DESIGN OF A GROUND-WATER-QUALITY MONITORING NETWORK FOR THE SALINAS RIVER BASIN, CALIFORNIA

By Patricia Showalter, J. P. Akers, and Lindsay A. Swain

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 83-4049

Prepared in cooperation with the

CALIFORNIA STATE WATER RESOURCES CONTROL BOARD

1984

UNITED STATES DEPARTMENT OF THE INTERIOR

WILLIAM P. CLARK, SECRETARY

GEOLOGICAL SURVEY

Dallas L. Peck, Director

For additional information
write to:

District Chief
U.S. Geological Survey
Federal Center, Room W-2235
2800 Cottage Way
Sacramento, CA 95825

Copies of this report
can be purchased from:
Open-File Services Section
Western Distribution Branch
U.S. Geological Survey
Box 25424, Federal Center
Denver, CO 80225
Telephone: (303) 236-7476

CONTENTS

	Page
Abstract	1
Introduction	2
Location and scope	2
Objectives	3
Approach	3
Project limitations	8
Well-numbering system	9
Topography	9
Climate	10
Land use	10
Previous reports	12
Acknowledgments	13
Geology and its relation to ground water	14
Geologic setting	14
Geologic formations	15
Consolidated rocks	15
Semiconsolidated deposits	15
Unconsolidated deposits	17
Basin hydrology	18
Precipitation	18
Streams	22
Stream regulation	22
Surface-water quality	24
Geohydrology	27
Occurrence of ground water	28
Upper basin	28
Lower basin	29
Direction of flow	36
Saltwater intrusion	36
Ground-water-flow patterns	38
Ground-water-flow barriers	42
Slope of the water table and the river channel	43
Historical water-level changes	44
Ground-water quality	45
Upper basin	45
Lower basin	47
Ground-water-quality interest areas	49
General causes	50
Upper basin	50
Lower basin	51
Ideal network	52
Network objectives	52
Approach	54
Monitoring locations	54
Sampling categories	66

	Page
Proposed network	67
Network objectives	67
Approach	68
Monitoring locations	68
Chemical constituents and frequencies	70
Ground-water levels	72
Operation of the network	72
References	74

PLATES

[Plates are in pocket]

Plates 1-7. Maps of the Salinas River basin, California, showing:
1. Land use.
2. Generalized geology and sections.
3. Average annual discharge at stream-gaging stations.
4. Surface-water quality in the Salinas River basin.
5. Ground-water quality types.
6. Ideal ground- and surface-water-monitoring network.
7. Proposed ground- and surface-water-monitoring network.

FIGURES

	Page
Figure 1. Map showing features of the study area	4
2. Graph showing average monthly rainfall at long-term precipitation stations in the Salinas River basin	19
3. Map showing average annual rainfall in the Salinas River basin	20
4-5. Maps showing:	
4. Geohydrologic subareas in the unconsolidated deposits in the Salinas River basin	30
5. Ground-water contours in the Salinas River basin for autumn 1980	34
6. Graph showing slope of the autumn 1980 water table and the Salinas River channel	37
7. Map showing ground-water-quality interest areas in the Salinas River basin	40
8. Graph showing acres of land affected by saltwater intrusion	53
9. Flow chart showing general steps required to implement network	73

TABLES

		Page
Table 1.	Objectives for establishing a ground-water-monitoring network for the Salinas River basin	6
2.	Cities and population centers in the Salinas River basin	11
3.	Geologic units of the Salinas River basin	16
4.	Description of water-quality diagrams shown in plate 4	25
5.	Geohydrologic characteristics of each subarea	32
6.	Average decline in the piezometric surface in the lower basin from 1944 to 1980	44
7.	Proposed surface-water-monitoring locations and sampling categories	55
8.	Ground-water-monitoring locations	56
9.	Number of wells in proposed ground-water-monitoring network by sampling category	69
10.	Ground-water-quality sampling categories	71

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
acres	0.4047	hm^2 (square hectometers)
acre-ft (acre-feet)	.001233	hm^3 (cubic hectometers)
acre-ft/yr (acre-feet per year)	.001233	hm^3/a (cubic hectometers per year)
$[(acre\text{-}ft)/yr]/mi^2$ (acre-feet per year per square mile)	.0004762	$(hm^3/a)/km^2$ (cubic hectometers per year per square kilometer)
ft (feet)	.3048	m (meters)
ft/mi (feet per mile)	.1894	m/km (meters per kilometer)
ft^3/s (cubic feet per second)	.02832	m^3/s (cubic meters per second)
(gal/d)/ft (gallons per day per foot)	.01242	m^2/d (meters squared per day)
gal/min (gallons per minute)	.003785	m^3/min (cubic meters per minute)
(gal/min)/ft (gallons per minute per foot)	.00124	m^2/min (meters squared per minute)
inches	25.4	mm (millimeters)
mi (miles)	1.609	km (kilometers)
mi^2 (square miles)	2.59	km^2 (square kilometers)
µmho/cm (micromhos per centimeter)	1.000	µS/cm (microsiemens per centimeter)

National Geodetic Vertical Datum of 1929 (NGVD of 1929): A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called mean sea level. NGVD is referred to as sea level (SL) in this report.

DESIGN OF A GROUND-WATER-QUALITY MONITORING NETWORK FOR THE SALINAS RIVER BASIN, CALIFORNIA

By Patricia Showalter, J. P. Akers, and Lindsay A. Swain

ABSTRACT

A regional ground-water-quality monitoring network was designed for the entire Salinas River basin by the U.S. Geological Survey. The network is to be implemented by the California State Water Resources Control Board and was designed to meet their needs.

The project was carried out in three phases. In phase 1, monitoring networks that exist in the region were identified. In phase 2, information about the wells contained in each network was collected. In phase 3, factors that influence the ground-water quality--such as geology, land use, hydrology and geohydrology--were studied and a regional network was designed. This report is the major product of phase 3.

Based on a review of available data, published reports, and discussions of known and potential ground-water-quality problems with local officials, an ideal ground-water-quality monitoring network was designed without regard to costs or existing monitoring. This network was then used as a guide in the design of the proposed network which utilizes existing wells and ongoing monitoring efforts. Because pumpage is higher in the basin's unconsolidated sediments than in the consolidated ones, the network is concentrated in the unconsolidated sediment. In areas where network wells are not available, new wells are proposed for addition to local networks. The proposed network is composed of 325 wells and 8 stream-gaging stations.

The data collected by this network will be used to assess the ground-water quality of the entire Salinas River basin. Previously, ground-water quality had only been considered locally or on a countywide basis. After 2 years of data are collected, the network will be evaluated to test whether it is meeting the network objectives. Subsequent network evaluations will be done every 5 years.

INTRODUCTION

A ground-water-quality monitoring network was designed for the Salinas River basin through a cooperative agreement between the U.S. Geological Survey and the California State Water Resources Control Board (State Board). This report describes the network and the methodology used to develop that network. Geology, land use, rainfall, and other background information on the Salinas River basin are also included.

Location and Scope

The Salinas River basin roughly parallels the coast in Monterey and San Luis Obispo Counties, and is the largest basin in California's Coast Ranges (fig. 1). Unlike most reports written about the Salinas River basin, this report is not limited to Monterey County or San Luis Obispo County, but considers the entire basin. In the past, looking at the ground-water system as two separate parts may have been adequate because a relatively small amount of ground water flows northward through the narrows between San Miguel and San Ardo. With the historically low level of agricultural and residential development in southern Monterey County and San Luis Obispo County, the water resources of the area have not been overly developed. Two factors tie the region together from a hydrologic point of view. One is that water released from Lakes Nacimiento and San Antonio in the upper part of the basin recharges the aquifer throughout much of the basin. The second factor is the increased development of the ground-water resources in the upper basin that has resulted from the conversion of approximately 35,000 acres of rangeland to vineyards in southern Monterey County and a similar, though less intense, conversion in San Luis Obispo County. As this development continues, it becomes more important to evaluate the water quality of the entire basin.

Designing a network for the Salinas River basin is only one part of a much larger project. The U.S. Geological Survey and the State Board are cooperating to develop ground-water-quality monitoring networks in 21 ground-water basins in California. The program was started in fiscal year 1979. The order in which these ground-water basins are being studied is specified by the State Board. The Salinas River basin was included in the first group of basins to be studied. Each basin is studied in three phases:

- Phase 1.- Reconnaissance study to determine size and location of ground-water-monitoring networks that are already operating.
- Phase 2.- Collection of data on well construction, sampling categories, monitoring frequency, and period of record for wells used in each network.
- Phase 3.- Design of a basinwide ground-water-monitoring network.

This report discusses the phase 3 study for the Salinas River basin.

Objectives

This project started with the general objective of designing a ground-water-monitoring network that would provide data to characterize the ground-water quality of the Salinas River basin and to evaluate water-quality trends in known problem areas. As the project progressed it became apparent that more specific objectives were required. Specific objectives for establishing a ground-water-monitoring network in the Salinas River basin are prioritized in table 1.

Approach

Numerous reports and information about water conditions in the Salinas River basin were studied to develop an understanding of the basin's structure, climatic variation, history, and development patterns. Several factors which control and affect water quality were identified. These factors include: rainfall distribution, surface-water flow, surface-water quality, ground-water-flow patterns, land use, ground-water recharge, and saltwater intrusion. Problems and potential problems to be addressed in the ground-water-monitoring network also were identified. These problems shaped the objectives of the network.

To address these problems an ideal network was designed first without considering cost or existing monitoring efforts. The ideal network is a conceptual network designed to evaluate the water-quality monitoring needs identified in phases 1 and 2 of the study. It represents the best monitoring scheme to meet the stated objectives. Physical and financial constraints were not considered. The ideal network was reviewed and approved by the California Regional Water Quality Control Board, Central Coast Region, and San Luis Obispo and Monterey County officials.

Using the ideal network as a guide, the authors then designed the proposed network--a practical and cost effective network that makes use of individual monitoring locations from the existing networks. For locations where monitoring was not being done, but where data are required to address important water-quality questions, it was proposed that additional wells be added to existing networks.

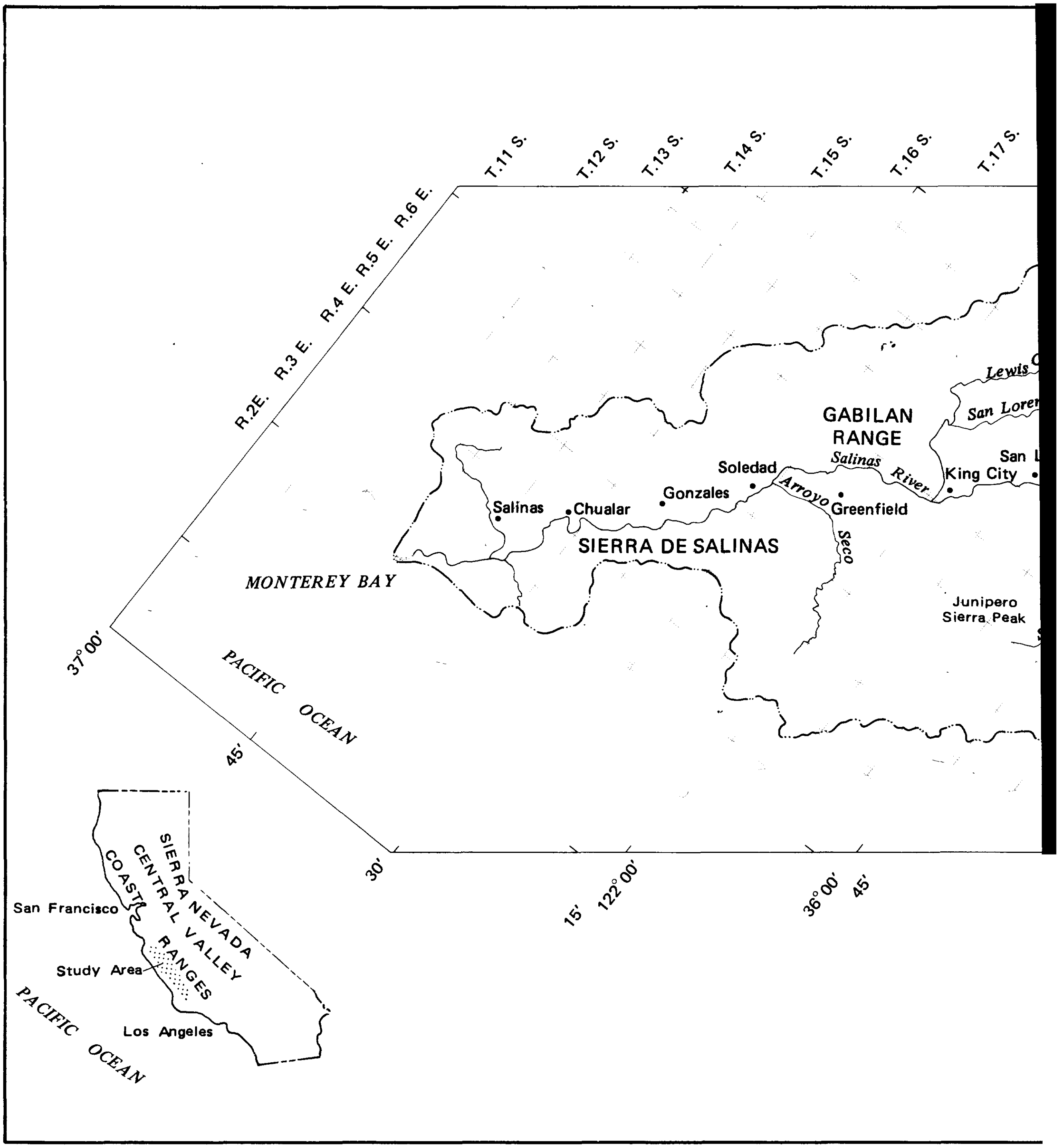


FIGURE 1.—Features of the study area.

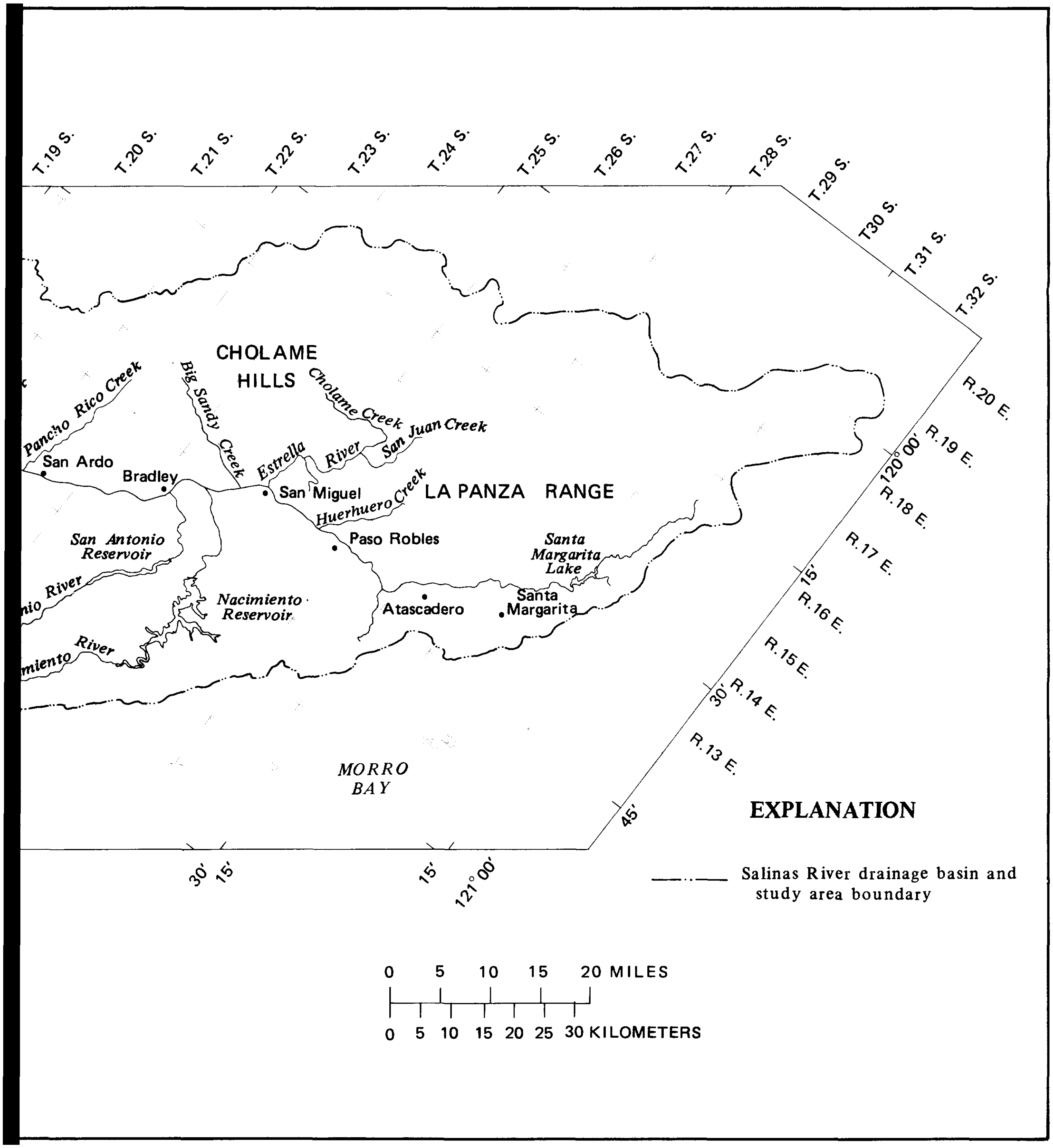

T.19 S.
T.20 S.
T.21 S.
T.22 S.
T.23 S.
T.24 S.
T.25 S.
T.26 S.
T.27 S.
T.28 S.
T.29 S.
T30 S.
T.31 S.
T.32 S.
R.20 E.
R.19 E.
R.18 E.
R.17 E.
R.16 E.
R.15 E.
R.14 E.
R.13 E.
120°00'
15'
30'
45'
30'
15'
15'
121°00'
CHOLAME HILLS
LA PANZA RANGE
Pancho Rico Creek
Big Sandy Creek
Cholame Creek
San Juan Creek
Estrella River
Huerhuero Creek
San Ardo
Bradley
San Miguel
Paso Robles
San Antonio Reservoir
Nacimiento Reservoir
Atascadero
Santa Margarita Lake
Santa Margarita
MORRO BAY
EXPLANATION
Salinas River drainage basin and study area boundary
0 5 10 15 20 MILES
0 5 10 15 20 25 30 KILOMETERS

TABLE 1. - Objectives for establishing a ground-water-monitoring network for the Salinas River basin

Objective	Priority (1 = highest)	Reason for choosing objective
1. To define ground-water flow regime of the basin, including the direction of flow, the rate of flow, and the flow across faults.	1	To determine direction and rate of ground-water flow. Flow rates are related to chemical transport rates and recharge potential. Also to determine if the faults are flow barriers or conduits.
2. To develop a regional water-quality baseline.	1	A data base that is consistent throughout the region is needed. This baseline can then be used to make current and future water-quality management decisions.
3. To monitor the intrusion of saltwater into the valley.	2	Saltwater has intruded the 180-foot and 400-foot aquifers, causing drinking water and irrigation wells to be abandoned. The movement of the saltwater into the aquifer needs to be monitored to assess mitigation measures.
4. To collect surface-water data that can be used to evaluate surface-water influence on ground-water quality.	2	Percolated surface water is the source of ground water. To a large degree, ground-water quality is determined by surface-water quality.
5. To determine the underflow and quality of water from San Lorenzo Creek drainage.	3	A plume of low-quality water flows into the Salinas Valley from the San Lorenzo Creek drainage. Amount of water and its concentration need to be determined so that its effect on the major aquifer can be assessed. In Peachtree Valley, the quality and magnitude of the water supply is unknown.
6. To determine the quality of the ground water in the area where the Estrella River and Huerhuero Creek join the Salinas River.	3	This area seems to function as a natural ground-water sink where chemical concentration of the ground water increases; the network should supply information to confirm or disprove this.
7. To determine the quality and quantity of the recharge resulting from releases from Lakes Nacimiento and San Antonio.	3	These lakes constitute the major source of recharge water in dry years and are an important source in wet years. High quality release water should have a positive effect on the quality of the entire ground-water basin upstream. The impact of release water on the ground-water quality should be quantified. Water-level data would provide better estimates of recharge than streamflow records currently used.
8. To determine the distribution and concentration of nitrates in areas that have been intensively cultivated.	4	The potential for nitrate pollution is high in large areas that have been cultivated for many years. Distribution of nitrates should be quantified.
9. To monitor the quality of ground water downgradient from municipal, industrial, and solid waste site discharges.	4	To determine the level of ground-water impact and whether more detailed monitoring is needed.
10. To determine the sources and approximate distribution of hazardous heavy elements in in the ground water.	5	Arsenic, lead, and mercury are potentially localized problems in the ground water throughout the Salinas River basin. High cadmium, arsenic, lead, and zinc concentrations are found in the phosphatic beds of th Monterey and Pancho Rico Formations, but ground-water samples are not analyzed (Majmundar, 1980). Sampling is recommended in areas of suspected contamination.

TABLE 1. - Objectives for establishing a ground-water-monitoring network for the Salinas River basin--Continued

Objective	Priority (1 = highest)	Reason for choosing objective
11. To determine the underflow and quality of water from Pancho Rico Creek drainage.	6	The flow from Pancho Rico Creek is low and highly mineralized. For example, on 3-6-81 the flow had a specific conductance of 3,176 micromhos per centimeter. Past sampling indicated a plume of low-quality ground water flows from the Pancho Rico Creek drainage. The quantity and quality of that underflow need to be determined.
12. To determine the effect of oil field development on aquifers that are near the ground surface.	6	Aquifers near the ground surface are monitored for evidence of contamination from past brine injection. No evidence of contamination has been found, but monitoring should be continued.
13. In the lower basin, to monitor migration from the Forebay to the Pressure Area and the leakage from the perched to the 180-foot confined aquifers.	6	Velocity of movement of pollutants from the Forebay to the 180-foot aquifer needs to be assessed. For many years the perched aquifer has been recharged by agricultural return flows. There is a need to assess how quickly water is percolating through confining beds to the 180-foot aquifer. Abandoned wells which penetrate the confining beds may serve as conduits between the perched aquifer and the 180-foot aquifer.
14. To provide background information that could be used to map the aquifers in southern Monterey County and in San Luis Obispo County.	7	Ground-water subareas have been delineated elsewhere in the drainage basin, even though it is known that the aquifer is confined in places and unconfined in others. As development continues, better understanding of the ground-water system in the south end of the drainage basin will be needed.
15. To spot monitor for radioactivity in the upper basin.	7	Radioactivity levels in excess of the drinking water standards have been found in one of San Miguel's domestic drinking-water wells. Uranium deposits in the Huerhuero Creek drainage might be the source. Military activities may also have contributed radioactivity.
16. To acquire baseline information that could be used in the future to assess the effect of recent vineyard cultivation on the ground-water quality.	8	Fertilizers and other chemicals applied to vineyards may contaminate underlying ground water. Baseline water-quality data are needed.
17. To quantify the arsenic levels in the Bitterwater area along San Juan Creek.	9	Wells have been abandoned in the Bitterwater area near San Juan Creek because of high arsenic levels. Distribution of the arsenic needs to be mapped.
18. To spot monitor for radioactivity in the lower basin.	10	The uranium deposits of the upper basin and some of the military activities around the drainage basin may have contributed radioactivity to the ground water. Radioactivity needs to be monitored.

