from the Arroyo Seco, the mean specific conductance rose from 2,793 to 3,002 µS/cm, but this decline in quality was not significant at the 95-percent confidence level. The Chalone Creek tributary may contribute poor-quality recharge water to the basin at this location. However, data are too sparse at this time to support such a conclusion.

The median values shown in table 17 are a better indication of the central tendency than the mean. In a normally distributed data set, the mean and the median are close if not equal. A median much lower than the mean (skewed toward lower values) indicates that most values are below the mean. This is particularly evident in T. 22 S., R. 10 E., at San Ardo, where the median is almost 500 µS/cm less than the mean. Generally, throughout the study area, the median specific-conductance value is less than the mean.

Specific conductance in the study area ranges from 198 to 6,150 µS/cm, or by a factor of more than 30. The wide range results from large water-quality differences between the east and west sides of the study area.

TABLE 17. - Summary of specific-conductance data, 1963-81

[μS/cm, microsiemen per centimeter at 25°C; N, number of measurements]

Town-ship/range	Number of wells	Specific conductance (μS/cm) Maximum	Minimum	Median	Time period (years)	N	Mean (μS/cm)	Standard error of the mean	Significant difference between means
17S/6E	29	1,900	292	1,125	1	58	1,217.61	45.46	Yes
					2	93	1,025.84	37.67	
18S/6E	24	1,600	270	711	1	50	841.33	44.24	No
					2	124	744.13	28.26	
18S/7E	14	4,433	848	3,080	1	42	2,792.58	139.77	No
					2	76	3,002.28	82.21	
19S/6E	7	1,272	445	966	1	9	1,003.33	29.62	No
					2	15	842.11	66.02	
19S/7E	20	3,700	620	1,418	1	67	1,650.17	86.29	No
					2	105	1,570.95	59.62	
19S/8E	9	6,017	750	3,648	1	29	3,945.34	163.80	Yes
					2	33	3,419.90	186.67	
20S/8E	15	4,363	467	1,277	1	42	1,722.14	166.16	No
					2	63	1,421.34	110.51	
20S/9E	2	4,463	3,000	3,867	1	6	3,818.33	195.65	Insufficient data
					2	1	3,000.00	--	
21S/8E	3	1,365	670	1,113	1	5	1,194.67	27.11	No
					2	13	983.59	65.24	
21S/9E	10	6,150	650	2,339	1	37	2,881.67	199.86	Yes
					2	25	2,232.07	212.07	
21S/10E	3	4,842	1,342	2,423	1	8	3,132.08	404.22	No
					2	17	2,965.98	300.80	
22S/8E	1	538	338	438	1	6	473.33	19.65	No
					2	5	414.33	30.63	
22S/10E	8	5,100	502	1,000	1	30	1,495.33	218.59	No
					2	41	1,480.49	171.85	
23S/8E	12	743	198	408	1	60	432.14	13.74	Yes
					2	37	382.97	11.96	
23S/9E	2	765	525	617	1	9	610.93	28.18	No
					2	6	627.50	31.46	
TOTAL	159	6,150	198	1,167	1	458	1,604.12	41.24	Yes
					2	654	1,343.73	38.81	

No tests were made to link the changes in specific conductance or chloride values to causes, so the possible causes are speculated to be (1) the high-quality water released from Lakes Nacimiento and San Antonio for recharge is improving the quality of the ground water in the study area; (2) the second period was wetter than the first period, so the improvement results from higher precipitation; and (3) the improvement is caused by a land-use change.

The 1970's were wetter than the 1950's and the 1960's. In spite of the 1976-77 drought in California, the average annual rainfall was 12.3 inches at King City for the 1970's; the average annual rainfall was 10.5 inches for the 1960's and was 10.2 inches for the 1950's. The increased rainfall of the 1970's would affect regional ground-water quality favorably, but locally the effect might be negative. For example, increased runoff from poor-quality east-side streams degrades ground-water quality. The magnitude of the improvement caused by the higher rainfall is not known.

The other reason for improved ground-water quality is releases from the reservoirs (Lake Nacimiento which began in 1957 and Lake San Antonio which began in 1966). Only Lake Nacimiento was operating during the first period (1963-71) analyzed for this study; both reservoirs were operating at full capacity during the second period (1972-81). The Salinas River flows between Bradley and Chualar all year because of these releases; before it usually dried up in that reach between June and October. Releases are timed so that no water escapes to the ocean. Released water either percolates to the ground-water system or is lost to evapotranspiration. The amount of water recharged from reservoir releases as calculated by MCFCWCD is shown in table 16. Durbin and others (1978) calculated mean ground-water recharge rate as 96,288 acre-ft/yr; approximately 65 percent of the recharge water is supplied from the reservoirs. Because this water has a low specific conductance relative to most water in the study area, its effect on ground-water quality would be beneficial. The major cause for improvement in specific conductance is probably the high-quality water released from the reservoirs.

The improvement in water quality should move downstream with time. It is beyond the scope of this report to calculate how much the regional ground-water quality of the study area will be improved by reservoir releases. Due to the difference between specific conductance of the release water and the mean for ground water, improvement may continue for several decades.

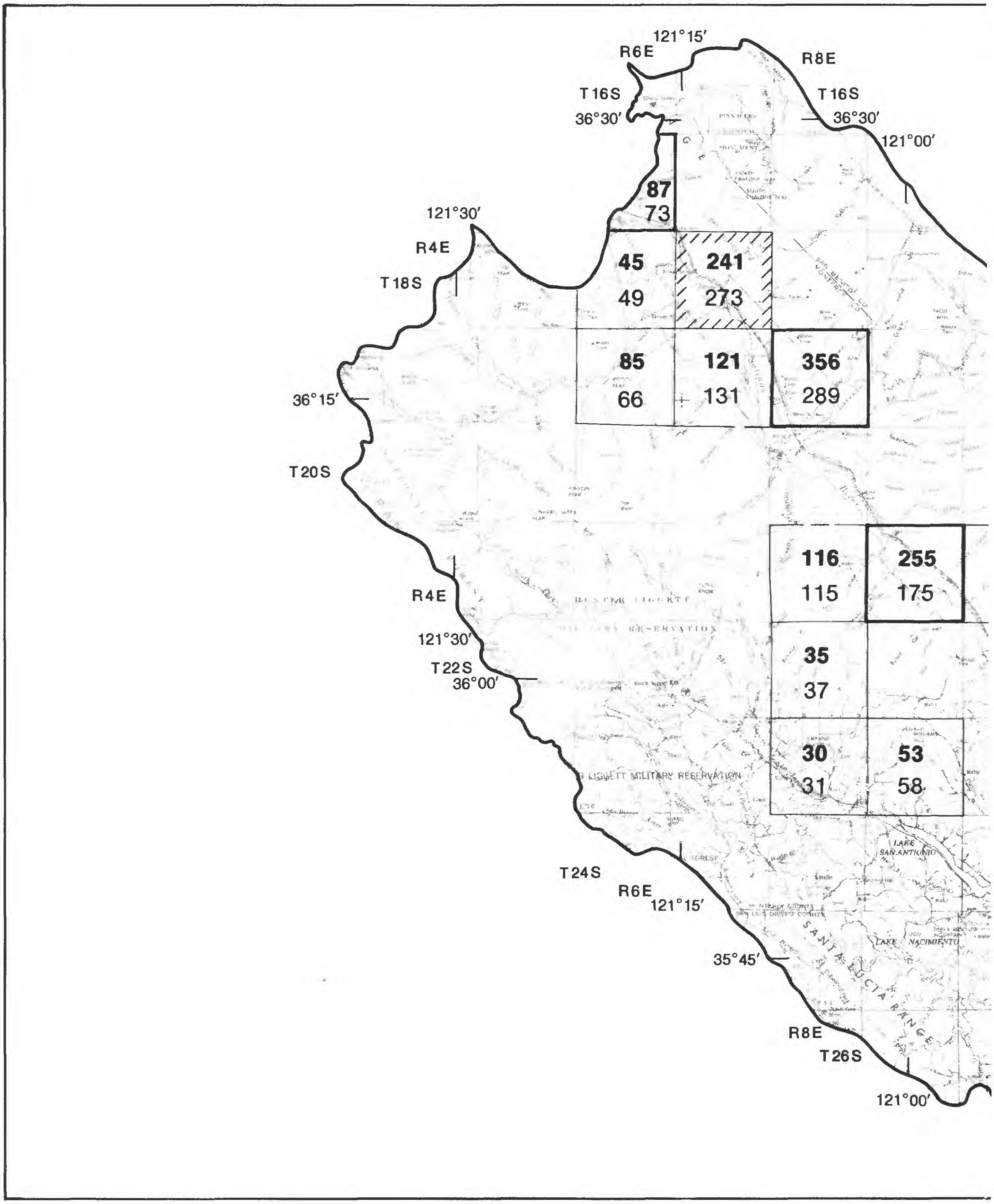
Quality of release water should be monitored because it represents a large percentage of annual ground-water recharge. Any undesirable constituents in release water may be percolated into the ground-water system. Even small concentrations of harmful constituents in release water could detrimentally affect ground water in the study area as a whole. Trace-metal concentrations of release water could be monitored to determine if trace metals are being transported into the main aquifer of the Salinas basin. However, at present, trace metals are not known to be a problem in this area. Any improvement caused by reservoir-release water could be overridden by poor land-use practices.

