State of California
The Resources Agency
Department of Water Resources
Southern District

REVISED FINAL DRAFT/Subject to Revision

WATER RESOURCES OF THE ARROYO GRANDE - NIPOMO MESA AREA

JANUARY 2000

Gray Davis	Mary D. Nichols	Thomas M. Hannigan
Governor	Secretary for Resources	Director
State of California	The Resources Agency	Department of Water Resources

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FOREWARD

San Luis Obispo County Flood Control and Water Conservation District, in recognition of changed conditions and lack of current information for the Arroyo Grande - Nipomo Mesa Area, contracted with the Department of Water Resources to reexamine the water resources of this area. The study was jointly funded by the county and the state.

The study sought to update hydrologic and hydrogeologic data, to refine understanding of the hydrologic and hydrogeologic systems, and to update water demand and supply projections for both the Santa Maria Groundwater Basin and the surrounding bedrock areas. This report provides the county and local agencies with a framework for making water resource planning and management decisions.

The Department appreciated being able to work with the county on this important assignment.

Charles R. White, Chief
Southern District
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ACKNOWLEDGMENTS

The Department of Water Resources gratefully acknowledges the cooperation and assistance of the following agencies and individuals who contributed data and materials for this study:

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EXECUTIVE SUMMARY

This study was designed to gain additional knowledge of the water resources in the Arroyo Grande - Nipomo Mesa area of the Santa Maria Groundwater Basin in San Luis Obispo County (Figure ES1) needed for improving the plans for management and operation of the basin. The study was carried out by the Department of Water Resources under an agreement with the San Luis Obispo County Flood Control and Water Conservation District.

It updates a study conducted by the Department in 1979. For the new study, the area covered was expanded to encompass 174 square miles (111,090 acres), including the watersheds of Arroyo Grande and Nipomo Creeks and a portion of the watersheds of Pismo Creek and the Santa Maria River. Underlying part of the study area is the northern portion of the Santa Maria Groundwater Basin within San Luis Obispo County. The last year of data for the earlier study, water year 1975 (September 30, 1974-October 1, 1975), was taken as the starting year for data in this study and the ending year is water year 1995. The hydrologic base period used to assess basin inflow and outflow is water years 1984-95.

Because of the study area's large size and differences in hydrologic and topographic characteristics, the study area was divided into three sections for this investigation, based on hydrologic (watershed) boundaries. The first section consists of those portions of Pismo and Oceano Hydrologic Subareas (HSA) that lie within the study area[1]. The Pismo HSA is drained by Pismo Creek and the Oceano HSA, by Arroyo Grande Creek and its tributaries. The second section of the study area is the Nipomo Mesa HSA, which contains Black Lake Canyon and Black Lake. The third section is that portion of the Guadalupe Hydrologic Area (HA) drained by Nipomo Creek and the Santa Maria River in San Luis Obispo County.

Given below are the findings made in the study and the conclusions drawn from them.

Water Demand

Population in the study area is estimated to have been 62,063 in 1995 and is projected to increase to 69,370 in 2000, 84,880 in 2010, and 98,740 in 2020. Crop acreage in 1995 was 14,750 and is projected to increase to 15,100 by 2000 and decrease to 14,750 by 2010 and 14,500 by 2020.

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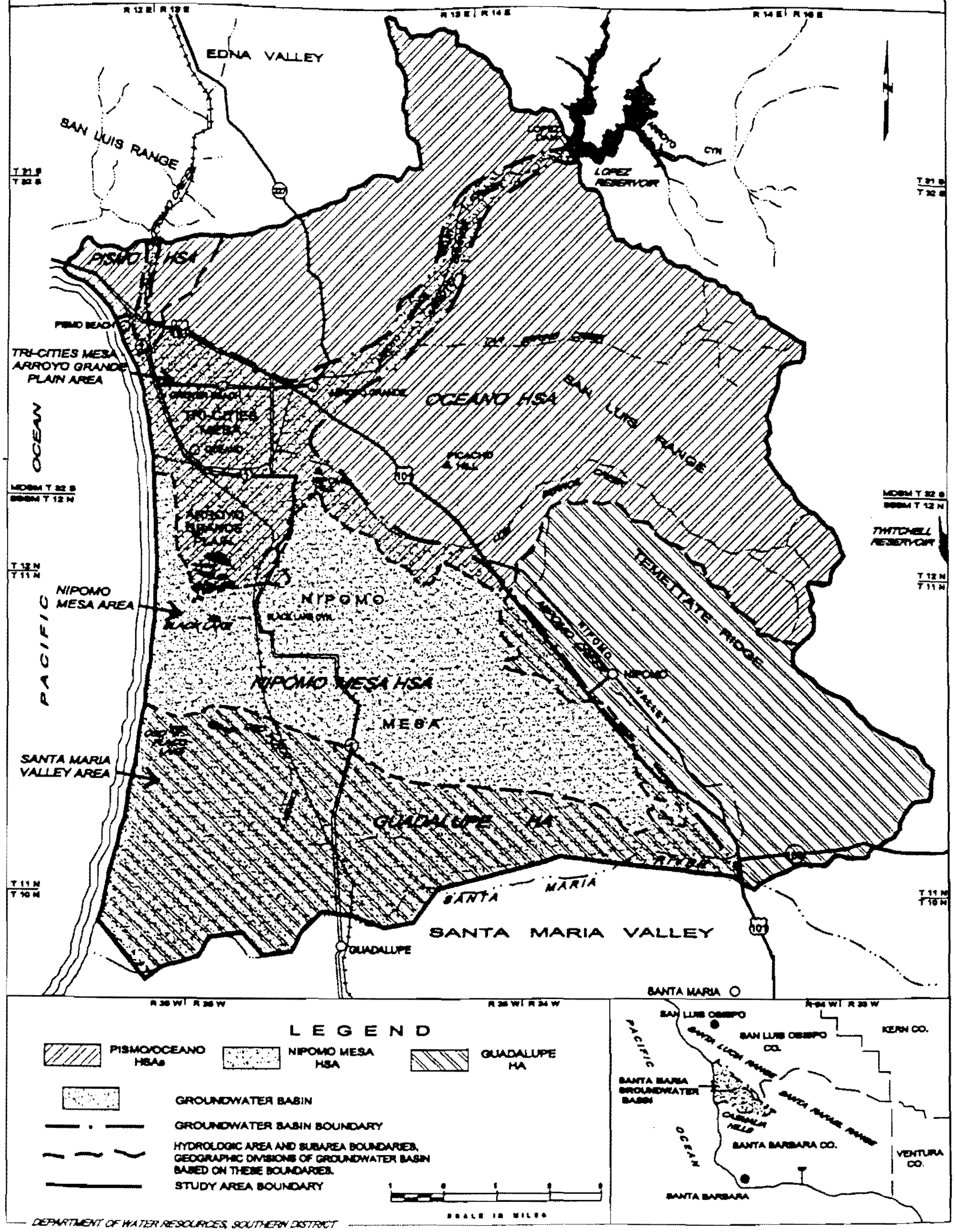
[1] Hydrologic Area and Hydrologic Subarea are the hierarchical nomenclature of watershed divisions in California. HSA is a subdivision of an HA.

FIGURE ES1 - ARROYO GRANDE - NIPOMO MESA STUDY AREA



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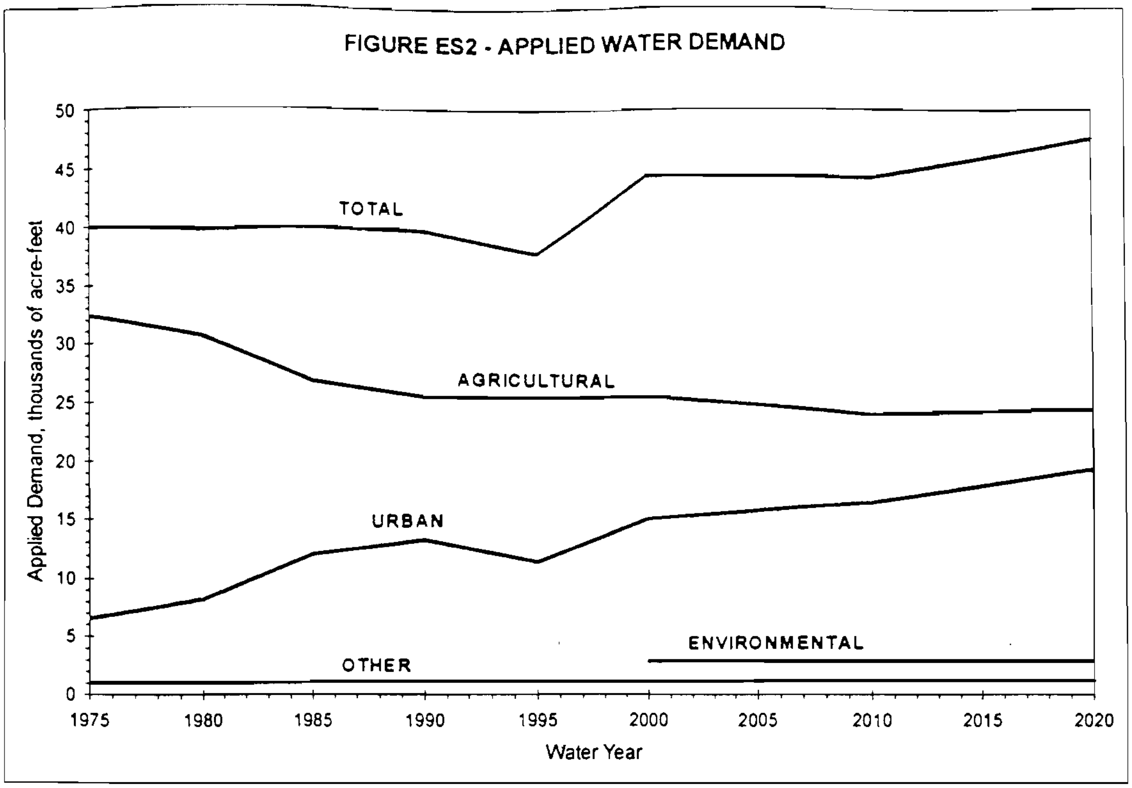

In 1995, the total applied water demand was estimated to be 37,700 acre-feet (AF); of this, about 25,300 AF was agricultural demand. This includes demand reduction achievable through implementing water conservation programs. Most of the rest of the demand was for urban uses. Conveyance losses, cooling, miscellaneous, and recreational demands used slightly more than 1,000 AF per year. Environmental demand, estimated at 2,800 AF, has been identified for maintaining steelhead habitat on Arroyo Grande Creek for 2000, 2010 and 2020. Projections are that by 2000, the demand for agriculture will be 25,500 AF and will decline to 23,900 AF by 2010 and to 24,300 AF by 2020. Total demand will be 44,400 AF by 2000, 44,200 AF by 2010, and 47,500 AF by 2020 (Figure ES2).

Water Supply

Groundwater is the major source of supply in the study area. Other available supplies are Lopez Reservoir water, imported State Water Project water, and reclaimed water. Lopez Reservoir, which was built in 1969 on Arroyo Grande Creek, impounds 52,500 AF of water.

Total water supply in the study area decreased by about 2,300 AF from the 40,100 AF in 1975 to 37,800 AF in 1995, while year 2020 water supply is expected to increase 9,700 AF over 1995 levels. Total groundwater supply in the study area decreased by about 4,400 AF from the 34,800 AF in 1975 to 30,400 AF in 1995, while year 2020 groundwater supply is expected to increase 4,700 AF over 1995 levels.

Groundwater Basin

Santa Maria Groundwater Basin is a large, hydraulically continuous aquifer system throughout its 250 square miles (160,000 acres) in the southwestern corner of San Luis Obispo County and the northwestern corner of Santa Barbara County. This study deals only with the 50,000 acres of the groundwater basin within San Luis Obispo County, about one-third of the entire basin. Within the study area, the groundwater basin is bordered and underlain on the north and east by bedrock and on the west by the Pacific Ocean, although the basin is hydraulically continuous offshore beneath the ocean. On the south, the county line with Santa Barbara County forms a political boundary within the basin, but it has no hydraulically physical significance to the groundwater system.

Because the groundwater basin underlies only portions of the hydrologic sections and because of the need to provide applicable information for the local agencies, the basin was divided into geographic areas based on the hydrologic boundaries, as seen on Figure ES1[2]. The Tri-Cities Mesa-Arroyo Grande Plain, Arroyo Grande Valley, and Pismo and Los Berros Creeks area of the basin lies within the Pismo and Oceano HSAs; the Nipomo Mesa area of the basin lies entirely within Nipomo Mesa HSA; and the Santa Maria Valley area of the basin lies within the Guadalupe HA. However, the groundwater basin is not symmetric with the surface water drainage system; no groundwater divides are in the hydrogeologic environment of the basin.

In the study area, the groundwater basin ranges in thickness from a few feet to about 1,500 feet under the Santa Maria River. It is filled with the semi-consolidated to unconsolidated sediments of the Squire Member of the Pismo Formation; the Careaga, Paso Robles, and Orcutt Formations; alluvium; and dune sands. These sediments consist of discontinuous sedimentary layers or lenses of varying composition, texture, and thickness, ranging from clays to boulders. The aquifer system is unconfined, with localized semi-confined to confined conditions and perched zones.

The most productive aquifers are the alluvium and the Paso Robles Formation, but groundwater is also produced from the Squire Member of the Pismo Formation and from the Careaga Formation.

Specific yield of the groundwater basin ranges from 5 to 21 percent, with a median of 12 percent. Nipomo Mesa has the largest variation in values. The Paso Robles Formation has the lowest values.

Natural recharge to the groundwater basin occurs from deep percolation of rainfall, seepage

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[2] Geographic names were used for the divisions of the groundwater basin because, with the exception of Nipomo Mesa, the basin underlies only portions of the hydrologic areas.

losses from streams, and subsurface inflow. Incidental recharge to the groundwater basin includes deep percolation of urban and agricultural return water, treated wastewater, and septic tank effluent.

Arroyo Grande Creek, regulated by Lopez Dam since 1969, recharges the Tri-Cities Mesa and Arroyo Grande Valley and Plain portions of the groundwater basin. Pismo Creek, which is unregulated, also recharges the northern portion of the groundwater basin. The Santa Maria River, regulated by Twitchell Dam since 1958, recharges the Santa Maria Valley part of the groundwater basin. Both Lopez and Twitchell Dams regulate surface releases to maximize groundwater recharge and provide flood control.