Project Limitations

The three major limitations to this project are: (1) no fieldwork was budgeted, (2) well-construction information was not available for all wells, and (3) the quality of available data varied throughout the region. As a result of these limitations the level of sophistication in the finished network varies from place to place. In some locations the network design is based on years of observations, but in other locations it is based only on physical characteristics, such as geology, rainfall, and land use.

Ideally, one round of water samples would be collected at the beginning of the network design. This would provide at least one set of consistent data throughout the study area that the designers could use as a baseline. In a study area as large as the Salinas River basin, collecting just one round of data costs a great deal of money. Consequently, a baseline round of data was not collected.

Well-construction data provides information on the depth of the well, the depth of the perforations, the screen type, the depth of seal, the intended use of the well, and other pertinent data. Well logs indicate which strata the well pumps water from. For shallow wells or wells that penetrate homogeneous sediments, an absence of construction information may not be critical if the depth of the well can be determined. For deep wells that penetrate several aquifers, an absence of construction data makes the wells less useful for water-quality sampling.

Well-construction data are not available for many wells in the monitoring networks presently operating in the Salinas River basin. To keep costs of the monitoring network as low as possible, some stratigically located wells were incorporated into the network even though the construction data for them were incomplete. Every effort should be made to acquire well-construction data for these wells. If the information cannot be located or developed by using well-logging techniques, these wells should be replaced with nearby suitable wells for which construction data are available.

The value of the chemical water-quality data that have been collected in the Salinas River basin varies greatly because of differences in data-collection methods and an absence of local well-construction data. At the north end of the basin, where land has been cultivated for more than a century, high-quality chemical analyses are available. Southward, however, the amount and quality of the data becomes irregular, and in some locations there are no data. In some areas, major changes in the network may be required after several rounds of data have been collected. In other areas, where a great deal of water-quality information is already available, only minor adjustments should be required.

Well-Numbering System

The well-numbering system used by the Geological Survey in California indicates the location of wells according to the rectangular system for the subdivision of public lands. For example, in the number 13S/1E-36R1, the part of the number preceding the slash indicates the township (T. 13 S.); the number after the slash indicates the range (R. 1 E.); the digits after the hyphen indicate the section (sec. 36); and the letter after the section number indicates the 40-acre subdivision of the section as indicated on the diagram below. Within each 40-acre tract the wells are numbered serially as indicated by the final digit of the well number. For wells not being used for data collection or not located in the field by the Geological Survey, the final digit has been omitted. The entire study area is included in the Mount Diablo base line and meridian system.

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

Topography

The Salinas River flows northward, emptying into the Pacific Ocean at Monterey Bay about 125 miles south of San Francisco (fig. 1). It drains an area that extends southward about 150 miles from the mouth and covers approximately 5,000 mi^{2}.

In the north half of the basin, the Salinas River is a braided stream that flows through a broad, flat, alluvial valley. The valley is almost 10 miles wide at Monterey Bay but narrows southward to about 1¼ miles near San Ardo. South of San Ardo, the river winds through a narrow valley bounded by low hills. Near San Miguel, the Salinas River is joined by the Estrella River which flows through a poorly defined shifting sand channel that drains the east half of the upper basin. The Salinas River is joined by Rinconada and Santa Margarita Creeks a few miles upstream from the city of Atascadero where it has a shifting braided channel and flood plains. In the headwaters region it flows through a steep-sided canyon. The headwaters of the Salinas River collect in Santa Margarita Lake behind the Salinas Dam.

The valley rises from sea level at the mouth of the Salinas River to an altitude of about 50 feet at Salinas, 540 feet at Bradley, 720 feet at Paso Robles, and 1,000 feet at Santa Margarita Lake. The Sierra de Salinas and Santa Lucia Range rise abruptly along the west side of the valley floor to a maximum altitude of 5,862 feet at Junipero Serra Peak. The Gabilan and Mount Diablo Ranges bound the east side of the valley. Smith Mountain, having an altitude of 3,947 feet, is the highest point in the eastern ranges.

The south end of the basin is bounded by the La Panza Range, which connects with the south end of the Santa Lucia Range. The highest point in the La Panza Range is Lopez Mountain at 2,868 feet.

Climate

The Salinas River basin has a moderate Mediterranean climate. The weather is moderated by the nearly constant temperature of the Pacific-Peruvian stream which flows northward along the coast. Temperature differences between the ocean and the land generate daily winds. In the late afternoon, a sea breeze cools off the north half of the valley and often brings in fog. In the morning, as the land heats up, the fog dissipates and a breeze develops. In general, the sea breeze is much stronger than the land breeze.

Land Use

The distribution of five land-use categories of the Salinas River basin--agricultural land, urban or developed land, rangeland, forest land, and water and wetlands--are shown on plate 1. This map, based on information collected between 1974 and 1976, was simplified from the U.S. Geological Survey open-file series on land use. More detailed information is available from the California Department of Water Resources, which has mapped land use on a scale of 1:24,000.

Agricultural land, rangeland, and forest land dominate the Salinas River basin. In the lower basin these categories are related to the slope of the land: agricultural land is flat, rangeland is rolling or steep, and forest land is steep. In the upper basin the relationship is not as distinct, but the agricultural land is flatter than the surrounding rangeland and forest land.

In the agricultural land, the intensity of cultivation varies greatly. The most intensely cultivated area is between Salinas and the coast where some of the land produces as many as three truck crops per year. Generally, the intensity of cultivation declines to the south, and south of King City most of the agricultural land is used for vineyards or for grain production. Much larger quantities of water are required to irrigate the intensely cultivated areas in the northern part of the basin.

Urban areas in the Salinas River basin are concentrated along the Salinas River. Salinas, by far the largest urban area in the basin, is less than ten miles from the river mouth. The next largest urban area is Atascadero at the southern end of the basin. Populations for the larger cities are given in table 2.

TABLE 2. - Cities and population centers in the Salinas River basin

[Data from Rand McNally Commercial Atlas & Marketing Guide for 1980, 112th edition]

City	Population
Salinas	80,438
Gonzales	2,906
Soledad	5,896
Greenfield	4,114
King City	5,473
Paso Robles	9,131
Atascadero	16,797

Most of the industries in the Salinas River basin are based on agricultural development and are related to food production. Some examples are vegetable cleaning and packing plants, food processing plants, feed lots, fertilizer distributors, trucking companies, and wineries. The San Ardo oil field, the third most productive oil field in the state, is the largest, non-agriculturally related industry in the basin.

The largest use of water in the Salinas River basin is irrigation. No water is applied to the rangeland or forest land, but virtually all of the agricultural areas are irrigated during the dry summer growing season. During the rainy winter months, very little water is used for irrigation. The quantities of water required vary depending on the weather and on the crop type. A report by Durbin and others (1978, fig. 28) illustrates the monthly distribution of pumping in the lower basin.

The next largest use of water in the Salinas River basin is for domestic and municipal purposes. The amount of water used for domestic purposes is fairly constant throughout the year except for the increase in the summer months for lawn watering. The use of domestic water is scattered throughout the basin, but it is concentrated in the urban areas (pl. 1).

Previous Reports

Several major hydrologic reports have been written about the Salinas River basin and may supply the reader with helpful background information.

U.S. Geological Survey Water-Supply Paper 89, "Water Resources of the Salinas Valley, California," by Hamlin (1904) identifies and evaluates dam sites that would be used for power supply and irrigation water storage. Hamlin provides an excellent description of the terrain and climate. The mineral resources of the area are also evaluated.

Bulletin 52, "Salinas Basin Investigation," California Department of Public Works (1946), is a comprehensive description of the hydrology of the Monterey County section of the Salinas River basin. Bulletin 52 identifies the ground-water subareas that are presently in use and describes the two confined zones that extend northward from Gonzales. Based on water use, projected water needs, and water availability, the report recommends actions required to maintain an adequate water supply. All the data analyzed for the project were published during the 1950's by the California Department of Water Resources and are available from their microfiche archive.

"Two-Dimensional and Three-Dimensional Digital Flow Models of the Salinas Valley Ground Water Basin, California," by Durbin and others (1978), includes all the background information that was needed to develop the flow models. Numerous maps showing the distribution of chemical constituents and physical properties of ground water around the valley are included. The report deals only with the ground-water subbasins that extend northward from San Ardo as outlined in Bulletin No. 52.

The Monterey County Flood Control and Water Conservation District has published annual data reports on surface water, ground water, and precipitation since 1959. These reports include contour maps of autumn water levels and maps of the general water quality. Areas subject to saltwater intrusion are also shown.

Following the development of the Salinas Valley flow models, a project to develop a water-quality model of the same area was started but the project was later suspended. The background information collected for the model study has been used extensively in this report.

The report, "San Luis Obispo and Santa Barbara Counties, Land and Water Use Survey, 1959," California Department of Water Resources Bulletin 103 (1964), presents land- and water-use figures by drainage area; terrain and climate of the counties are briefly described.

"Ground Water in the Paso Robles Basin," by Johanson (1979), summarizes previous reports and the data available in state and county records. Johanson includes a comprehensive description of the hydrologic system and clearly explains the relations between the geology, surface water, and ground water of the Paso Robles basin. The report concludes that although the basin is in a mild state of overdraft, corrective measures are not required.

San Luis Obispo County published biennial hydrologic and climatological data reports from 1969 to 1976. These reports contain contour maps of the county's water levels. The data are still being collected and are available for public use in the County Engineer's office in San Luis Obispo.

The California Regional Water Quality Control Board, Central Coast Region, has jurisdiction over activities that may affect water quality over the area from Santa Cruz to Santa Barbara including the Salinas River basin. Over the years reports have been prepared by the Regional Board and by consulting firms retained by them for the entire region. "Water Quality Control Plan, Central Coastal Basin," (1975) establishes water-quality objectives for surface and ground waters for the purpose of protecting beneficial uses of those waters, and it identifies prohibitions and implementation plans designed to achieve those objectives. Permits to discharge waste from industrial and municipal facilities within the region contain conditions that implement the plan.

Acknowledgments

We thank William A. Leonard of the California Regional Water Quality Control Board, Central Coast Region, Robert L. Binder and Gene H. Taylor of the Monterey County Flood Control and Water Conservation District, and Clinton Milne of the San Luis Obispo County Engineering Department who helped us throughout the project. They provided local insight into the area's water-quality problems and needs as well as data from their monitoring systems.

This report was written in sections. J. P. Akers wrote the geology section. He also served as the technical advisor on the project. In 1978, Lindsay Swain wrote an unpublished report on the ground-water quality of the Salinas Valley (San Ardo north) for another project. His figures and draft were incorporated into the section on ground-water quality. Patricia Showalter, the project chief, is responsible for the remainder of the text and illustrations.

GEOLOGY AND ITS RELATION TO GROUND WATER

The following description of the geology and ground-water hydrology of the Salinas River basin is abstracted mostly from Durham (1974), Durbin and others (1978), the California Department of Public Works, (1946), and Johanson (1979). Ground water accounts for more than 95 percent of the total water used each year in the basin (California Department of Water Resources, Memorandum Report, 1969). Virtually all the ground water used in the basin is pumped from the alluvium and the Paso Robles Formation, the main aquifers in the basin.

The main parts of the Salinas River basin considered in this report are the areas underlain by the unconsolidated alluvial and terrace deposits along the Salinas River and its larger tributaries, and the areas in the upper basin underlain by older unconsolidated deposits where most of the ground-water development has taken place.

Geologic Setting

The Salinas River basin is part of the Salinian Block, a northwest-alined structural-depositional basin that ranges from 10,000 to 15,000 feet in depth (Burch and Durham, 1970). This block is bounded on the northeast by the San Andreas Fault and on the southwest by the Jolon-Rinconada fault zone (see sections B-B' and C-C', pl. 2). The block is characterized by a basement complex of granitic and metamorphic rock overlain by a thick sequence of marine and nonmarine sedimentary rock. The trough is asymmetrical having the thicker sedimentary sequence on the southwest side.

Mountains of the Coast Ranges border the Salinas River basin on the northeast and southwest. The southernmost part of the basin is bounded by the La Panza Range. The mountains on the southwest are complexly faulted and consist of marine sedimentary rock of Miocene and older age, and crystalline and metamorphic rocks of pre-Tertiary age. Those on the northeast are less disturbed and are formed of marine and nonmarine sedimentary rocks of Pliocene and younger age. Southeast of San Ardo is a hilly area formed of nonmarine sedimentary rock of Pliocene and Pleistocene age.

Geologic Formations

This report groups the geologic formations into three general units on the basis of their capacity to yield ground water as was done by Durbin and others (1978). These units are: (1) consolidated rocks that yield only a small quantity of water, in places insufficient to sustain even domestic and stock wells; (2) semiconsolidated deposits that yield small to appreciable quantities of water to wells; and (3) unconsolidated deposits that generally are prolific aquifers. A generalized geologic map showing the areal distribution of these units and their stratigraphic relations is shown on plate 2. Table 3 (from Durbin and others, 1978, p. 16) lists the formations in each unit and summarizes their water-bearing characteristics.

Consolidated Rocks

The consolidated rocks include the basement complex and older marine rocks. The basement complex of pre-Tertiary age (Compton, 1966) is composed of igneous and metamorphic rocks exposed mostly in the Gabilan and La Panza Ranges and in the Sierra de Salinas. These rocks, where sufficiently fractured and (or) weathered, supply small quantities of water to domestic and stock wells.

The older marine rocks include, in ascending order, an unnamed formation of Cretaceous and Tertiary age, and the Reliz Canyon, Berry, Vaqueros, Tierra Redonda, Monterey, and Santa Margarita Formations, all of pre-Pliocene age (Durham, 1974). These rocks are exposed mostly in the mountainous areas on the southwest side of the basin and at the northern end of the La Panza Range (pl. 2). They consist mostly of mudstone, but also have a substantial quantity of conglomerate, sandstone, limestone, and chert. Wells in the sandstone beds generally yield enough water for domestic and stock use; those in the mudstone units generally do not. Most of the oil in the San Ardo oil fields is extracted from sandstone units in the Monterey Formation.

Semiconsolidated Deposits

The semiconsolidated deposits consist of interbedded units of sandstone, conglomerate, and mudstone of the Pancho Rico Formation of Miocene age (Durham, 1974). The Pancho Rico Formation is exposed in large areas on the northeastern side of the Salinas Valley downstream from San Ardo and in small areas near the mountains on the southwest side of the valley. Wells in the Pancho Rico Formation yield small to moderate quantities of water, depending on the texture and saturated thickness of the sandstone and conglomerate penetrated.

TABLE 3. - Geologic units of the Salinas River basin

[Modified from Durbin and others, 1978, p. 16]

Geologic unit		Age	Maximum thickness, in feet	Lithology	Water-bearing characteristics
Unconsolidated deposits	Alluvial deposits	Holocene and Pleistocene	200	Windblown sand--Unconsolidated to semiconsolidated, well-sorted, fine to medium sand.	Generally above water table.
			300	River deposits--Loose, moderately to well-sorted gravel; coarse to fine sand; silt; and clay.	Wells yield 500 to 4,000 gal/min.
			500	Alluvial fan deposits--Unconsolidated to semiconsolidated, poorly sorted gravel, sand, and silt, grading into coarse gravel near fan heads.	Locally wells yield as much as 1,000 gal/min on east side of valley; near Salinas, yields are considerably less.
	Paso Robles Formation	Pleistocene and Pliocene	2,000	Nonmarine deposits--Deposits consisting of unconsolidated to consolidated gravel, sand, and silt.	Wells yield as much as 4,000 gal/min.
Semiconsolidated deposits	Pancho Rico Formation	Miocene	1,200	Younger marine deposits--Deposits of marine sandstone, conglomerate, and mudstone.	In southern part of study area yields are small. In upper units of northern part, wells yield moderate quantities.
Consolidated rocks	Santa Margarita Formation Monterey Formation Tierra Redonda Formation Vaqueros Formation Berry Formation Reliz Canyon Formation Unnamed formation	Tertiary and older	10,000	Older marine deposits--Marine mudstone with some sandstone near base.	Sandstone units yield water sufficient for individual homes. Mudstone facies yield virtually no water.
	Basement complex	Pre-Tertiary	--	Basement complex--Igneous and metamorphic rocks.	Locally, wells yield small quantities from fractures or weathered zone.

Unconsolidated Deposits

The unconsolidated deposits include the nonmarine Paso Robles Formation of Pliocene and Pleistocene age, and alluvium and terrace deposits of Pleistocene and Holocene age. These formations consist of lenticular interbeds of sand, gravel, and silt and are difficult to differentiate in drill cuttings. A few lenticular beds of gypsum occur in the Paso Robles Formation in the upper reaches of the San Lorenzo Creek drainage. The gypsum beds affect ground-water quality because they dissolve into ionic Ca and SO_4.

The Paso Robles Formation is widely exposed in the area between San Ardo, Shandon, and Atascadero where it probably is at least 1,000 feet thick. It is also exposed in small areas mostly on the west side of the Salinas River, and in the upper area of the San Antonio River. It underlies the alluvium at depth in some areas north of San Ardo and is as much as 1,500 feet thick near Greenfield. The Paso Robles Formation is an important aquifer in the Salinas River basin. Wells in this aquifer generally yield from 200 to 4,000 gal/min.

The alluvium includes river deposits, alluvial fan deposits, and windblown sand deposits. It consists of lenticular, interconnected beds of sand, gravel, silt, and clay that have a cumulative thickness of as much as 300 feet. The clay beds are more prevalent and thicker in the lower reaches of the valley where they probably represent estuarine deposits.

The alluvial fan deposits are present on both sides of the valley and represent materials eroded and washed down from the mountains. The 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 usually are composed of finer-grained and better-sorted materials. The maximum thickness of the alluvial fan deposits is probably about 500 feet. In general, the alluvial fan deposits on the southwest side of the valley 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 side commonly yield from 10 to 40 gal/min, although some yield as much as 2,000 gal/min.

The windblown sand deposits are common over large areas on both sides of the river northwest of Salinas, and in small areas that are not adjacent between San Ardo and King City. The windblown sand is well sorted and ranges from a maximum thickness of 200 feet northwest of Salinas to a few tens of feet in the San Ardo-King City area. The sand deposits are not utilized as aquifers, although northwest of Salinas they are partly saturated. They are important to the ground-water system because they facilitate local direct recharge from precipitation.

The remainder of this report concentrates on the unconsolidated water-bearing sediments of the Salinas River basin. Because water is pumped from these sediments, our efforts have been focused on them.

BASIN HYDROLOGY

In the Salinas River basin, where much of the ground water is unconfined and near the surface, the relations between precipitation, streamflow, and ground-water levels are particularly strong.

The distribution of precipitation both in space and time has major impact on surface-flow patterns. Because most recharge to the ground water in the basin takes place through stream channels, the amount and duration of flow determines how much water is recharged to the aquifer. The quality of the recharge water and the chemical makeup of the materials it infiltrates determines the quality of the ground water. To understand the ground-water quality, the precipitation and surface-water patterns must be studied.

Precipitation

Except for occasional snowfalls at high elevations in the Coast Ranges, rain is the only form of precipitation in the Salinas River basin. More than 87 percent of the rain falls from November through April in an average year. Almost no rain falls from June through August. This pattern is apparent in figure 2 which shows the average monthly rainfall for several long-term stations in the basin.

Average annual rainfall in the Salinas River basin is shown in figure 3 (modified from Rantz, 1969, and from Stewart H. Hoffard, U.S. Geological Survey, written commun., 1981). Because of orographic effects and wind patterns, there are large variations in the average annual precipitation throughout the basin. Precipitation is greater along the mountain ridges than in the valley, and it is greater on the west ridge near the ocean than on the east ridge. Average annual rainfall exceeds 30 inches along much of the west ridge and is less than 20 inches along most of the eastern ridge. Annual precipitation along much of the lower Salinas River valley averages less than 14 inches, but increases in the upper part of the basin because of the greater distance from the ocean's moderating winds and the higher elevation.

The amount of rainfall varies greatly from year to year: from 1951 to 1960, total annual rainfall averaged 13.36 inches at Paso Robles; only 6.80 inches fell in 1953; and in 1958, 23.08 inches fell. This high variability is typical throughout California.

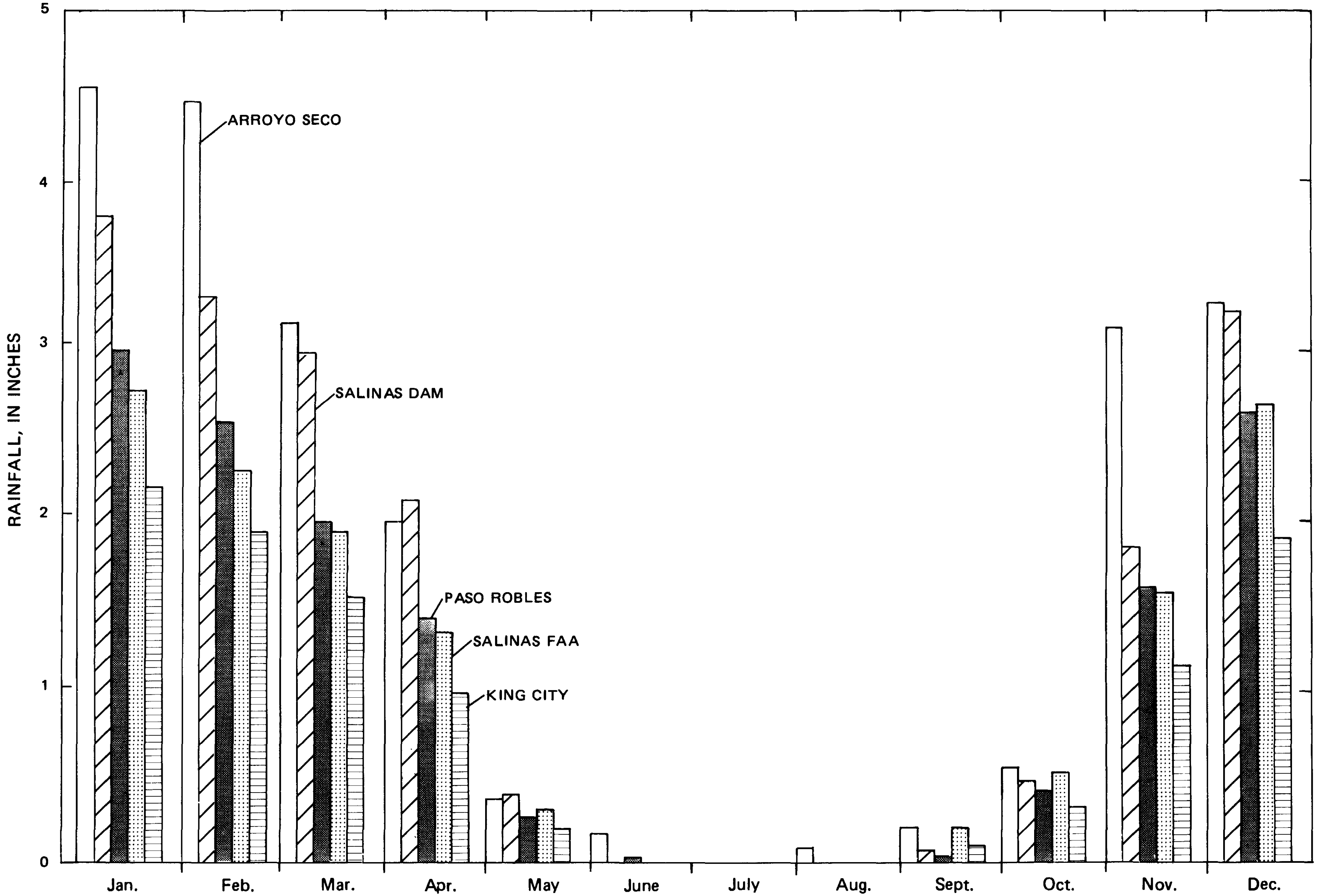


FIGURE 2.—Average monthly rainfall at long-term precipitation stations in the Salinas River basin.