Chloride

MCFCWCD has collected chloride-concentration data for many years. Chloride is an important component of salt and an indicator of salt-water intrusion in coastal aquifers. In this section of the county where salt-water intrusion is not a hazard, chloride data are less valuable. Chloride data are summarized in figures 22 and 23. Although the mean chloride value did improve (drop) at the 95-percent confidence limit for 1972-81 (fig. 22), fewer townships showed a significant change in chloride than for specific conductance.

In T. 18 S., R. 7 E., a significant increase in chloride concentrations was noted between early and late periods--that is, the quality declined. Specific-conductance values also increased but not significantly. This localized decline in quality probably results from agricultural development or from the poor-quality outflow from Chalone Creek.

The mean and median chloride concentrations (fig. 23) in the northern one-half of the study area are close, indicating that the values are not skewed; in the southern end of the study area most of the median concentrations are below the mean. In the Lockwood area (Tps. 22 and 23 S., R. 8 E.), the mean and median values are close.



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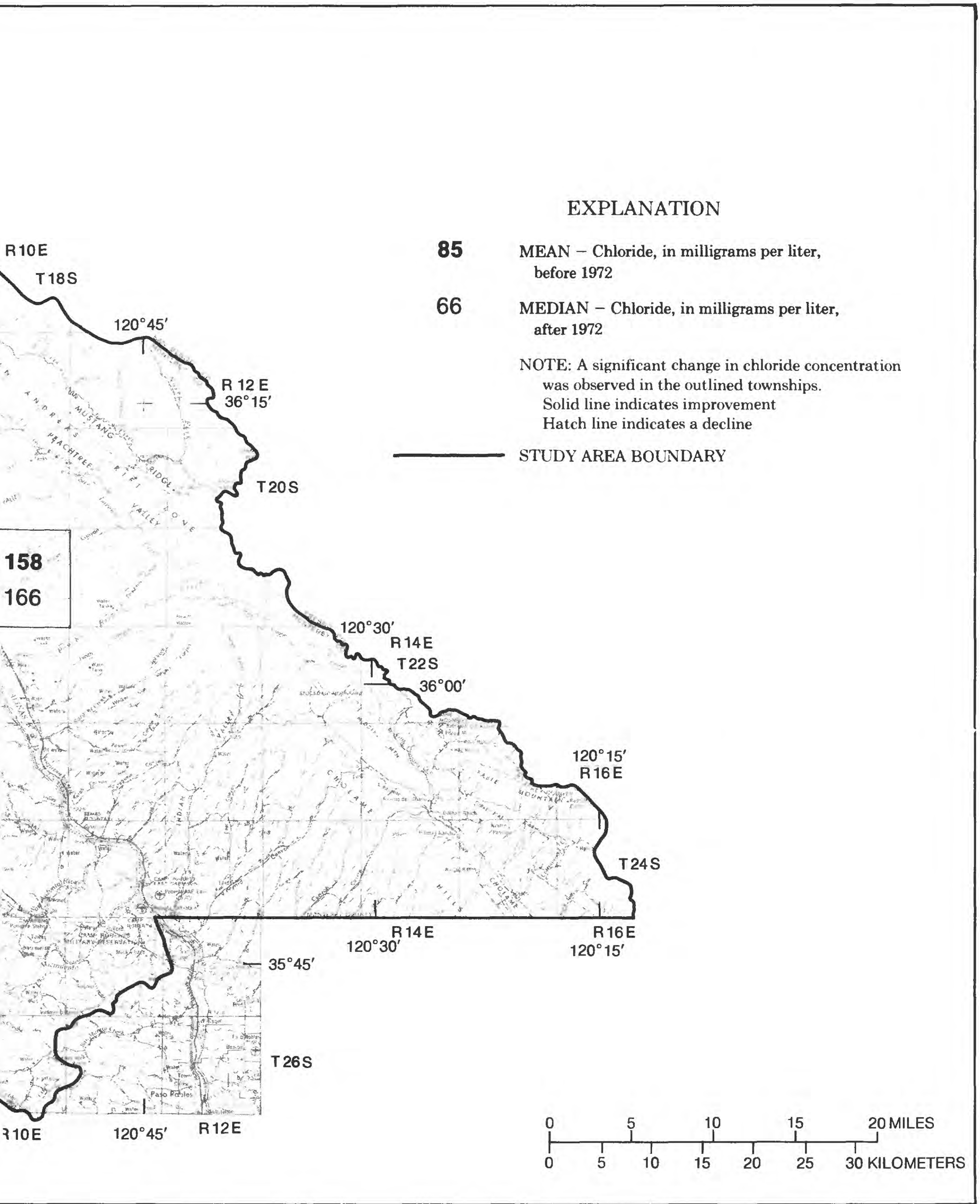
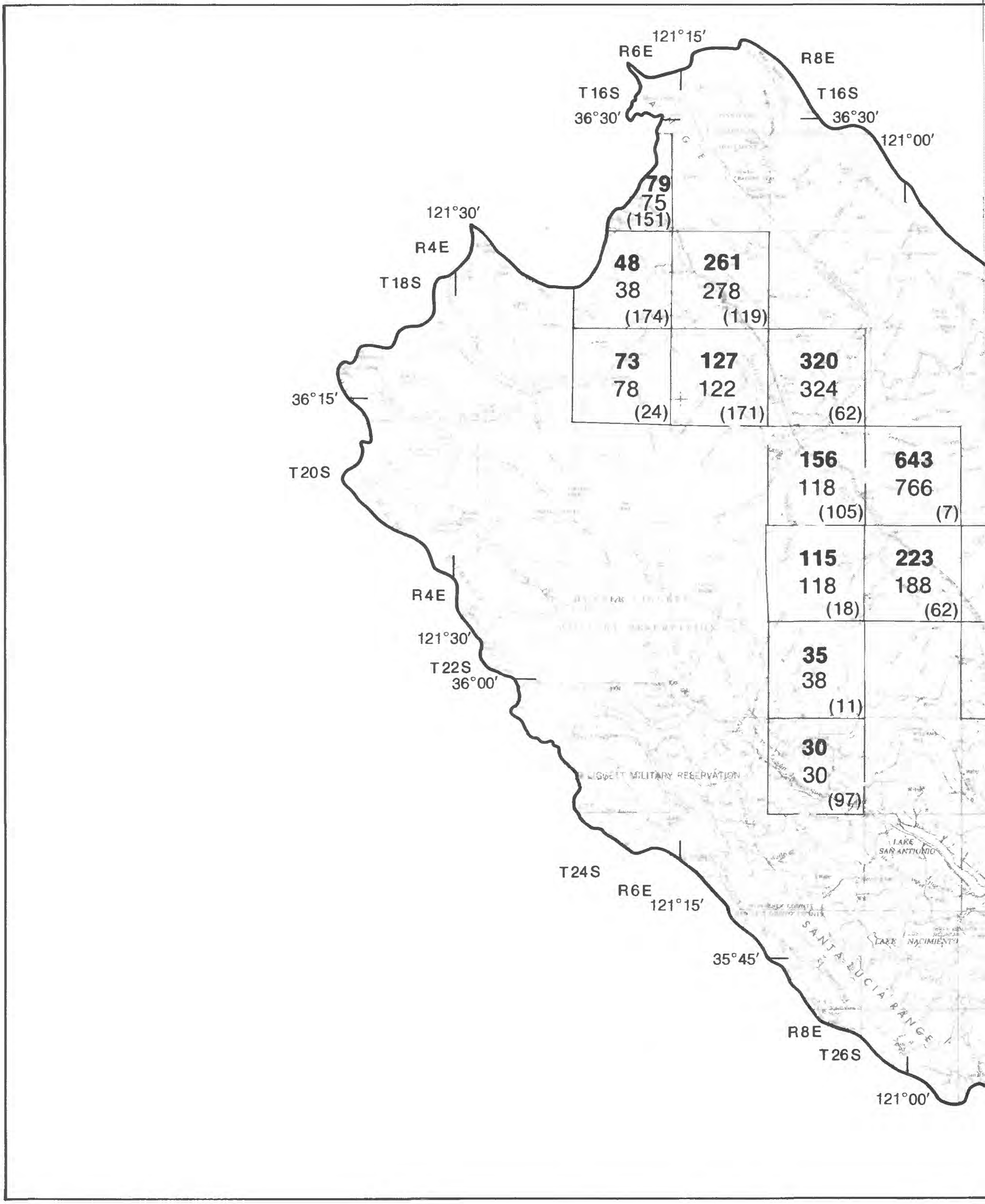