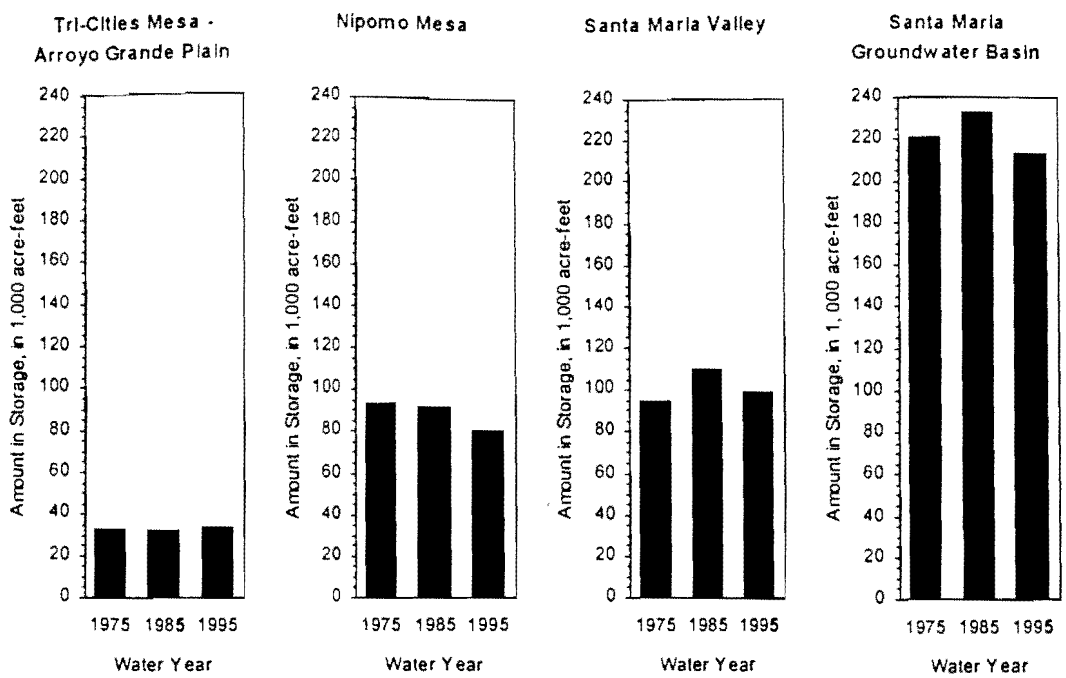
No surface waters flow into or out of Nipomo Mesa; therefore, the major source of natural recharge is deep percolation of precipitation. Additional natural recharge for the mesa is from subsurface inflows.

Groundwater is discharged from the basin by pumping, subsurface flow to the ocean, evapotranspiration, flow of groundwater into streamcourses, springflow, and percolation into the underlying bedrock.

Groundwater level contours in the springs of 1975, 1985, and 1995 revealed that the regional direction of flow within the basin is westerly and west-northwesterly toward the ocean. Coastal elevations were above mean sea level and a seaward hydraulic gradient prevented sea water intrusion. Within the basin, groundwater flows from northern Nipomo Mesa to Arroyo Grande Plain. In spring 1995, a large pumping depression in south-central Nipomo Mesa altered the direction of flow, moving groundwater from Santa Maria Valley into the mesa, but not affecting the westward direction of flow near the county line. A smaller pumping depression exists in northern Nipomo Mesa, affecting local flow patterns, but not yet affecting subsurface outflow to Arroyo Grande Plain. With the significant recharge from the record rainfall of water year 1998, the magnitude of these depressions lessened. However, if in the future, the depression in the south-central mesa enlarges from the increasing extractions that exceed recharge in the area, an enlarged depression could result in increased inflow from Santa Maria Valley and decreased outflow to the ocean from the mesa and the valley. The depressions could result in sea water intrusion, if the seaward hydraulic gradient is reversed and subsurface outflow to the ocean ceases.

Groundwater level measurements from wells over the period of record through 1998 were analyzed to determine their net changes over time. Fluctuations in groundwater levels in the basin are affected by variations in rainfall (a measure of available recharge), which affect the balance between groundwater recharge and discharge, and also to changes in the groundwater system caused by increasing or decreasing withdrawals of groundwater for use. In some parts of Nipomo Mesa, increasing withdrawals have led to declining trends in groundwater levels, despite two recent periods of about 40 percent above average precipitation (1978-83 and 1992-98). The

FIGURE ES3 - ESTIMATED GROUNDWATER IN STORAGE ABOVE MEAN SEA LEVEL, SANTA MARIA GROUNDWATER BASIN, SAN LUIS OBISPO COUNTY



declining water levels in wells reflect the loss in storage that is occurring in the mesa and may cause adverse conditions, such as localized well interference and possible quality degradation. In the other areas of the basin, the long-period fluctuations in groundwater levels are generally proportional to the net fluctuations of recharge and withdrawals.

Amounts of groundwater in storage, both above and below mean sea level, for the springs of 1975, 1985, and 1995 were estimated from the volume of saturated sediments in the groundwater basin and the specific yield of those saturated sediments. The amount in storage above mean sea level (Figure ES3) is important, because of the physical limitation placed on this coastal basin by the need to maintain a seaward hydraulic gradient to prevent sea water intrusion.

For the Tri-Cities Mesa - Arroyo Grande Plain area, the estimates of amount in storage above mean sea level for the three years were about the same, a little more than 30,000 AF. In this area the amount of groundwater in storage between 1975 and 1985 declined 1,000 AF and between 1985 and 1995 increased 2,000 AF. Nipomo Mesa was estimated to have 80,000 AF above mean sea level in 1995, which is about 12 percent less than the amount in storage above mean sea level in 1985. The mesa also showed a small decline in storage of 2,000 AF between 1975 and 1985.

This loss in storage is consistent with the significant declining trends found in groundwater levels in wells in parts of the mesa. The loss is not mesawide, but is associated with areas of pumping depressions. The continuous declines in groundwater levels in some areas of the mesa and the loss in storage are evidence that withdrawals are exceeding recharge in those areas. Santa Maria Valley was estimated to have 99,000 AF in storage above mean sea level in 1995, 4,000 AF more than the amount estimated to be in storage in spring 1975. In 1985, the valley had a net gain in storage above mean sea level of 15,000 AF, from 95,000 to 110,000 AF, because of higher groundwater elevations from the substantial seepage losses of the Santa Maria River from the 1983 wet water year. Seepage losses from the Santa Maria River from the 1995 wet water year were not yet reflected in groundwater elevations in Santa Maria Valley, and based on the trend in groundwater elevations, the amount in storage did increase in the succeeding years as the recharge mound traveled away from the river. Part of the amount of the change in storage from 1985 to 1995 in Santa Maria Valley reflects the movement of groundwater from the valley into Nipomo Mesa caused by the pumping depression in the south-central mesa.

In 1995, the entire groundwater basin within the study area had about 213,000 AF in storage above mean sea level, 8,000 AF less than in 1975.

Hydraulic conductivity and transmissivity quantify the rate at which groundwater flows. Values of hydraulic conductivity are highest in the alluvium, up to about 7,000 gallons per day per squared foot. Hydraulic conductivity for the Paso Robles Formation ranged from 1 to almost 3,000 gallons per day per squared foot. Lower conductivity values were generally found in the oldest formations-- the Careaga Formation and the Squire Member of the Pismo Formation, ranging from 1 to 600 gallons per day per squared foot.

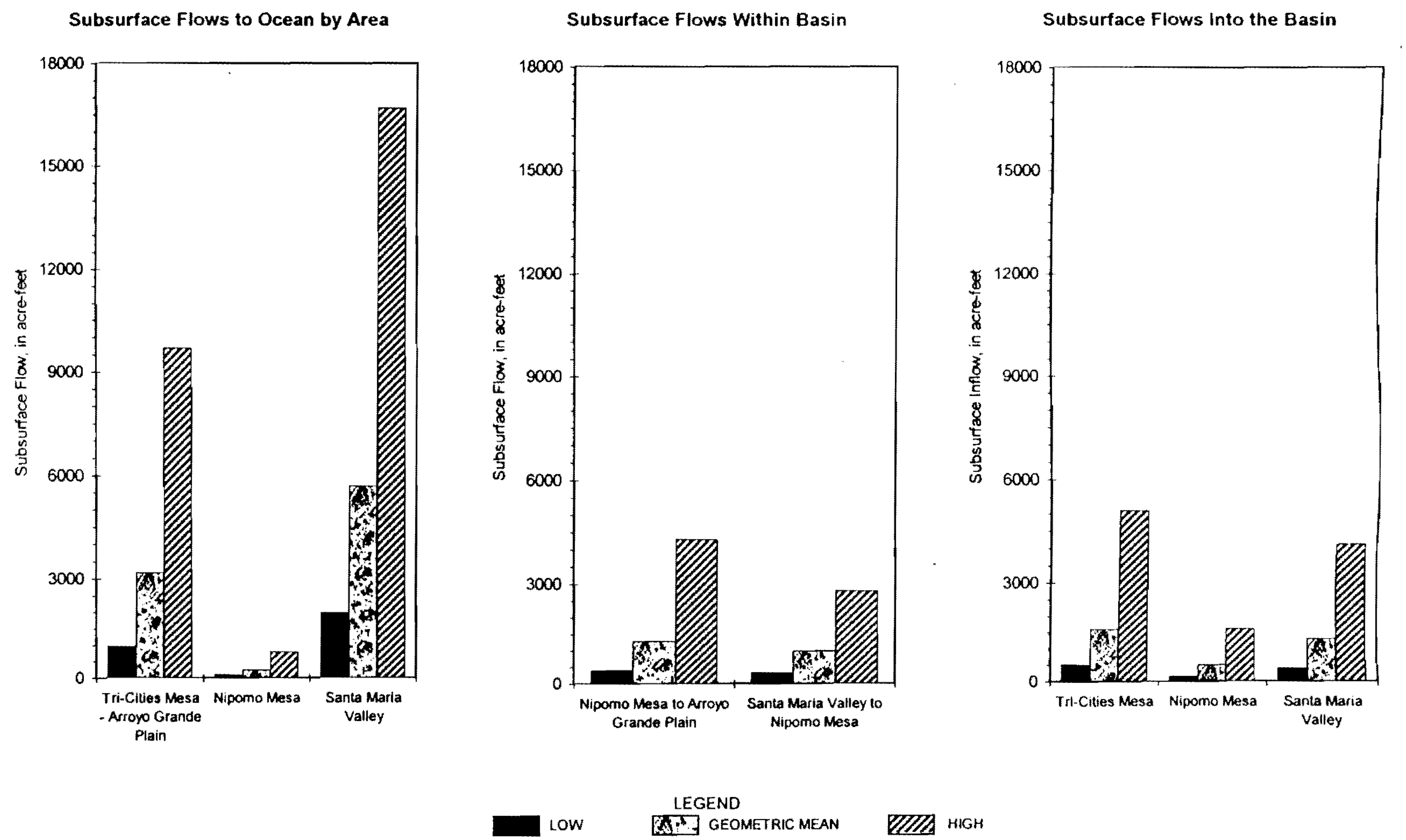
The estimates of transmissivity for 1995 within the basin ranged from 125 to 850,000 gallons per day per foot of saturated thickness. The highest transmissivity values are found in Santa Maria Valley, where the aquifer is the thickest. The lowest values of transmissivity are found in Nipomo Mesa, where the groundwater basin is shallower in areas of risen bedrock or the area is affected by the pumping depressions.

Groundwater flows in the subsurface from the basin to the Pacific Ocean and, within the basin, groundwater flows in the subsurface from Nipomo Mesa to Arroyo Grande Plain and, in 1995, from Santa Maria Valley in San Luis Obispo County to Nipomo Mesa. Also, groundwater flows into the basin from the surrounding bedrock areas and, in Santa Maria Valley, from the upstream portion of the basin. These subsurface flows were estimated for the springs of 1975, 1985, and 1995. Low, high, and geometric mean subsurface flows were estimated, because hydraulic conductivity ranges over several orders of magnitude.

Figure ES4 illustrates the 1995 subsurface flow estimates. Subsurface outflows to the ocean in 1995 ranged from 100 AF from Nipomo Mesa to about 17,000 AF from Santa Maria Valley. In 1995, estimates of subsurface flow from Nipomo Mesa to the Arroyo Grande Plain ranged between 420 and 4,300 AF and from Santa Maria Valley to Nipomo Mesa, between 350 and

FIGURE ES4 - 1995 ESTIMATED SUBSURFACE FLOWS

In acre-feet



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2,800 AF. Estimated geometric mean subsurface inflows into the entire basin within the study area were 3,400 AF per year for hydrogeologic conditions in 1995. Subsurface inflows into the basin were about three times greater in the Tri-Cities Mesa area and in Santa Maria Valley than in Nipomo Mesa.

Bedrock Areas

The bedrock areas are experiencing increasing development and associated use of groundwater. These areas, surrounding the Santa Maria Groundwater Basin, consist primarily of the semi-consolidated to consolidated sandstone Pismo and Santa Margarita Formations in the northern part of the study area and the consolidated shale Monterey Formation and the volcanic tuff and lava Obispo Formation in the southeastern part of the study area.

The bedrock has a limited capacity to store and transmit water, but fracturing can augment its capacity. Well yields from the Pismo Formation range from 10 to 100 gallons per minute and from the Obispo and Monterey Formations, 5 to 750 gallons per minute. "Dry" boreholes can be encountered in both the Obispo and Monterey Formations.

Natural recharge to the bedrock aquifers is by deep percolation of precipitation and runoff, and discharge of groundwater is from well extractions, evapotranspiration, and subsurface outflow to the adjoining groundwater basin.

Of the bedrock formations, the Pismo Formation had the highest estimates of hydraulic conductivity, up to 1,000 gallons per day per foot squared, although the fractured tuff Obispo Formation had the highest estimate of transmissivity, 37,500 gallons per day per foot. The Monterey Formation had estimates of hydraulic conductivity between 15 and 25 gallons per day per foot squared.

Specific yield values of the Pismo Formation ranged from 5 to 20 percent, with a median value of 10 percent. The total storage capacity (the total volume of water that could theoretically be held in underground storage) of the Pismo Formation was estimated to be about 270,000 AF. Specific yield values of the Obispo and Monterey Formations ranged from 3 to 6 percent, with a median value of 4 percent. The total groundwater storage capacity of the Monterey and Obispo Formations was estimated to be about 360,000 AF.

Artificial Recharge

Artificial recharge is currently being used in the study area. Surface water is supplied from Lopez Reservoir to agencies that would otherwise extract groundwater from the Tri-Cities Mesa and Arroyo Grande Plain. This in lieu method has been operating for almost 30 years.

Hydrogeologically, artificial recharge projects in the study area could be sustained. In Nipomo Mesa, a project (including "in lieu") would be beneficial in alleviating some of the loss in storage that has occurred. Nipomo Mesa has only about 13 percent of its total storage capacity above mean sea level filled with groundwater; therefore, it has adequate space to store artificially recharged waters. Also, the high infiltration rates of the dune sands are favorable for artificial recharge projects. Identifying a source of water supply would be a foremost consideration for a recharge project on the mesa.