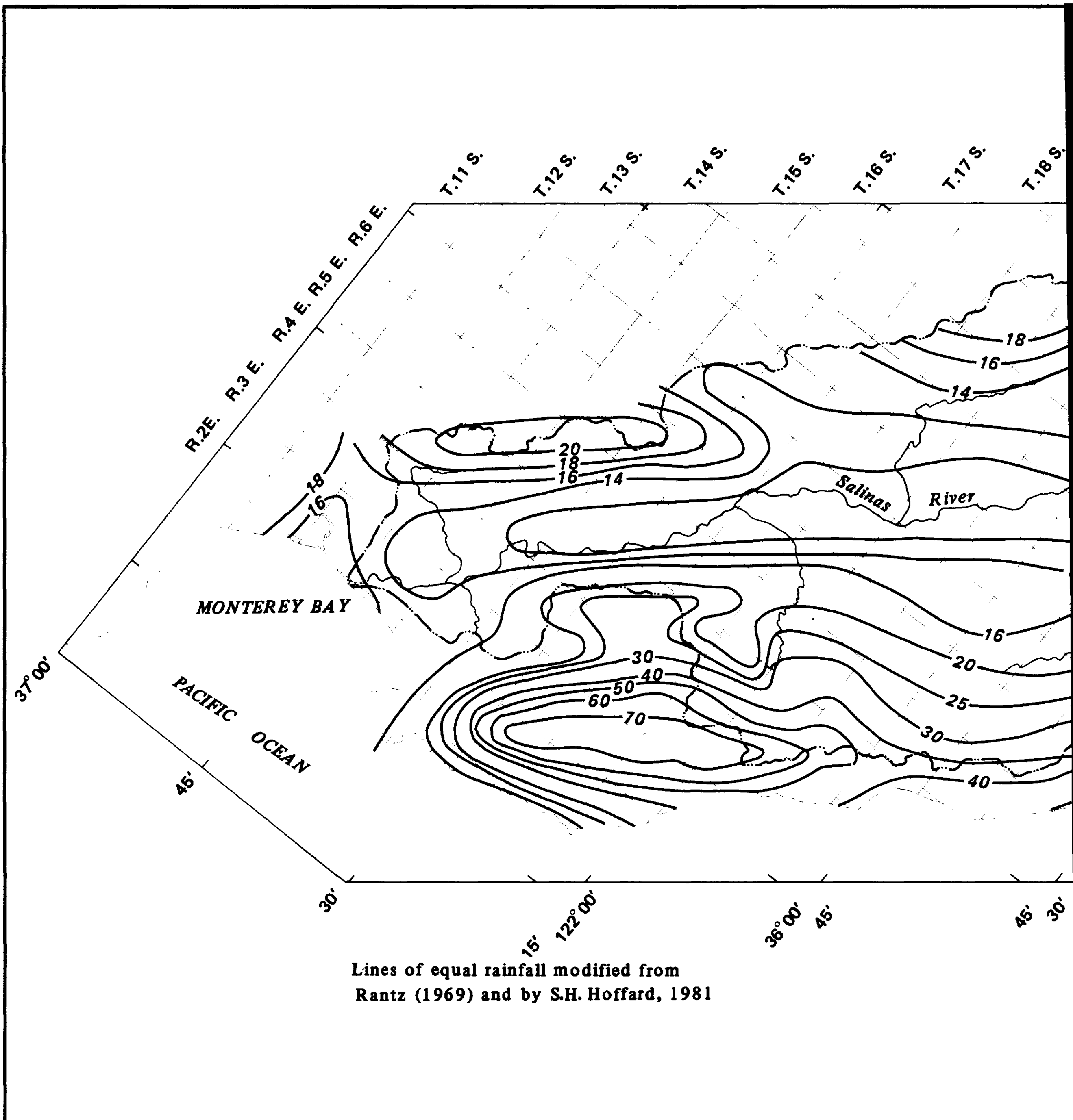
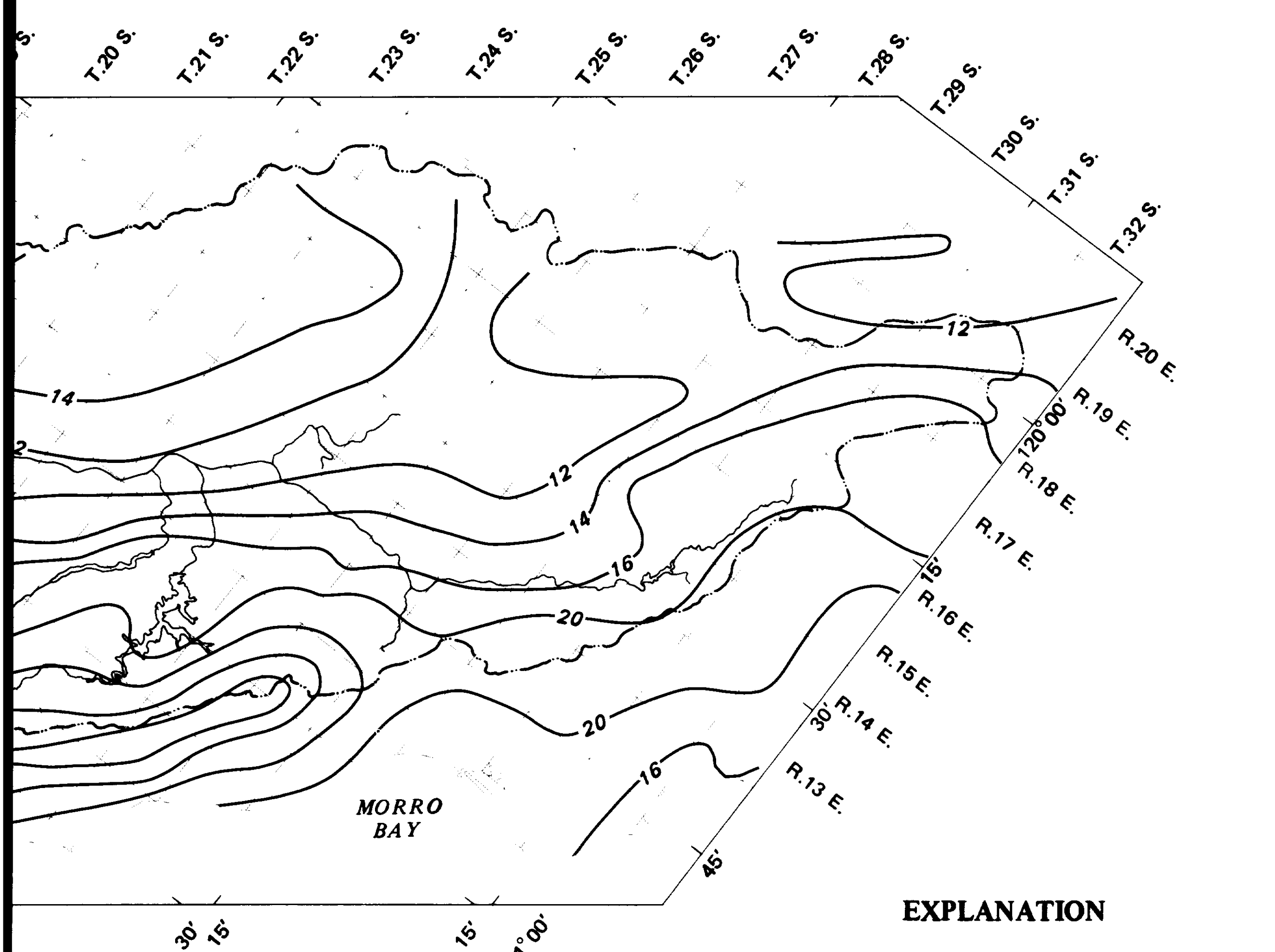


FIGURE 3.— Average annual rainfall in the Salinas River basin.



EXPLANATION

—12— LINE OF EQUAL AVERAGE ANNUAL RAINFALL, IN INCHES; INTERVAL VARIABLE

0 5 10 15 20 MILES

0 5 10 15 20 25 30 KILOMETERS

Streams

None of the streams in the Salinas River basin are naturally perennial throughout their entire length. The length of time and the distance over which each stream is dry vary annually depending on rainfall distribution and general weather patterns. In general, the streams on the west side of the basin flow for greater lengths of time and greater distances than the streams on the east side of the basin. The Salinas River is made perennial artificially in the reach downstream of Spreckles by effluent from two city of Salinas wastewater-treatment plants and from major agricultural drains. In the reach between Bradley and Chualar, the flow of the Salinas River is maintained by releases from reservoirs.

The average annual precipitation in the area that Lake Nacimiento drains is much greater than the average annual precipitation in the area that Lake San Antonio drains (fig. 3). The inflow to Lake Nacimiento is approximately three times the inflow to Lake San Antonio. Consequently, more water is released from Lake Nacimiento than from Lake San Antonio.

The average annual discharge of the major streams of the Salinas River basin is shown in plate 3. The length of record, drainage area, average annual discharge, and the ratio of average annual discharge to drainage area also are shown for each station. Throughout the basin this ratio ranges from 23.5 (acre-ft/yr)/mi^2 at the Estrella River to 933 (acre-ft/yr)/mi^2 for a small drainage area on the Nacimiento River above the dam. Note that the discharge per area ratio from the west-side streams is much greater than for the east-side streams because of the high precipitation in the western mountains.

Stream Regulation

The Salinas River is not perennial throughout most of its length. To enhance recharge to the unconfined aquifer, water is released from Lakes Nacimiento and San Antonio during the dry months of the year. The releases are timed to maintain continuous flow in the streambed from Bradley to Chualar. Downstream of Chualar recharge to the aquifer is limited by clays that separate the aquifer from the surface, cutting off direct percolation. Visual checks are made weekly at Chualar to ensure that the proper amount of water is being released.

Monterey County Flood Control and Water Conservation District reports on the lakes' operation and maintenance annually in their "Summary of Water Resources Data." The following description of the dams is extracted from the 1977 report:

> "Nacimiento and San Antonio Dams were constructed as the first steps in a solution of the water supply and flood control problems of the Salinas Valley. Nacimiento Dam was completed in 1957 and San Antonio Dam was completed in 1965. Each reservoir has a storage capacity of 350,000 acre-feet allocated for the following uses.

Reservoir	Flood Control	Water Conservation	Minimum Pool	Total Acre-ft
Nacimiento	150,000	190,000	10,000	350,000
San Antonio	50,000	280,000	20,000	350,000

> Different operational criteria have been established for each reservoir since Nacimiento Dam receives nearly three times as much inflow from runoff as does San Antonio Dam. Minimum pools provide for recreation, silt accumulation and for the preservation of fish. The water conservation storage at Nacimiento Reservoir includes 17,500 acre-feet which is allocated to San Luis Obispo County in accordance with the agreement between the two County Districts."

The Salinas Dam, which formed Santa Margarita Lake, also exerts some controls on flow in the upper end of the Salinas River. It was constructed during World War II by the U.S. Army to ensure that Camp San Luis Obispo, if fully utilized, would have an adequate water supply. As no major development at Camp Roberts has been necessary, the reservoir provides water to the city of San Luis Obispo. This is the only export of water outside of the Salinas River basin. No water is imported to the Salinas River basin. The dam also provides flood protection for the southern end of the Salinas River drainage basin.

Surface-Water Quality

Surface-water quality, land use, and geology all affect the ground-water quality and must be considered when designing a ground-water-quality monitoring network. Recharge to the aquifers is principally from the percolation of surface waters through the streambed. Consequently, the quality of the surface water and the variations in that quality must be known in order to understand the variation and distribution of ground-water quality.

Just as average annual precipitation varies markedly from one side of the valley to the other, so does surface-water quality. Because precipitation is higher on the west side of the basin than on the east side, the runoff per square mile is higher (pl. 3), and the mineral concentration of the surface water on the west side of the basin is generally lower than that of streams on the east side. More importantly, geologic differences between the east and west sides affect the water quality. The granite in the Sierra de Salinas on the west side is relatively insoluble compared to the metamorphic and faulted basement complex in the Gabilan Range on the east side. Gypsum beds in the Gabilan Range are particularly soluble.

The water quality for some of the streams in the Salinas River basin is shown in plate 4. Where possible a number of chemical analyses were averaged to construct the water-quality diagrams in plate 4. The number of analyses averaged to produce each Stiff diagram is indicated in table 4. Except for the station at Bradley, the shape of the diagrams for individual analyses at each station were similar. At Bradley the diagrams of individual analyses indicated that there are two distinct types of water depending on whether flow from the upper basin--particularly from the Estrella River drainage--dominates, or flow from Lakes Nacimiento and San Antonio dominates. The diagrams illustrate the difference between the water types of the east and west sides.

The average surface water quality for the Salinas River basin as a whole is a mixed-type water with calcium and carbonate ions dominating. The water from the west side of the basin is a mixed type dominated by calcium carbonate. Arroyo Seco has the purest example of a calcium-carbonate water in the basin, but the water at Bradley is more typical of the average type throughout the basin. Although calcium and carbonate are also the dominant ions at Bradley, they do not constitute 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 at Bradley.

TABLE 4. - Description of water-quality diagrams shown in plate 4

Station number and name	Date	Number of analyses averaged	Specific Conductance (μmho/cm at 25°C)	Average daily flow rate (ft^3/s)	Dominant ions	Remarks
11143500 Salinas River near Pozo.	Water year 1980	3	506	1.3-6.8	Ca, Mg, HCO_3, and SO_4; Na slightly less dominant.	Concentrations fluctuate depending on flow, but percent of ionic concentration remains the same. Ionic concentration declines as flow increases.
11144600 Salinas River below Salinas Dam near Pozo.	Water year 1980	3	448	1.7-4.0	Ca, Mg, HCO_3, and SO_4.	Slightly less mineralized than water at 11143500.
11147500 Salinas River at Paso Robles.	Water year 1980	2	790	13-105	Ca and HCO_3 dominate, but Mg, SO_4, Na, and Cl also important.	Of the samples analyzed along the Salinas River itself, the sample from Paso Robles has the highest mineral content.
26S/15E-2N[1] Chalone Creek near Shandon.	Jan. 1965 and Feb. 1954	2	833	Not available	Na, HCO_3, and Cl.	These analyses were made 11 years apart, and flow measurements were not available; therefore, they do not have as much significance as other diagrams. There is little development in this area; the chemical difference represents the natural variation.
26S/13E-12L[1] Estrella River.	Oct. 1953	1	1,325	5	Na, HCO_3 with Ca, Mg, SO_4, and Cl also important.	These samples were collected on the same day within a few miles of each other. The upstream sample is more highly mineralized than the downstream one, which indicates that runoff from the western part of the Estrella River drainage becomes diluted as it picks up flow from the eastern part.
26S/13E-5D[1] Estrella River.	Oct. 1953	1	1,350	Not available	Na, HCO_3 with Ca, Mg, SO_4 and Cl also important.	
San Antonio River below dam/reservoir.	Water year 1981	6	567	Not available	Ca and HCO_3 dominate with SO_4 also important.	Similar to water-quality type at Paso Robles but with smaller ionic concentration. Indicates quality of water used for artificial recharge.
11149400 Nacimiento River below dam.	Water year 1981	6	253	247-3,090	Ca and HCO_3.	Low total ionic concentration. Indicates the high quality of water released for artificial recharge.

[1]Township, range, and section number where sample was collected; not a gaging station.

TABLE 4. - Description of water-quality diagrams shown in plate 4--Continued

Station number and name	Date	Number of analyses averaged	Specific Conductance (µmho/cm at 25°C)	Average daily flow rate (ft^3/s)	Dominant ions	Remarks
11150500 Salinas River near Bradley.	Water year 1980	12	425	30-2,500 (Instantaneous flow rate)	Ca, HCO_3 with Mg, Na, and SO_4 also important.	The shape of the water-quality diagram varies depending on whether flow is dominated by reservoir-release water, upper Salinas River runoff, or Estrella River runoff. During most of the year the release water dominates, so the quality reflects that of the release water. When Estrella River runoff is significant, SO_4 and Na components are much greater. Runoff from upper Salinas is similar to release water but has a higher mineral content.
Pancho Rico Creek[3]	Jan. 20, 1955	1	1,960	[2]4	Ca, Na, and SO_4.	Low-quality, high sulfate water. Indicates exposure to gypsum.
11151300 San Lorenzo Creek below Bitterwater Creek, near King City.	Nov. 8, 1977	1	>3,500	0.15	Na and SO_4.	This sample was collected at a low flow, so water probably has higher mineral content than normal. San Lorenzo Creek probably has poorest-quality water of entire basin. Water quality is distinct from stations along Salinas River. Although the mineral content is much higher than water from the Estrella River drainage, the chemical makeup is similar.
11151870 Arroyo Seco near Greenfield.	Water year 1980	3	290	18-2,800	Ca and HCO_3.	Highest quality surface water observed in Salinas River basin. Concentration decreases with increased flow.
18S/7E-21H Chalone Creek.	Feb. 19, 1958	1	346	Not available	None dominate.	Mixed type of water quality, with low total ionic concentration. Illustrates that runoff of east side in northern part of the Salinas Basin is much higher quality than farther south, particularly San Lorenzo and Pancho Rico Creeks.
11152300 Salinas River near Chualar.	Water year 1980	12	578	13-5,560 (Instantaneous flow rate)	Ca and HCO_3.	Quality varies with flow rate. Average is similar to Paso Robles, but lower mineral content. Quality of high flows very similar to quality of Arroyo Seco.
13S/3E-35L Gabilan Creek.	Jan. 13, 1956	1	457	Not available	Ca and HCO_3	High-quality calcium carbonate water.

[2]Instantaneous discharge.
[3]Exact location on Pancho Rico Creek is not known.

The water from the east side of the basin, such as from San Lorenzo Creek drainage, is a mixed type dominated by sodium and sulfate ions and containing high concentrations of magnesium and chloride. This highly mineralized water has a specific conductance of more than 2,500 μmho/cm. Fortunately, the flow from streams on the east side is very low, so their effect on the overall water quality of the basin is less destructive than it would otherwise be. These streams flow intermittently during the winter months and are dry during the summer. The sporadic nature of the flow probably causes great variations in the quality of the ground water near King City.

Table 4 lists each of the stations for which the water-quality diagrams are plotted in plate 4, the number of analyses averaged to produce each diagram, the range of flow values they represent, and the dominant ions in each diagram.

Geohydrology

Over geologic time, the Salinas River and its tributaries have deposited lenses of clay, silt, sand, and gravel to form a porous aquifer. Generally, the ground-water basin is thicker near the mouth of the river and thinner toward the south. At the mouth, the ground-water basin is more than 2,000 feet thick, but between the mouth and San Ardo the basin averages about 1,000 feet in thickness (Durbin and others, 1978). This aquifer supplies more than 95 percent of the water used in the Salinas River basin. The remainder of the report concentrates on the part of the ground-water basin which is composed of the unconsolidated sediments.

At the northern end of the Salinas Valley two major confining zones separate the alluvial fill into three developed aquifers: the perched aquifer, the 180-foot aquifer, and the 400-foot aquifer. The 180-foot and 400-foot aquifers are highly developed sources of water for irrigation and domestic use. The perched aquifer yields water slowly, is of relatively poor quality, and is rarely tapped as a water source. Agricultural tile drains are used to lower the water table over much of the perched aquifer. Clay layers beneath the 400-ft aquifer also separate the alluvial sediments into permeable and non-permeable zones.

A 900-foot aquifer has been identified and tapped by three test wells. The 900-foot aquifer is being considered as a source of water supply, but high sodium concentrations may restrict its use for irrigation (W. R. Leonard, oral commun., Oct. 6, 1982). South of Chualar, the fill forms an aquifer that functions as a single unconfined hydraulic unit although clay layers cause local confinement and the hydraulic characteristics vary from place to place.

Water use is concentrated north of Soledad where agricultural development is greatest. Municipal pumping is greatest near the city of Salinas. Generally, the amount of water pumped in that part of the basin south of King City is relatively small. The land-use map (pl. 1) shows that developed areas are larger at the north end of the valley, and are smaller and farther apart in the south end of the basin. In the north, where development and pumpage are high, the geohydrology is dominated by artificial factors such as pumpage, disposal of wastewater, and artificial recharge. Toward the south, the level of development declines and man-induced factors become less important to the geohydrologic system. In San Luis Obispo County, the geohydrology is dominated by natural factors, even though pumpage is significant. The geohydrology of the Salinas River basin includes both a stressed system in the north where development is high and a system under a fairly low stress level in the south where development is low.

Occurrence of Ground Water

To facilitate discussion, the Salinas River ground-water basin below the San Ardo oil fields was divided by the California Department of Public Works (1946) into four areas: Upper Valley, Forebay, East Side, and Pressure Area. In this report they are also collectively referred to as the lower basin. To encompass the area of this report, a fifth division--the upper basin--was added. The upper basin includes the area up-drainage from the San Ardo oil fields and most of the area described by Johanson (1979) as the Paso Robles basin.

On the basis of topography, surface-water drainages, and specific capacities of wells, the unconsolidated sediments of the upper basin were divided into three subareas: Upper Narrows, Estrella Valley, and Headwaters (fig. 4). The geohydrologic characteristics of each subarea are shown in table 5. This information was compiled primarily by the California Department of Public Works (1946), Durbin and others (1978), and Johanson (1979), and from hydrologic data.

Upper basin.--Ground-water confinement in the upper basin varies from place to place because of the lenticular nature of the alluvium, particularly the Holocene alluvium. Most of the ground water in the Paso Robles Formation is confined. Near the river the water level is within a few feet of the land surface. In some of the hilly areas it is more than 100 feet below the land surface. Water levels in wells in the unconsolidated deposits in the upper basin in 1980 are shown in figure 5.

The main sources of recharge to that part of the upper basin south of the Monterey County line are deep percolation of precipitation, streamflow, irrigation-return water, applied urban water, treated wastewater, and subsurface inflow. The California Department of Water Resources estimated the annual recharge to the aquifer to be about 19,000 acre-ft from streamflow, about 27,000 acre-ft from urban and agricultural return water and about 7,300 acre-ft from subsurface inflow. The amount of water leaving the upper basin annually was estimated to be about 77,300 acre-ft, of which about 6,000 acre-ft was subsurface outflow mostly to the lower basin. These figures are not calculated on a common base period and were not presented as a precise water balance, but they do indicate magnitudes. The net annual change in storage of ground water in the upper basin was estimated to be about 30,000 acre-ft (Johanson, 1979).