FIGURE 22. – Townships in which the chloride concentrations have increased or decreased since 1972.



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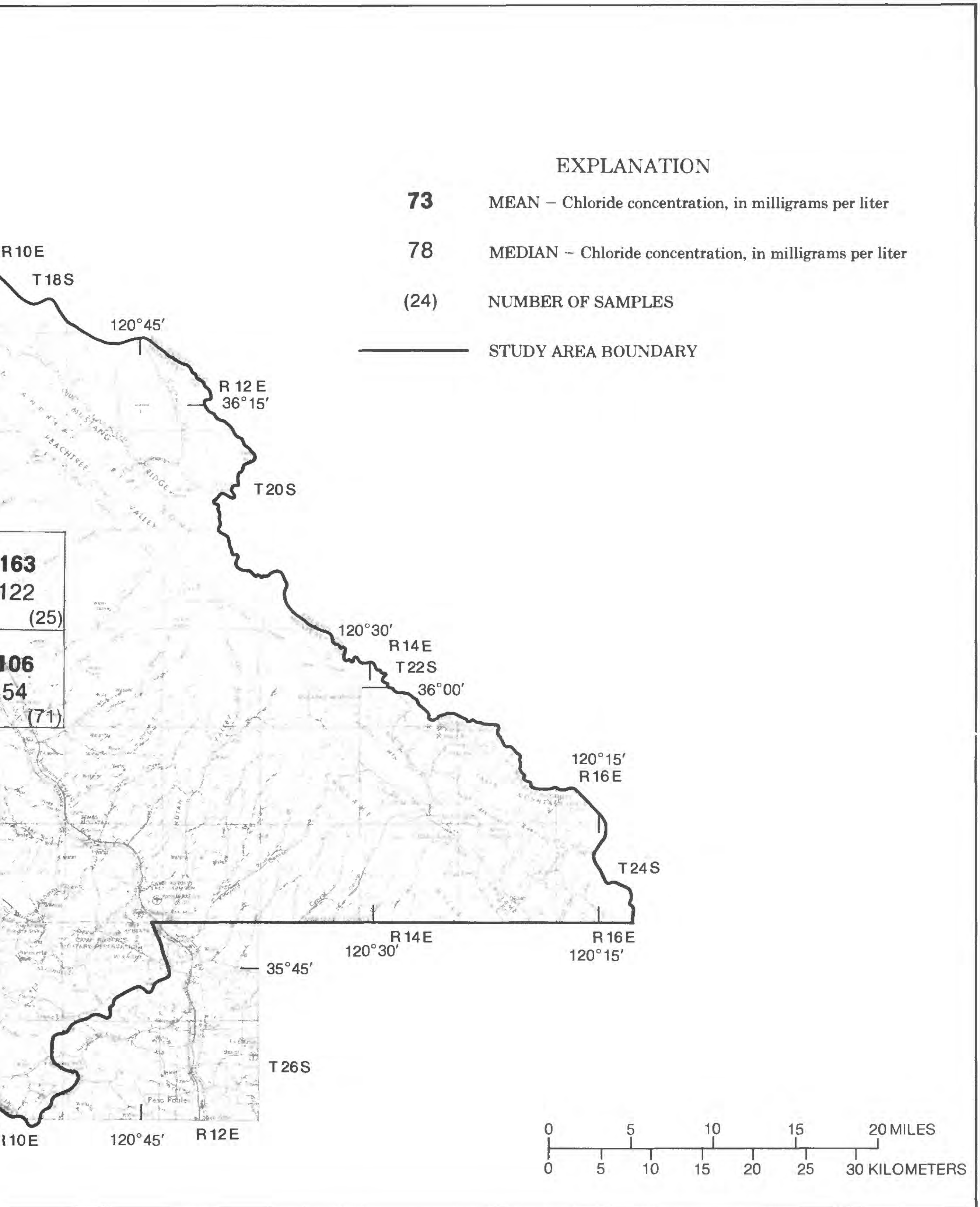


FIGURE 23. – Mean and median chloride concentrations by township, 1963-81.

Nitrate

Drinking-water criterion as set by the U.S. Environmental Protection Agency (1976) require that nitrate concentrations (as NO_3) be below 45 mg/L. The nitrate data collected by MCFCWCD during 1978-81 are summarized in table 18. Because only 3 years of data were available, trend analyses were not attempted. The mean value, 43.7 mg/L as NO_3, is close to the drinking-water criterion. The mean, median, and number of nitrate values analyzed in each township and range are shown in figure 24. The plotted values are so random that contour lines were not constructed. Wells with high values commonly were adjacent to wells with low values. This may indicate different depths that the wells draw from, because nitrate concentrations are often higher near the surface. Sources of nitrate are scattered throughout the study area. In a nonurbanized agricultural area such as the study area, fertilizer and septic-tank effluents are likely sources of nitrate.

The values for each constituent were plotted against those for each of the others to determine relations between the constituents. Nitrate does not relate well with specific conductance or chloride; however, the relation is good between specific conductance and chloride.

Because the relation is high between chloride and specific conductance, it probably is not necessary to continue to measure both at each well. Specific conductance can be measured easily onsite, and measurements should be continued at each well. Chloride analyses are proposed at various locations throughout the study area.

TABLE 18. - Nitrate-concentration data, 1978-81

Mean------------------	43.7 mg/L as NO_3
Median----------------	34.3 mg/L as NO_3
Number of samples-----	207
Minimum---------------	1.5 mg/L as NO_3
Maximum---------------	203.8 mg/L as NO_3
Standard deviation----	33.7 mg/L as NO_3

Proposed Ground-Water Network

Method of Analysis

Definition of objectives.--Network objectives describe information the network is expected to supply. This information probably is not available from raw data alone; instead the raw data must be analyzed in conjunction with other known system facts. Some network objectives are definitely attainable, but others represent goals.