Water Quality

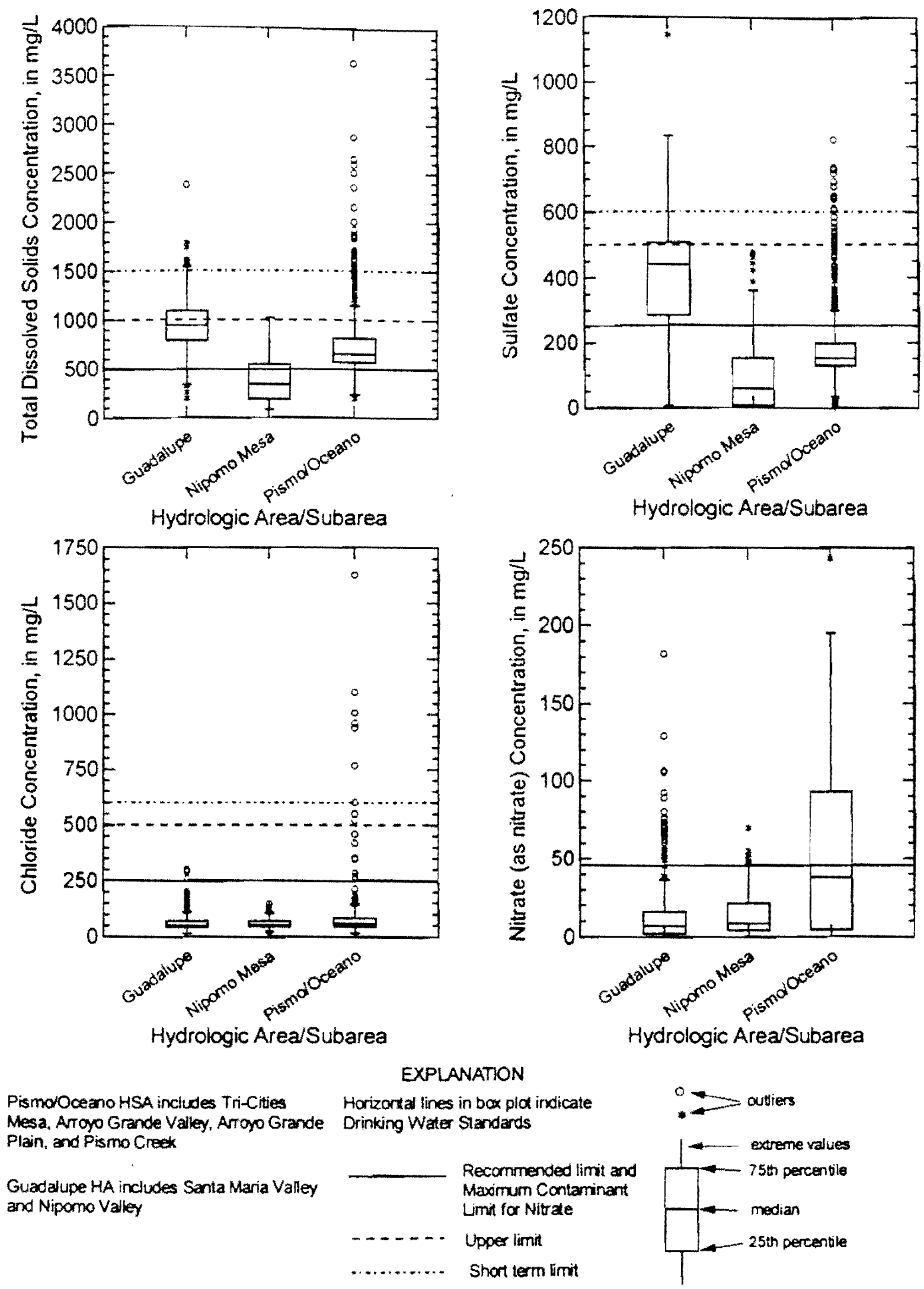
The mineral water quality data for this study were compiled from numerous sources and covered the period of record, which was up to 70 years in Santa Maria Valley. Wells in many parts of the study area have not been sampled recently or not at all. With the exception of Lopez Reservoir water, surface water has been minimally sampled and not recently.

Figure ES5 depicts the concentrations of mineral constituents found in sampled well waters by means of schematic box plots. On the figure, it can be seen that the mineral quality of groundwater in Nipomo Mesa HSA is generally of a better quality than that found in the other areas and mostly meets recommended drinking water standards. The poorest quality groundwater occurs in the alluvium of Pismo Creek in the Pismo HSA. Figure ES5 shows that concentrations of total dissolved solids (TDS), sulfate, and chloride in some sampled well waters in Pismo and Oceano HSAs and Guadalupe HA exceeded short-term drinking water limits. Nitrate (NO_3) concentrations exceeded the 45 milligrams per liter (mg/L) maximum contaminant level for drinking water in about 50 percent of sampled wells in the Oceano HSA, mainly in water from wells less than 200 feet deep. In the Santa Maria Valley of Guadalupe HA, concentrations of nitrate in about 25 percent of sampled well waters exceeded the maximum contaminant level. Concentrations of mineral constituents in some groundwaters in Arroyo Grande Valley, Santa Maria Valley, and Pismo Creek do not meet water quality guidelines for agricultural irrigation. Very hard groundwater is typically found in the study area; however, soft groundwater is found in about 50 percent of the sampled wells in Nipomo Mesa HSA.

No significant trend of mineral degradation of groundwater was found in the study area. No evidence of sea water intrusion was found with the available data. Groundwater in the Pismo and Oceano HSAs and Guadalupe HA has been impaired mainly by irrigation return waters. Poorer quality groundwaters may also be associated with older rocks and sediments, mineralized zones, residual saline deposits, or waters influenced by tidal action. If the pumping depression on Nipomo Mesa pulls in water from Santa Maria Valley, the possibility exists for the poorer quality groundwater of the valley, containing high concentrations of dissolved solids, to locally degrade the quality of the groundwater in the mesa. Existing data were not sufficient to show evidence of this possible situation.

Water from Lopez Reservoir is of high quality and meets drinking water standards. TDS

FIGURE ES5 - BOX PLOTS OF TOTAL DISSOLVED SOLIDS, SULFATE, CHLORIDE, AND NITRATE CONCENTRATIONS IN WELL WATERS IN THE ARROYO GRANDE - NIPOMO MESA AREA



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concentrations of the water range between 400 and 600 mg/L and the chemical character is calcium-magnesium bicarbonate. The quality of surface waters of the various creeks and the Santa Maria River varies, depending on the flow, with TDS concentrations measured at up to about 2,000 mg/L.

Water Budget

Water budgets were developed for this study as a means of providing information for water supply planning. Water budgets are itemized accountings of all inflows and outflows that occur in hydrologic systems and can reveal opportunities and constraints for water supply development.

A water budget, using the equation "Inflow - Outflow = Surplus/Deficiency," was computed for each of the three sections that the study area was divided into: Pismo/Oceano HSAs, Nipomo Mesa HSA, and Guadalupe HA. The groundwater basin is encompassed within each of these sections (Figure ES1).

The surplus or deficiency for each year of the water budget is actually the amount of change in groundwater in storage that takes place. Thus, for this study, the amount of change in storage includes change in both the bedrock areas and the groundwater basin for the Pismo/Oceano HSAs section and the Guadalupe HA section. Only in the Nipomo Mesa HSA section is the amount of change in storage solely for the groundwater basin.

For the entire study area, inflow was greater than outflow by 6,600 AF in the base period. In 2000, inflow is projected to exceed outflow by 4,800 AF and in 2010, by 3,100 AF, but in 2020 outflow is projected to exceed inflow by 800 AF.

For Pismo/Oceano HSAs within the study area, inflow during the base period exceeded outflow by 6,800 AF (Figure ES6). Projections of future amounts show the inflow exceeding outflow by 5,700 AF in 2000, 5,100 AF in 2010 and 3,700 AF in 2020.

Outflow in Nipomo Mesa HSA exceeded inflow by 600 AF in the base period. Outflow is projected to continue to exceed inflow (by increasing amounts) in the future: in 2000, by 800 AF; in 2010, by 1,000 AF; and in 2020, by 2,100 AF.

During the base period, inflow exceeded outflow by 400 AF in the Guadalupe HA. Outflow is projected to exceed inflow (by increasing amounts) in the future: in 2000, by 100 AF; in 2010, by 1,000 AF; and in 2020, by 2,400 AF.

Both the cumulative water budget method and the "specific yield" method estimated a loss of groundwater in storage between 1975 and 1995 in Nipomo Mesa HSA. The loss was estimated to be between 8,000 and 13,000 AF. The declining trend in groundwater levels found in some parts of the mesa substantiates the loss. The loss is not mesawide, but is associated with the areas

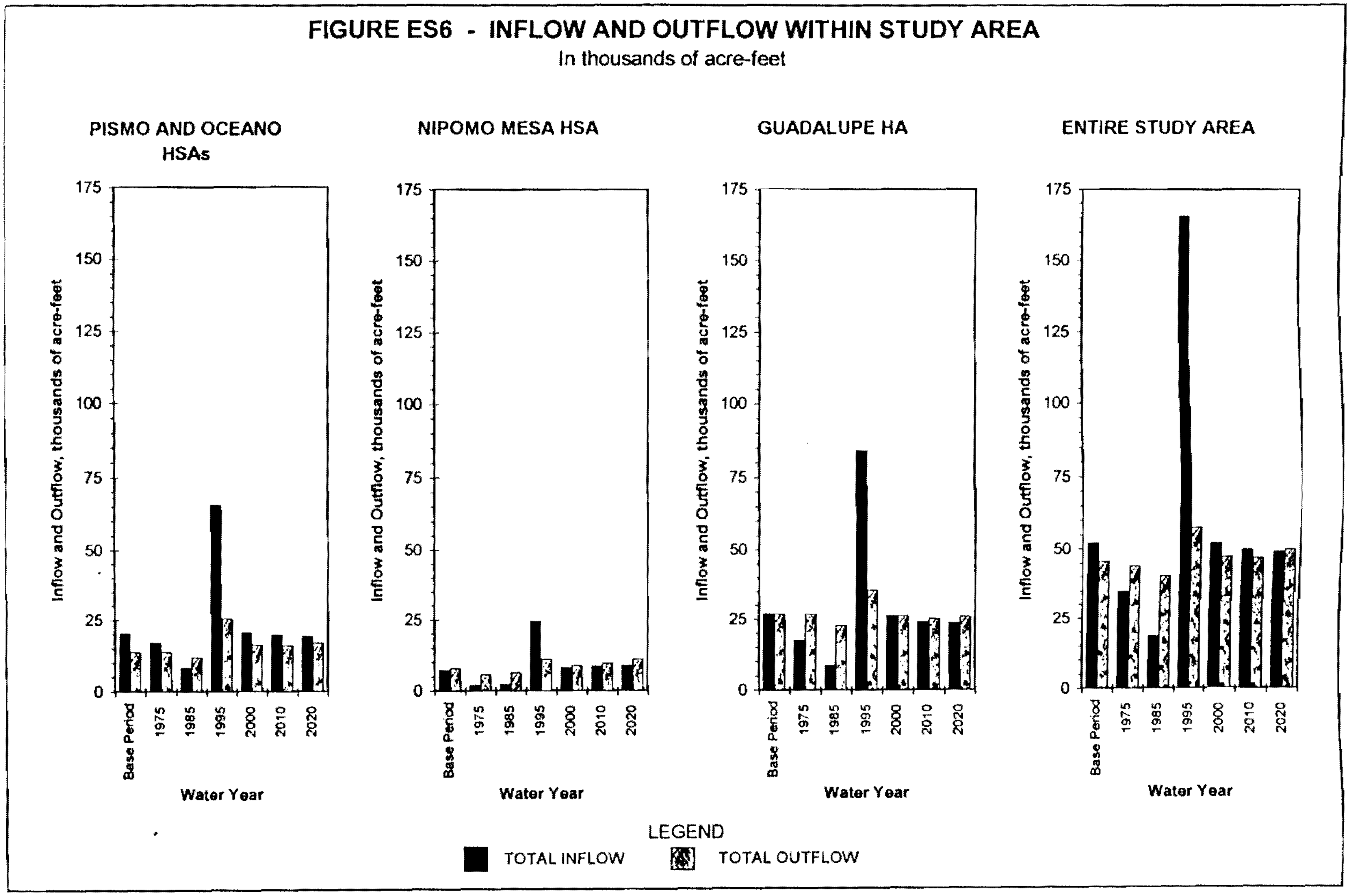
FIGURE ES6 - INFLOW AND OUTFLOW WITHIN STUDY AREA
In thousands of acre-feet
PISMO AND OCEANO HSAs
NIPOMO MESA HSA
GUADALUPE HA
ENTIRE STUDY AREA
Inflow and Outflow, thousands of acre-feet
175
150
125
100
75
50
25
0
Base Period
1975
1985
1995
2000
2010
2020
Water Year
LEGEND
TOTAL INFLOW
TOTAL OUTFLOW

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of the pumping depressions.

The future water budgets are based on projected land use changes and associated changes in water demands and on the base period, which represents long-term average hydrologic conditions. The surpluses/deficiencies represent the possible amount of change of groundwater in storage that could take place, if average long-term hydrologic conditions prevailed.

In Pismo/Oceano HSAs, the projected surpluses in the budget represent the potential amount of increase in groundwater in storage within the section. However, given the size of the section (55,300 acres), the forecast surplus would amount to less than a tenth of a foot rise in groundwater levels over the section.

The projected future deficiencies in the water budget for Nipomo Mesa HSA represent the potential loss in groundwater in storage in that year if average long-term hydrologic conditions prevailed. While the projected deficiencies would amount to about one-tenth of a foot decline in groundwater levels in that year over the section, the loss would not occur mesawide, but would be associated with areas of the pumping depressions and the declining trends in groundwater levels. The projected increase in urban extractions is the major factor contributing to the projected future deficiencies. Because Nipomo Mesa HSA's major source of recharge is deep percolation of precipitation, it is vulnerable to protracted dry periods.

Reductions in subsurface outflows from Nipomo Mesa HSA to the ocean and to Oceano HSA (Arroyo Grande Plain) and increased subsurface inflows from Guadalupe HA (Santa Maria Valley) could possibly offset the future negative imbalances between inflow and outflow and reduce the amount of loss in groundwater in storage. However, if in the future, subsurface outflows to the ocean cease and the seaward hydraulic gradient is reversed, this condition could lead to sea water intrusion of the groundwater resources.

In Guadalupe HA, the projected future deficiencies in the water budget represent the potential loss in groundwater in storage in that year if average long-term hydrologic conditions occurred in that year. Given the size of the section (36,790 acres), the forecast deficiencies would amount to less than a tenth of a foot decline in groundwater levels in 2020 over the entire section. The estimated reduction of deep percolation of precipitation in future years, because of projected land use changes and associated changes in water demands, is the major factor contributing to the projected future deficiencies. Also, the estimated subsurface outflow to Nipomo Mesa HSA in the future contributes to the deficiencies.

Because subsurface outflow to the ocean accounts for about 40 percent of the total outflow in the future years in Guadalupe HA, the negative imbalances between inflow and outflow could be offset by reductions in subsurface outflow to the ocean. The same concern regarding sea water intrusion, as mentioned above, applies.

As discussed in Chapter V, in the Santa Maria Valley area of the groundwater basin (a part of

Guadalupe HA), the long-term trend in groundwater levels and hence groundwater in storage were found to have been generally proportional to the net fluctuations of rainfall and withdrawals for use. By water year 1998, groundwater levels along the Santa Maria River were found to have returned to the high levels of 1944. Twitchell Reservoir has served to augment recharge of this part of the groundwater basin.