Lower basin.--Ground water in the Upper Valley and Forebay (see fig. 4) is mostly unconfined, that in the East Side is semiconfined, and that in the Pressure Area is confined. The Pressure Area contains a shallow, perched water table and at least three confined aquifers that are separated by interconnecting clay layers. These aquifers are formed of alluvium and the Paso Robles Formation or its equivalents. The confined aquifers are known as the 180-foot, 400-foot, and 900-foot aquifers based on the general depth to the top of each. The 180-foot and 400-foot aquifers (see section A-A', pl. 2) are heavily utilized and both of these aquifers are being intruded by saltwater in areas of heavy pumping near Monterey Bay. In 1981 the front of the advancing saltwater (defined as the point where the chloride concentration exceeds 500 mg/L) was about 4.6 miles inland in the 180-foot aquifer and about 1.8 miles inland in the 400-foot aquifer (Gene Taylor, Monterey County Flood Control and Water Conservation District, oral commun., Oct. 18, 1982).

Water levels in wells in the lower basin near the Salinas River upstream of Chualar are generally within 5 feet of the bottom of the river channel. However, downstream of Chualar the water level in the East Side and the piezometric surface in the Pressure Area are depressed more than 10 feet below the river channel.

The main source of recharge to the Upper Valley, East Side, and Forebay is infiltration from the Salinas River (whose dry-season flow is sustained largely by releases from Lakes San Antonio and Nacimiento) and from its tributaries. The estimated recharge north of San Ardo in 1970 was about 490,000 acre-ft from infiltration of streamflow, irrigation return, and underflow, and about 10,000 acre-ft from saltwater intrusion (Durbin and others, 1978). Ground-water withdrawals for agricultural and municipal use in 1970 totaled about 482,000 acre-ft, of which about 290,000 acre-ft was consumptively used. This intense pumping has depressed the water table near the mouth of the valley, so saltwater intrudes and damages the water quality.

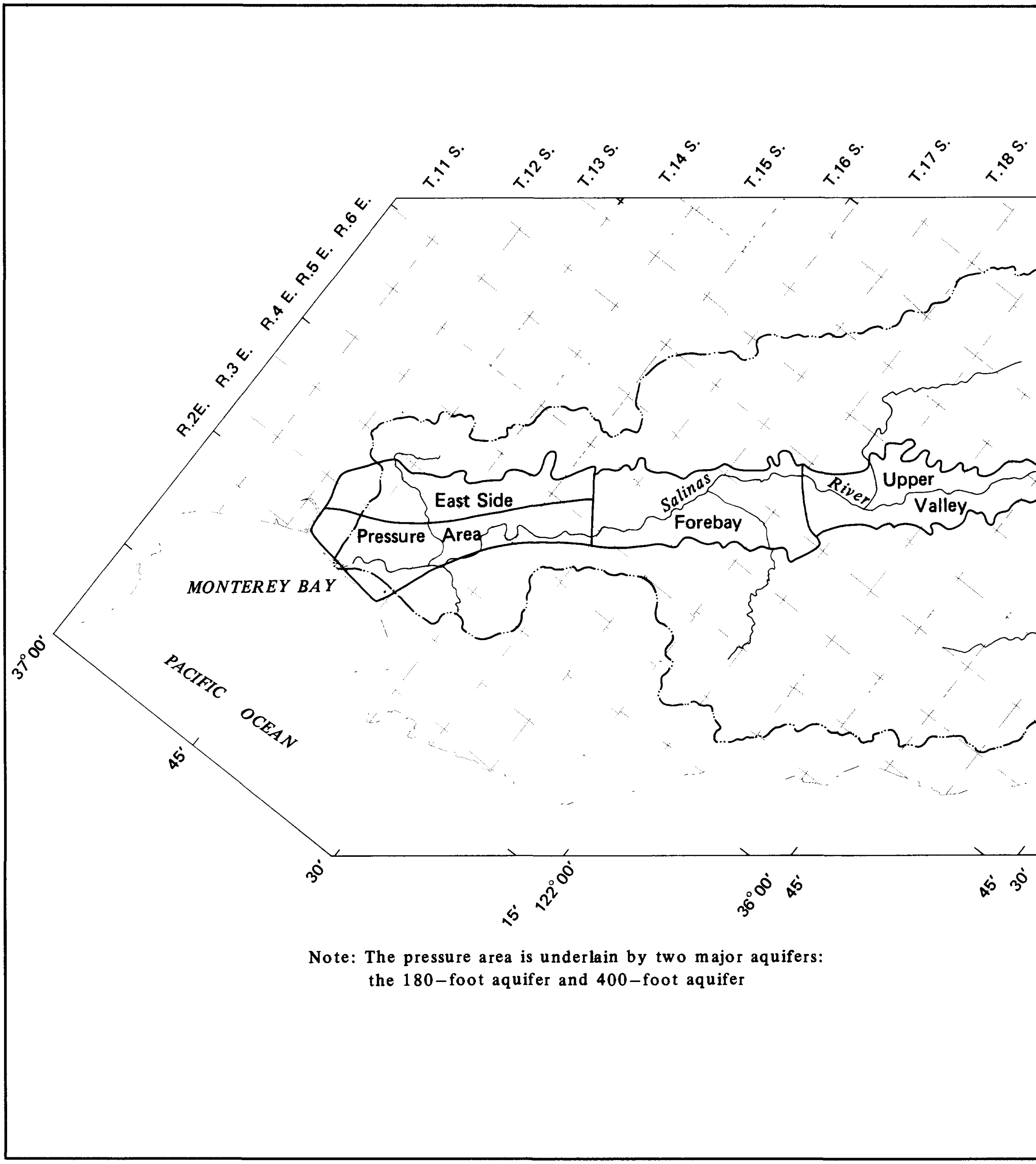


FIGURE 4.–Geohydrologic subareas in the unconsolidated deposits in the Salinas River basin.

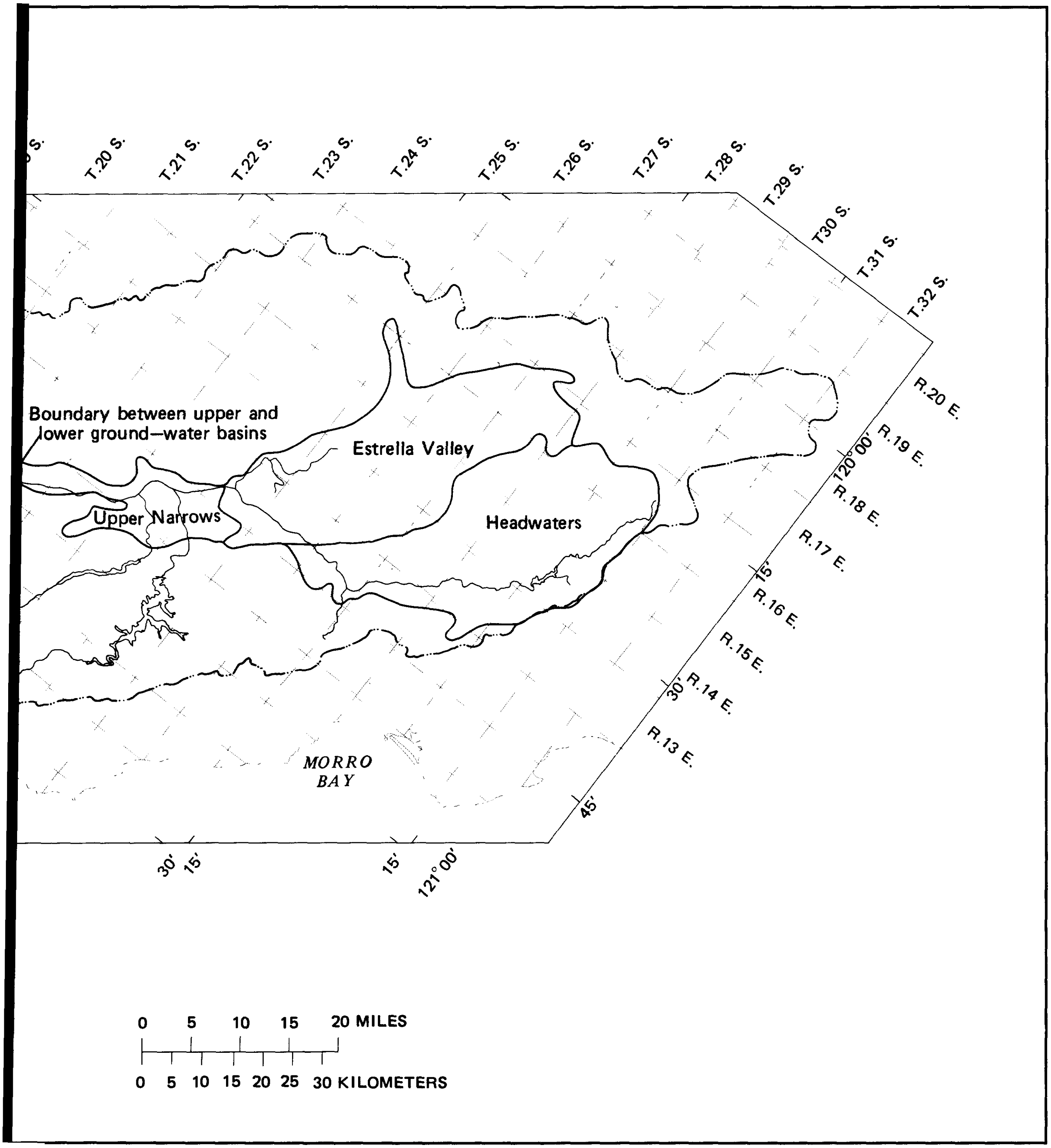

T.20 S.
T.21 S.
T.22 S.
T.23 S.
T.24 S.
T.25 S.
T.26 S.
T.27 S.
T.28 S.
T.29 S.
T30 S.
T.31 S.
T.32 S.
R.20 E.
R.19 E.
R.18 E.
R.17 E.
R.16 E.
R.15 E.
R.14 E.
R.13 E.
120°00'
15'
30'
45'
30'
15'
15'
121°00'
Boundary between upper and lower ground–water basins
Estrella Valley
Upper Narrows
Headwaters
MORRO BAY
0 5 10 15 20 MILES
0 5 10 15 20 25 30 KILOMETERS

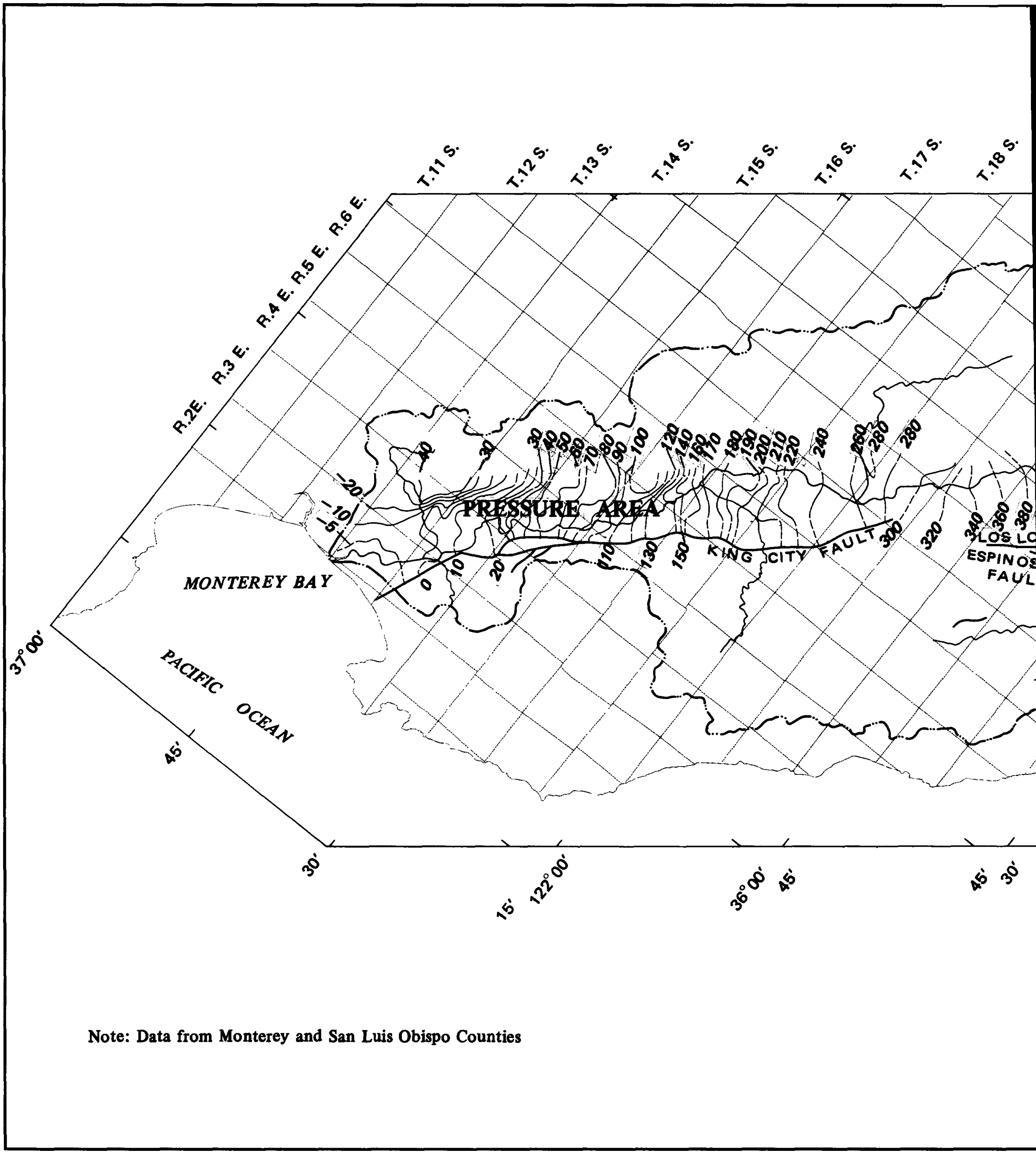
TABLE 5. - Geohydrologic characteristics of each subarea

Subarea	Confinement	Aquifer thickness (ft)	Depth to water (ft)	Annual piezometric surface fluctuation (ft)	Average specific capacity [(gal/min)/ft of drawdown]	Recharge source	Transmissivity (ft^2/d)	Remarks
Pressure Area								
180-foot aquifer	Almost complete. Gap at Spence.	35-179 [1]Averages 100.	11-82	10	63	Underflow from Forebay, some direct percolation along Quail Creek at Spence.	[3]7.5×10^5	Lowering of water table has allowed saltwater to intrude into this aquifer, forcing many wells out of service.
400-foot aquifer	Almost complete. Gap at Spence.	[1]100	13-89	30	Not available	Underflow from Forebay, percolation through confining layer from 180-foot aquifer.	Not available.	After saltwater intrusion began contaminating wells in the 180-foot aquifer, wells were lowered to the 400-foot aquifer. Excessive pumping lowered the potentiometric surface, allowing saltwater to intrude. Intrusion less severe than in 180-foot aquifer.
900-foot aquifer	Not available. Insufficient data	-- Unknown	-- Unknown	-- Unknown	--	Percolation through confining layer from 400-foot aquifer	Not available.	This aquifer is being explored as a possible source of water supply in the areas affected by saltwater intrusion. High sodium concentrations may limit water use for irrigation.
East Side	Unconfined	[2]200-1,000	26-301	24	21	Percolation from streams, underflow from Pressure Area and Forebay.	[3]2.5×10^5	Due to high pumpage and a low recharge capacity, the water table is lower here than anywhere else in the basin.
Forebay	Unconfined	[2]200-2,250 (Most <40)	12-285	20	109	Percolation from Salinas River and Arroyo Seco. Underflow from Upper Valley.	8.1×10^5	This is an area of high permeability, so recharge is high. Even with heavy irrigation pumping water tables have remained high.

TABLE 5. - Geohydrologic characteristics of each subarea--Continued

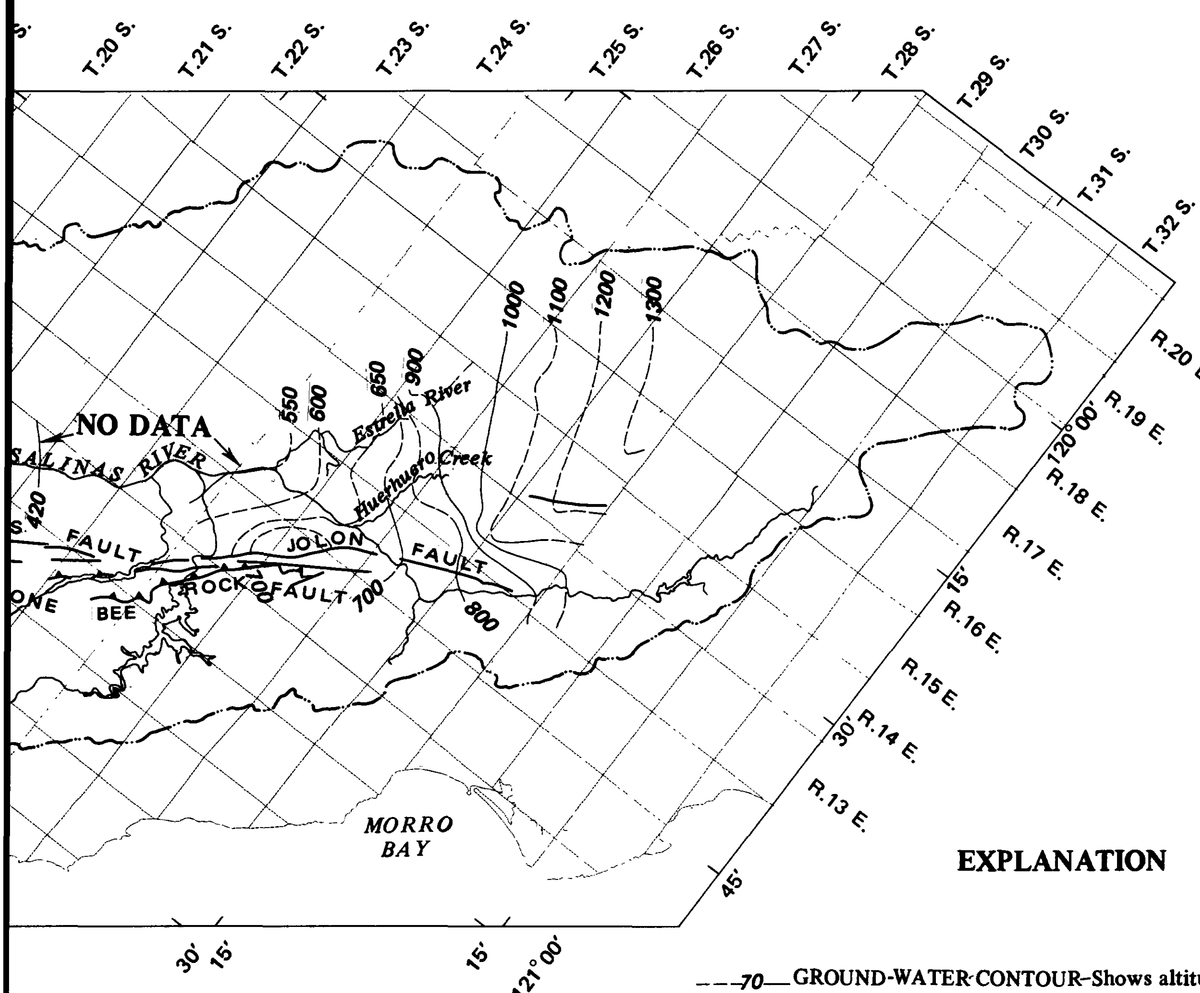
Subarea	Confinement	Aquifer thickness (ft)	Depth to water (ft)	Annual piezometric surface fluctuation (ft)	Average specific capacity [(gal/min)ft of drawdown]	Recharge source	Transmissivity (ft^2/d)	Remarks
Upper Valley	Unconfined	[2]400-1,400	10-285	7	192	Percolation from Salinas River and tributaries; 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	[4]<600	[5]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 may form in water table at south end of area restricting flow from upper basin.
Estrella Valley	Partial[4]	[4]1,050-1,750	20-200	17	18.8	Percolation from Estrella River, and Cholame, Huerhuero, and San Juan Creeks; some percolation from precipitation.	Not available.	Very thick part of the aquifer. Moderate levels of irrigation pumping.
Headwaters	Partial[4]	[4]125-1,400	[6]0-20	[6]10	64	Percolation from Salinas River and Rinconada Creek.	Not available.	Aquifer thick at center part of subarea, but thins at north and south ends. Low levels of municipal pumping. High specific capacities.

[1]Department of Public Works, 1946.
[2]Durbin and others, 1978.
[3]Monterey County Flood Control and Water Conservation District, 1967.
[4]Johanson, 1979.
[5]Estimate based on wells outside of area.
[6]Based on only two wells.



Note: Data from Monterey and San Luis Obispo Counties

FIGURE 5.–Ground-water contours in the Salinas River basin for autumn 1980.



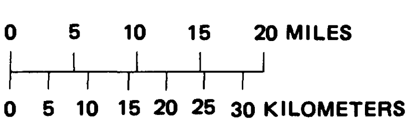
EXPLANATION

---70— GROUND-WATER CONTOUR–Shows altitude of the isopotential surface in feet above sea level. Solid where sufficient data were available. Dashed where data were insufficient.

—··— SURFACE–WATER BASIN BOUNDARY

—— FAULT– Approximately located

—▲—▲— THRUST FAULT– Approximately located. Sawteeth on upper plate



Direction of Flow

In the Salinas River basin, ground-water flow generally parallels the surface-water flow. In the unconsolidated alluvial deposits of the Salinas Valley, the ground water flows north-northwest. In the valleys of the tributaries to the Salinas River, the ground water also follows the direction of the surface water.

Ground-water levels in the Salinas River basin in autumn 1980 are shown in figure 5 (Gene Taylor, Monterey County Flood Control and Water Conservation District, and Clinton Milne, San Luis Obispo County Engineering Department, written commun., 1981). The contour lines on this figure represent lines of equal water-level altitude. Because ground water flows downgradient and perpendicular to the lines, figure 6 shows that the direction of ground-water flow is generally to the north and in the direction of surface-water flow. The similarity of flow directions between the ground and surface waters of the Salinas River basin indicates the interdependence of surface water and ground-water flow.

Saltwater Intrusion

At the north end of the Salinas River basin where water levels are below sea level, saltwater is moving inland, intruding the freshwater aquifer to collect in an area of depressed water levels created by pumping. Ground water flows into the area of depressed water levels from all directions.

The piezometric surface (surface to which water levels rise in wells tapping confined aquifers) was generally above sea level in the 180-foot aquifer before pumping began. In 1904, Hamlin reported several zones near Salinas where the ground water flowed without pumping from wells that perforated the 180-foot aquifer. Over time, as pumping increased, the piezometric surface dropped below sea level, allowing saltwater to flow landward. Until the piezometric surface is raised above sea level or a hydraulic barrier is constructed, saltwater intrusion will continue.