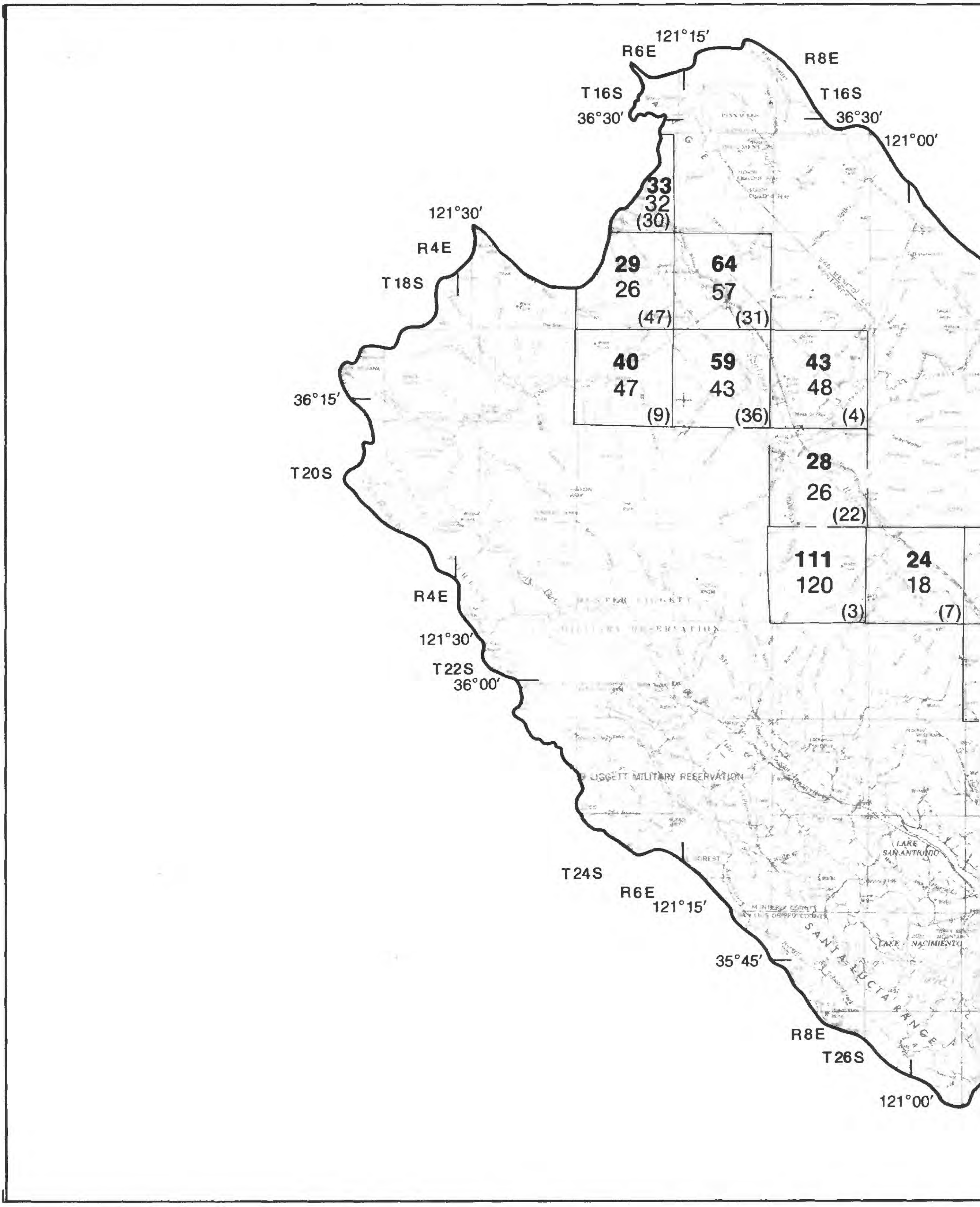
The objectives and priority ratings for the ground-water network were developed cooperatively by the staff of MCFCWCD and the authors. The county staff members made the recommendations cited below. Several iterations were made before the objectives were acceptable. Objectives and their priorities are shown in table 19; 1 indicates the highest priority and 11 the lowest.

The objectives relate to both water-level and water-quality monitoring. Both will be done at each well selected for monitoring because water-level changes sometimes can be used to interpret water-quality changes and vice versa.

Objectives 1, 2, 4, 6, 7, 12 through 16, 21, and 22 relate to water-level monitoring. To meet these objectives, water levels would be measured at each well in the network at least twice each year. MCFCWCD has a dual water-level monitoring system; most wells are measured annually, but some are measured monthly.

Two water-level measurements made annually would separate the recharge period (autumn to spring) from the discharge period (spring to autumn). During autumn to spring, strongest influences on the aquifer are natural, such as rainfall and geology. During spring to autumn, strongest influences are manmade, such as pumping and artificial recharge. One measurement made annually would lump together recharge and discharge phases and provide information about year-to-year changes only instead of information on the range of conditions that occurred during the year.

Objectives 6 and 16 deal with improving the accuracy of water-level measurements to show annual and seasonal changes in storage. To address these objectives, continuous water-level monitoring is suggested at three or more sites in the study area. Although it may not be possible to meet these accuracy objectives with the data collected by this network, the data would improve the understanding of water-level fluctuations. For maximum control, continuous monitoring could be conducted in wells drilled explicitly for that purpose. Water levels could be telemetered to the MCFCWCD offices, and real-time basis or more conventional recorders which require monthly servicing could be used.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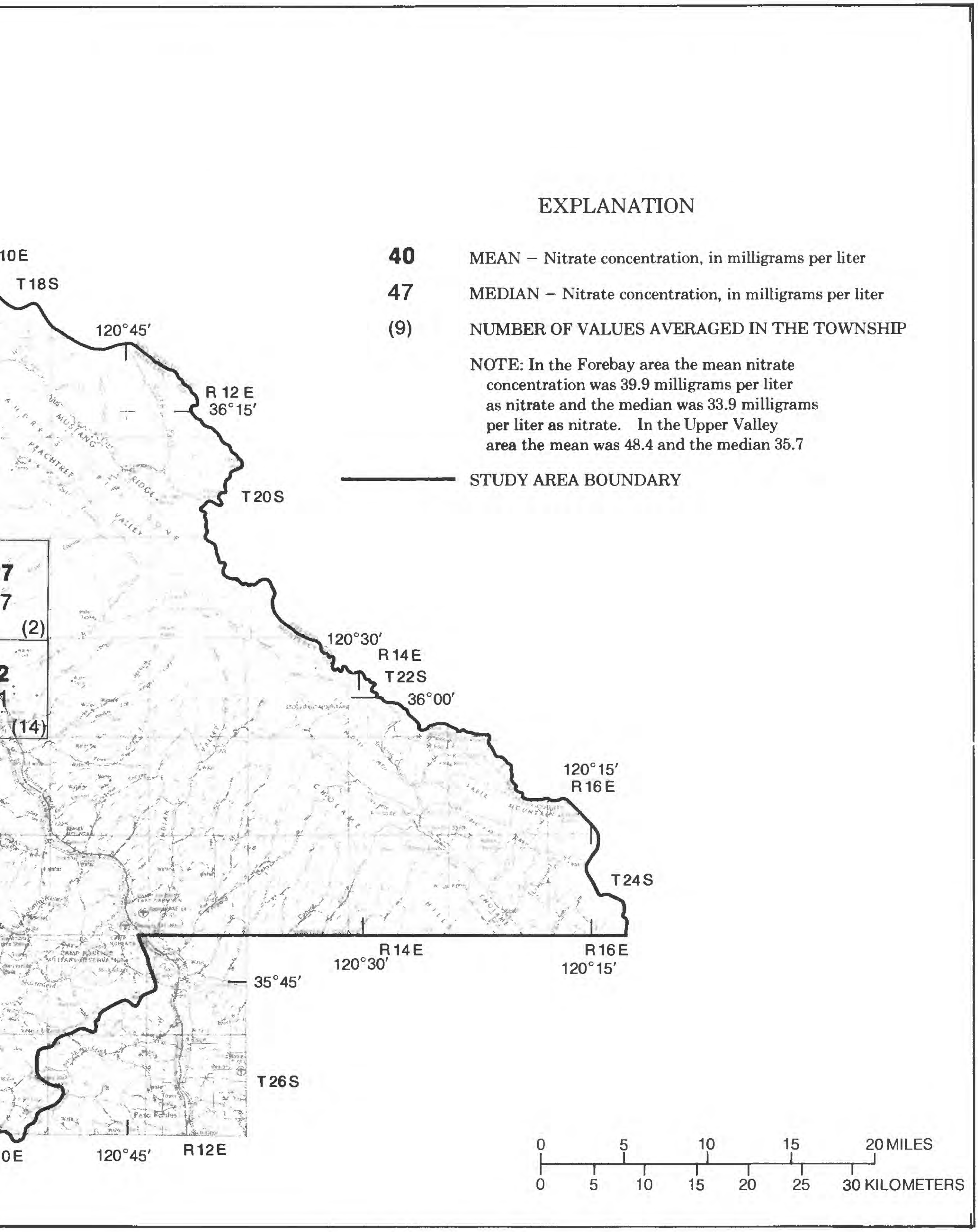


FIGURE 24. — Mean and median nitrate concentrations by township,1978-81.