The study area is an area of dynamic growth, subject to constantly changing conditions, which affect water supply, use, and disposal, and consequently the water budget. Human activities that can modify the water balance include items such as: extent of extractions, possible transfers of water use, land use changes, and alteration of groundwater hydraulic gradients. Also, because precipitation is the single most important item related to availability of water in the study area, protracted dry or wet periods will significantly affect future water budgets. Thus, it needs to be recognized that any water budget will be superseded in the future as conditions change.

Recommendations

On the basis of the findings made in this investigation, it is recommended that San Luis Obispo County undertake the following:

- Continue the groundwater level monitoring program and expand the program to include key wells in the bedrock areas;
- Develop an annual groundwater quality monitoring program of key wells for both the groundwater basin and the bedrock areas;
- Annually monitor the 23 piezometers in the seven wells along the coast for sea water intrusion;
- Enact measures to halt the continuous declining groundwater levels in parts of Nipomo Mesa to protect the resource;
- Expand the monitoring of streamflow to the ocean; and
- Consider developing a comprehensive water management plan that would include reevaluation of the operation of Lopez Reservoir and an artificial recharge program on Nipomo Mesa.

I. INTRODUCTION

As the population of San Luis Obispo County has increased in recent years, concern about the adequacy of its water supply, particularly its groundwater[1] supply, has also increased. Nowhere is this more true than in the Arroyo Grande - Nipomo Mesa area. In 1979, when the Department of Water Resources conducted an assessment of the available groundwater resources within the Santa Maria Groundwater Basin, it cautioned that groundwater extractions had resulted in declining water levels in all parts of the basin and that the basin's groundwater resources could in time become permanently damaged.[2]

The San Luis Obispo County Flood Control and Water Conservation District and the Department have, therefore, entered into an agreement to update the 1979 report, expanding the area of study. This is a report on the findings made in the new study.

Objective and Scope

The objective of the updated investigation is to gain more knowledge needed to be able to improve upon plans for management and operation of the basin.

It expands the study area to include: (1) alluvial deposits from Lopez Dam downstream to the City of Arroyo Grande, (2) fringe areas around the Cities of Pismo Beach and Arroyo Grande, and (3) east of Highway 101 near Nipomo.

The work to be performed was documented in Contract DWR 165165 as:

- Review previous studies and refine scope of this study.
- Collect available surface and groundwater levels and quality data.
- Prepare a geologic map of the Arroyo Grande Hydrologic Subarea and surrounding canyon areas.
- Collect and review well drillers' reports and other subsurface geologic information.
- Construct geologic cross sections.
- Determine groundwater basin characteristics, including water levels, storage

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[1] A glossary of terms as used in this report is at the back.

[2] California Department of Water Resources, Southern District, *Ground Water in the Arroyo Grande Area*, District Report, June 1979. Selected references are in Appendix A.

capacity, water in storage, safe yield, transmissivity, and natural and artificial replenishment.

- Determine quantity and quality of water available--groundwater, surface water, and reclaimed water.
- Make projections of population and land use.
- Determine present and projected water demand--agricultural, municipal, environmental, and "other."
- Examine relationship between water supply and water demand.
- Examine factors influencing water demand.

Because this report is an update of the Department's 1979 investigation, the last year of data for that study, water year 1975[3], is taken as the starting year of data in this study and the ending year is 1995. The hydrologic base period for this study, which was used to assess basin inflow and outflow parameters for various time periods, is water years 1984-95.

A thorough search of reports of investigations pertaining to water supply and its availability within the study area was conducted. Where possible, this report seeks to correct any inaccuracies or misconceptions that may have been carried over from past reports.

Area of Investigation

The study area occupies the southwestern portion of San Luis Obispo County, 15 miles south of the City of San Luis Obispo (Figure 1). Its 174 square miles (111,090 acres) encompass the watersheds of Arroyo Grande Creek and Nipomo Creek, a portion of the watershed of Pismo Creek, and that portion of the watershed of Santa Maria River within San Luis Obispo County (Figure 2).

Thus, the study area lies in three hydrologic areas–Point Buchon Hydrologic Area (HA), Arroyo Grande HA, and Guadalupe HA–and in only the Pismo Hydrologic Subarea (HSA) of the Point Buchon HA, the Oceano HSA and Nipomo Mesa HSA of the Arroyo Grande HA, and that part of the Guadalupe HA within San Luis Obispo County (Figure 2 and Table 1)[4].

The Pismo HSA contains Pismo Creek watershed, the Oceano HSA is drained by Arroyo Grande Creek and its tributaries, the Nipomo Mesa HSA contains Black Lake Canyon and Black Lake, and the Guadalupe HA is drained by Nipomo Creek and the Santa Maria River.

Underlying a part of the study area is the Santa Maria Groundwater Basin, which extends into

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[3] A water year is October 1 of one year through September 30 of the next year. It is usually designated by the second year. An explanation of how the base period was determined is given in Appendix B.

[4] Hydrologic Area and Hydrologic Subarea are the hierarchical nomenclature of watershed divisions in California. HSA is a subdivision of an HA.

FIGURE 1 - LOCATION OF STUDY AREA

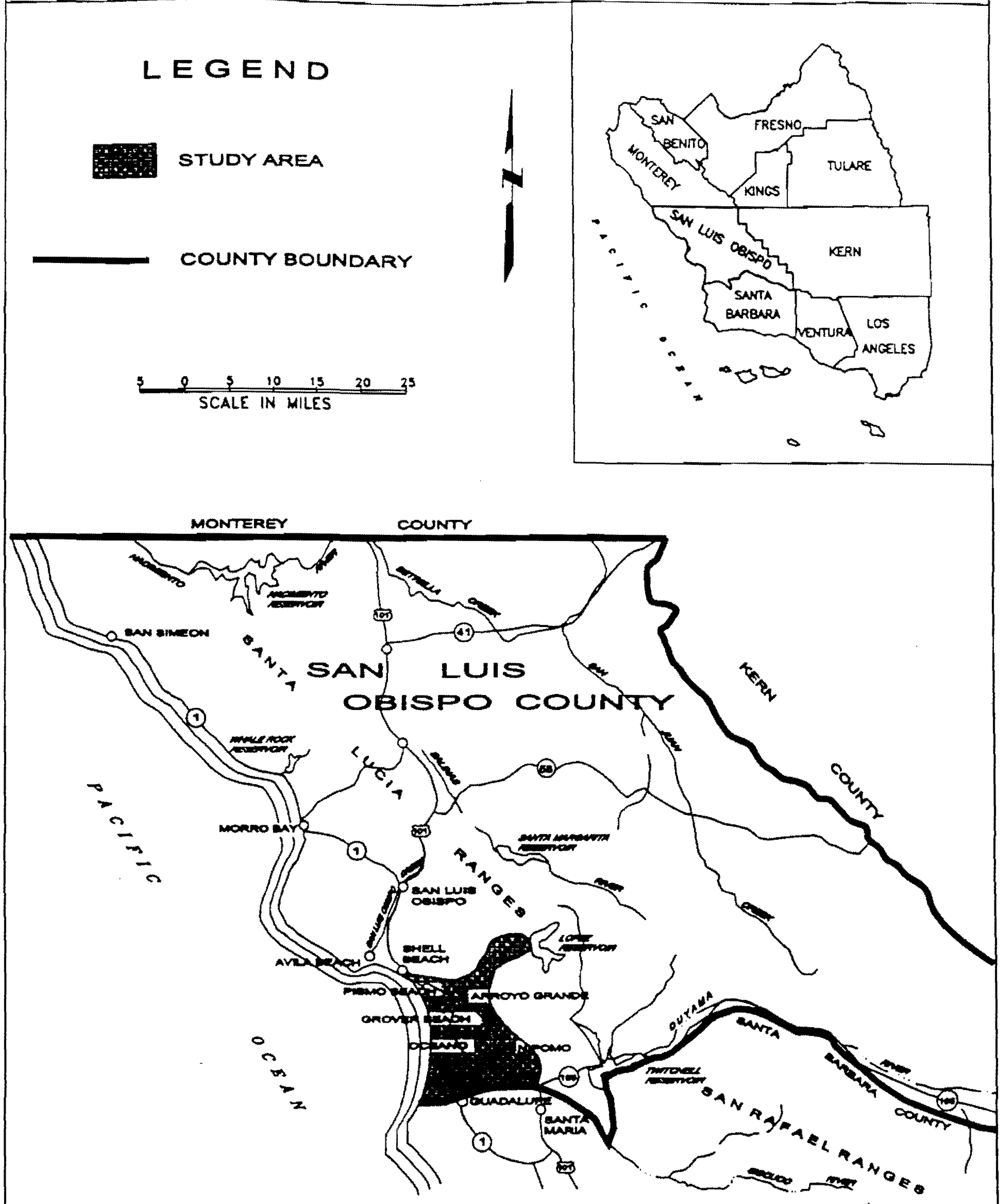

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FIGURE 2 - WATERSHEDS

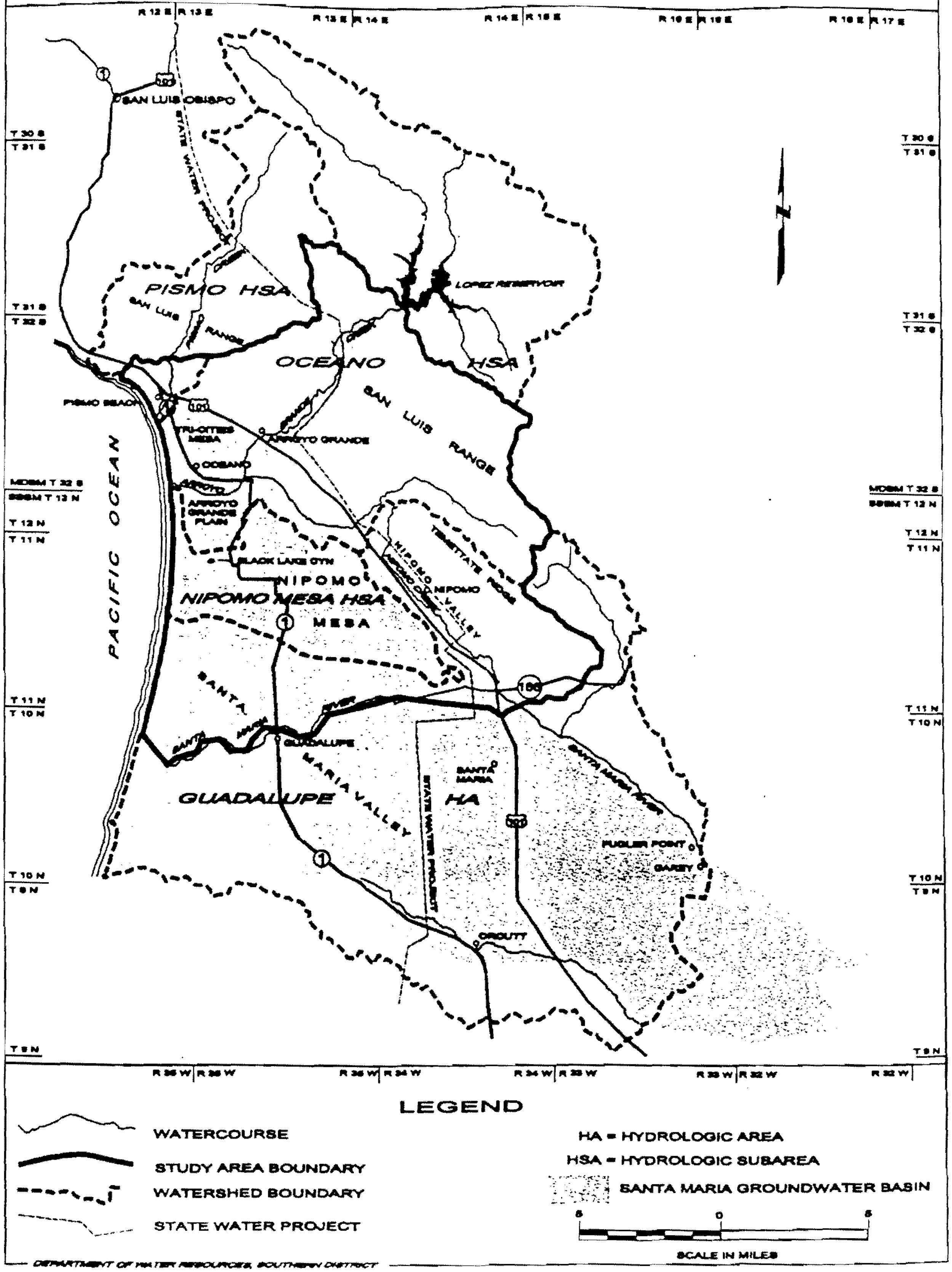

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TABLE 1
SURFACE AREAS OF HYDROLOGIC AREAS AND SUBAREAS

HYDROLOGIC DESIGNATIONS	SURFACE AREA		AMOUNT WITHIN STUDY AREA		AMOUNT WITHIN GROUNDWATER BASIN	
	ACRES	SQUARE MILES	ACRES	SQUARE MILES	ACRES	SQUARE MILES
Point Buchon HA						
Pismo HSA	30,270	47.3	2,370	3.7	400	0.6
Arroyo Grande HA						
Oceano HSA	94,550	147.7	52,930	82.7	10,800	16.9
Nipomo Mesa HSA	19,000	29.7	19,000	29.7	19,000	29.7
Guadalupe HA	150,250	234.8	36,790	57.5	19,300	30.2
TOTAL	294,070	459.5	111,090	173.6	49,500	77.4

HA: Hydrologic Area
HSA: Hydrologic Subarea
Note: Acre values rounded to the nearest 10 acres and square mile values rounded to the nearest one-tenth of a square mile.

Santa Barbara County.

Because of the study area's large size and differences in hydrologic and topographic characteristics, the study area was divided into three sections for this investigation, based on hydrologic (watershed) boundaries. The first section consists of those portions of Pismo and Oceano HSAs that lie within the study area. These two HSAs were combined in this study because they have similar characteristics. The second section of the study area is the Nipomo Mesa HSA. The third section is that portion of the Guadalupe HA within San Luis Obispo County.

The study area is bounded on the north and east by the Santa Lucia and San Rafael Ranges and on the west by the Pacific Ocean. The southern boundary is defined by the San Luis Obispo-Santa Barbara County line. Its terrain is characterized by mildly sloping foothills on the north and east, which descend into alluvial valleys near the coast. Interspersed among the coastal alluvial valleys are tall eolian sand mesas.

The climate of the study area is typical of Central California coastal communities. Precipitation varies widely both temporally and spatially. Rain gages located near Pismo Beach frequently measure about 16 inches of precipitation annually, while those around Lopez Reservoir measure 20 to 22 inches annually. Close to Guadalupe, precipitation averages slightly more than 12 inches annually and, in the vicinity of Santa Maria, about 14 inches annually. About 75 percent of the precipitation falls in December through March.

The Cities of Arroyo Grande, Grover Beach, and Pismo Beach and the communities of Oceano and Nipomo lie within the study area. All these communities receive all or a portion of their water supply from the Santa Maria Groundwater Basin. Lopez Reservoir is an important source of water within the study area. In August 1997, the Coastal Branch of the State Water Project began bringing water into several of the communities. Its general alignment is shown on Figure 2.

Historically, the area has been and continues to be dominated by its agricultural production, and tourism is close behind as a substantial economic source.