The lowest water levels shown in figure 5 (about 45 feet below sea level) occur in the East Side along a barrier to ground-water movement that runs through the contact between the consolidated rocks of the Gabilan Range and the unconsolidated alluvium. This barrier is probably an unmapped fault. The low transmissivities in the East Side, as well as the ground-water barrier, may intensify the effects of overpumping there.

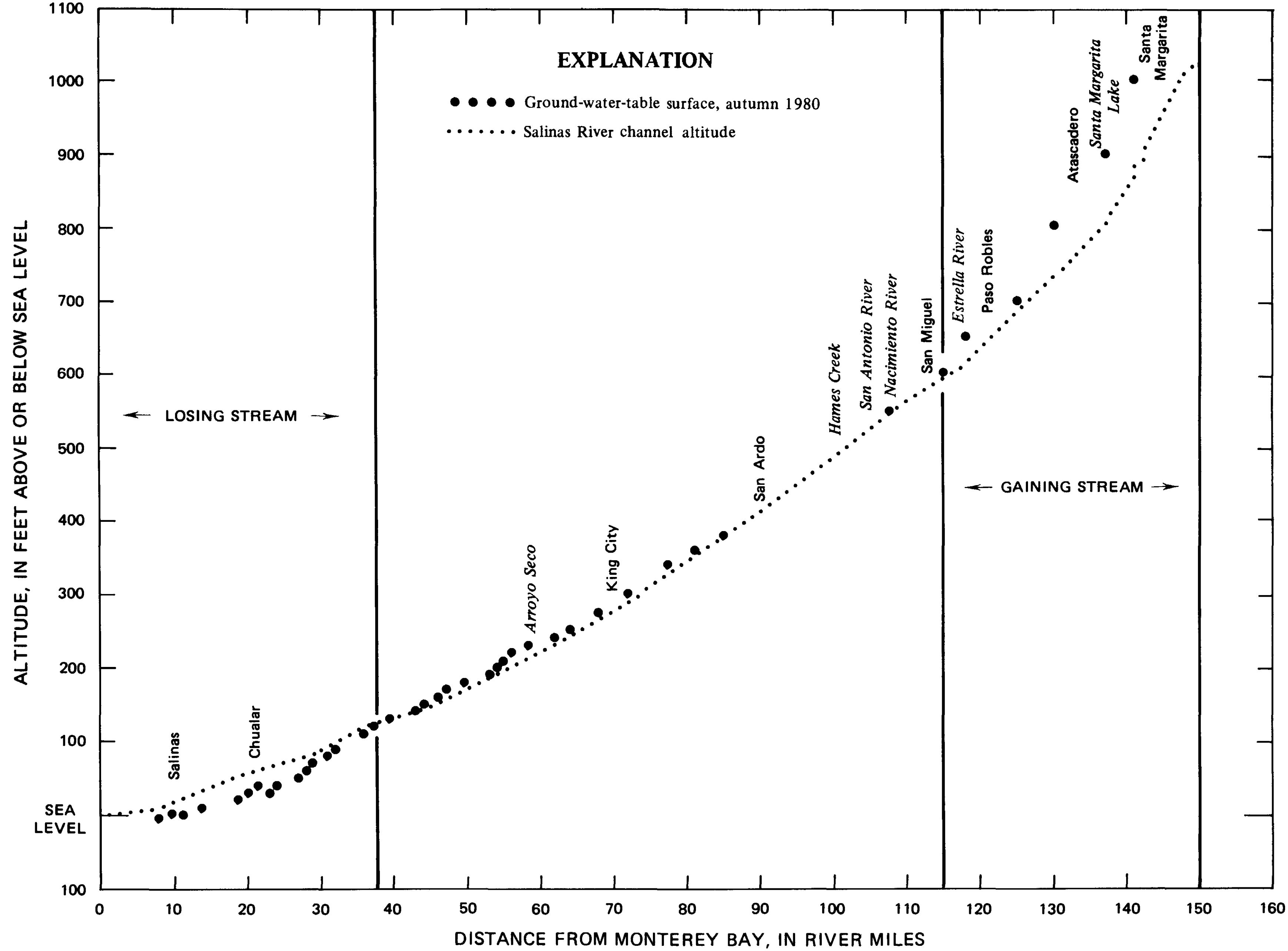


FIGURE 6.–Slope of the autumn 1980 water table and the Salinas River channel.

The point at which the ground-water level is equal to sea level (SL) moves slowly up and down the valley depending on the balance between pumping and recharge. Over the years, the trend has been for the zero SL line of the 180-foot aquifer to move southward up the valley. As shown in figure 4, in the autumn of 1980 the zero SL line of the 180-foot aquifer meandered across the valley in an east-west direction just north of Salinas. In autumn 1971, the zero SL line was several miles north of Salinas. In autumn 1965, the location of the line was about the same as in 1971, but the shape was different. The zero SL line in 1977, the year of the severe drought, was even farther south than in the autumn of 1980. The east end of the zero SL line seems to have stabilized near the outflow from El Toro Creek. This apparent stabilization is probably caused by high local transmissivity and (or) local recharge to the aquifer.

The zero SL line in the 400-foot aquifer responds similarly to the zero SL line in the 180-foot aquifer. In the 400-foot aquifer, the line is several miles farther north than it is in the 180-foot aquifer and saltwater intrusion is not as far advanced. Although the location of the zero SL line moves up and down the valley from year to year, the number of acres impacted by the saltwater intrusion has continually increased. Figure 7 shows the acreage underlain by water containing 500 mg/L of chloride or more for both the 180-foot and 400-foot aquifers. Water with 500 mg/L choride is not usable for most domestic and agricultural purposes, so wells in these impacted areas must either be abandoned or deepened.

Ground-Water-Flow Patterns

The 20-foot contour line in figure 5 seems to mark the dividing line between the zone in the 180-foot aquifer where the flow pattern is dominated by pumping and the zone in the aquifer where other factors, such as recharge, significantly affect the flow pattern. This line also coincides with the end of the confining layer between the confined zone and the perched aquifer. In the confined zone, the almost random configuration of the contour lines indicates that pumping dominates the ground-water-flow pattern. The regional pressure gradient is also apparent, i.e., the pressure declines toward the northwest. The Salinas River as a recharge source does not directly affect the ground-water-flow regime in the confined zones, because the confining clay separates the river from the aquifer. In the unconfined zones south of the 20-foot contour line, the configuration of the contour lines near the Salinas River indicates that the river is a source of recharge. Around the cities south of Chualar, such as Gonzales and Soledad, where pumpage is high, the natural flow pattern is slightly disturbed. Just north of Greenfield, where the Arroyo Seco flows into the valley, the contours indicate the importance of the recharge from the stream.

No water-level data are available in the King City area between Greenfield and San Lucas where San Lorenzo Creek enters the valley. Because San Lorenzo Creek has extremely low quality water, the extent to which the stream recharges the unconfined aquifer must be known to determine its effect on the quality of the ground water of the Salinas River Valley.

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

The alluvium is particularly narrow and shallow in the Upper Narrows area (fig. 4) between Bradley and San Miguel, so the flow of ground water may be restricted. Without water-level information, the amount of water flowing through this area, which separates the upper from the lower basin, cannot be directly calculated. Quality differences between the ground waters of the upper and lower basins are distinct, which suggests that the quantity of ground water flowing from the upper basin to the lower basin may be small. These differences in quality are discussed in a later section of this report.

In the upper basin many of the contour lines (fig. 5) indicate that ground water is moving into the stream. This does not mean that the water table is near the surface everywhere. South of Atascadero, the Salinas River flows through a steep-sided canyon. Although the elevation of the water table is above the elevation of the river channel, in some areas much of the land surface in the upper reaches of the stream is several hundred feet above the water table.

In an unconfined or partially confined aquifer like the upper basin, the slope of the water table commonly follows the slope of the land. Thus, the slope of the water table is much steeper in the upper basin than in the lower basin. The flattest part of the water table in the upper basin is where the Estrella River and Huerhuero Creek join the Salinas River. The water-bearing material is more than 1,100 feet thick in this area (Johanson, 1979). The wide distance between the contour lines in figure 5 indicates that the ground water probably flows more slowly, and, therefore, may have a longer residence time here than in most of the upper basin. The apparent reduced velocity could result from lower permeability, topography, aquifer thickness, pumping, or combinations of these factors. In some years, pumping has produced a shallow trough of depressed water levels causing ground water from San Miguel to flow southward into this area (San Luis Obispo County Engineering Department, 1974). The trough probably develops here in years when rainfall is low or pumpage high. Over time this trough has periodically divided the upper basin from the lower basin from a water-quality point of view. Differences in water quality are discussed later.

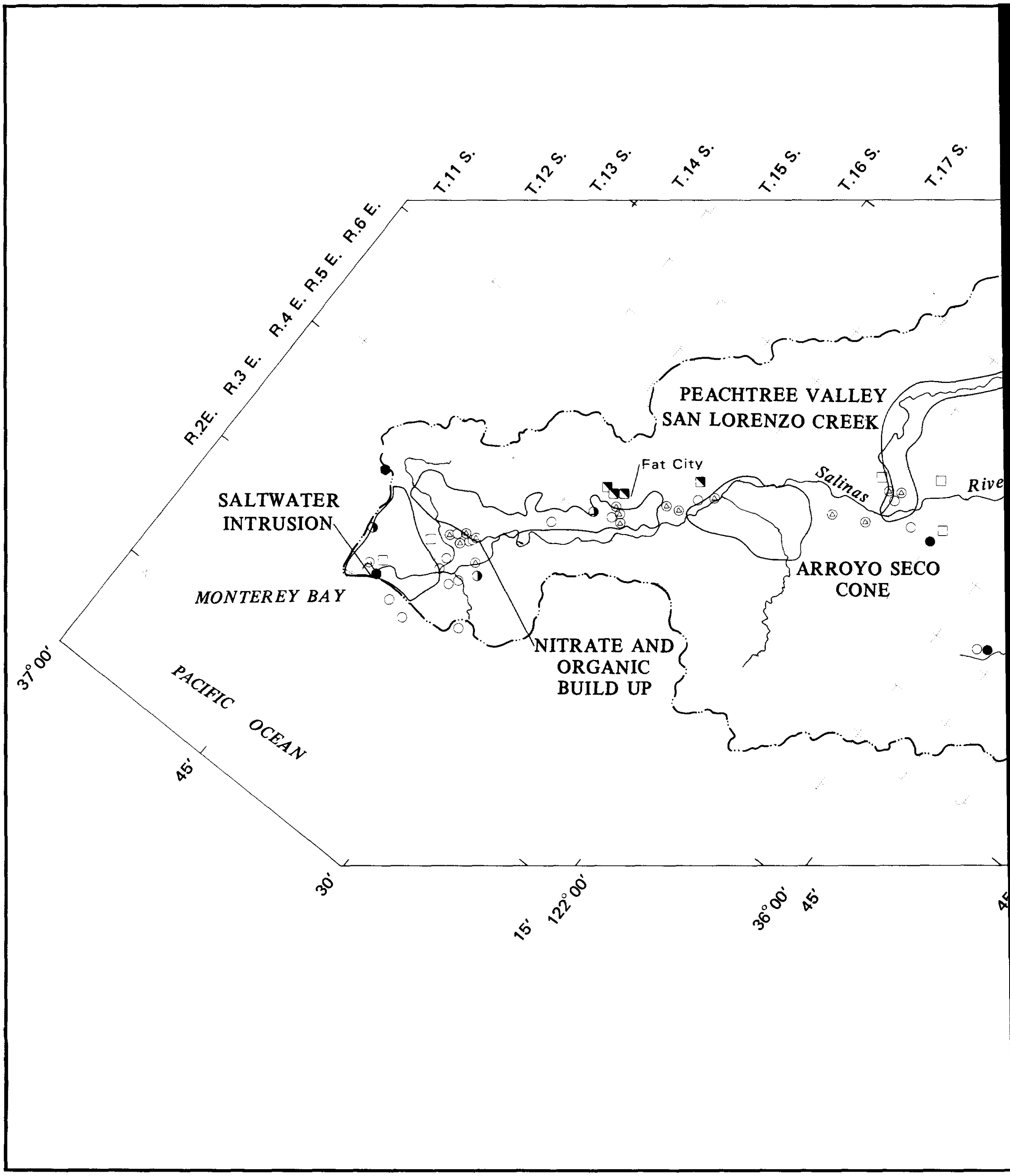
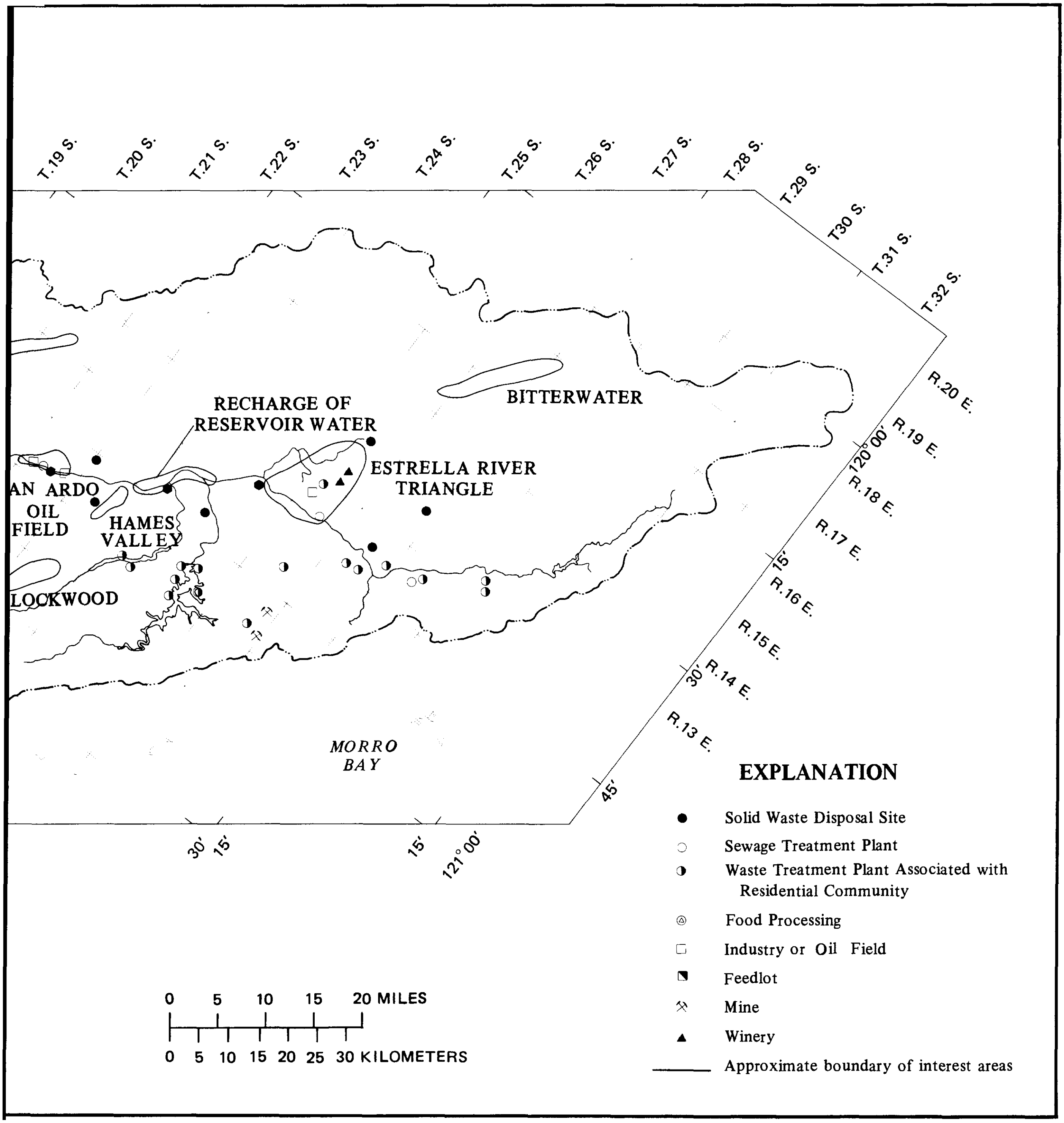


FIGURE 7.–Ground-water-quality interest areas in the Salinas River basin.



T.19 S.
T.20 S.
T.21 S.
T.22 S.
T.23 S.
T.24 S.
T.25 S.
T.26 S.
T.27 S.
T.28 S.
T.29 S.
T30 S.
T.31 S.
T.32 S.
R.20 E.
R.19 E.
R.18 E.
R.17 E.
R.16 E.
R.15 E.
R.14 E.
R.13 E.
120°00'
15'
30'
45'
30'
15'
15'
121°00'
BITTERWATER
RECHARGE OF
RESERVOIR WATER
ESTRELLA RIVER
TRIANGLE
AN ARDO
OIL
FIELD
HAMES
VALLEY
LOCKWOOD
MORRO
BAY
0 5 10 15 20 MILES
0 5 10 15 20 25 30 KILOMETERS
EXPLANATION
Solid Waste Disposal Site
Sewage Treatment Plant
Waste Treatment Plant Associated with Residential Community
Food Processing
Industry or Oil Field
Feedlot
Mine
Winery
Approximate boundary of interest areas

Ground-Water-Flow Barriers

Faults can act either as ground-water-flow barriers or conduits, or they may have no effect on ground-water flow. The same fault can function as a barrier in some places and a conduit in others. Slippage during earthquakes may change the hydraulic characteristics of the faults.

Data are not available to describe the hydraulic characteristics of many of the faults (pl. 2) in the Salinas River basin. The shape of the water table as shown in figure 5 reflects the hydraulic properties of the faults in a few places.

At the north end of the valley, an abrupt change in the water-table surface indicates a fault that is acting as a ground-water barrier. In well 14S/3E-14D, on the upthrown side of the fault, the water table was 89.1 feet above SL, and in well 14S/3E-14N1 it was 40.9 feet below SL on November 28, 1977. That is a difference of 130 feet in water levels in wells that are within 1 mile of each other. Other wells in the area also demonstrate this abrupt change.

Faults seem to exercise some control over the water table between the Nacimiento River and the city of Paso Robles. The higher water levels (fig. 5) on the east side of the fault zone are at least partially due to the mound of unconsolidated rock that protrudes there. Upwelling of water along the fault may also raise the water table locally. Mineralized hot springs and wells have been reported in this area since the late 18th century. Health resorts associated with the hot springs and wells flourished there in the late 19th and early 20th centuries (Johanson, 1981).

The Rinconada fault, which forms the drainage divide between the Salinas River and Huerhuero Creek near Atascadero, does not appear to affect the water table but more water-level measurements are required to confirm this.

The constriction in the alluvial valley between San Miguel and Bradley also functions as a flow restraint. The alluvium is much more permeable than the underlying Paso Robles Formation. Although flow probably occurs 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 weir there, and the ground water may not always be high enough to reach the notch in the weir at the base of the alluvium. In order to determine the amount of ground-water flow from the upper to the lower basin, additional information on the depth of the alluvium, water-table gradient, and transmissivity is needed.

Slope of the Water Table and the River Channel

The elevation of the water table along the Salinas River and the elevation of the lowest point of the river channel are plotted in figure 5.

The channel's slope indicates where the topography of the river valley changes. The first 8 miles of the river are a tidal zone that has an extremely flat channel slope of approximately 0.8 ft/mi. 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. The Salinas agricultural industry is centered here. From King City, where San Lorenzo Creek joins the Salinas River, to the confluence of the Salinas and Estrella Rivers, the channel slope averages about 7 ft/mi. The alluvial valley narrows in this reach and at Bradley is less than a mile wide. Between Atascadero and the confluence of the Estrella and Salinas Rivers, the river-channel slope averages approximately 10 ft/mi. The channel in this reach is fairly well defined and does not tend to shift as it does farther north. Between Atascadero and Santa Margarita Lake, the average river-channel slope increases to 19 ft/mi. In this reach, the Salinas River flows through a steep-sided canyon.

In the Pressure Area that extends from the mouth of Salinas River to about river mile 38 the water table fluctuates because of local pumping. The water table is generally below the elevation of the channel. From the end of the Pressure Area to near San Miguel, the slope of the water table is similar to the slope of the land surface (fig. 6). The water table rises southward at about 5 ft/mi between the Pressure Area and King City and about 7 ft/mi between King City and San Miguel. Upstream of the confluence of the Estrella River and the Salinas River, the water table rises evenly at a rate of about 13 ft/mi.

In areas where the water table is above the channel bottom, the river receives ground water and is considered a gaining stream. In areas where the water table is below the channel bottom, the river recharges the ground-water aquifer and is called a losing stream. The concept of a gaining or losing stream only relates to aquifers that are unconfined. In confined areas, the aquifer is not directly connected to the surface water flowing above it. Some impermeable zones, such as clay layers, separate the confined aquifer from the surface flow. In the Pressure Area the river is hydraulically connected with the perched aquifer which is not used as a water supply. The 180-foot aquifer and the 400-foot aquifer are not hydraulically connected to the river. For instance, a contaminated ground-water source would affect surface-water quality only where the stream was gaining.

At the north end of the valley, for the first 40 miles of the river, the potentiometric surface is below the land surface and this reach of the river is losing water (fig. 6). Between river mile 40 and river mile 115, the water table is approximately the same elevation as the Salinas River channel. The river is neither gaining nor losing except near the mouth of Arroyo Seco where the stream recharges the ground-water system. Streamflow has been artificially maintained during the summer months by release water from Nacimiento Reservoir since the dam was completed in 1956. Prior to that time, the Salinas River went dry at times along this reach, indicating a losing stream. In wet winter months swampy conditions often developed in this reach. Land around Salinas has been filled in to solve this problem. South of San Miguel, throughout the upper basin, the Salinas River is a gaining stream, except at Paso Robles where the land surface and water-table elevation are very close.

Understanding the relationship between the land surface and the water table is important for making water-management decisions such as locating recharge facilities and tracking the flow of contaminants.

Historical Water-Level Changes

Ground-water levels for each subarea of the Salinas Basin in Monterey County have been monitored since 1944. The State of California monitored ground-water levels from 1944-51; since 1951, monitoring has been done by Monterey County Flood Control and Water Conservation District (MCFCWCD). The average water-level change is calculated by averaging the water-level measurements taken in each subarea. The change from 1944 to 1980, 36 years, is shown in table 6. The decline in the East Side subarea has been most severe where transmissivities are low and recharge slow. Because saltwater intrusion was already a problem in the Pressure Area in 1944, an additional decline of 18 feet since then is serious. Water-level declines in the Pressure Area near the coast are somewhat stabilized by the intrusion of seawater. The rate of decline has not been constant over time. During the 1976-77 drought, the water levels dropped substantially throughout the basin. By 1980, the water levels in the Forebay and Upper Valley had recovered to their predrought levels, but the water levels in the Pressure Area and East Side had not. Areas of water-level increase and decrease in the upper basin between 1960 and 1975 are shown in a report by Johanson (1979, fig. 23). In most locations the change in water-level elevation is small, usually less than 6 feet. It is beyond the scope of this report to evaluate changes in water levels except as they influence the direction of ground-water flow. Evaluations of changes in storage are made annually by the Monterey County Flood Control and Water Conservation District.