TABLE 19. - Ground-water monitoring network objectives

Objective	Priority points
1. Determine annual water balance of basin with a breakdown of significant inflow and outflow components	1
2. Determine effect of reservoir-release water on ground-water storage	2
3. Develop a water-quality baseline	2
4. Determine quantity of ground water in storage	2
5. Determine distribution of specific conductance in ground water	3
6. Determine accuracy of annual water-level measurements in monitoring annual changes in storage	4
7. Determine annual ground-water pumpage	4
8. Determine annual consumptive water use by agricultural and urban areas	4
9. Determine distribution of nitrates in ground water	4
10. Determine effect of reservoir-release water on ground-water quality	4
11. Determine need for establishing a ground-water data base in tributary areas	5
12. Monitor ground-water flow patterns	5
13. Determine ground-water outflow and quality from a. San Lorenzo Creek, b. Pancho Rico Creek, and c. Chalone Creek.	5
14. Determine instream locations where river percolation could be enhanced to increase ground-water storage	5
15. Determine characteristics of ground-water aquifers	6
16. Determine accuracy of monthly water-level measurements in monitoring changes in storage due to seasonal pumping demands	6
17. Determine boundaries of the aquifer	8
18. Determine area of influence or cone of depression for large and small wells	9
19. Develop a baseline of organics in ground water	9
20. Determine quality and quantity of flow across Monterey-San Luis Obispo County line	9
21. Establish hydraulic characteristics of faults	10
22. Monitor effect of San Ardo oil field on near-surface aquifer	11

Objectives 3, 5, 9, 10, 11, 13, 17, 20, 21, and 23, which relate to ground-water quality considerations, fall into two general categories: (1) Defining background ground-water quality and change trends, and (2) assessing magnitude of known or suspected water-quality problems. For instance, in many locations around the study area, nitrate occurs in concentrations above drinking-water standards. Increased levels of nitrate could restrict usefulness of ground water as a drinking-water supply. Cadmium identified in sediments of the Arroyo Seco (Majmundar, 1980) may occur in ground water of the Arroyo Seco Cone and should be quantified. The concentration of organics in ground water recently has become a major issue. Because the issue is so complex, it can be dealt with only generally by this network.

Several of the objectives discussed below will not be met by the proposed network; consequently, those objectives were given minimal consideration in choosing wells for monitoring.

Objective 7 is intended to determine annual ground-water pumpage. Changes in the water table monitored by this network could be used, with numerous other necessary factors, to run the flow model of the Salinas Valley described in Durbin and others (1978). The model could generate an estimate of the amount of water pumped. Running the model to get the pumpage estimate is a difficult and time-consuming task beyond the scope of this network-design study.

Objective 8 relates to the determination of annual consumptive water use by agricultural and urban areas. Information collected by the network could be used in programming the model mentioned in objective 7. The model also can be used in estimating consumptive use. Water-level data collected by the network will supply part of the information required to determine the amount of water consumptively used.

Objective 15 was set up to determine the hydraulic characteristics of aquifers. Water-level and water-quality information collected by this network will supply information useful in characterizing aquifers in the study area. Information collected from pump tests and well logs might be equally important in characterizing the aquifers.

Objective 17 was structured to determine the boundaries of the aquifer. Water-level and ground-water-quality information would be useful in delineating hydraulic boundaries of the aquifer. The information will not be sufficient, by itself, to delineate geologically caused boundaries.

Objective 18 was set up to determine the area of influence or cone of depression for large and small wells. Water-level data materially aid in meeting this objective. However, this objective could be better met by a series of aquifer tests to evaluate the transmissivities in the study area.

Objective 19 indicates that more study is required before a monitoring program for organics can be initiated in Monterey County. Monitoring locations for organics are shown in table 20. This distribution was based on land use and the need to develop a baseline of organics throughout the study area. The density of suggested monitoring locations is greater in the Forebay subarea, where agricultural activity is more intense.

Specific organic constituents the samples should be tested for are not given in this report, as the investigation required to pinpoint these constituents was beyond the scope of this study. The Agricultural Extension of the California Department of Agriculture in Salinas compiles records on amounts of controlled substances--generally fertilizers and pesticides--applied in Monterey County; those records may provide a starting place for such an investigation. Knowledge of the behavior of these chemicals (what they degrade to and whether they are transported to the ground water) also would be required.

Objective 21 is to establish the hydraulic characteristics of faults. This information could be better supplied by a series of carefully located aquifer tests.

Other factors considered in selecting monitoring wells.--Data collected in the past by MCFCWCD and information gleaned from analyzing the data were the most important factors considered in choosing wells for this network. In areas where the water quality has improved, less intensive monitoring is suggested.

The range in quality also was an important factor. Generally, the greater the range of specific conductance or nitrate values in a township, the more wells chosen for monitoring. The distribution of wells was chosen by the authors to provide the necessary areal coverage.

Wells with long periods of record were chosen whenever possible. Data from these wells are more useful for statistical analysis, such as the Student's T-test described earlier in this report, than data from wells with short-term records.

Wells designated in Showalter and others (1984) for a ground-water network for the entire Salinas River drainage basin, which was designed to meet the needs of the California State Water Resources Control Board, were chosen for this network whenever possible to avoid duplication of effort. The objectives for the two networks are similar, and commonly the same wells could be chosen. The same sampling categories were chosen whenever possible. Generally, the detail required by the county is greater than that required by the California State Water Resources Control Board, so the network proposed for the county is denser than the network for the State Board.

Good areal distribution was an important consideration in choosing wells for the monitoring network. This resulted in decreasing the number of wells at the north end of the study area and increasing the number at the south end.

Wells Selected

The network of selected wells is summarized in table 20, and the locations are shown in figure 25. The wells are shown in table 21 along with depth of well, depth to perforations, subarea, and sampling categories.

Where monitoring is needed, if a nearby well is not currently used for monitoring, the site is listed by township, range, section, and subsection and is marked in the table with an asterisk to distinguish it from wells. A well should be selected as close as possible to the listed site, based on the following criteria:

1. Perforation data are available, and perforations are at the required depth.
2. Both water-level and water-quality samples can be collected from the well.
3. There is access to the well.
4. The well is maintained in good condition and is serviced regularly.
5. The owner will cooperate.

If a nearby well is not available, the county may need to consider having a well drilled for monitoring.

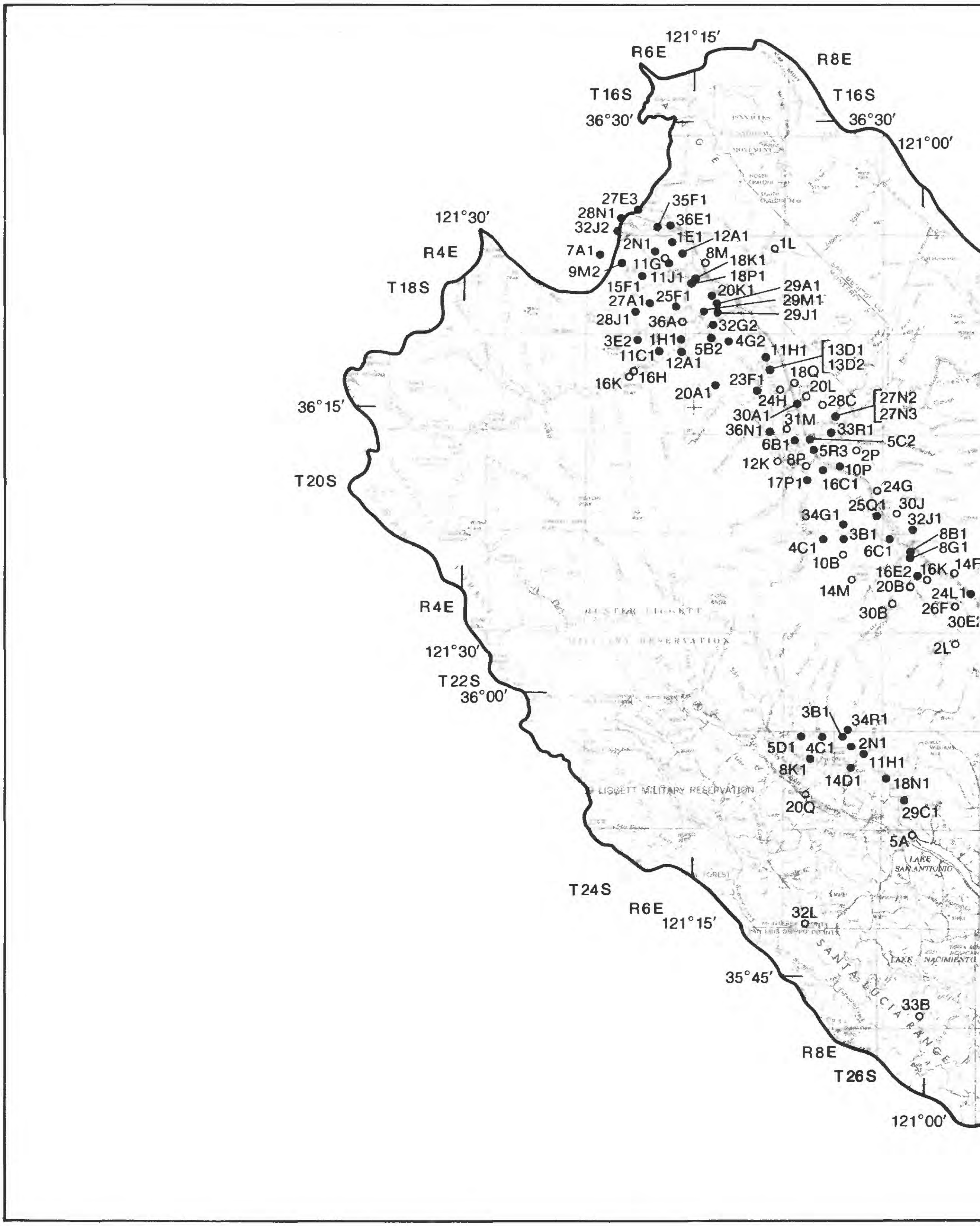
Key wells.--Drilling of three key wells in each subarea is suggested for the network. These key wells are intended for three major purposes:

1. To continuously monitor water-level fluctuations,
2. To collect geologic data, and
3. To better define the geohydrologic characteristics of the study area.

Continuous water-level monitoring would determine the seasonal peak and trough in the water level. This information could be used to time semiannual water-level monitoring runs. Even if operational considerations forced the monitoring runs to be offset several weeks from the peak or trough observed at the key well, the offset would be known.

TABLE 20. - Ground-water network summary

Sampling category	Number of wells	Frequency of measuring
Field tests------------------	145	Annually
General mineral analysis-----	17	Annually
Trace elements---------------	48	Annually first 3 years
Organic pesticides-----------	48	Annually first 3 years
Continuous water-level monitoring-----------------	3	Continuous



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12A1
2N1
7A1
9M2
11G
8M
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1L
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3E2
1H1
5B2
4G2
11C1
12A1
11H1
13D1
13D2
16K
16H
18Q
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4C1
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14D1
18N1
LIGGETT MILITARY RESERVATION
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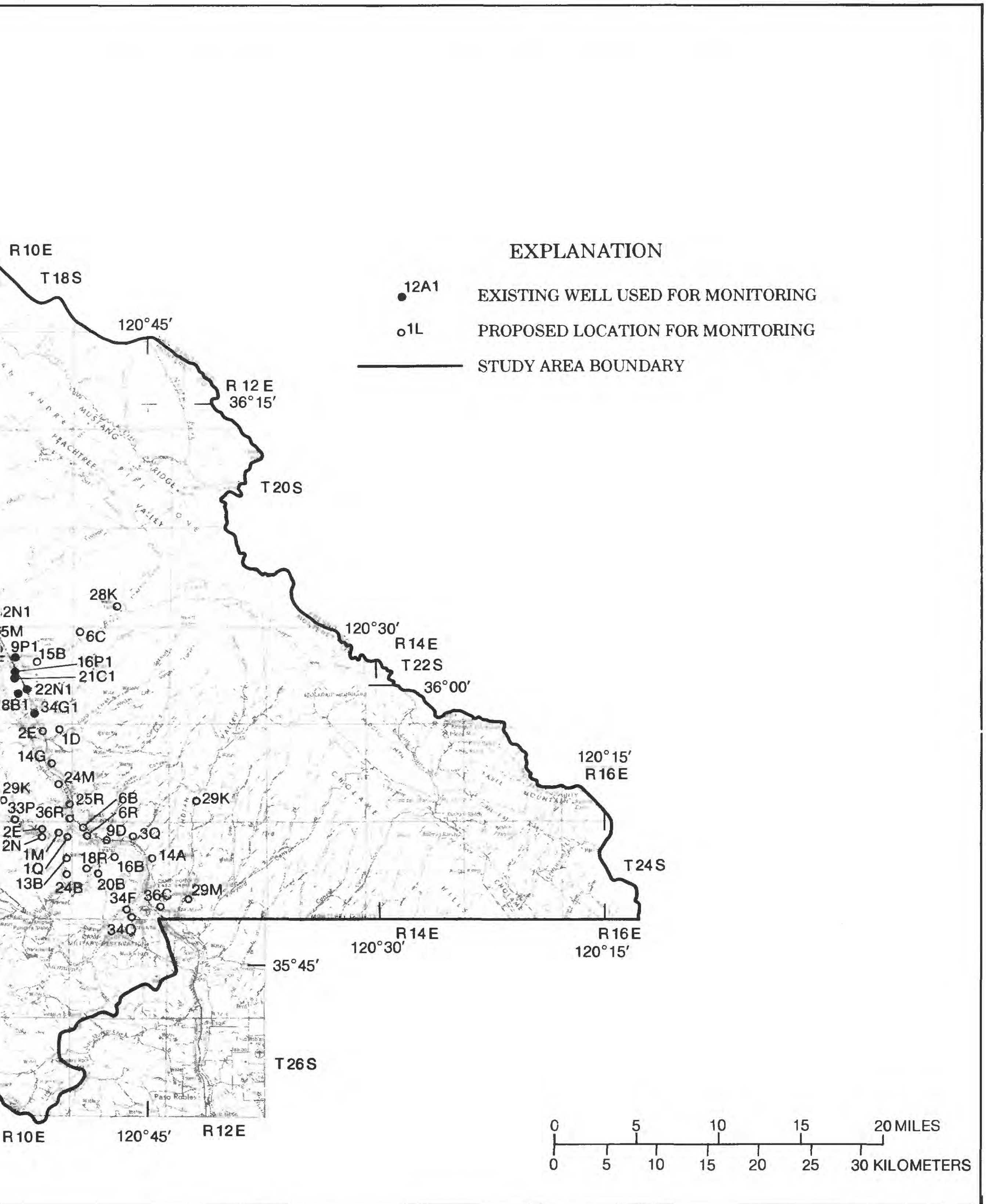

FIGURE 25. — Location of proposed ground-water monitoring network wells.

TABLE 21. - Proposed ground-water monitoring network

[Sampling categories: T, trace elements; O, organic pesticides; GM, general mineral; and C, continuous water-level fluctuations]