II. GEOLOGY

The study area overlies portions of three geologic depositional basins--Pismo, Santa Maria, and Huasna Basins[1] (Figure 3). These basins contain thick, mostly marine sedimentary Tertiary[2] deposits that unconformably lie on a basement of Jurassic (?)-Cretaceous Complex.

The triangularly shaped Santa Maria Depositional Basin opens toward the west and extends offshore to the Hosgri fault zone. The basin is bounded on the north by the San Rafael Mountains and is in contact with the mountains along the largely concealed system of the Santa Maria River-Foxen Canyon-Little Pine faults[3]. On the south, the basin is bounded by the Santa Ynez Mountains of the Transverse Ranges and is in contact with the mountains along the Santa Ynez River fault. The study area overlies only the Santa Maria Valley portion of the basin within San Luis Obispo County.

The Pismo Depositional Basin, smaller than the Santa Maria, is flanked by strike-slip faults and trends west-northwest. The basin is bounded on the northeast by the West Huasna fault zone and on the southwest by the Santa Maria River fault (Heasler and Surdam, 1984; Stanley and Surdam, 1984; Hall, 1981). It extends west offshore to the Hosgri fault zone (Clark et al., 1994; Heasler and Surdam, 1984; Kablanow and Surdam, 1984). The portion of the basin southeast of Price Canyon is within the study area.

The Huasna Depositional Basin lies between the West Huasna fault zone on the west and the East Huasna fault zone on the east (outside the study area) (Heasler and Surdam, 1984; Kablanow and Surdam, 1984; Hall and Corbato, 1967). The Huasna Basin underlies only 3 percent of the study area at the upper watershed area of Tar Spring Creek and east of the West Huasna fault zone.

More details on the geologic setting are given in Appendix C.

Rock Types

Rocks in the study area are predominantly marine sediments and pyroclastics, which range in age from Jurassic (?) to Holocene. The lithologic units are grouped into three categories: (1) basement complex, (2) volcanic rocks, and (3) sedimentary rocks. A generalized geologic map

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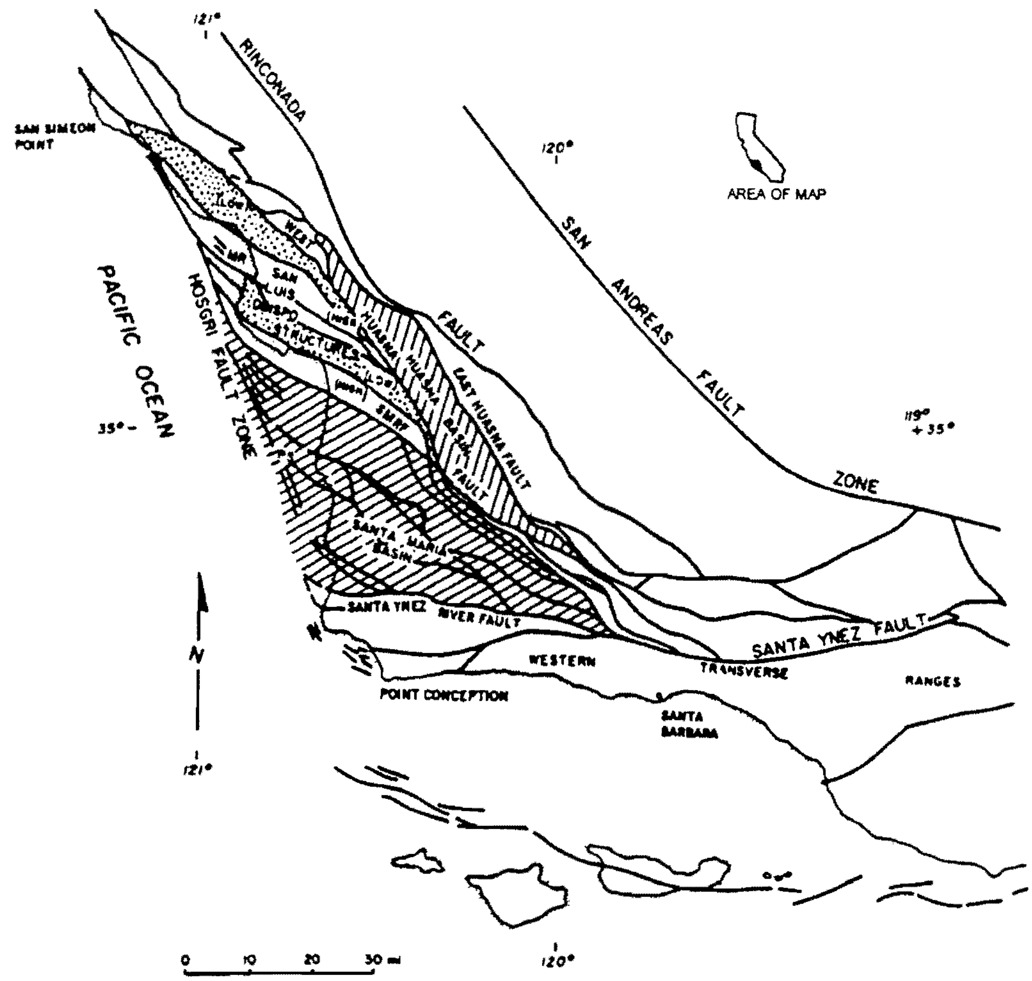
[1] The Santa Maria Groundwater Basin formed within the Pismo and Santa Maria Geologic Depositional Basins.

[2] Geologic Time Scale is included in Appendix C.

[3] The Foxen Canyon-Little Pine faults are in Santa Barbara County, outside the study area.

FIGURE 3 - GENERALIZED GEOLOGIC MAP OF THE SOUTHWESTERN COAST RANGES AND THE WESTERN TRANSVERSE RANGES, CALIFORNIA



Modified from Hall (1981). Figure depicts three structural regions: (1) San Luis Obispo structures, Pismo Basin (stippled pattern and intervening blank areas), consisting of horst-graben-like pull-apart structures between faults; (2) Huasna Basin (vertically ruled pattern), a pull-apart structure; and (3) Santa Maria basin (diagonally ruled pattern), a pull-apart structure. Abbreviations are Morro Rock (MR), Point Sal (PS), and Santa Maria River Fault (SMRF).

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(Plate 1, in pocket) depicts the geographic extent of the different exposed sediments and rocks. Three cross-sections (Plates 2-4, in pocket) were constructed for this study from water well and oil well lithologs and electric logs (locations shown on Plate 1). A stratigraphic column of the formations, Jurassic through Pleistocene, found in each of the three geologic basins is presented in Figure 4.

Basement Complex

The oldest rocks found in the study area are those referred to as basement complex. These rocks include the Jurassic(?) Franciscan Formation and the Cretaceous Knoxville Formation (only in Santa Maria Depositional Basin) and unnamed Cretaceous strata (only in Huasna Depositional Basin). The basement complex unconformably underlies the younger Tertiary and Quaternary deposits. Outcrops are found along an area between the West Huasna and Edna faults in the vicinity of Lopez Reservoir and in the southern end of the Nipomo Valley near the junction of Highways 101 and 166.

The Franciscan Complex is notable for its vast extent throughout the Coast Ranges of California and its enigmatic character. The complex is a heterogeneous assemblage of both marine and continental metasedimentary materials. The predominant rock is graywacke, but shale, altered mafic volcanic rock, chert, and minor limestone are also present (Woodring and Bramlette, 1950; Worts, 1951; Hall, 1973; Hall and Corbato, 1967; Hanson, et al, 1994).

Volcanic Rocks

Early Miocene volcanic and pyroclastic rocks in the study area comprise: (1) tuff, altered tuff, and tuffaceous breccia of the Lospe Formation, (2) tuff and diabase within the Rincon Shale, and (3) tuffs of the largely pyroclastic Obispo Formation. The entire Tertiary volcanic wedge is nearly coincident with the West Huasna fault zone, Santa Maria River fault, and associated fault zones in the San Luis Obispo region (Hall, 1981). Within the study area, the pyroclastic Obispo Formation is exposed along the north side of Highway 101 in the vicinity of Picacho Hill and the northern and eastern highlands that flank the Nipomo Valley.

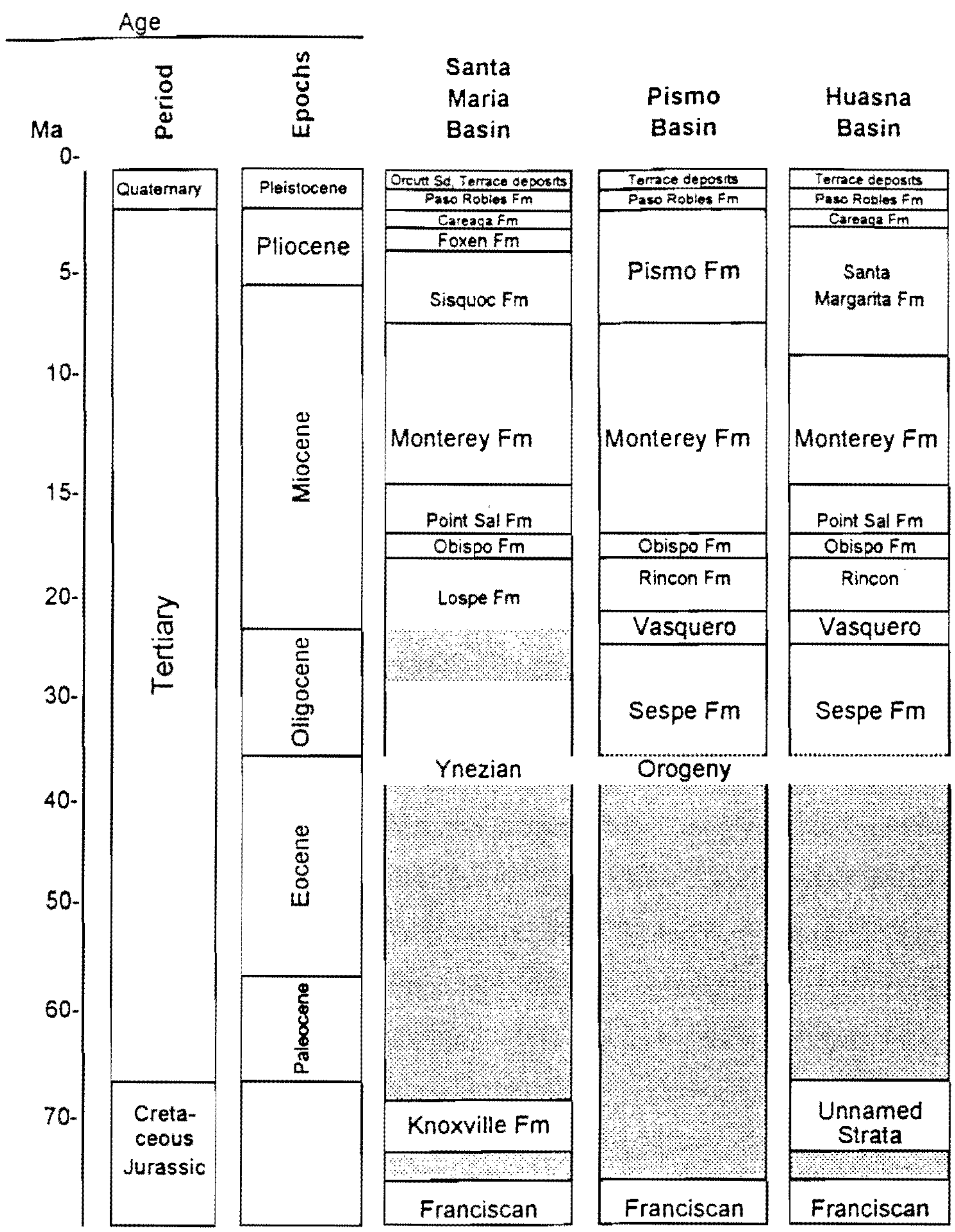
Because of the importance of the Obispo Formation as an aquifer in the bedrock area, a more detailed lithologic description is given.

Hall and Corbato (1967) and Hall (1973) reported the formation consists of resistant silicified or zeolotized tuff and fine- to coarse-grained crystalline tuff, interbedded with basaltic and andesitic lavas, calcareous siltstone or claystone and mudstone.

Locally, the tuff is cut by dikes or sills. The interbedded lavas, dikes, and sills are black or dark green and contain as much as 40 percent montmorillonite[4] clay. The ashy matrix of the coarse-grained tuff is commonly altered to montmorillonite clay. On the lithologs of drillers' reports, the

[4]Montmorillonite clays are characterized by swelling in water and extreme colloidal behavior.

FIGURE 4 - STRATIGRAPHIC CORRELATION DIAGRAM*



*Stratigraphy shown is through only Pleistocene epoch. Diagram modified from Namson and Davis, 1990; Santa Maria Basin (Namson and Davis, 1990; Stanley and Surdam, 1984), Pismo Basin (Stanley and Surdam, 1984; Hall, 1973), and Huasna Basin (Hall and Corbato, 1967)

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Obispo Formation is described as either volcanic sandstone, volcanic shale--often black--or volcanic rock, hard or soft, and sometimes fractured or broken, with interbeds of hard or soft shale--often black--or clay, and sometimes with crystals of quartz and pyrite.

Sedimentary Rocks

The Santa Maria, Pismo, and Huasna Depositional Basins are largely filled with thick accumulations of mostly marine Cenozoic age consolidated to unconsolidated sedimentary rocks.

The Oligocene through mid-Pliocene undifferentiated consolidated sedimentary deposits include: coarse-grained nonmarine redbeds and poorly to well-consolidated, unlaminated to well-laminated, fine- to coarse-grained marine sandstones, siltstones, and mudstones; cherty, diatomaceous, and siliceous shales; dolomite; and diatomite. These deposits include the Monterey Formation, from which significant amounts of petroleum products are produced.

In this study, the consolidated Miocene Monterey Formation is significant for functioning as an aquifer. Hall and Corbato (1967) and Hall (1973) described the formation as consisting of silicified siltstone, claystone, and sandstone, well-bedded claystone or cherty or porcelaneous shale, and some dolomitic shale. The upper part of the formation grades into generally softer, less resistant siltstone and sandstone, with local claystone layers. The formation is commonly fractured and sheared. On the lithologs of drillers' reports, the Monterey Formation was described as hard or soft Monterey shale or shale, usually fractured, with some clay.

With the exception of the unexposed late Pliocene Careaga Formation and late Pleistocene Orcutt Sand, the other deposits--the late Miocene through early Pliocene Santa Margarita Formation, the late Miocene through Pliocene Pismo Formation, and the succeeding younger sedimentary deposits--are differentiated on Plate 1.

Santa Margarita Formation. This marine formation is found in the Huasna Depositional Basin. The formation is a distinctive white-weathering massive bedded, poorly to moderately consolidated, coarse arkosic sandstone and siltstone, with some siliceous claystone and diatomite (Hall and Corbato, 1967).