TABLE 6. - Average decline in the piezometric surface in the lower basin from 1944 to 1980

Subarea	Decline (feet)
Pressure Area	18
East Side	43
Forebay	2
Upper Valley	1

Ground-Water Quality

Variations in the quality of ground water in the Salinas River drainage basin are shown on plate 5. The pie diagrams on this plate represent the percentages of the major cations (calcium, magnesium, and sodium) and anions (bicarbonate, sulfate, and chloride) present in the ground water. The analyses used to draw the pie diagrams in plate 5 were done on samples collected in the early 1970's. The results of individual samples, not the average of several samples, were used to draw these diagrams. Plate 5 illustrates the variation in ground-water quality in the Salinas River basin in the early 1970's. Although the overall variations in ground-water quality are probably still the same, values at any specific point have probably changed.

Water-quality types may be distinguished by the predominance of a specific chemical constituent expressed as a percentage of the total anions or cations. For example, (1) A calcium-bicarbonate water is one in which calcium amounts to more than 50 percent of the cations and bicarbonate to more than 50 percent of the anions, in milliequivalents per liter; and (2) a mixed-type water is one in which no anion or cation amounts to more than 50 percent of the total anions or cations.

Plate 5 illustrates that the dissolved-solids concentrations range from approximately 300 to 3,000 mg/L in the lower basin. This range is much greater than in the upper basin where the range is 500 mg/L to 1,500 mg/L. The greater range in the lower basin results from natural causes, such as differences in rock type, precipitation, streamflow, and saltwater intrusion; and from man-induced causes, such as agricultural development, sewage treatment, and industrial development. The variations, both natural and man-made, are not as pronounced in the upper basin. In general, this range indicates that the lower basin is under greater hydrologic stress than the upper basin.

The ground water of the lower basin generally is more highly mineralized and contains a much higher percentage of sulfate than that of the upper basin. The gypsum beds of the Gabilan Hills are the most likely source of the sulfate. Water in the lower basin also has a higher concentration of bicarbonate than that of the upper basin.

<u>Upper basin</u>.--The total dissolved-solids concentration of the ground water in the upper basin ranges from 218 to 727 mg/L (pl. 5). Although the ground water is a mixed type, bicarbonate is the dominant anion.

An analysis of water from well 30S/15E-21D1 in the Headwaters subarea shows a mixed-type water with calcium and bicarbonate predominating. This is very similar to the surface water near Pozo which is hard and has a similar dissolved-solids concentration.

The ground water of the Huerhuero Creek drainage in the Estrella Valley subarea is a mixed type (wells 26S/12E-14K1, 27S/13E-36R1). The dissolved-solids concentration seems to be higher in the Huerhuero Creek drainage than in the Headwaters subarea, but too few analyses are available to be certain.

Well 25S/12E-32K1 is downstream from where Huerhuero Creek enters the Salinas River in the thick part of the aquifer discussed earlier. This well has a mixed-type water similar to the Headwaters subarea. The dissolved-solids concentration of 544 mg/L is higher than that of the other upstream analyses.

Ground water of the Estrella Valley subarea is a mixed type, and contains a smaller percentage of sulfate than anywhere else in the study area. Analyses from well 25S/15E-11C3 indicate that ground water in Cholame Valley has the highest dissolved-solids concentration in the upper basin; the boron concentration is greater than 1 mg/L and restricts the use of ground water for irrigation.

The ground-water quality at Shandon, downstream from Cholame and San Juan Creeks, is a mixed type with low dissolved-solids concentrations (wells 26S/15E-20B2, 26S/15E-20N1). Sodium and calcium are the dominant cations, and bicarbonate and chloride are the dominant anions. Downstream from Shandon, along the Estrella River, wells 26S/13E-11F1 and 25S/13E-19R1 indicate that the cations are evenly mixed but that bicarbonate is the dominant anion. These wells are located in the thick part of the aquifer described earlier.

The Upper Narrows subarea is downstream from the Headwaters subarea and the Estrella Valley subarea. The water in well 25S/12E-16N1 has a high dissolved-solids concentration and is a mixed-type water. The cations are evenly mixed, but the concentration of sulfate is lower than that of the other anions.

Little is known about the quality of ground water between San Miguel and T. 22 S. Monitoring will have to be done in this area to assess the impact of the ground-water quality of the upper basin on that of the lower basin. The impact of the release water that enters the Salinas River just north of Bradley also should be assessed.

Normally, the temperature of ground water is constant at a few degrees above the local mean annual air temperature. In the Estrella Valley, the areal variations in ground-water temperature are greater than the variations in the average annual temperature. The temperature variation is probably due to the shallow water table or to leakage from the surface through broken well seals. This variation might be investigated to evaluate recharge and discharge zones and variations in water quality.

Lower basin.--The dissolved-solids concentration of the ground water varies an order of magnitude in the lower basin. As with the surface water, the lowest-quality ground water comes from San Lorenzo Creek drainage, and the highest-quality ground water from the Arroyo Seco drainage. South of the confined zone, ground water on the east side is generally a sodium-sulfate type with high dissolved-solids concentrations. Ground water on the west side is generally a mixed bicarbonate type with low dissolved-solids concentrations. In the confined zone saltwater intrusion has adversely affected the ground-water quality. Heavy agricultural development has also impacted the ground-water quality in the confined zone. The variations of the lower basin's ground-water quality (see pl. 5) are described below.

The quality of ground water at well 22S/10E-17N1 (pl. 5) is representative of the ground-water quality entering the lower basin at its southern end. The ground water at this location is a mixed type having a low dissolved-solids concentration similar to the ground-water quality of the upper basin. The surface water at Bradley is also a mixed type with a low dissolved-solids concentration.

The analyses in T. 21 S. and Rs. 9 and 10 E. indicate higher dissolved-solids concentrations than upstream analyses. The ground water is a calcium-sulfate type, unlike ground water upstream, which generally is a mixed- or bicarbonate-type water. The quality of ground water in this area is probably affected by recharge from Pancho Rico Creek through the marine deposits of the Pancho Rico Formation or by the gypsum beds of the Paso Robles Formation.

As mentioned previously, the eastern tributaries in this area, such as Pancho Rico Creek and San Lorenzo Creek, have high dissolved-solids concentrations and a sodium-sulfate type water. Except for San Lorenzo Creek which flows year round, these streams are intermittent. Flow is greatest during winter storms and is very low or nonexistent during the summer. Recharge is also greatest after winter storms. The intermittent nature of the surface flow and recharge causes the underflow from these side streams to come in surges. Each time there is a surge from these side streams, a slug of low-quality water enters the valley of the Salinas River. As these slugs of ground water move downgradient, they form localized patches of low-quality ground water. Sharp variations in ground-water quality result from this intermittent flow of low quality ground water into the valley. The flows of high-quality water from the west side are greater and more continuous, and they dilute the slugs of poor quality water from the east side.

Well 19S/8E-27N2 which was abandoned in 1978 near King City has the lowest-quality water of all the wells shown on plate 5. This well is in the San Lorenzo Creek drainage. San Lorenzo Creek also has the lowest-quality surface water in the study area. Salt deposits line the banks of San Lorenzo Creek indicating the extremely high dissolved-solids content of the water. Gypsum beds in the Paso Robles Formation are probably responsible for the poor quality of both the surface and ground water here, but flow through the marine Pancho Rico Formation may also be responsible.

The large volume of ground-water inflow from the Arroyo Seco Basin dilutes the calcium-sulfate water to a low concentration calcium-bicarbonate water as shown by the pie diagrams for wells 18S/6E-25E1 and 28J1, and 19S/6E-1H1 (pl. 5). Because the inflow from the Arroyo Seco Basin is high, its dilution is effective over most of the width of the basin from the inflow to Gonzales as evidenced by the distribution of the calcium-bicarbonate type water in this reach (pl. 5).

Along the east side of the valley from Pancho Rico Creek to about Gonzales, the ground water is predominantly a sodium-sulfate type (well 19S/7E-11H1), but some analyses indicate calcium-sulfate (well 18S/6E-11J1) or mixed types with no dominant cations or anions. The high dissolved-solids content in the ground water of this area probably results from recharge through, and runoff over the gypsum beds of the Paso Robles Formation.

Ground water in the East Side subarea from Gonzales to Castroville generally contains less than 1,000 mg/L dissolved solids. It is principally a sodium-chloride or sodium-calcium-chloride type water, but in a few scattered areas is a calcium-bicarbonate type. Because the dissolved solids concentration is relatively low, the chloride dominance in some of these wells probably does not result from saltwater intrusion.

Comparison of the quality of ground water in the 180-foot aquifer with that in the 400-foot aquifer indicates that both aquifers generally contain the same type of water, but water from the 180-foot aquifer has a higher dissolved-solids concentration. In a few areas percolation from irrigation return may have reached the 180-foot aquifer but not the 400-foot aquifer. The semipervious clay layers between the two aquifers may protect the ground-water quality of the deeper aquifer (compare analysis for well 14S/3E-31F1 of the 180-foot aquifer with well 31Q2 of the 400-foot aquifer). Many wells have been drilled through the confining zones that separate the perched, 180- and 400-foot aquifers. Unless the seals in the confining zones are properly constructed, the wells act as pathways allowing water to flow from one aquifer to the other. Migration of water through poorly constructed wells has probably affected the quality of both the 180-foot and 400-foot aquifers (William Leonard and Gene Taylor, Monterey County Flood Control and Water Conservation District, oral commun., 1981). As expected, the 180-foot aquifer, which is nearer the perched aquifer, is more highly mineralized than the 400-foot aquifer. Saltwater intrusion affects the ground-water quality of both aquifers.

The localized increase in the dissolved-solids concentration of the ground water near the city of Salinas may result from the migration of irrigation return water through poorly constructed wells. In the 180-foot aquifer at this locale, the ground-water ionic concentration varies from dominance by calcium-sulfate to dominance by calcium-sodium-bicarbonate-sulfate. In the 400-foot aquifer the ground water has a lower dissolved-solids concentration dominated by calcium-bicarbonate ions or by sodium-calcium-bicarbonate ions. The difference in ground-water-quality types indicates the poor hydraulic connection between the permeable zones at this location.

The separation between the two aquifers is not as effective (or complete) southeast of Salinas near Spence. The water-quality types are almost identical in both aquifers, but the ground water from the 400-foot aquifer has a lower dissolved-solids concentration. Aquifer tests suggest that there may be a gap in the confining layer at Spence (Monterey County Flood Control and Water Conservation District, 1967).

The aquifers near the shoreline of Monterey Bay have been significantly affected by saltwater intrusion. As a result of pumpage, the hydraulic gradient is reversed, and saltwater infiltrates landward into the aquifer. If the only process involved in the intrusion were mixing, the ground-water along the bay would be a mixture of sodium-chloride saltwater having a dissolved-solids concentration of about 34,000 mg/L and a mixed type native ground water having a dissolved-solids concentration of less than 1,000 mg/L. Unless minute quantities of saltwater were involved, the mix of water resulting from the saltwater intrusion would probably be a sodium-chloride type.

In near-shore wells 13S/2E-29R1, 16D1, 14S/2E-6D2, and 16A1, however, the waters are calcium-chloride rather than sodium-chloride types. Even though the samples have high percentages of chloride and high dissolved-solids concentrations, the mixed water is not the same water-quality type as seawater. This is probably due to cation exchange taking place within the aquifer. As the high sodium-chloride saltwater moves from the ocean into the aquifer, the calcium ions in clay beds are replaced by sodium ions. This phenomenon has also been observed in Hawaii (Swain, 1973). The extent to which this cation exchange is taking place indicates that the 180-foot aquifer probably contains more clay in the near-shore or offshore area than is evident in the aquifer farther up the valley.

Saltwater intrusion in the 400-foot aquifer is not as extensive as in the 180-foot aquifer, nor has the water in the 400-foot aquifer been as affected by cation exchange as the water in the 180-foot aquifer. The wells showing saltwater intrusion (14S/2E-31N2; 13S/2E-19H1, 30A1, and 31D2) in the 400-foot aquifer all have predominantly sodium-chloride-type water with greater percentages of calcium than seawater, but sodium is still the dominant cation. This indicates that the clay content of the 400-foot aquifer at the ocean interface is probably less than the clay content of the 180-foot aquifer.

GROUND-WATER-QUALITY INTEREST AREAS

Ground-water-quality interest areas may be related to geology, land use and (or) hydrology. These areas are shown in figure 7. They represent general areas of known or suspected ground-water-quality problems or areas where differences in water quality are suspected, but not documented zones of ground-water contamination. With the aid of local officials, these problem and special interest areas were outlined as places where water quality needs to be investigated. The monitoring network described later in this report was designed to provide information that would define the extent of these areas.

General Causes

Many natural factors have combined to create ground-water-quality variations in the Salinas River basin. Precipitation patterns, surface-water flow patterns, distribution of rock types, and faults all function together creating the natural ground-water-quality variation of the Salinas River basin. Man's activities, such as pumping, recharge, fertilizer application, and waste disposal, have further influenced the ground-water quality. Land-use practices described earlier have a major impact on ground-water quality in an unconfined system. The longevity of land-use practices is particularly important--the longer a practice is in use, the more likely it is to impact the ground-water quality. It takes long periods of time for certain chemical constituents to migrate from the surface downward to the water table, so past land-use practices can continue to affect the ground-water quality for many years after the land use has changed.

Problem areas or areas of special interest can be caused by point sources. The California Regional Water Quality Control Board is responsible for issuing point-source discharge permits in the study area. Even though these discharges are regulated, they represent potential point sources of ground-water contamination that should be considered in developing a ground-water-quality monitoring network. Locations of the permitted discharges and mines, which can also be point sources, are shown in figure 7. Most of the permitted discharges are in the King City area and north.

Upper Basin

Compared to the lower basin, the upper basin is relatively undeveloped. Although some localized ground-water-quality problems have undoubtedly been caused by development of the upper basin, the most significant regional ground-water-quality problems of the upper basin stem from natural causes. Two areas have been identified in the upper basin.

Along San Juan Creek, the ground water is highly mineralized. Boron and arsenic levels in this area, locally called the Bitterwater area, have restricted the use of ground water. Because the distribution of these constituents is unknown, the area along San Juan Creek is considered a ground-water-quality problem area.

The area where Estrella River and Huerhuero Creek join the Salinas River is also identified as a ground-water-quality interest area. Because ground water from the entire upper basin flows into this area from time to time, the quality here should be representative of the quality throughout the upper basin.

Lower Basin

Ground-water development and land-use practices have increased the ground-water-quality variations in the lower basin. Most of the problem and special interest areas shown in figure 7 are located in the lower basin. As discussed earlier, the major natural cause of the variation of ground-water quality in the area relates to the gypsum beds of the Paso Robles Formation and the Pancho Rico Formation. In time, the recharge of large quantities of high-quality water from Lakes San Antonio and Nacimiento may improve the ground-water quality of the entire lower basin.

The Monterey County Flood Control and Water Conservation District calculates that for the period 1959-77 total recharge to the aquifer averaged 271,000 acre-ft/yr and of that amount an average of 153,600 acre-ft was from reservoir releases. On the average, 57 percent of the water recharged to the Salinas River basin comes from Lakes Nacimiento and San Antonio. Release water from the lakes is high quality, and it improves the ground-water-quality northward from Bradley. The improvement in ground-water quality resulting from this major recharge source should be quantified. Consequently, the recharge zone near of Bradley is an area of ground-water-quality interest.

The area near San Ardo is a problem area for two reasons. First, low-quality outflow from Pancho Rico Creek degrades the quality of the ground water on the east side of the valley. Second, there is potential for ground-water contamination from the San Ardo oil field. The California Division of Oil and Gas requires monitoring near San Ardo for contamination of the near-surface aquifer by past brine injection. To date, there has been no evidence in the wells monitored that the injected brines have migrated upward into the aquifer. However, ground-water near the oil field and the low-quality outflow from Pancho Rico Creek, both warrant monitoring.

Peachtree Valley is drained by San Lorenzo Creek, which has the lowest quality surface-water in the entire study area. The quality of the ground water is very poor east of King City where the San Lorenzo Creek flows into the Salinas Valley (pl. 5). Because data were not available from Peachtree Valley, little is known about the quantity and quality of the ground water there. Only after a definitive ground-water-quality inventory has been done for this area can long-term monitoring stations be chosen.

Hames Valley and Lockwood are both small agricultural areas on the western side of the upper basin. In both areas there is concern about the availability of ground water and the quality of the water. Monterey County Flood Control and Water Conservation District requested that both of these areas be included as special interest areas.

Except for the releases from Lakes Nacimiento and San Antonio, Arroyo Seco is the major source of recharge in the basin and its ground-water quality is of regional importance. The agricultural development of this area makes monitoring the ground-water quality particularly important. Arroyo Seco is also the site of a proposed water-supply dam (CH_2M Hill, 1982). Water from the Arroyo Seco reservoir would be diverted to the East Side subarea and to the Monterey Peninsula.

The effects of agricultural and industrial development between Salinas and Soledad need to be evaluated (fig. 7). Residuals of fertilizers and irrigation water, such as nitrates and organics in the soils, may be leached out by water percolating to the water table. Because several potential point sources (such as the feed lot at Fat City) are located in this area, the quality of ground water should be monitored. The unconfined area between Chualar and Soledad is particularly vulnerable to ground-water contamination.

For many years most of the agriculture in the Salinas Valley has been concentrated between Salinas and the coast. Pumping large volumes of ground water to supply the required irrigation water in the confined zone north of Salinas has caused saltwater intrusion. From an economic standpoint, this saltwater intrusion is the most severe water-quality problem in the study area. The amount of land impacted is shown on figure 8. The cost of the ground-water quality deterioration from saltwater intrusion has been enormous when the additional pumping, drilling, and well-abandonment costs are considered. The zone threatened by saltwater intrusion shown in figure 7 extends to approximately the 0-foot contour for the 180-foot aquifer. This indicates an area much larger than the zone where the ground water has been contaminated by chloride (see Monterey County Flood Control and Water Conservation District's Summary of Water Resources Data for the yearly location of the 100 mg/L chloride line, 1959-77).

IDEAL NETWORK

Network Objectives

Developing a set of specific objectives for a network is a crucial task and a difficult one because it is not possible to predict all the future uses of the hydrologic information collected by the network. The best that can be done is to develop a network based on the important water-quality questions of the present and those that are expected to be important in the future. Initially, the general project objectives were described as follows:

> "The objective of this investigation is to design a ground-water-monitoring system for the water-bearing sediments of the Salinas Valley that will supply adequate data to characterize the ground-water quality. The monitoring network should also provide data to evaluate significant water-quality changes in known problem areas. Conceptually, two ground-water networks will be designed, because the project has two major objectives. One of the conceptual networks should provide data to characterize the natural water-quality patterns throughout the basin. The other conceptual network should provide data to alert officials of significant water-quality changes in areas with known problems. The two conceptual networks should function as a single comprehensive network providing the data needed to characterize the basin's ground-water quality."

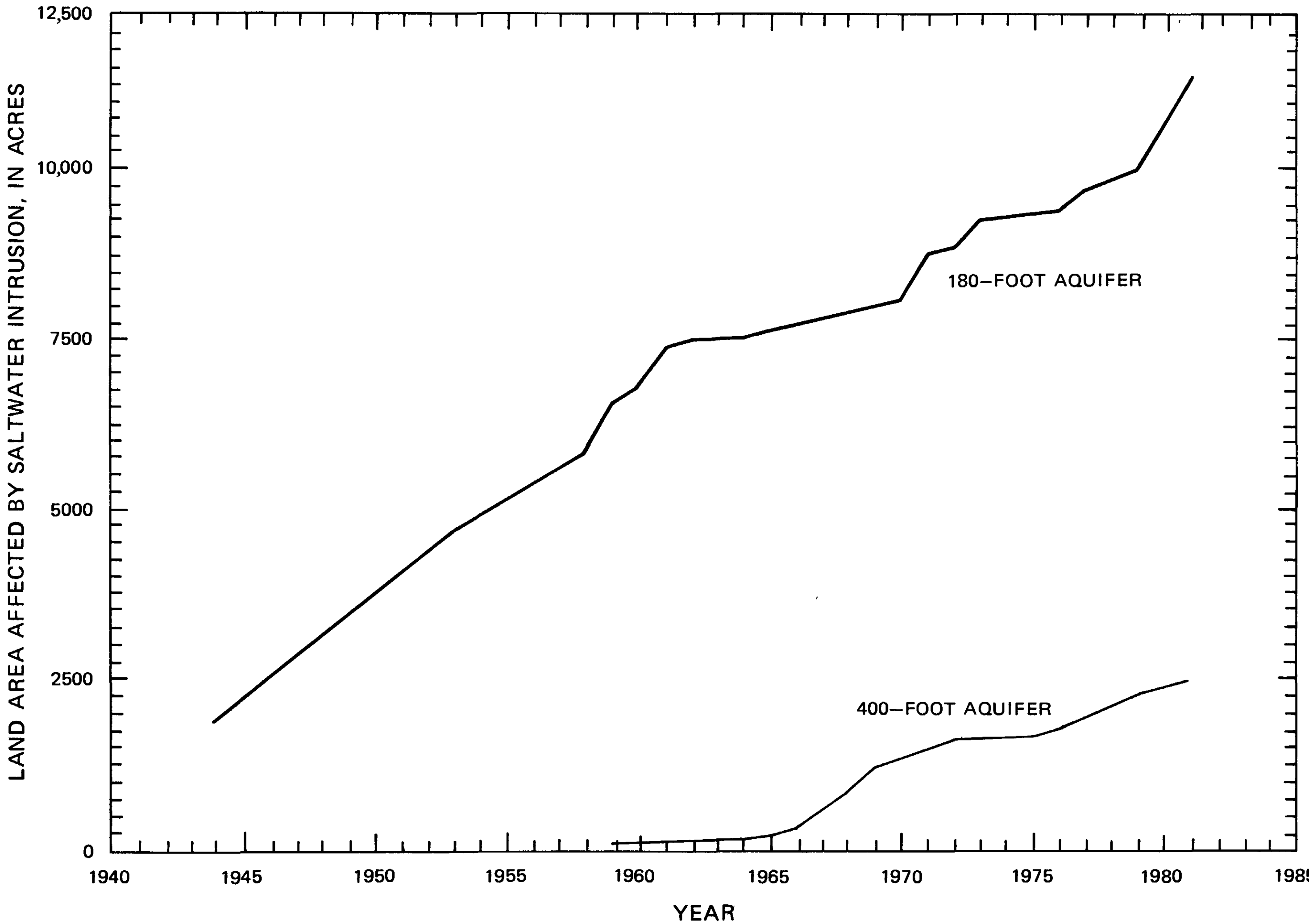


FIGURE 8.– Acres of land affected by saltwater intrusion (chloride content of the ground water is 500 milligrams per liter or greater).

During the course of the project, more specific objectives for determining what kinds of information are needed about the known or suspected problem areas and about the Salinas River basin as a whole were identified. These specific objectives, in order of their importance, are given in table 1.