State well No. or location	Depth of well (feet)	Depth to perfor-ations (feet)	Wells monitored as of 1983 Levels	Quality	Subarea	Sampling categories[1]	Objectives in addition to 1,3,5,7,9,12,15 (see table 19)
17S/6E-27E3	220	188	X	X	Forebay	T,O	2,8,10,14,20
-28N1	260			X	Forebay		2,8,10,14
-32J2	250	83		X	Forebay		2,8,10,14
-35F1	242		X	X	Forebay	T,O	2,8,10,14,20
-36E1					Forebay		2,8,10,14
18S/6E-1E1	218	90	X	X	Forebay	T,O	2,8,10,17,20
-2N1	274	80	X	X	Forebay	T,O	8,17,20
-7A1				X	Forebay	T,O	8,17,20
-9M2	589	153	X	X	Forebay	T,O	8,17,20
-11G[2]					Forebay	GM,T,O,C	6,8,16,17,20
-11J1	235	106	X	X	Forebay	T,O	8,17,20
-12A1	244	87	X	X	Forebay	GM,T,O	2,8,10,17,20
-15F1	288	104	X	X	Forebay	GM,T,O	8,17,20
-25F1	120		X	X	Forebay	T,O	8,17,20
-27A1	343		X	X	Forebay	T,O	8,17,20
-28J1	754			X	Forebay	T,O	8,17,20
-36A[2]					Forebay		8,17,20
18S/7E-1L[2]					Forebay		13
-8M[2]	170	75			Forebay		2,8,10,14
-18K1				X	Forebay	T,O	2,8,10,14
-18P1	175			X	Forebay	T,O	2,8,10,14,20
-20K1	200	164	X	X	Forebay	T,O	2,8,10,14,20
-28K1	120		X	X	Forebay	T,O	2,8,10,14,20
-29A1				X	Forebay		2,8,10,14
-29J1				X	Forebay	GM,T,O	2,8,10
-29M1			X	X	Forebay		8
-32G2			X	X	Forebay	T,O	8,20
19S/6E-1H1			X	X	Forebay		17
-3E2			X	X	Forebay	T,O	22,8,11,17,20
-11C1			X	X	Forebay	T,O	22,11,17,20
-12A1				X	Forebay		17
-16K[2]					Forebay		22,11,17
-16H[2]	100	50			Forebay		22,11,17
19S/7E-4G2					Forebay	T,O	2,8,10,20
-5B2			X	X	Forebay	T,O	8,20
-11H1				X	Forebay	T,O	2,8,10,14,20
-13D1			X	X	Upper Valley		2,8,10,14
-13D2				X	Upper Valley		2,8,10,14
-20A1			X	X	Upper Valley		8
-23F1				X	Upper Valley	T,O	2,8,10,14,20
-24H[2]			X	X	Upper Valley	T,O	2,8,10,14,20
-36N1				X	Upper Valley	T,O	2,8,10,14,20
19S/8E-18Q[2]	200	100			Upper Valley		11,13
-20L[2]	150	75			Upper Valley		11,13
-27N2				X	Upper Valley	T,O	20
-27N3	473	402	X		Upper Valley		11,13
-28C[2]	150	75			Upper Valley		
-30A1	228	74		X	Upper Valley		8,11,13
-31M[2]					Upper Valley		
-33R1				X	Upper Valley	GM,T,O	11,13,20

See footnotes at end of table.

TABLE 21. - Proposed ground-water monitoring network - Continued

State well No. or location	Depth of well (feet)	Depth to perfor- ations (feet)	Wells monitored as of 1983		Subarea	Sampling categories[1]	Objectives in addition to 1,3,5,7,9,12,15 (see table 19)
			Levels	Quality			
20S/7E-12K[2]	150	75			Upper Valley		14
20S/8E-2P[2]	150	75			Upper Valley		8
-5C2	296	151		X	Upper Valley		8,11,13
-5R3			X	X	Upper Valley		8,11,13
-6B1	203	70		X	Upper Valley		8,11,13
-8P1[2]	93			X	Upper Valley		2,8,11,13,14
-10P	100	50			Upper Valley		8,11,13
-16C1			X	X	Upper Valley		8,11,13
-17P1	100	50			Upper Valley		8,11,13
-24G[2]	100	50			Upper Valley		8
-25Q1			X	X	Upper Valley	T,O	2,8,14,20
-34G1	432	120	X	X	Upper Valley		8,14
20S/9E-30J[2]					Upper Valley		
-32J1			X	X	Upper Valley		
21S/8E-3B1			X		Upper Valley		
-4C1				X	Upper Valley		
-10B[2]					Upper Valley		
-14M[2]					Upper Valley		
21S/9E-6C1				X	Upper Valley		2,10,14
-8B1				X	Upper Valley	GM,T,O	2,10,14,20
-8G1				X	Upper Valley		2,10,14
-14F[2]	150	75			Upper Valley		2,10,14
-16E2				X	Upper Valley		3,10,14
21S/9E-16K[2]	150	75			Upper Valley	GM,T,O,C	2,6,10,14,16,20
-20B[2]	150	75			Upper Valley		2,10,14
-24L1	120	72	X		Upper Valley		2,10,14
-26F[2]	150	75			Upper Valley		2,10,14
-30B[2]	150	75			Upper Valley		2,10,14
21S/10E-30E2	140	86		X	Upper Valley		2,10,14,23
-32N1			X	X	Upper Valley	T,O	2,10,14,20,23
21S/11E-28K[2]	100	50			Upper Valley		13
22S/8E-34R1				X	Lockwood		11
22S/9E-2L[2]	150	75			Upper Valley		2,13
22S/10E-5M[2]	150	75			Upper Valley		2,10,13,14,23
-8F[2]	150	75			Upper Valley		2,10,13,14,23
-9P1			X	X	Upper Valley		2,10,13,23
-15B[2]	150	75			Upper Valley		2,10,13,23
-16P1	178	40	X	X	Upper Valley		2,10,13,14,23
-21C1	285	40		X	Upper Valley	GM,T,O	2,10,13,14,20,23
-22N1	192	135		X	Upper Valley		2,10,14,23
-28B1	106	36		X	Upper Narrows		2,10,14,23
-34G1	182	85	X	X	Upper Narrows	T,O	2,10,14,20,23
22S/11E-6C[2]	100	50			Upper Valley		2,10,14,23

See footnotes at end of table.

TABLE 21. - Proposed ground-water monitoring network - Continued

State well No. or location	Depth of well (feet)	Depth to perforations (feet)	Wells monitored as of 1983 Levels	Wells monitored as of 1983 Quality	Subarea	Sampling categories[1]	Objectives in addition to 1,3,5,7,9,12,15 (see table 19)
23S/8E-2N1	271	70	X	X	Lockwood		11
-3B1			X	X	Lockwood		11
-4C1				X	Lockwood		11
-5D1				X	Lockwood	GM,T,O	11,20
-8K1			X	X	Lockwood		11
-11H1			X	X	Lockwood		11
-14D1			X	X	Lockwood	GM,T,O	11,20
-20Q[2]					Lockwood		11
23S/9E-18N1			X	X	Lockwood		11
-29C1			X	X	Lockwood	GM,T,O	11,20
23S/10E-1D[2]	150	75			Upper Valley		2,10,14
-2E[2]	150	75			Upper Valley		2,10,14
23S/10E-14G[2]	250	100			Upper Valley	GM,T,O	2,10,14,20
-24M[2]					Upper Valley		2,10,14
-25R[2]	150	75			Upper Valley		2,10,14
-29K[2]					Upper Valley		11
-33P[2]					Upper Valley		11
-36R[2]	150	75			Upper Valley		2,10
23S/12E-29K[2]	100	50			Upper Valley		2,10
24S/8E-32L[2]	100	50			Lockwood		11
24S/9E-5A[2]					Lockwood		11
24S/10E-1M[2]					Upper Narrows		2,10,14
-1Q[2]					Upper Narrows		2,10,14
-2E[2]					Upper Narrows		2,10
-2N[2]					Upper Narrows		2,10
-13B[2]	150	75			Upper Narrows		2,10
-24B[2]	125	75			Upper Narrows		2,10
24S/11E-3Q[2]	100	75			Upper Narrows		2,10,14
-6B[2]	100	75			Upper Narrows	GM,T,O	2,10,14
-6R[2]	100	75			Upper Narrows		2,10,14
-9D[2]	100	75			Upper Narrows		2,10,14
-14A[2]	100	75			Upper Narrows		2,10,14
-16B[2]	100	75			Upper Narrows		2,10,14
-18R[2]	100	50			Upper Narrows		2,10,14
-20B[2]	100	50			Upper Narrows		2,10,14
-34F[2]	100	50			Upper Narrows		2,10,14
-34Q[2]	100	50			Upper Narrows		2,10,14
-36C[2]	100	50			Upper Narrows	GM,T,O,C	2,6,16,20,21
24S/12E-29M[2]	200	100			Upper Narrows		11,21
25S/9E-33B[2]	100	50			Upstream from Nacimiento	GM,T,O	11,20

[1]All wells should be sampled for field tests. In addition some wells should be sampled for general mineral, trace elements, organic pesticides, and continuous water-level fluctuations as listed.

[2]Proposed sampling location. Not the site of a known existing well. A well suitable for monitoring should be found near this location. If no well is available for monitoring, a well should be drilled.

Monitored fluctuations at key wells should be as typical of fluctuations throughout the subarea as possible. In other words, interference from pumping should be kept to a minimum--whether pumping comes from nearby wells or from the monitoring well itself. If possible, interference from other sources such as the river also should be minimized. Although seasonal fluctuations are of primary interest, records of daily and monthly fluctuations would be available for other purposes.