Pismo Formation. The Pismo Formation of the Pismo Depositional Basin consists of marine claystone, sandstone, or siltstone, poorly to moderately well consolidated, and friable nonbituminous and bituminous arkosic or quartz sandstone with some conglomerate, diatomite, dolomitic sandstone, and fossils (Hall, 1973; Nitchman, 1988; Stanley and Surdam, 1984; Hanson et al., 1994). It is made up of three depositional sequences of relatively conformable successions of genetically related strata bound by unconformities (Stanley and Surdam, 1984). Hall divided the formation into five members: Miguelito--interbedded diatomaceous claystone and siltstone; Edna--bituminous and nonbituminous sandstone and minor conglomerate beds; Gragg--sandstone and conglomerate; Bellview--sandstone and mudstone; and Squire--sandstone and interbeds of silts and clays (1973; Hall and Surdam, 1967).

In particular, the Squire Member of the Pismo Formation is an important source of groundwater in the study area. As described on the lithologs of drillers' reports, the Squire Member within the study area generally consists of coarse- to fine-grained gray to greenish sand with some gravel, interbedded by discontinuous layers of gray silt and clay, with sea shells being common. Nitchman (1988) attributed the distinctive greenish tint to the glauconite content. The Squire Member tends to be poorly consolidated in the upper part, becoming increasingly consolidated with depth. Hall (1973) noted that fracturing is common. Nitchman's work (1988) indicates about 325 feet of the Squire Member unconformably overlies the Edna Member, south of Highway 101 at the northern edge of Tri-Cities Mesa. Hall (1973) reported a maximum of 550 feet of the Squire Member in the Pismo Basin.

Careaga Formation. The shallow-water marine late Pliocene Careaga Formation of the Santa Maria Depositional Basin in the study area is typically described on the lithologs of drillers' reports as unconsolidated to well consolidated, coarse- to fine-grained, blue to bluish-gray, white, gray, green, yellow, or brown to yellowish-brown sand, gravel, silty sand, silt, and clay. Sea shells or shell fragments in clays, sometimes in sands or gravels, are locally common, but the distinctive sand dollar fossils (*Dendraste, sp.*), reported in outcrops of the formation south of the study area (Dibblee, 1950; Woodring and Bramlette, 1950), were not identified on the lithologs. Occasional mention was made of Monterey shale chips. Where the formation was found to lie on the Sisquoc Formation, sands were described as black or dark brown and tarry. Within the study area, the Careaga Formation occurs only at depth. The formation is very thin or absent at the margins of the Santa Maria Basin under Nipomo Mesa (Plates 3 and 4) and progressively thickens to about 700 feet toward the southwest portion of the study area, along the Santa Maria River (Plate 3).

Whether the Pismo Formation or Careaga Formation underlies the Tri-Cities Mesa and northern part of the Arroyo Grande Plain is uncertain. The Pismo Formation accumulated in the Pismo Depositional Basin, which has a southwestern boundary of the Santa Maria River fault. Previously published hydrogeology works name the Careaga Formation as underlying the Tri-Cities Mesa and northern part of the Arroyo Grande Plain. Hanson et al. (1994, Plate 3) indicates either Pismo or Careaga Formation underlying this area. From the lithologs of water well drillers' reports, it is difficult to differentiate the Squire Member of the Pismo Formation from the Careaga Formation and from the older members of the Pismo Formation. As a consequence, cross-section A-A' (Plate 2) shows either formation as present in this area.

Paso Robles Formation. The Pliocene-Pleistocene Paso Robles Formation was deposited in the three depositional basins under a variety of conditions, ranging from fluvial and estuarine-lagoonal in inland areas to nearshore marine at the coast. Consequently, the formation exhibits a wide range of lithologic character and texture.

As described on the lithologs of drillers' reports, the Paso Robles Formation typically consists of unconsolidated to poorly consolidated to sometimes cemented lenticular beds of gray, brown, tan, white, blue, green, or yellow, coarse- to fine-grained gravel and clay, sand and clay, shale gravel, silt, clay, silty clay, and sandy clay, with some lenses of gravel and sand. It occurs in discontinuous beds and lenses, ranging in thickness from 1 foot to an 82-foot bed of yellow clay. The shale gravel is usually porcelaneous pebbles from the Monterey Formation and is rarely reported on lithologs of boreholes southwest of the Santa Maria River fault in the study area. The nearshore marine deposits can be fossiliferous near the base of the formation.

The Paso Robles Formation lies conformably upon the Careaga Formation in the Santa Maria Depositional Basin, except at the margins of the basin, where it unconformably lies upon undifferentiated Tertiary rocks, Miocene Obispo pyroclastics, or basement complex.

Where the Paso Robles Formation overlies the Careaga Formation or the Squire Member of the Pismo Formation, the contact is often difficult to distinguish on the basis of borehole litholog descriptions. Woodring and Bramlette (1950) identified the base of the Paso Robles Formation by the occurrence of the characteristic, but discontinuous and absent in many places, beds of clay and freshwater limestone. Where these were absent, they used conglomerate as the base, and where there was none of these, they considered the base doubtful and arbitrary. The criteria for identifying the base established by Woodring and Bramlette (1950) was used in this study, along with cross-sections and reports by Hanson et al. (1994), Worts (1951), Department of Water Resources (1958, 1970), and Cleath & Associates (1996a).

Thickness of the formation within the study area varies considerably between the Pismo Depositional Basin and the Santa Maria Depositional Basin and within the basins themselves. In the Pismo Basin, the formation ranges from about 50 feet near Pismo Creek to about 250 feet near Arroyo Grande Creek and the Santa Maria River fault (Plate 2). In the Santa Maria Basin, the formation progressively thickens from about 50 feet along the northwestern margin of the basin to about 700 feet at the Santa Maria River (Plate 3).

Individual layers in the Paso Robles Formation are laterally discontinuous and difficult to correlate between wells. Worts (1951, p. 32) commented that "The logs show that, ... there is no correlation possible between beds from place to place in the formation, and that the deposits are lenticular." In the study area, distinct clay, sand, or gravel layers can sometimes be correlated confidently only between wells close to each other. The abrupt lateral discontinuity of the beds within the formation is typical of sediments deposited in a coastal environment under conditions of rising and falling sea levels (Swift and Palmer, 1978).

Using both lithologs and electric logs of water and oil wells, the Department (1970, cross-sections A-A′ through D-D′) identified fairly continuous clayey silt to silty clay layers within the Paso Robles Formation along the coast and inland. The coastal cross-section A-A′ (Plate 2) prepared for this study includes the correlations from the 1970 investigation. However, no correlation of layers was possible on cross-sections B-B′ and C-C′ (Plates 3 and 4).

Orcutt Formation. Worts reported that the late Pleistocene, essentially nonmarine, Orcutt Formation may be present beneath the Santa Maria Valley within the study area, where the lower alluvium is missing (1951). The formation, if present, is found only at depth. Based on the lithologs of the drillers' reports, Worts (1951) describes the formation as consisting of an upper fine-grained sand member and a lower coarse-grained member. The upper member consists of loosely compacted, massive, medium-grained, reddish-brown sand, with lenses of clay; the lower member consists of loosely compacted, coarse, gray to white gravel and sand. The formation ranges in thickness from a featheredge to possibly about 100 feet (Plate 3) and is fine grained near the coast, where, in part, it may be of marine origin.

Older Alluvium and Terrace Deposits. Mid- to late Pleistocene older alluvium is found on the floor of Nipomo Valley. The deposit consists primarily of brown to reddish-brown, red, yellow, and gray gravel, boulders, sand, and other coarse detrital material of local origin imbedded in a dense matrix of silt and clay, intermixed to varying degrees, crudely stratified, poorly consolidated, only locally cemented. Thickness of these deposits ranges from about 10 to 90 feet.

Mid- to late Pleistocene terrace deposits consist of unconsolidated boulders, cobbles, pebbles, sand, silt, and clay. These deposits are remnants of abandoned marine wave-cut platforms or older fluvial deposits, subsequently uplifted and preserved as terraces. Marine terrace deposits are 1 foot to 15 feet thick (Hall, 1973), well to moderately sorted, typically subrounded to rounded, and consist of Franciscan Complex, Obispo, Monterey, and Pismo Formation lithologies (Hanson et al., 1994). Marine terraces are exposed along the coast at Pismo Beach and buried beneath a thick mantle of sand dunes and alluvium in the Arroyo Grande and Nipomo Mesa areas of the San Luis Range. Uplifted fluvial terrace deposits are preserved along the north side of Arroyo Grande Creek.

Holocene Alluvium. Alluvium underlies the floor of Arroyo Grande Plain and the valley bottoms of Arroyo Grande and Pismo Creeks, extending in tongues up the valleys of their tributaries and the floor of Santa Maria Plain. It consists of unconsolidated, poorly bedded, poorly sorted to sorted sand, gravel, silt, and clay, with cobbles and boulders.

Worts (1951) divided the alluvium of the Santa Maria Valley into an upper fine-grained member and a lower coarse-grained member. He also considered the lower member to be missing from the Oso Flaco District[5] of the Santa Maria Plain that is within San Luis Obispo County. The Department (1970) divided the alluvium of the Pismo Creek area and the Arroyo Grande Creek and Plain into upper fine-grained and lower coarse-grained zones. However, for this investigation, the alluvium is considered a single unit.

In the Pismo Depositional Basin, the alluvium overlies the Paso Robles Formation on the Arroyo Grande Plain, and it overlies older sedimentary, volcanic, or Franciscan Complex, along Arroyo Grande Valley and its tributaries and Pismo Creek. The alluvium on the Arroyo Grande Plain ranges from about 130 feet thick near the confluence of Los Berros Creek with Arroyo Grande Creek to about 40 feet at the coast. Near Pismo Beach, the alluvium at the coast is about 50 feet thick. In Arroyo Grande Valley, a geophysical survey conducted by Goss and Reed (1969, p. 72) found the alluvium averaged about 100 feet, with a maximum thickness of about 175 feet just

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[5] Oso Flaco District is local nomenclature for the northern wedge-shaped part of the alluvial plain of the Santa Maria Valley lying northwest of the Santa Maria River in San Luis Obispo County (Worts, 1951, p. 19).

above the confluence of Tar Spring and Arroyo Grande Creeks. Along tributaries of Arroyo Grande Creek, the alluvium ranges from a thickness of about 80 feet to a thin veneer in the upper reaches.

In the Huasna Depositional Basin along upper Tar Spring Creek, the alluvium, which overlies the Santa Margarita Formation, was found to be about 80 feet thick.

In the Santa Maria Depositional Basin, alluvium overlies the Orcutt Formation, if present, or the Paso Robles Formation throughout most of the Santa Maria Plain. The alluvium was found to be about 130 feet thick near Highway 101 at the county line, gradually thickening toward the coast where, along the Santa Maria River, it is about 230 feet thick. However, in the Oso Flaco District, the absence of Worts's lower member results in thinning of the alluvial deposits to about 60 feet at Oso Flaco Lake, a former outlet of the Santa Maria River. The only alluvium found in Nipomo Mesa is in Black Lake Canyon, where it is about 30 feet thick.

Clay beds within the alluvium were found to range in thickness from 1 foot to 30 feet in the Arroyo Grande Plain and from 1 foot to 170 feet in the Santa Maria Plain. As with the Paso Robles Formation, the individual layers in the alluvium are laterally discontinuous and difficult to correlate between wells. In 1951, Worts noted that individual clay beds within the alluvium are relatively extensive, especially near the surface. However, he also reported: "from the data at hand it cannot be definitively concluded that individual clay beds extend as one continuous unit entirely across the west end of the valley" (1951, p. 38).

Using both lithologs and electric logs of water and oil wells, the Department (1970, cross-sections A-A' through D-D') identified fairly continuous clayey silt to silty clay layers within the alluvium along the coast and inland. The coastal cross-section prepared for this study as cross-section A-A' (Plate 2) includes the correlations from the 1970 investigation.

Dune Sand. Both late Pleistocene and Holocene eolian-deposited dune sand is within the study area (Plate 1). The older dune sands form Tri-Cities Mesa and Nipomo Mesa and may range in age from 40,000 to 120,000 years (The Morro Group, 1990). Holocene dune sands occur along a coastal belt up to about 1 3/4 miles from Pismo Beach south into Santa Barbara County. The dune sands overlie either alluvium or the Paso Robles Formation.

The Nipomo triangular lobe of older dune sands is more than 4 miles wide and extends inland more than 12 miles to a little east of Highway 101. The dunes hardly resemble dunes, but are a disorganized assemblage of rounded hillocks and hollows.

The dune sands consist of coarse- to fine-grained, well-rounded, massive sand with some silt and clay. The sands are largely quartz and are loosely to slightly compacted. The older dune sands are anchored by vegetation and have a well-developed soil mantle. Also, iron oxides may locally cement the dune surface into a crust and stain the sand dark reddish-brown.

The older dunes have a maximum thickness of about 60 feet on the Tri-Cities Mesa and 390 feet near the southern edge of Nipomo Mesa. The younger dunes along the coast are generally less than 50 feet thick, but may reach about 100 feet thick.

Structure

The study area, which is a unique area, is set apart structurally and geomorphically from surrounding areas in the southern coastal region. The period of deformation has been so recent that the current topography reflects the structure. The dominant structural features in the region are the Santa Maria Valley, Pismo, and Huasna synclines, west-northwest-trending neotectonic[6] San Luis/Pismo and Santa Maria Valley structural blocks (Figure 5), and a series of faults.

Synclines

The Santa Maria Valley syncline is a broad asymmetrical fold that developed within the northern part of the Santa Maria Depositional Basin. The syncline is evident only from subsurface data. It is bounded along its north and south sides by inactive high-angle right-lateral faults that juxtapose Mesozoic basement rocks against Tertiary strata within the syncline (Hall, 1978, 1981). Within the study area, the northern boundary is the Santa Maria River fault. The axis of the syncline lies about 6 miles south of the county line, not along the middle of Santa Maria Valley.

The northern flank of the syncline, which lies within the study area, is a large, very open, subsurface fold, with a gentle southerly average dip of about 3° (The Morro Group, 1990). The Santa Maria syncline and its margins are cut by numerous faults of middle and late Cenozoic age.

Field evidence gathered by Nitchman (1988) indicates the Pismo syncline is an open, doubly plunging syncline composed of numerous small folds and subparallel axial traces. The syncline is bounded along the northeast and southwest sides by the inactive Edna and San Miguelito faults that juxtapose Mesozoic basement rocks against Tertiary strata within the syncline (Hall, 1973; Hall et al., 1979; Nitchman, 1988). The syncline is the dominant structural element of the San Luis Range and is exposed as a result of uplift associated with the San Luis/Pismo structural block during late Quaternary times.

The Huasna syncline is a pair of doubly plunging en echelon synclines with an associated anticline and smaller synclines and anticlines along the limbs of the larger fold (Hall and Corbato, 1967). It is bounded on the west by the West Huasna fault and on the east by the East Huasna fault (outside the study area). A small portion of the western limb is within the study area.