Approach

The ideal network was designed jointly by the authors and the California Regional Water Quality Control Board, Central Coast Region (Regional Board). Everything known about the hydrologic system of the Salinas River drainage basin was considered, particularly those factors that might impact the water quality, including: geology; land use--past, present, and future; water levels; known water-quality problems; suspected water-quality problems; earlier reports; and hydrological data. Local information that contributed to understanding the ground-water quality was considered. Access problems, manpower limitations, laboratory limitations, and budgetary limitations are examples of practical considerations that might hamper network implementation. These factors were not considered in the design of the ideal network.

The ideal network was designed to provide the regional ground-water-quality information needed by the Regional Board. These needs are described by the objectives in table 1. Only monitoring locations and parameters that directly address the objectives were chosen.

The water-quality problems of both Monterey and San Luis Obispo Counties were discussed with the county representatives. These discussions identified parameters that had been neglected and areas where additional monitoring locations were required. The suggestions from the County officials, as well as those from Geological Survey reviewers, were incorporated into the ideal network (pl. 6).

Monitoring Locations

The monitoring locations in the ideal network are shown on plate 6 with the symbols indicating the proposed sampling categories and frequency of sample collection. Autumn and spring water-level measurements should be collected at each well. The sampling categories and the suggested frequency of measurement are listed in tables 7 and 8.

Some surface-water-quality sampling is suggested as part of the ground-water-quality monitoring network because infiltration through stream channels is the major source of recharge to the ground water. U.S. Geological Survey gaging stations are proposed as monitoring locations because flow records for those stations are available. Monthly sampling is suggested so that seasonal variations can be observed. Sampling surface-water flow during storms is also suggested. These collections can correspond with regular maintenance visits so that little additional manpower will be required.

TABLE 7. - Proposed surface-water-monitoring locations and sampling categories

Gaging station number and name		Sampling categories for each station	Frequency	Objectives
11147500	Salinas River at Paso Robles	Specific conductance pH Temperature Dissolved oxygen Dissolved nitrate Chloride Sulfate[2]	Monthly[1]	2, 4
11148500	Estrella River near Estrella		Monthly[1]	2, 4
11149400	Nacimiento River below Nacimiento Dam, near Bradley		Monthly	2, 4, 7
11150500	Salinas River near Bradley		Monthly	2, 4, 7
	Pancho Rico		Monthly[1]	2, 4, 11
11151300	San Lorenzo Creek below Bitterwater Creek near King City		Monthly	2, 4, 5
11152000	Arroyo Seco near Soledad		Monthly	2, 4, 8
11152300	Salinas River near Chualar		Monthly	2, 4, 8

[1]No flow during summer months; measurements taken monthly when stream is flowing.
[2]Only at stations 11151300 and 11148500.

TABLE 8. - Ground-water-monitoring locations

Asterisk (*) indicates location (township, range, and section number) where ground-water monitoring is suggested, not the location of a known monitoring well. An existing well near the indicated location can be identified and added to an existing network. If no suitable well can be found nearby, a monitoring well can be drilled. The well added to the network should have approximately the depth shown. Dashes (--) indicate that data are not available. The numbers 900, 400, and 180 refer to identifying depths of those subarea aquifers. Objectives are given in table 1.

Locality No.	Depth of well (ft)	Depth to first opening (ft)	Subarea aquifer	Objectives
13S/2E-31N2	576	324	400	1, 2, 3, 13
13S/2E-32E3	885	356	400	1, 2, 3, 13
13S/2E-32N1	602	369	400	1, 2, 3, 13
13S/2E-32Q3	680	517	400	1, 2, 3, 13
13S/2E-33H3	380	150	180	1, 2, 3, 13
13S/2E-36J1	580	207	East Side	1, 2, 3, 13
13S/3E-30P1	703	--	East Side	1, 2, 3, 13
*13S/3E-33Q	250	200	East Side	1, 2, 3, 13
14S/2E-2M1	--	--	400	1, 2, 3, 13
14S/2E-3M2	587	400	400	1, 2, 3, 13
14S/2E-5F4	582	406	400	1, 2, 3, 13
14S/2E-5P2	616	464	400	1, 2, 3, 13
14S/2E-6J3	550	375	400	1, 2, 3, 13
14S/2E-6R2	604	371	400	1, 2, 3, 13
14S/2E-7F2	612	361	400	1, 2, 3, 13
14S/2E-8C3	556	395	400	1, 2, 3, 13
14S/2E-8M2	500	314	400	1, 2, 3, 13
14S/2E-9L2	646	400	400	1, 2, 3, 13
14S/2E-9N1	716	412	400	1, 2, 3, 13
14S/2E-10R1	--	--	400	1, 2, 3, 13
14S/2E-12E1	848	535	400	1, 2, 3, 13
14S/2E-12Q1	619	--	400	1, 2, 3, 13
14S/2E-13P1	178	130	400	1, 2, 3, 13
14S/2E-16E2	214	156	180	1, 2, 3, 13
14S/2E-16H1	620	449	180	1, 2, 3, 13
14S/2E-17B2	505	202	180	1, 2, 3, 13
14S/2E-21L1	250	--	180	1, 2, 3, 13
14S/2E-22P2	304	255	180	1, 2, 3, 13
14S/2E-23F1	364	240	180	1, 2, 3, 13
14S/2E-24E1	467	284	400	1, 2, 3, 13

TABLE 8. - Ground-water-monitoring locations--Continued

Locality No.	Depth of well (ft)	Depth to first opening (ft)	Subarea aquifer	Objectives
14S/2E-24P2	451	333	400	1, 2, 3, 13
14S/2E-25D3	--	--	--	1, 2, 3, 13
14S/2E-34A1	469	135	180, 400	1, 2, 3, 13
14S/2E-34B3	346	306		1, 2, 3, 13
14S/2E-35L2	469	135	400	1, 2, 3, 13
14S/2E-36E1	--	--	180, 400	1, 2, 3, 13
14S/2E-36G1	416	336	400	1, 2, 3, 13
14S/3E-10F3	706	160	East Side	1, 2, 13
14S/3E-11H1	394	140	East Side	1, 2, 13
14S/3E-16K3	473	154	East Side	1, 2, 13
14S/3E-18J1	513	245	400	1, 2, 13
14S/3E-19H1	150	125	180	1, 2, 13
*14S/3E-24C	500	300	East Side	1, 2, 13
14S/3E-25L2	800	160	East Side	1, 2, 13
14S/3E-28B2	588	412	400	1, 2, 13
14S/3E-28F2	537	420	400	1, 2, 13
14S/3E-30E1	430	337	400	1, 2, 13
14S/3E-30N1	385	--	180	1, 2, 13
14S/3E-31F2	518	337	400	1, 2, 13
14S/3E-31Q2	420	353	400	1, 2, 13
14S/3E-33G1	342	120	180	1, 2, 13
14S/3E-35H3	660	227	East Side	1, 2
*14S/4E-30L	400	250	East Side	1, 2
*14S/4E-32G	400	250	East Side	1, 2
15S/2E-1A3	480	366	400	1, 2, 13
15S/2E-2A2	365	--	400	1, 2, 3, 13
15S/2E-3C1	500	289	400	1, 2, 3, 9, 13
15S/2E-3C3	342	290	180	1, 2, 3, 9, 13
*15S/2E-9G	350	250	180	1, 2, 3, 9, 13
15S/2E-12C2	293	144	180	1, 2, 3, 13
*15S/2E-14A	350	250	180	1, 2, 3, 13
15S/2E-25B2	610	290	400	1, [1]2
15S/3E-3C1	500	126	400	1, 2, 13
15S/3E-4H4	463	307	400	1, 2, 8, 9, 13
15S/3E-5C2	614	357	180	1, 2, 13

TABLE 8. - Ground-water-monitoring locations--Continued

Locality No.	Depth of well (ft)	Depth to first opening (ft)	Subarea aquifer	Objectives
15S/3E-5Q4	252	132	180	1, 2, 8, 13
15S/3E-6F2	500	332	400	1, 2, 8, 13
15S/3E-7G1	376	164	180, 400	1, 2, 8, 13
15S/3E-8F5	494	266	180	1, 2, 8, 9, 13
15S/3E-12F2	595	198	400	1, 2, 8, 13
15S/3E-13J2	380	116	180	1, 2, 8, 13
15S/3E-14H1	277	85	180	1, 2, 8, 13
15S/3E-15B1	452	318	400	1, 2, 8, 13
15S/3E-16B2	528	415	400	1, 2, 8, 9, 13
15S/3E-18F1	456	248	400	1, 2, 9, 13
15S/3E-26H2	208	120	180	1, 2, 8, 13
15S/3E-27J1	520	403	400	1, 2, 8, 13
15S/3E-28G1	325	115	180	1, 2, 8, 13
15S/3E-35B5	251	200	180	1, 2, 8, 13
15S/4E-6D4	1,100	202	East Side	1, 2, 13
15S/4E-7A1	772	212	East Side	1, 2, 8, 13
15S/4E-16E2	501	--	East Side	1, 2, 8, 13
15S/4E-17P2	467	157	400	1, 2, 8, 13
15S/4E-19H3	325	232	180	1, 2, 8, 13
15S/4E-22L2	500	--	East Side	1, 2, 8, 13
15S/4E-27G1	608	--	400	1, 2, 8, 13
15S/4E-29Q1	535	--	400	1, 2, 8, 13
15S/4E-33A1	279	117	180	1, 2, 8, 13
15S/5E-30G1	326	--	East Side	1, 2, 8, 9
*15S/5E-30P	450	300	East Side	1, 2, 13
*16S/3E-1A	400	250	180, 400	1, 2, 8, 13
*16S/3E-1G	400	250	180, 400	1, 2, 8, 13
*16S/4E-1G	250	200	East Side	1, 2, 8, 13
16S/4E-8J1	175	--	180	1, 2, 8
16S/4E-13K1	233	170	180	1, 2, 8
16S/4E-14M2	582	428	400	1, [2]2, 8
16S/4E-15D1	384	170	180	1, 2, 8
16S/4E-24A1	564	336	400	1, 2, 8
16S/4E-25K1	694	641	400	1, 2, 8
*16S/4E-27F	300	200	180	1, 2, [3]8

TABLE 8. - Ground-water-monitoring locations--Continued

Locality No.	Depth of well (ft)	Depth to first opening (ft)	Subarea aquifer	Objectives
*16S/4E-28H	300	200	180	1, 2, [3]8
*16S/4E-28Q	300	200	180	1, [3]2
16S/4E-36B1	183	--	180	1, 2, 8
16S/5E-8F1	796	--	East Side	1, 2, 9
*16S/5E-8H	200	150	East Side	1, 2, [4]9
*16S/5E-9P	200	150	East Side	1, 2, [4]9
*16S/5E-14N	200	150	Forebay	1, 2, [4]9
*16S/5E-15L	200	150	Forebay	1, 2, [4]9
*16S/5E-17G	200	150	East Side	1, 2, 8, [4]9, 13
16S/5E-17R1	299	--	East Side	1, 2, [4]9
*16S/5E-27E	200	150	Forebay	1, 2, [4]9
16S/5E-32B1	217	95	Forebay	1, 2, 8, 9
16S/5E-32B2	250	80	Forebay	1, 2, 8, 9
16S/5E-35C1	735	300	Forebay	1, 2
17S/5E-1Q1	807	250	Forebay	1, 2, [5]9
17S/5E-3B1	500	140	Forebay	1, 2, 9
17S/5E-4C1	614	--	Forebay	1, 2, 8
17S/5E-6Q1	170	90	Forebay	1, 2, 8
17S/5E-9Q1	156	80	Forebay	1, 2
17S/5E-10Q1	200	46	Forebay	1, [2]2
17S/5E-12P3	725	250	Forebay	1, 2, [5]9
*17S/5E-22K	200	100	Forebay	1, 2
*17S/5E-24G	200	100	Forebay	1, 2, [6]9
17S/5E-25L1	--	--	Forebay	1, 2
17S/5E-36F2	234	80	Forebay	1, 2
*17S/6E-8N	200	100	Forebay	1, 2
17S/6E-20Q3	370	140	Forebay	1, 2, 8, 9, 10
17S/6E-21N2	264	84	Forebay	1, 2, 8, 10
17S/6E-27K1	250	--	Forebay	1, 2, 10
17S/6E-28N1	260	--	Forebay	1, 2, 8, 10
17S/6E-29C1	303	86	Forebay	1, 2, 8, 10
17S/6E-32G1	--	--	Forebay	1, 2, 8, 10
17S/6E-35F1	242	--	Forebay	1, 2, 8, 10
18S/6E-1E1	218	90	Forebay	1, 2, 8, 10
18S/6E-2N1	274	80	Forebay	1, 2, 8, 10

TABLE 8. - Ground-water-monitoring locations--Continued

Locality No.	Depth of well (ft)	Depth to first opening (ft)	Subarea aquifer	Objectives
*18S/6E-4E	200	90	Forebay	1, 2, 8, 10
18S/6E-7A1	--	--	Forebay	1, 2, 8, 10
18S/6E-9M2	589	153	Forebay	1, 2, 8, 10
18S/6E-12A1	244	87	Forebay	1, [2]2, 8, 10
18S/6E-15M1	288	104	Forebay	1, [2]2, 8, 10
*18S/6E-21D	200	100	Forebay	1, 2, 8, 10
*18S/6E-24H1	238	80	Forebay	1, 2, 8, 10
*18S/6E-25F1	120	--	Forebay	1, 2, 8
18S/6E-27A1	343	--	Forebay	1, 2, 8, 10
18S/6E-28J1	754	--	Forebay	1, 2, 8, 10
*18S/7E-8M	170	75	Forebay	1, 2, 8, 10
18S/7E-18P1	175	--	Forebay	1, 2, 8, 10
18S/7E-20K1	200	164	Forebay	1, 2, 8, 10
*18S/7E-26M	150	75	Forebay	1, 2
18S/7E-28K1	120	--	Forebay	1, 2, 8, 10
18S/7E-29G1	--	--	Forebay	1, 2, 8, 10
*19S/5E-22J	41	22	Forebay	1, 2, 10
*19S/6E-2K	100	50	Forebay	1, 2, 8, 10
*19S/6E-3C	100	50	Forebay	1, 2, 8, 10
*19S/6E-9K	100	50	Forebay	1, 2, 8, 10
*19S/6E-16H	100	50	Forebay	1, 2, 8, 10
*19S/7E-1G	100	50	Upper Valley	1, 2
19S/7E-4G1	210	95	Forebay	1, 2
19S/7E-10P1	245	90	Forebay	1, 2
19S/7E-13D1	--	--	Upper Valley	1, 2
19S/7E-16D1	513	--	Forebay	1, 2, [7]9
*19S/7E-22Q	250	100	Upper Valley	1, 2
*19S/8E-18Q	200	100	Upper Valley	1, 2, 5
*19S/8E-20L	150	75	Upper Valley	1, 2, 5
19S/8E-27N3	473	402	Upper Valley	1, 2, 5
*19S/8E-28C	150	75	Upper Valley	1, 2, 5
19S/8E-30A1	228	74	Upper Valley	1, 2, 5
19S/8E-33P1	600	195	Upper Valley	1, 2, 5
*20S/7E-12K	150	75	Upper Valley	1, 2, 5
*20S/8E-2P	150	75	Upper Valley	1, 2, 5

TABLE 8. - Ground-water-monitoring locations--Continued

Locality No.	Depth of well (ft)	Depth to first opening (ft)	Subarea aquifer	Objectives
20S/8E-5C2	296	151	Upper Valley	1, 2, 5
20S/8E-6B1	203	70	Upper Valley	1, 2, 5
20S/8E-7F1	189	70	Upper Valley	1, 2, 5
20S/8E-8H2	116	64	Upper Valley	1, 2, 5
20S/8E-8P1	93	--	Upper Valley	1, 2, 5
20S/8E-8Q1	100	52	Upper Valley	1, 2, 5
*20S/8E-10P	100	50	Upper Valley	1, 2, 5
20S/8E-16C1	--	--	Upper Valley	1, 2, 5
*20S/8E-24G	100	50	Upper Valley	1, 2
*20S/8E-27D	100	50	Upper Valley	1, 2
20S/8E-34G1	432	120	Upper Valley	1, 2
20S/9E-32J1	--	--	Upper Valley	1, 2
*21S/9E-8P	150	75	Upper Valley	1, [2]2, 14, 16
*21S/9E-14F	150	75	Upper Valley	1, 2, 14, 16
*21S/9E-20B	150	75	Upper Valley	1, 2, 14, 16
21S/9E-24L1	120	72	Upper Valley	1, 2, 14, 16
*21S/9E-26F	150	75	Upper Valley	1, 2, 14, 16
*21S/9E-30B	150	75	Upper Valley	1, 2, 14, 16
21S/10E-30E2	140	86	Upper Valley	1, 2, 14, 16
*21S/11E-28K	100	50	Upper Valley	1, 2, 11, 14
*22S/9E-2L	150	75	Upper Valley	1, 2, 14, 16
*22S/10E-5M	150	75	Upper Valley	1, 2, 11, 12, 14, 16
*22S/10E-8F	150	75	Upper Valley	1, 2, 11, 12, 14, 16
*22S/10E-9E	150	75	Upper Valley	1, 2, 11, 12, 14, 16
*22S/10E-15B	150	75	Upper Valley	1, 2, 11, 12, 14, 16
22S/10E-16P1	178	40	Upper Valley	1, 2, 11, 12, 14, 16
22S/10E-17B1	118	54	Upper Valley	1, 2, 11, 12, 14, 16
22S/10E-21C1	285	40	Upper Valley	1, 2, 11, 12, 14, 16
22S/10E-22N1	192	135	Upper Valley	1, 2, 12, 14, 16
22S/10E-28B1	106	36	Upper Narrows	1, 2, 12, 14, 16
22S/10E-28M2	298	138	Upper Narrows	1, 2, 11, 12, 14, 16
22S/10E-34G1	182	85	Upper Narrows	1, 2, 12, 14, 16
*22S/11E-6C	100	50	Upper Valley	1, 2, 11
*23S/7E-32L	100	50	Lockwood	1, 2, 10, 18
23S/8E-2N1	271	70	Lockwood	1, 2

TABLE 8. - Ground-water-monitoring locations--Continued

Locality No.	Depth of well (ft)	Depth to first opening (ft)	Subarea aquifer	Objectives
*23S/10E-1D	150	75	Upper Narrows	1, 2, 14, 16
*23S/10E-2E	150	75	Upper Narrows	1, 2, 14, 16
*23S/10E-14G	250	100	Upper Narrows	1, 2, 14, 16
*23S/10E-25Q	150	75	Upper Narrows	1, 2, 7, 14, 16
*23S/10E-36R	150	75	Upper Narrows	1, 2, 7, 14, 16
*23S/12E-29K	100	50	Upper Narrows	1, 2
*24S/8E-33B	100	50	Lockwood	1, 2, 10
*24S/10E-13B	150	75	Upper Narrows	1, 2, 7, 14, 16
*24S/10E-24B	125	75	Upper Narrows	1, 2, 7, 14, 16
*24S/11E-3Q	100	75	Upper Narrows	1, 2, 7, 14
*24S/11E-6B	100	75	Upper Narrows	1, 2, 7, 14, 16
*24S/11E-6R	100	75	Upper Narrows	1, 2, 7, 14, 16
*24S/11E-9D	100	75	Upper Narrows	1, 2, 7, [8]9, 14,
*24S/11E-14A	100	75	Upper Narrows	1, 2, 7, 14, 16
*24S/11E-16B	100	75	Upper Narrows	1, 2, 7, 14, 16
*24S/11E-18R	100	50	Upper Narrows	1, 2, 7, 14, 16
*24S/11E-20B	100	50	Upper Narrows	1, 2, 7, 14, 16
24S/11E-24Q1	395	--	Upper Narrows	1, 2, 7, 14, 16
24S/11E-25N1	600	145	Upper Narrows	1, [2]2, 7, 14, 16
24S/11E-26C1	238	--	Upper Narrows	1, 2, 7, 14, 16
24S/11E-26N1	636	118	Upper Narrows	1, 2, 7, 14, 16
24S/11E-34P1	612	--	Upper Narrows	1, 2, 7, 14, 16
24S/11E-35C1	712	133	Upper Narrows	1, 2, 7, 14, 16
*24S/12E-29M	200	100	Upper Narrows	1, 2, 7, 14
*25S/8E-13L	100	50	Lockwood	1, 2
25S/11E-1A1	960	100	Upper Narrows	1, 2, 7, 14
*25S/11E-6J	100	50	Upper Narrows	1, 2, 7, 14
25S/11E-9M1	200	--	Upper Narrows	1, 2, 7, 14
*25S/11E-24F	150	75	Upper Narrows	1, 2, 10, 14
*25S/11E-36P	100	50	Estrella	1, 2, 10, 14
25S/12E-10N	200	100	Estrella	1, 2, 6, 14
25S/12E-16N1	300	100	Estrella	1, 2, 6, 14
25S/12E-17J1	210	100	Estrella	1, 2, 6, 14
25S/12E-17R1	205	105	Estrella	1, [2]2, 6, 14
25S/12E-21C1	125	--	Estrella	1, 2, 6, 10, 14,
*25S/12E-26C	200	100	Estrella	1, 2, 6, 14

TABLE 8. - Ground-water-monitoring locations--Continued

Locality No.	Depth of well (ft)	Depth to first opening (ft)	Subarea aquifer	Objectives
*25S/12E-26J	200	100	Estrella	1, 2, 6, 14
*25S/12E-27F	200	100	Estrella	1, 2, 6, 14
*25S/12E-28Q	200	100	Estrella	1, 2, 6, 14
*25S/12E-34G	200	100	Estrella	1, 2, 6, 14
25S/13E-19R1	--	--	Estrella	1, 2, 6, 14
*25S/13E-31K	200	100	Estrella	1, 2, 6, 14
*25S/13E-33E	200	100	Estrella	1, 2, 6, 10, 14
25S/14E-33Q1	--	--	Estrella	1, 2, 14
25S/15E-11C3	--	--	Estrella	1, 2, 10, 14
*25S/16E-19B	--	--	Estrella	1, 2, 10, 14
*25S/16E-30M	--	--	Estrella	1, 2, 10, 14
*26S/10E-14N	200	100	Estrella	1, 2, 9, 10, 14
*26S/10E-26N	200	100	Estrella	1, 2, [9]9, 10, 14
*26S/10E-34E	200	100	Estrella	1, 2, [10]9, 10, 14
*26S/11E-20E	200	100	Estrella	1, 2, 10, 14
*26S/11E-22G	200	100	Estrella	1, 2, [11]9, 10, 14
26S/12E-1L1	1,250	--	Estrella	1, 2, 6, [12]9, 14
*26S/12E-2A	150	75	Estrella	1, 2, 6, 10, 14
*26S/12E-3F	150	75	Estrella	1, 2, 6, 14
*26S/12E-10K	150	75	Estrella	1, 2, 6, 14
*26S/12E-11D	150	75	Estrella	1, 2, 6, 14
26S/12E-13D1	214	100	Estrella	1, 2, 6, 14
26S/12E-14G1	840	--	Estrella	1, 2, 6, 10, 14
*26S/12E-16G	150	75	Estrella	1, 2, 6, 14
*26S/12E-17G	150	75	Estrella	1, 2, 6, 10, 14
26S/12E-21L1	--	--	Estrella	1, 2, 6, 9, 14
26S/12E-21L2	--	--	Estrella	1, 2, 6, 9, 14
26S/12E-22J1	775	275	Estrella	1, 2, 6, 14
26S/12E-22P2	400	--	Estrella	1, 2, 14
26S/12E-33B2	--	--	Estrella	1, 2, 14
26S/12E-33Q1	70	21	Headwaters	1, 2, 14
*26S/13E-4E	200	100	Estrella	1, 2, 6, 14
26S/13E-11F1	890	--	Estrella	1, [2]2, 6, 14
26S/13E-15L1	--	--	Estrella	1, 2, 6, 14
*26S/13E-17J	150	75	Estrella	1, 2, 6, 14