Key wells perforated in the same zone as most wells in the subarea would represent the fluctuations of most subarea wells. A survey of perforation intervals and pumping depths would be required to determine what depth to set the perforations in the key well.

Key wells also would serve as a source of geologic data. As each well is drilled, samples should be collected to be analyzed for grain-size distribution and mineralogy. Logs, such as E-logs and gamma logs, should be run to provide data for correlation with other subarea wells. Geologic information provided by these wells should be useful in future modeling work in the area.

Aquifer tests run on key wells would provide better estimates of storage and transmissivity values of the study area. Few aquifer tests have been documented in the Salinas River basin (Showalter and others, 1984), but the information would have widespread use. Storage and transmissivity data would be particularly valuable in any modeling efforts. In order to conduct aquifer tests, observation wells will need to be drilled at key well sites. Key wells would need to be large enough to accommodate whatever capacity pump is required to conduct the aquifer test. The size requirement should be determined early in the test planning.

Key wells would need to be newly constructed wells in order to fulfill their three purposes. If MCFCWCD conducts the drilling, they can maintain more control over the well, such as specifying perforation interval, size, depth, and construction techniques, rather than if an abandoned pumping well was outfitted for continuous water-level monitoring.

Key well should be sited so that a nearby well could be used for periodic water-quality sampling; this periodic sampling is not proposed as part of this study, but the data would be useful for special studies that correlate water-quality and water-level changes.

Sampling Program

All wells would be measured twice annually for water levels--in spring before heavy pumping begins and in autumn when the system is most stressed. If only one measurement is made per year, it could be timed to correspond to the seasonal low. The seasonal low would be determined separately for each subarea based on the continuous record of water levels in the suggested key wells. The key well locations suggested in table 21 as requiring continuous monitoring are 18S/6E-11G, 21S/9E-16K, and 24S/11E-36C, which represent a minimum number of key wells.

Samples could be collected from all the wells in the network to measure specific conductance, temperature, pH, and nitrate. This group of tests, referred to as field tests, should be conducted annually. Nitrate, included in the field test group even though it requires laboratory analysis, should be tested at all wells in the network on a yearly basis. This is a continuation of MCFCWCD's current practice. Because a sample cannot be collected unless the well is operating, these samples cannot be collected at the same time the water level is measured. The county's current practice of collecting samples in midsummer would be continued.

At the 17 selected wells throughout the study area, samples would be collected annually for general mineral analysis including calcium, magnesium, sodium, potassium, iron, total alkalinity, sulfate, chloride, nitrate, fluoride, and boron (table 21). Boron, not normally included in a general mineral analysis, is suggested here because of its importance in agriculture. The analyses would indicate the range in concentration of constituents, identify water-quality types throughout the study area, and be useful for correlating data from field tests. The chloride analysis can be used to check the correlation with specific conductance.

Selected wells also should be analyzed for trace elements including arsenic, boron, cadmium, chromium, iron, lead, mercury, molybdenum, selenium, and zinc. Samples could be collected annually from these wells for the first 3 years and less frequently thereafter.

Data collected by this network should be evaluated for quality control and to test the objectives, and, at least annually, the results should be reviewed for anomalies in the data. Every fifth year a major network evaluation should be made and the network adjusted as needed.

Careful consideration should be taken to insure that the network objectives continue to reflect needs of the MCFCWCD. The network should be tested to see whether it is meeting the objectives. For instance, if sufficient trace-metal data were collected to meet objective 3--develop a water-quality baseline, then trace-metal collection might be curtailed or discontinued.

Data dissemination.--MCFCWCD is probably the major collector of water-resources data in the county, although the U.S. Geological Survey, California Department of Water Resources (DWR), and numerous water purveyors also collect data. Although many data are available to the public, they are not available from a central location. U.S. Geological Survey data are published annually in data reports; DWR's data are available on microfiches prepared annually; Monterey County provides computer printouts on request and plans to resume publication of their annual reports; and the water purveyors, depending on their size, submit their data to either the State or county health departments whose files are available to the public. The data would be easier to access and consequently would be used more frequently if they were available from a single centralized location. To make transfer easy, the data should be maintained in computer readable form. The system could be maintained by MCFCWCD, the major contributors, or by another agency or private contractor. Inherent in developing a countywide data system is the need for a standardized data-reporting system which would include a standard location description and numbering of sampling sites, such as the State well-numbering system, and a standard format for recording data.

SELECTED REFERENCES

Bras, R. L., and Rodriguez-Iturbe, I., 1976, Rainfall network design for run-off prediction: Water Resources Research, v. 12, no. 6, p. 1197-1208.

Burch, S. H., and Durham, D. L., 1970, Complete Bouquer gravity and general geology of the Bradley, San Miguel, Adelaida, and Paso Robles quadrangles, California: U.S. Geological Survey Professional Paper 646-B, 14 p.

California Department of Public Works, Division of Water Resources, 1946, Salinas basin investigation: California Division of Water Resources Bulletin 52, 230 p.

California Department of Water Resources, 1981, California rainfall summary--Monthly total precipitation, 1849-1980: 43 p.

Carrigan, P. H., Jr., and Golden, H. G., 1975, Optimizing information transfer in a stream gaging network: U.S. Geological Survey Water-Resources Investigations 30-75, 25 p.

CH2M Hill, 1982, Arroyo Seco Dam feasibility study final report: Report for Monterey County Flood Control and Water Conservation District, 109 p.

Chang, M., 1977, An evaluation of precipitation gage density in a mountainous terrain: Water Resources Bulletin, v. 13, no. 1, p. 39-46.

Colby, B. R., 1956, Relationship of sediment discharge to streamflow: U.S. Geological Survey open-file report, 169 p.

Dawdy, D. R., Kubik, H. E., and Close, E. R., 1970, Value of streamflow data for project design--a pilot study: Water Resources Research, v. 6, no. 4, p. 1045-1050.

Durbin, T. J., Kapple, G. W., and Freckleton, J. R., 1978, Two-dimensional and three-dimensional digital flow models of the Salinas Valley ground-water basin, California: U.S. Geological Survey Water-Resources Investigations 78-113, 134 p.

Durham, D. L., 1974, Geology of the southern Salinas Valley area, California: U.S. Geological Survey Professional Paper 819, 111 p.

Hardison, C. H., 1969, Accuracy of streamflow characteristics, in Geological Survey Research 1969: U.S. Geological Survey Professional Paper 650-D, p. D210-D214.
Maddock, Thomas, III, 1974, An optimum reduction of gauges to meet data program constraints: Bulletin of the International Association of Hydrologic Sciences, v. 19, no. 3, p. 337-345.
Majmundar, H. H., 1980, Distribution of heavy elements hazardous to health, Salinas Valley region, California: California Division of Mines and Geology Special Report 138, 57 p.
Monterey County Department of Agriculture, 1981, Annual crop report: 16 p.
Monterey County Flood Control and Water Conservation District, 1957, Water supply of Monterey County and plans for its use: 31 p.
Monterey County Planning Department, 1980, Physical features and natural resources of Monterey County: 121 p.
Moss, M. E., and Tasker, G. D., 1979, Progress in the design of hydrologic-data networks: Reviews of Geophysical and Space Physics, v. 17, no. 6, p. 1298-1306.
Nordenson, T. J., 1968, Preparation of co-ordinated precipitation, runoff and evaporation maps: Secretariat of the World Meteorological Organization, 20 p.
Rantz, S. E., 1969, Mean annual precipitation in the California region: U.S. Geological Survey open-file report, 2 maps.
Showalter, Patricia, Akers, J. P., and Swain, L. A., 1984, Design of a ground-water quality monitoring network of the Salinas River drainage basin, California: U.S. Geological Survey Water-Resources Investigations Report 83-4049, 74 p.
Thornthwaite, C. W., 1948, An approach toward a rational classification of climate: The Geographical Review, v. 38, p. 55-94.
U.S. Environmental Protection Agency, 1976, Quality criteria for water: 256 p.
U.S. Geological Survey, 1978, Water resources data for California, water year 1977: U.S. Geological Survey Water-Data Report CA-77-2, 544 p.
Waananen, A. O., and Crippen, J. R., 1977, Magnitude and frequency of floods in California: U.S. Geological Survey Water-Resources Investigations 77-21, 96 p.