Structural Blocks

The most significant neotectonic structural features in the area are the San Luis/Pismo and Santa Maria Valley structural blocks (Figure 5). The structural blocks were defined on the basis of

[6]Post Miocene structures

FIGURE 5 - MAP OF STRUCTURAL BLOCKS IN THE SOUTH-CENTRAL CALIFORNIA COAST REGION

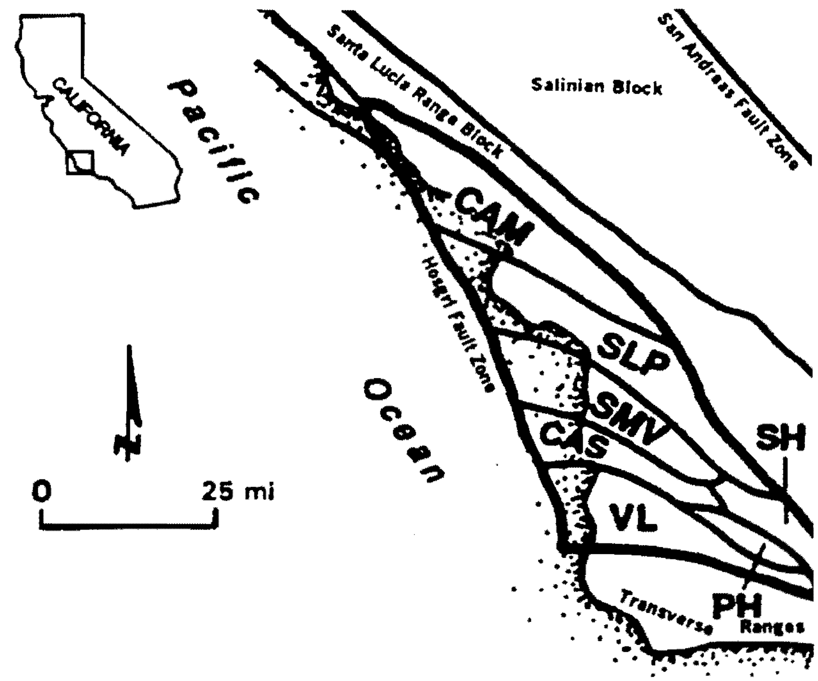


Figure simplified from Lettis, et al., 1994. Abbreviations are: CAM = Cambria block, SLP = San Luis/Pismo block, SMV = Santa Maria Valley block, CAS = Casmalia block, VL = Vandenberg/Lompoc block, PH = Purisima Hills block, SH = Solomon Hills block.

relative differences in uplift/subsidence rates, surface morphology, separation by zones of reverse faulting, and termination against the more northerly-trending Hosgri fault zone (Weber et al., 1987). Topographic uplands and lowlands coincide with the structural blocks.

The San Luis/Pismo block consists of the San Luis Range, including the Pismo syncline, and associated boundary and internal faults. The block is undergoing uplift as a relatively rigid crustal block with little or no internal deformation (Pacific Gas and Electric Company, 1988; Lettis et al., 1994). The southwest margin of the block is bordered by a complex zone of late Quaternary west-northwest-trending, northeast-dipping reverse faults that separate it from the Santa Maria Valley structural block. Within the study area, the faults are the Wilmar Avenue fault and the Oceano fault. The northeast side of the block is bounded by the west-northwest-trending, southwest-dipping comparatively discrete Los Osos fault zone (Hall et al., 1979; Mezger et al., 1987; Nitchman, 1988; Nitchman and Slemmons, 1994). On the west, the block is bordered by the Hosgri fault zone and on the southeast, by the West Huasna fault zone. Both Pismo and

Arroyo Grande Creeks established their channels prior to uplift of the block (Lettis and Hall, 1994).

The Santa Maria Valley structural block, with its substantial Quaternary sediments and lack of emergent marine terraces, has been either a subsiding or static block since at least mid-Pleistocene (Lettis et al., 1994). Within the Santa Maria structural block, convergence and crustal shortening resulted in the deformation of Tertiary and Quaternary deposits and, in late Quaternary, tilting of the structural block, subsidence, and continued sedimentation derived from adjacent uplifted structural blocks (Nitchman, 1988; Lettis et al., 1994). The block is bounded on the northeast by the San Luis/Pismo block. On the west, the block is bordered by the Hosgri fault zone and on the south, the block is bounded by the blocks shown on Figure 5.

Faults

Faults within the study area generally strike west-northwest and often intersect the coast at acute angles, extending offshore. Within the study area, two types of faults share this trend: (1) largely inactive, right strike-slip faults; and (2) potentially active reverse and thrust faults. Locations of the faults within the study area are shown on Plate 1.

Santa Maria River Fault. Hall (1978, 1981, 1982) proposed the existence of the Santa Maria River fault to explain (1) the southward truncation of a thick section of early Miocene pyroclastics and tuffaceous siltstone or claystone, (2) northward truncation of late Miocene and early Pliocene diatomaceous mudstone and siltstone associated with the Santa Maria Depositional Basin, (3) an up to the northeast vertical offset of Franciscan basement, and (4) other stratigraphic contrasts evident from subsurface data[7]. The fault is buried by sediments of Holocene age. It appears to have played a major role in the formation of the Santa Maria Depositional Basin (Hall, 1978, 1981, 1982). The fault continues offshore and merges with the offshore north-striking Hosgri fault zone. Nitchman (1988), Stanley and Surdam (1984), and Vittori et al. (1994) recognize the Santa Maria River fault as being active during the late Oligocene to early Pliocene tectonic regime, characterized by strike-slip displacement.

Cross-section B-B′ (Plate 3) shows the juxtaposition of Franciscan basement rocks against Tertiary sediments across the Santa Maria River fault, and cross-section C-C′ (Plate 4) shows vertical offset of about 80 feet of Tertiary sediments across the fault. At the coast, the Santa Maria River fault coincides with the Oceano fault, where it is not known how much, if any, of the about 90 feet of vertical offset of Tertiary sediments across the faults may be attributed to activity of the Santa Maria River fault. The Franciscan basement high on the northeast side of the fault is at greater depth under Arroyo Grande Plain and Tri-Cities Mesa, as can be seen from cross-sections A-A′ (Plate 2) and B-B′ (Plate 3).

West Huasna Fault Zone. This major northwest-trending fault zone transects the northeastern

[7] The Santa Maria River fault is coincident with Namson and Davis's (1990) Point San Luis anticline. They interpreted a large Franciscan cored structural high along the northeast margin of the Santa Maria Basin as a regional anticline associated with a ramp in a south-verging blind thrust at depth.

edge of the study area, crossing the Arroyo Grande Valley approximately a mile downstream from Lopez Dam and bounding Pismo and Huasna Depositional Basins. Hall (1973) found the fault zone to consist of low to high angle reverse faults cut by a younger set of nearly vertical faults. Because of the complexity and differing styles of faulting observed within the fault zone, the predominant sense of displacement is obscured, and movement along the fault zone, as inferred from late Tertiary tectonic conditions and other indirect evidence, is believed to be largely right strike-slip in nature (Nitchman, 1988). Buchanan-Banks et al. (1978) reported that the fault is believed to offset late Pleistocene deposits locally.

Edna Fault. The west-northwest-trending right strike-slip fault borders the northern limb of the Pismo syncline, juxtaposing Miocene and Pliocene strata against Franciscan basement rocks. It branches from the West Huasna fault zone and forms a zone across the northeastern study area, transecting the Arroyo Grande Valley approximately 2½ miles below Lopez Dam. The fault is believed to have been active during the late Oligocene to early Pliocene tectonic regime (Vittori et al., 1994; Nitchman, 1988). Hall (1973) stated that the Edna fault cuts late Pliocene and Pleistocene strata.

Pismo Fault. Hall (1973) interpreted the fault as a west-northwest trending, high-angle fault with predominantly right, normal strike-slip displacement, juxtaposing Miocene and Pliocene volcanic and sedimentary rocks against Franciscan basement rocks on the southwest. The fault bounds the southwestern margin of the Pismo syncline. It has not been active during the late Quaternary (Lettis et al., 1994). In 1978 and 1981, Hall showed the Pismo fault as the southern extent of the San Miguelito fault. Nitchman (1988) also interpreted the Pismo fault, as mapped by Hall in 1973, as the possible southern extent of the San Miguelito fault.

Wilmar Avenue Fault. The west-northwest-striking, northeast-dipping late Quaternary reverse Wilmar Avenue fault was investigated and described by Nitchman (1988). The fault follows the alignment of Highway 101 from Arroyo Grande north to Pismo Beach, where the only exposure of the fault is in a sea cliff near Wilmar Avenue. The range front fault is characterized by two distinct structural segments: a western segment that exhibits block uplift with little tilting or folding and an eastern segment that forms a monoclinal fold in the upper Pliocene strata (Nitchman, 1988). Cross-section A-A′ (Plate 2) intersects the western segment of the fault, and cross-section B-B′ (Plate 3) intersects the eastern segment. The base of the Squire Member of the Pismo Formation is vertically offset along the western segment between 820 and 980 feet (ibid). The fault extends offshore, veering slightly to the west for at least 3 miles (Lettis et al., 1994).

The fault may extend south of Arroyo Grande along the front of the San Luis Range and the northeast margin of Nipomo Mesa to the northern part of Santa Maria Valley, where it may truncate against the Santa Maria River fault. Along this segment, the fault is inferred by the alignment of geomorphic and geologic features. Cross-section C-C′ (Plate 4) illustrates about 150 feet of vertical offset of Tertiary rocks across this postulated extension of the Wilmar Avenue fault, which is similar to displacement found by Lettis et al. (1994).

Oceano Fault. The northwest-trending, northeast-dipping late Quaternary reverse Oceano fault underlies Nipomo Mesa and extends offshore south of Oceano. Within the onshore segment, the fault is not geomorphically expressed because of the relatively thick alluvial and eolian cover. The fault was first recognized by the Department in a 1970 cross-section (A-A′) along the coast, and later by Pacific Gas and Electric Company (1988) based on interpretation of onshore and offshore seismic reflection and oil well data. It displaces Franciscan Complex basement and overlying Tertiary strata. A southeasterly decrease in vertical separation suggests that the fault probably dies out in the northern Santa Maria Valley near the Santa Maria River (Lettis et al., 1994). The fault may have been active in the past 500,000 years (Pacific Gas and Electric Company, 1988).

Cross-sections B-B′ and C-C′ illustrate the vertical displacement across the Oceano fault, which ranges from about 300 feet (Plate 4) to 400 feet (Plate 3) under central Nipomo Mesa. At the coast, the Oceano fault coincides with the Santa Maria River fault. As noted earlier, how much of the about 90 feet of vertical offset of Tertiary sediments that can be attributed solely to activity of the Oceano fault is not known. The displacement agrees with that of Lettis et al. (1994) and Cleath & Associates (1996a).

III. APPLIED WATER DEMAND AND SUPPLY

This chapter contains a discussion of all the water demands and supplies within the study area. Information was compiled for water demand in the urban, agricultural, environmental, and other categories. Groundwater, Lopez Reservoir, State Water Project, and reclaimed water provide the area's water supply. Water demand/supply totals may not sum due to rounding.

Water demand in the urban, agricultural, other, and environmental categories was derived using the Department's Bulletin 160 methodologies. (See Bulletins 160-93 and 160-98 for details.)

Land use in the study area was surveyed by the Department in 1977, 1985, and 1995, and the resultant maps were digitized into AutoCAD. GIS software GEO/SQL and Spatial Analyst were used to determine the spatial distributions and acreages of the various land uses. Analysis of the acreages contributed to the present urban, agricultural, other, and environmental water demand estimates and facilitated the forecasting of future demand.

Water supply data were obtained from the counties of San Luis Obispo and Santa Barbara, U. S. Geological Survey (USGS), local agencies, and Department records.

Applied Water Demand

Table 2 depicts applied water demand in the study area for 1975-2020 for urban, agricultural, environmental, and other categories. Applied water is that water delivered to the intake of a

TABLE 2
APPLIED WATER DEMAND IN STUDY AREA
Thousands of acre-feet

WATER DEMAND	1975	1980	1985	1990	1995	2000	2010	2020
URBAN	6.6	8.1	12.0	13.2	11.3	15.0	16.3	19.2
AGRICULTURAL	32.4	30.6	26.8	25.3	25.3	25.5	23.9	24.3
OTHER*	1.0	1.0	1.1	1.1	1.1	3.9	4.0	4.0
TOTAL	40.0	39.7	39.9	39.6	37.7	44.4	44.2	47.5

Note: All values rounded to the nearest 100 acre-feet.
*Values for 2000, 2010 and 2020 include 2,800 AF of applied environmental demand.

water system or farm headgate. Total applied water demand decreased by about 2,300 acre-feet (AF) from the 40,000 AF in 1975 to 37,700 AF in 1995. Year 2020 total applied water demand is expected to increase about 9,800 AF over 1995 levels. The large increase in total applied demand from 1995 to 2020 is attributable to increased urban demand of almost 8,000 AF and environmental demand estimated at 2,800 AF. Average annual decreases of about 115 AF for applied water demand were realized in the 20-year period 1975-95 and an average annual increase of almost 400 AF of applied water demand is expected between 1995 and 2020.

Urban Applied Demand

The population is concentrated in small communities. Small family homesteads are also distributed throughout the study area. Table 3 depicts population for 1975-2020 with values obtained from the State of California Department of Finance. Total population increased by almost 21,000 between 1975 and 1995 and is expected to increase by almost 37,000 by 2020, with a total population in 2020 of more than 98,000.

TABLE 3
POPULATION IN STUDY AREA
State of California Department of Finance*

Hydrologic Area/Subarea	1975	1980	1985	1990	1995	2000	2010	2020
Pismo/Oceano HSA	32,905	33,501	39,151	44,801	47,089	51,440	60,440	67,810
Nipomo Mesa HSA	5,820	6,939	7,975	9,177	10,947	13,300	18,850	24,170
Guadalupe HA	2,462	2,601	3,151	3,700	4,027	4,630	5,590	6,760
Study Area Total	41,187	43,041	50,277	57,678	62,063	69,370	84,880	98,740

* All values from DOF Special Projections for DWR, May 1996

Urban applied water demand for each hydrologic area and hydrologic subarea in the study area for 1975-2020 is shown in Table 4. Population figures for each hydrologic area and hydrologic subarea listed in Table 3 were multiplied by each hydrologic area and subarea per capita unit use values listed in Table D2 of Appendix D to obtain the urban applied water use values. Total urban applied water demand increased by 4,700 AF from the 6,600 AF in 1975 to 11,300 AF in 1995, whereas population increased by about 51 percent during the same period. Year 2020 urban applied water demand is expected to increase about 7,900 AF over 1995 levels, with population increasing by about 59 percent in the same period.

Agricultural Applied Demand

Crop acreage and evapotranspiration of applied water (ETAW) by crop type for 1975-2020 are depicted in Table 5. Crop acreage decreased by about 2,850 acres from the 17,603 acres in 1975

TABLE 4
URBAN APPLIED WATER DEMAND *
Thousands of acre-feet

Hydrologic Area/Subarea	1975	1980	1985	1990	1995	2000	2010	2020
Pismo/Oceano HSA	4.8	5.7	8.5	8.7	7.7	9.8	10.4	11.7
Nipomo Mesa HSA	1.5	2.1	3.0	3.9	3.1	4.5	5.2	6.6
Guadalupe HA	0.3	0.3	0.5	0.6	0.5	0.7	0.7	0.9
Study Area Total	6.6	8.1	12.0	13.2	11.3	15.0	16.3	19.2

Note: All values rounded to the nearest 100 acre-feet.
* Demand values derived by multiplying population by per capita water use

to 14,749 acres in 1995, while ETAW decreased almost 3,400 AF in the same time period. Year 2020 crop acreage and ETAW values, which have been estimated by Department Land and Water Use staff, are expected to decrease also. Crop acreage will decrease by about 240 acres and ETAW by about 250 AF from 1995 levels. This is based on personal communication with the local Agricultural Commissioner and University of California Cooperative Extension staff and review of the Department's land use maps for the last three decades.