TABLE 8. - Ground-water-monitoring locations--Continued

Locality No.	Depth of well (ft)	Depth to first opening (ft)	Subarea aquifer	Objectives
*26S/13E-18C	150	75	Estrella	1, 2, 6, 9, 14
26S/13E-30B1	441	--	Estrella	1, 2, 6, 14
26S/14E-16R1	--	--	Estrella	1, 2, 14
*26S/14E-18L	150	75	Estrella	1, 2, 6, [13]9, 14
26S/14E-35D1	290	--	Estrella	1, 2, 10, 14
26S/15E-20B2	400	200	Estrella	1, [2]2, 14, 15
26S/15E-20N1	390	50	Estrella	1, 2, 14, 17
26S/15E-21G2	575	--	Estrella	1, 2, 14, 17
26S/15E-21P1	--	--	Estrella	1, 2, 14, 17
26S/15E-28Q2	150	--	Estrella	1, 2, 14, 17
*26S/15E-31K	150	75	Estrella	1, 2, 14
27S/12E-2D2	850	160	Estrella	1, 2, 14
27S/12E-2E1	--	175	Estrella	1, 2, 14
27S/12E-2F2	600	275	Headwaters	1, 2, 10, 14
27S/12E-4K2	400	175	Headwaters	1, 2, 14
27S/12E-9M2	220	60	Headwaters	1, 2, 14
27S/12E-17H2	245	140	Headwaters	1, 2, 14
27S/12E-20G3	260	120	Headwaters	1, [2]2, 10, 14
*27S/12E-28D	200	100	Headwaters	1, 2, 14
27S/12E-29P4	73	29	Headwaters	1, 2, 10, 14
27S/13E-9K1	--	--	Estrella	1, 2, 14
27S/13E-9P1	120	--	Estrella	1, 2, 10, 14
*27S/13E-29F	150	75	Estrella	1, 2, 14, 15
*27S/13E-34C	150	75	Estrella	1, 2, [14]9, 14
27S/13E-36R1	--	--	Estrella	1, 2, 14
*27S/14E-16R	200	100	Estrella	1, 2, 10, 14
27S/15E-10R2	--	--	Estrella	1, 2, 14, 17
*27S/15E-12B	100	50	Estrella	1, 2, 14, 17
*27S/15E-35K	100	50	Estrella	1, 2, 10, 14,
*27S/16E-17K	100	50	Estrella	1, 2, 14, 17
27S/16E-23N1	--	--	Estrella	1, 2, 14, 17
*27S/16E-28P	100	50	Estrella	1, 2, 14, 17
28S/12E-10B1	500	150	Headwaters	1, 2, 14
28S/12E-10H4	450	150	Headwaters	1, 2, 14
28S/12E-10R2	49	10	Headwaters	1, 2, 14

TABLE 8. - Ground-water-monitoring locations--Continued

Locality No.	Depth of well (ft)	Depth to first opening (ft)	Subarea aquifer	Objectives
28S/12E-11N6	90	20	Headwaters	1, 2, 9, 10, 14
28S/12E-14K1	60	20	Headwaters	1, 2, 14
28S/12E-25B4	--	--	Headwaters	1, 2, 14
28S/13E-4H1	--	--	Headwaters	1, 2, 14
*28S/13E-23G	150	75	Headwaters	1, 2, 10, 14
28S/13E-31F2	310	55	Headwaters	1, 2, 14
*28S/14E-25K	150	75	Headwaters	1, 2, 10, 14, 17
*28S/15E-35A	150	75	Headwaters	1, 2, 10, 14
*28S/16E-11P	150	75	Estrella	1, 2, 10, 14, 17
*28S/16E-26K	150	75	Estrella	1, 2, 10, 14, 17
*29S/13E-5J	150	75	Headwaters	1, 2, 14
29S/13E-19H2	50	30	Headwaters	1, 2, 10, 14
29S/14E-4D4	72	25	Headwaters	1, 2, 10, 14
*29S/16E-17A	100	50	Headwaters	1, 2, 10, 14, 17

[1]El Toro Creek drainage outflow to Salinas basin.

[2]Samples from these wells will be analyzed for general minerals which include dissolved calcium, iron, magnesium, manganese, potassium, silica, sodium, nitrate, phosphorus, chloride, fluoride, and sulfate in addition to laboratory total alkalinity, pH, and specific conductance. They will indicate the variation in water quality type throughout the length of the basin.

[3]These wells were chosen to indicate movement of ground water across the Jolan-Rinconada fault.

[4-14]Represent names of industrial or municipal discharge that the well was selected to monitor: [4]Fat City and Fat City annex, [5]Soledad Prison, [6]Camphora Station, [7]Inglis, [8]Bradley Solid-Waste Disposal Site, [9]Buena Vista Mine, [10]Klau Mine, [11]Hoffman Ranch, [12]Paso Robles School for Boys Sewage Treatment Plant, [13]Paso Robles Solid Waste, and [14]Chevron Atascadero.

Except along faults, the ground-water sampling locations chosen are in the unconsolidated sediments. These sediments sustain high well yields and form flat areas suitable for cultivation. Most of the ground water pumped in the Salinas River basin is pumped from the unconsolidated sediments. Because more water is pumped from the unconsolidated sediments than the consolidated, its quality is important. Sampling sites are located along faults where the faults intersect consolidated or unconsolidated sediments. An abrupt change in the water-table elevation on either side of a fault indicates that the fault restricts ground-water flow.

Sampling Categories

The information needed to answer the objectives are grouped into six sampling categories. A minimum number of groups of sampling categories was chosen to simplify operating the network.

Water levels measured at each well in the network twice per year--one measurement in the autumn to record the yearly low and another in the spring to measure the yearly high--would meet objective 1 in table 1. The difference between the spring and autumn water levels provides information necessary to determine the seasonal change in storage. Water levels indicate the direction of ground-water flow; when coupled with hydraulic conductivity and porosity data, they indicate the velocity of flow. The flow information supplied by the water-level data is useful for predicting where and the rate at which changes in ground-water quality occur.

The suite of analyses included in the general mineral category determine the ionic balance of the sampled water and define the water-quality type. Twenty locations were chosen where samples for general mineral analyses are to be collected annually. The monitoring locations for general mineral analysis are scattered throughout the basin. These sites were chosen to indicate how the quality of the ground-water changes from upgradient to downgradient in the basin. Well sites were also chosen so that the impact of important tributaries on the basin's ground-water quality can be assessed. These locations also serve as key ground-water-quality wells for monitoring. They can be used to correlate with nearby wells where less complete analyses are made. The first few rounds of samples from these locations will provide a baseline of water-quality data for the basin. Later samples will provide data to assess changes in the water quality. These 20 data points will also be useful for correlation with nearby wells where fewer analyses are made. The general mineral analysis provides information to meet objectives 2 through 9, 11 through 14, and 16 on table 1.

Field tests should be conducted at each sampling location. Electrical conductivity, pH, and temperature can be measured in the field with probes. Electrical conductivity coupled with temperature indicates the level of mineralization of the ground water; pH indicates water-quality type on a general basis. The information supplied by these field tests is basic and applies to all the quality-related objectives.

The agricultural-test category differs from the general mineral category in that it includes boron instead of phosphate. The general mineral category was developed to include the anion and cation data required to draw pie and Stiff diagrams (pl. 4). Water that contains more than 1 mg/L of boron cannot be used to irrigate many crops, and so boron analysis is also included in this category. The agricultural-test category supplies information for objectives 4, 8, and 16 on table 1.

The chloride sampling category includes the field tests conducted at each of the wells and a laboratory analysis for chloride. The purpose of this test category is to track saltwater intrusion. Monterey County Flood Control and Water Conservation District currently conducts chloride analyses and could continue operating this part of the network.

The trace-elements category was developed to supply the information required for objectives 9, 10, and 17 on table 1. Because these analyses are expensive, they will be done only once every network-evaluation period. The first network-evaluation period should be 2 years, so that half of the wells can be tested the first year and the rest tested the second year. Subsequent network-evaluation periods are to be longer, probably 5 years, so that one-fifth of the wells can be sampled for heavy metals in any 1 year.

The radioactivity category supplies information on objectives 15 and 18. Because the analyses are expensive, and the objectives are of relatively low priority, each well should be tested once every network-evaluation period. The State of California requires that all water-supply systems must be analyzed for radioactivity once every 4 years (California Department of Health Services, 1977). These data can also be collected to meet objectives 15 and 18.

PROPOSED NETWORK

Network Objectives

The same objectives apply for the proposed network as for the ideal network (table 1), although less emphasis was placed on the low priority objectives. One of the objectives listed in table 1 addressed the monitoring of the migration of water from the Forebay to the Pressure Area and the leakage from the perched zone to the 180-foot aquifer. This objective was considered to be beyond the scope of a regional network. The information collected in the proposed monitoring network will provide valuable information that can be used in an in-depth study of the problem, but it will not supply information sufficiently detailed to quantify interaquifer movement of water.

The proposed network was designed to develop the best possible ground-water-quality monitoring network within the practical limitations of manpower costs and constraints. The proposed network was also designed to make maximum use of existing monitoring efforts and available wells. If existing monitoring wells were near ideal network sites, they were included in the proposed network regardless of the priority of the objective they represent. New monitoring sites were proposed to meet ideal network objectives rated from 1 to 5. Distance from main roads and the distance from other monitoring sites have also been considered.

Approach

The general approach was to compare the ideal network to the existing local networks and select from the local networks those wells that are near the monitoring locations of the ideal network. In many areas where no local network monitoring wells exist, new wells are proposed.

The first step was to locate and generate a computer plot of the local network monitoring wells inventoried in phase 2 of this project which was completed in 1980. The next step was to develop a skeleton ideal network based on the ten most important priorities (table 1) which were rated from 1 to 5. The skeleton network delineated the minimum number of monitoring locations that could be used to meet the ten most important criteria.

Finally, the monitoring locations for the actual network were selected. Wells with perforation interval data were chosen whenever possible. The skeleton network and the existing local networks were compared visually. Where existing wells with perforation information overlapped with or were close to skeleton network monitoring locations, the well with the perforation information was included in the proposed network. It was necessary to incorporate some existing wells without perforation information or have no monitor well at all in an important locale. If no existing wells were near the skeleton network monitoring location, a new well was proposed. New wells were added to the actual network only to reflect the most important objectives--those rated from 1 to 5. The proposed network and the existing local networks were also compared with the locations of permitted discharges and mines. Existing wells located near the point sources on the potential problem areas shown on figure 7 were added to the proposed network.

Monitoring Locations

The locations of wells and surface-water-monitoring sites for the proposed network are shown on plate 7. The general purpose of a regional network is to serve as an early warning system for ground-water-quality problems. Serious ground-water-quality problems will require detailed special studies.

The surface-water-sampling sites are the same for the ideal and the proposed network. Table 7 gives the surface-water-monitoring locations and the sampling categories to be monitored. All surface-water-monitoring locations are at existing Survey gaging stations when flow data are available.

Ground-water-monitoring locations proposed for the proposed network, well owners, and objectives associated with each well are given in table 8. The number of wells in each sampling category is given in table 9. The proposed network includes a total of 325 wells and 8 stream-gaging stations.

TABLE 9. - Number of wells in proposed ground-water-quality-monitoring network by sampling category

Sampling category	Number of wells
General mineral	20
Field tests	325
Agricultural tests	176
Chloride	40
Trace elements	101
Radioactivity	48
Water levels	325

The information collected from wells with perforation data is more useful than information collected from wells without perforation data because the depth and usually the aquifer that the sample comes from is known. Because of substantial variations in ground-water quality with depth, wells in the same location that are perforated at different levels can have completely different water-quality types, particularly when extensive clay layers separate aquifers, as is the case at the north end of the Salinas River basin. Commonly, even within a single water-bearing zone, water quality changes with depth. An effort needs to be made to collect perforation data from drillers' or owners' records or electrical borehole surveys. These surveys could be run only when the well is being serviced and the pumps are removed from the casing. If the perforation intervals of these wells cannot be obtained, they should be replaced with new wells for which perforation interval data are available. Statistical methods might be also used to correlate quality and water-level measurements in wells with defined perforations to quality and water-level measurements in nearby wells with unknown perforations.

In locations where monitoring is proposed in the ideal network but no monitoring wells are nearby, new wells are proposed. Because of the abundance of wells in the Salinas River basin, it is unlikely that many wells would have to be drilled. Instead, existing private or municipal wells should be added to the monitoring networks if: (1) the well is in the desired location, (2) perforation data are available and the perforations are at the required depth, (3) both water levels and water-quality samples can be collected from the well, (4) there is access to the well, (5) the well is maintained in good condition and serviced regularly, and (6) the owner is cooperative. Only as a last measure should new wells be drilled.

No monitoring networks operate along San Lorenzo Creek in Peachtree Valley, so the location of wells there was not available from the phase 2 inventory. Suggested monitoring sites for this area are shown on plate 7. The surface- and ground-water quality there is the lowest in the entire Salinas River basin. Before long-term monitoring can be set up, a special study should be done in the Peachtree Valley by people who will be involved in the monitoring program for many years, such as the Monterey County Flood Control and Water Conservation District or the California Regional Water Quality Control Board, Central Coast Region. The study could include locating existing wells, collecting ground-water-quality data, assessing the ground-water quality, and selecting wells for the monitoring network.

Chemical Constituents and Frequencies

The groups of chemical constituents and their sampling frequencies are the same for the proposed network as for the ideal network. The chemical tests are included in the six groups, and their monitoring frequencies are given in table 10.

Data are not collected at each well every time it is visited because of two major operational constraints. First, a meaningful water-level measurement can only be taken if the well is not pumping and has not been pumping long enough for the water level to have recovered to the level of the surrounding aquifer. Nearby wells should not be pumping either because their drawdown might lower the water table at the measuring point. Second, a meaningful water-quality sample can only be collected if the well is pumping. The pumps must be run long enough to pump out the water that has been inside the well casing and gravel pack before a sample can be collected. Monterey County Flood Control and Water Conservation District (MCFCWCD) visits wells as many as three times per year to collect samples and take measurements. In any sampling season, samples are only collected at 60 percent of their sites (oral commun., Gene Taylor, 1982). The rate at which data will be collected in the proposed network will probably be similar to the MCFCWCD rate of 60 percent per year.

TABLE 10. - Ground-water-quality sampling categories

Sampling category	Chemical and physical tests	Frequency of measurement
General mineral	Ca, Fe, Mg, Mn, K, SiO_2, Na, NO_3, PO_4, Cl, F, SO_4, alkalinity, pH, temperature, and specific conductance.	Yearly.
Field tests	Temperature, specific conductance, and pH.	Yearly.
Agricultural tests	Ca, Fe, Mg, Mn, K, SiO_2, Na, NO_3, B, Cl, F, SO_4, alkalinity, pH, temperature, and specific conductance.	Yearly.
Chloride	Cl, temperature, pH, and specific conductance.	Yearly.
Trace elements	As, Cd, Cr, Fe, Pb, Hg, Mo, Se, Zn, B, temperature, pH, and specific conductance.	Once per network evaluation period.
Radioactivity	Gross α, gross β, tritium, and strontium-90.	Once per network evaluation period.

Ground-Water Levels

At each of the wells shown on plate 7, water levels should be measured twice a year--in the spring and autumn when annual water-level extremes usually occur. Because of variations in weather and pumping patterns, the high and low water levels occur at slightly different times each year. Continuous water-level recorders should be placed on at least one representative well in each subarea. The well runs should be timed to coincide as closely as possible with the time of expected lowest and highest water levels. Water-level data will be valuable in special studies of recharge response and in evaluations of ground-water-flow patterns and ground-water discharge.

The high measurement in spring, before the onset of pumping, indicates the level to which the water table has recovered during the wet winter period. Because relatively little pumping occurs during the winter, the spring water table is representative of the ground-water-flow system when it is under the least stress.

The low measurement in autumn indicates the level to which the water table has fallen during the dry summer months of heavy pumping. This is also the optimum period when water released from the reservoirs can percolate through the Salinas River channel. The low water table is representative of the ground-water-flow system when it is under the most stress, particularly man-induced stress, in the yearly cycle.

Operation of the Network

The network proposed here is a combination of existing networks run by Monterey County Flood Control and Water Conservation District, San Luis Obispo County Engineering Department and the U.S. Geological Survey. Because separate agencies are concerned, careful coordination will be required to ensure that: (1) The samples are collected in a consistent manner, (2) the analyses are done in a consistent manner, and (3) the data are easily accessible. This coordinated effort will provide the quality control for the network.

The implementation of the network and operation plan are beyond the scope of this report. A flow chart showing the general steps required to implement the network is shown in figure 9. This chart was included to illustrate that network design, implementation, and operations are complicated iterative procedures that must be repeated and reevaluated to remain current.

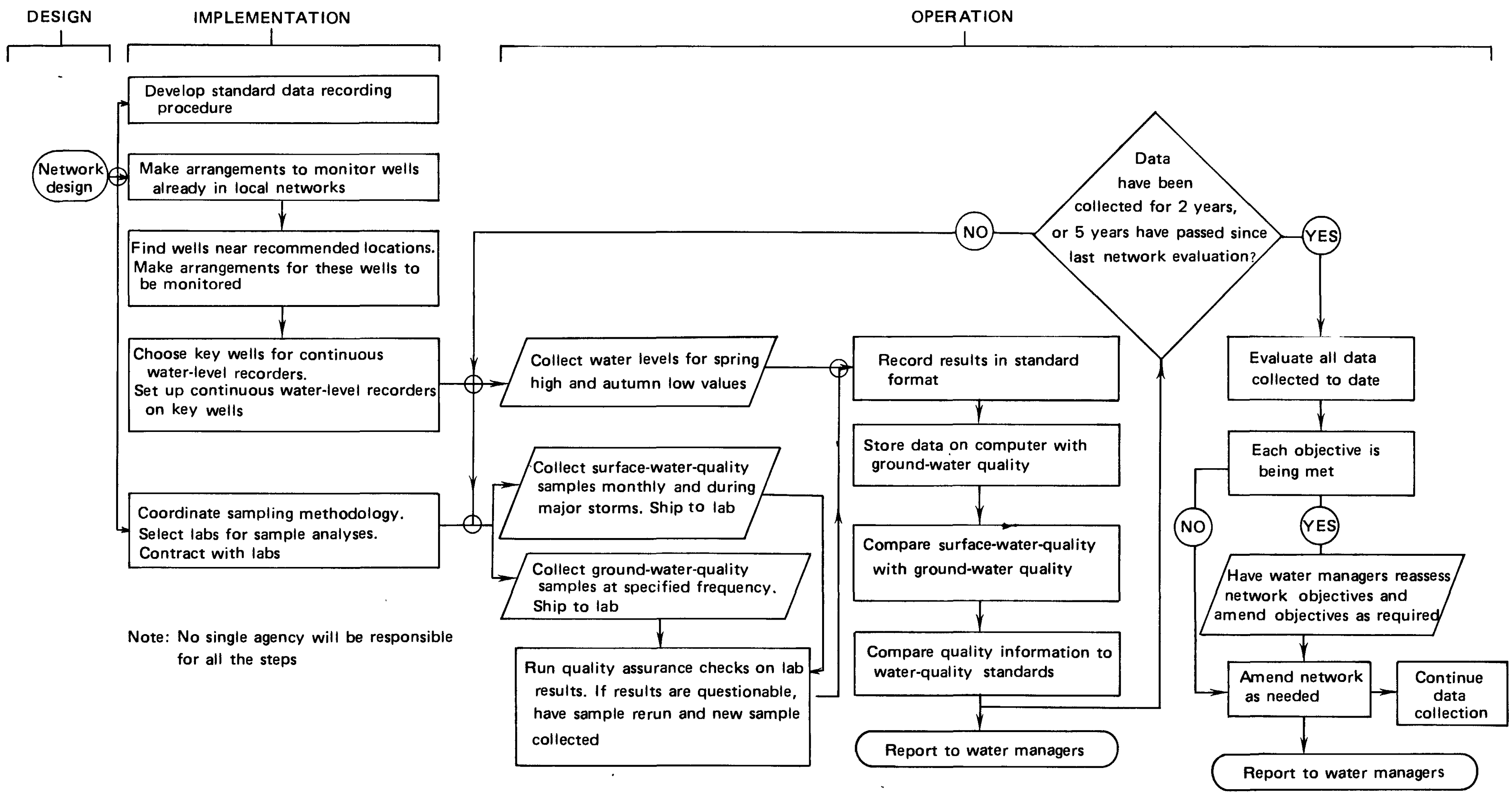


FIGURE 9.—Flow chart showing general steps required to implement network.

REFERENCES

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: Bulletin 52, 230 p.

California Department of Water Resources, 1964, San Luis Obispo and Santa Barbara Counties land and water use survey, 1959: Bulletin 103, 62 p.

----- January 1969, Special investigation: Salinas River basin: San Joaquin District, Memorandum report prepared for the Regional Water Quality Control Board, Central Coast Region, 67 p.

----- 1975, California's ground water: Bulletin 118, 135 p.

California State Water Resources Control Board and Regional Water Quality Control Board, Central Coast Region, 1975, Water quality control plan report: Central Coastal basin: Part 2.

CH_2M Hill, 1982, Arroyo Seco Dam feasibility study: San Francisco, Calif., project no. F 14944.AO, 87 p.

Compton, R. R., 1966, Granitic and metamorphic rocks of the Salinian block, California Coast Ranges, in Geology of Northern California: California Division of Mines and Geology Bulletin 190, p. 277-287.

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.

Hamlin, Homer, 1904, Water resources of the Salinas Valley, California: U.S. Geological Survey Water-Supply Paper 89, 91 p.

Johanson, Stig, 1979, Ground water in the Paso Robles basin: California Department of Water Resources Southern District report, 88 p.

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 Flood Control and Water Conservation District, May 1960, Salinas Valley geologic investigation: 11 p.

----- December 1967, A study of underground hydraulic properties in selected areas of the Salinas Valley: 41 p.

----- 1959-77, Summary of water resources data: Salinas, Calif., published annually.

Rand McNally Commercial Atlas and Marketing Guide for 1980, 112th edition.

Rantz, S. E., 1969, Mean annual precipitation in the California region: U.S. Geological Survey basic-data compilation, 2 plates.

San Luis Obispo County Engineering Department, 1974, Hydrologic and climatological data, seasons of 1970-71 and 1971-72: San Luis Obispo County, Calif., first in biennial series published through water year 1976, 260 p.

Swain, L. A., 1973, Chemical quality of ground water in Hawaii: Hawaii Division of Water and Land Development Report R-48, 54 p.

U.S. Geological Survey, 1978, Land use series: U.S. Geological Survey Open-File Report 78-1037-1, map.