Agricultural applied water demands by hydrologic area and hydrologic subarea for 1975-2020 are shown in Table 6. Unit applied water for each crop category is determined by dividing ETAW by irrigation efficiency. Unit applied water is then multiplied by the crop acreage of each crop category. The results are summed to obtain applied water demand for each year. Agricultural applied water demand decreased by about 7,100 AF from the 32,400 AF in 1975 to 25,300 AF in 1995. Year 2020 agricultural applied water demand is expected to decrease about 1,000 AF over 1995 levels. The reduction in applied demand for the two periods is attributable to a reduction in crop acres and increased irrigation efficiency.

All agricultural applied water demands are met by groundwater extractions in the study area. In the Pismo/Oceano HSAs, the downstream releases from Lopez Reservoir are extracted also.

Environmental Applied Demand

San Luis Obispo County operates and maintains the Lopez Project including Lopez Reservoir. The reservoir's safe yield includes 4,200 acre-feet per year (AF/Y) for releases into Arroyo Grande Creek for downstream groundwater recharge with the average historical releases of 2,500 to 3,000 AF/Y. The county is conducting a Habitat Conservation Plan to determine requirements for water to be released into Arroyo Grande Creek from Lopez Dam for steelhead trout within the creek. Until the study is completed, the county is conducting an interim supplemental release program of 2,800 AF/Y from Lopez Dam for maintaining steelhead habitat. The supplemental

TABLE 5 IRRIGATED CROP ACREAGE AND EVAPOTRANSPIRATION OF APPLIED WATER BY CROP *

IRRIGATED CROP	1975 TOTAL ACRES	1975 ETAW AF	1980 TOTAL ACRES	1980 ETAW AF	1985 TOTAL ACRES	1985 ETAW AF	1990 TOTAL ACRES	1990 ETAW AF
Grain	71	14	58	12	42	8	50	10
Cotton	0	0	0	0	0	0	0	0
Sugarbeets	231	392	128	218	0	0	0	0
Corn	360	431	268	322	154	185	12	14
Other Field	4,000	4,000	2,267	2,267	101	101	46	46
Alfalfa	687	1,374	576	1,152	438	876	400	800
Pasture	246	492	412	824	619	1,239	248	495
Tomatoes	257	463	199	358	126	227	162	291
Other Truck	10,276	10,276	10,912	10,912	11,706	11,706	10,806	10,806
Deciduous	178	303	124	212	57	97	85	144
Citrus and Subtropical	1,291	1,936	1,413	2,120	1,566	2,350	1,743	2,615
Vineyard	6	5	169	135	372	297	812	649
TOTAL	17,603	19,687	16,526	18,530	15,181	17,085	14,364	15,872

IRRIGATED CROP	1995 TOTAL ACRES	1995 ETAW AF	2000 TOTAL ACRES	2000 ETAW AF	2010 TOTAL ACRES	2010 ETAW AF	2020 TOTAL ACRES	2020 ETAW AF
Grain	52	10	50	10	50	10	50	10
Cotton	0	0	0	0	0	0	0	0
Sugarbeets	0	0	0	0	0	0	0	0
Corn	12	14	10	10	10	10	10	10
Other Field	48	48	50	50	50	50	50	50
Alfalfa	406	812	410	830	410	810	400	800
Pasture	253	506	260	520	250	510	250	500
Tomatoes	164	295	170	300	160	300	160	290
Other Truck	11,109	11,109	11,350	11,350	11,110	11,110	10,930	10,930
Deciduous	87	148	90	150	90	150	90	150
Citrus and Subtropical	1,794	2,691	1,830	2,750	1,790	2,690	1,760	2,650
Vineyard	824	659	840	670	820	660	810	650
TOTAL	14,749	16,293	15,060	16,640	14,740	16,300	14,510	16,040

* ETAW values were based on a combination of direct field measurements and theoretical calculations Recommendations of the Farm Advisors of San Luis Obispo and Santa Barbara Counties and the Natural Resources Conservation Districts were also taken into consideration. For details see DWR Bulletin 113-4 Crop Water Use in California," April 1986.

TABLE 6
AGRICULTURAL APPLIED WATER DEMAND
Thousands of acre-feet

Hydrologic Area/Subarea	1975	1980	1985	1990	1995	2000	2010	2020
Pismo/Oceano HSA*	10.5	10.6	9.0	9.4	9.6	9.5	9.0	8.8
Nipomo Mesa HSA	1.5	1.6	1.9	1.8	1.8	1.8	1.8	1.8
Guadalupe HA	20.4	18.4	15.9	14.1	13.9	14.2	13.1	13.7
Study Area Total	32.4	30.6	26.8	25.3	25.3	25.5	23.9	24.3

Note: All values rounded to the nearest 10 acre-feet.
*The irrigated cropped acres in Pismo HSA for 1975: 7.9, 1985: 26.69, 1995: 0.0. Demand associated with these acreages amounts to less than 100 AF and the demand for the two HSAs were combined.

releases were initiated in the fall of 1998 and are expected to continue until the Habitat Conservation Plan is completed and a permanent release program is negotiated with the State Water Resources Control Board and California Department of Fish and Game.

The environmental applied demand is included in the Pismo/Oceano HSA other applied water demand values for 2000, 2010 and 2020 in Table 7.

There are several Sensitive Resource Areas (SRA) within the study area (San Luis Obispo County Department of Planning and Building, 1992, 1995). The Nipomo Dunes SRA extends about 12 miles along the coast and is habitat for many endemic flora species, including the threatened beach spectaclepod, surf thistle, and la graciosa thistle. The Nipomo Dunes support such unique vegetative associations as the central foredune and central dune scrub communities. Ten freshwater lakes (Dune Lakes SRA) lie inland of the coastal dunes and support a coastal freshwater marsh, which in turn provides habitat for birds in the Pacific Flyway and local waterfowl. The Oso Flaco Lake SRA serves as a local wetland complex providing habitat for numerous birds including the endangered least tern and threatened western snowy plover. Black Lake Canyon SRA serves as habitat for birds in the Pacific Flyway and local waterfowl. Both the Oso Flaco Lake and Black Lake Canyon SRAs provide the marsh habitat required to support endangered Gamel's watercress and marsh sandwort plants. The source of water for these SRAs is precipitation and runoff and is therefore not considered an environmental demand.

Although not identified as SRAs, Pismo Creek and Santa Maria River also provide important aquatic habitats for threatened and endangered fauna. Both watercourses support the endangered tidewater goby for a short distance (1 to 3 miles) upstream of the ocean. The Santa Maria River and its tributaries also support the threatened California red-legged frog. Habitat for the

TABLE 7
OTHER APPLIED WATER DEMAND*
Thousands of acre-feet

Category	1975	1980	1985	1990	1995	2000	2010	2020
Pismo/Oceano HSA**	0.05	0.05	0.09	0.09	0.09	2.90	2.92	2.94
Nipomo Mesa HSA	0.95	0.95	0.96	0.96	0.97	0.97	0.97	0.98
Guadalupe HA	0.03	0.04	0.04	0.05	0.06	0.06	0.07	0.08
Study Area Total	1.03	1.04	1.09	1.10	1.12	3.93	3.96	4.00

Note: All values rounded to the nearest acre-foot.
* Values for 2000, 2010 and 2020 are estimated based on historical trends.
** Values for 2000, 2010 and 2020 include 2,800 AF of applied environmental demand.

red-legged frog and the endangered Pismo clarkia plant is found in the Arroyo Grande watershed. The source of water for this habitat is precipitation and runoff and is therefore not considered an environmental demand.

Other Applied Demand

The other applied water demand category consists of conveyance losses, cooling, miscellaneous, recreational, and environmental water demands. Table 7 lists other applied water demands by hydrologic area or subarea for 1975-2020. Water demand for this category increased by about 90 AF from the 1,030 AF in 1975 to 1,120 AF in 1995, mostly attributable to increased use at recreational facilities. Year 2020 other water demand is expected to increase about 2,900 AF over 1995 levels. Environmental demand estimated at 2,800 AF makes up the largest portion of the increase between 1995 and 2020 with increased use of the area's recreational facilities responsible for about 50 AF of the expected increase. Increased Lopez Reservoir deliveries to contractors resulting in increased conveyance losses, increased cooling requirements, and increased miscellaneous uses account for the remainder of the increase from 1995 through 2020. The recreational water demand at Lopez Reservoir is not included in this study because it is considered part of the natural supply of the reservoir and so does not enter into any of this study's calculations.

The impact of the large stands of eucalyptus trees on the water demand in Nipomo Mesa is problematical and beyond the scope of this study. Chipping Geological Services (1994) reviewed the hydrologic impacts of eucalyptus on Nipomo Mesa. Its report found that: "Data from India and Australia suggests that eucalyptus does not use any more water than other trees. There are water-saving advantages to removing eucalyptus trees in the riparian corridor, but very little to removing trees higher in the slopes around the canyon." (p.69)

Water Supply

Groundwater is the major source of supply in the study area. Other available supplies are Lopez Reservoir water, imported State Water Project water, and reclaimed water.

Water supply for each hydrologic area and hydrologic subarea in the study area for 1975-2020 is shown in Table 8. Total water supply in the study area decreased by about 2,300 AF from the 40,100 AF in 1975 to 37,800 AF in 1995, while year 2020 water supply is expected to increase 9,700 AF over 1995 levels.

TABLE 8
STUDY AREA WATER SUPPLIES
Thousands of acre-feet

Hydrologic Area/Subarea Category	1975	1980	1985	1990	1995	2000	2010	2020
Pismo/Oceano HSA								
Groundwater	10.1	10.3	9.1	8.6	10.0	10.3	10.1	11.0
Surface*	5.3	6.1	8.5	9.6	7.4	11.9	12.2	12.4
Nipomo Mesa HSA								
Groundwater	4.0	4.7	5.9	6.7	5.9	7.3	8.0	9.4
Guadalupe HA								
Groundwater	20.7	18.7	16.4	14.8	14.5	15.0	13.9	14.7
Study Area Total								
Groundwater	34.8	33.7	31.4	30.1	30.4	32.6	32.0	35.1
Surface*	5.3	6.1	8.5	9.6	7.4	11.9	12.2	12.4
Total	40.1	39.8	39.9	39.7	37.8	44.5	44.2	47.5

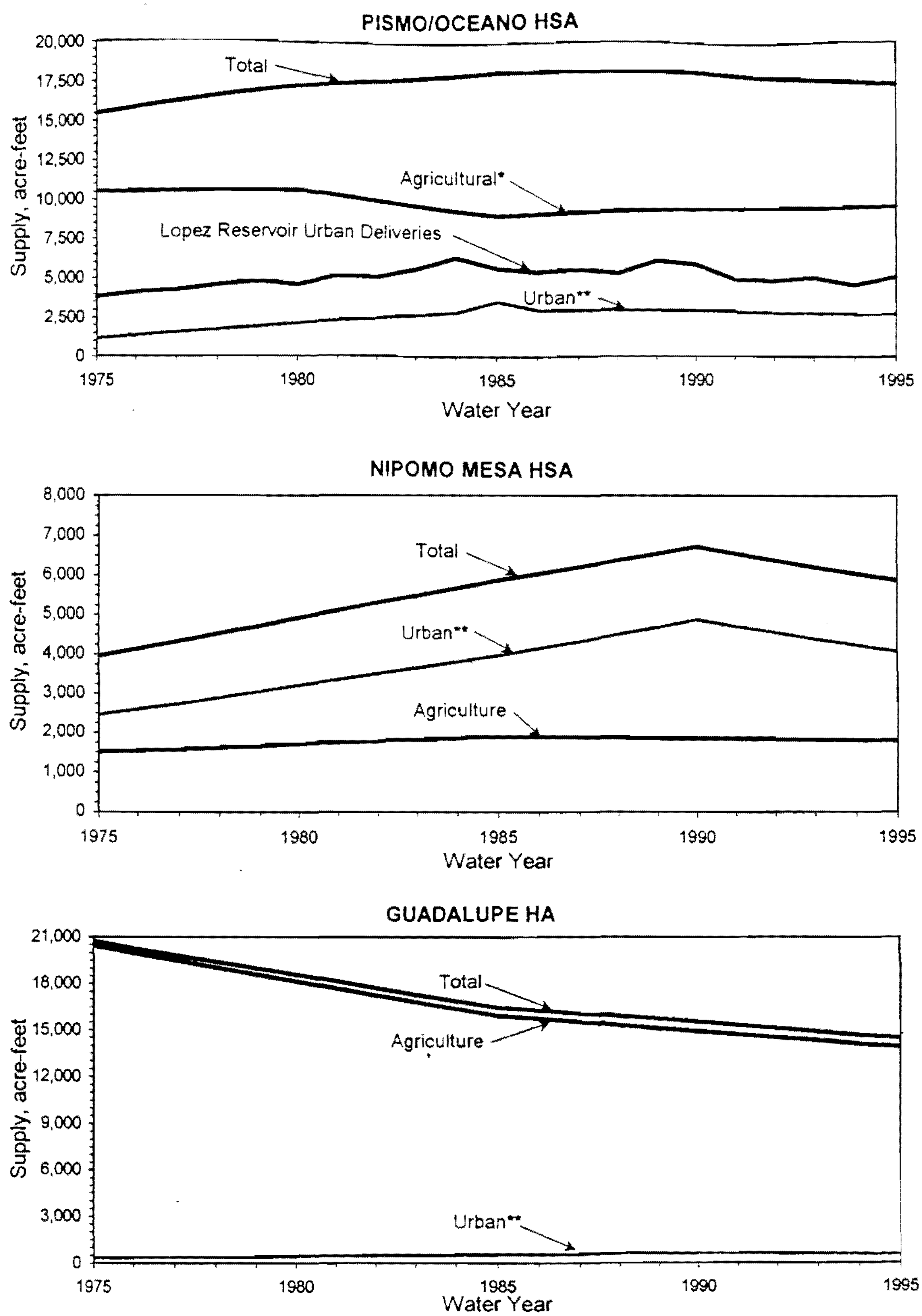
Note: All values rounded to the nearest acre-foot. Water demand/supply totals may not sum due to rounding.
* Values for 1975 through 1995 include Lopez Reservoir deliveries to urban agencies and downstream releases for agriculture (see Table 10). Values for 2000, 2010 and 2020 include State Water Project deliveries of: 1,100 AF, 1,350 AF, and 1,590 AF, respectively; Lopez Reservoir deliveries and releases of 8,000 AF for urban and agricultural demands and environmental releases of 2,800 AF.

Figure 6 shows how the relative amounts from Lopez Reservoir and the groundwater basin have changed since 1975.

Groundwater

Table 8 shows that groundwater is the largest single source of water supply in the study area.

FIGURE 6 - WATER SUPPLIES



* Includes downstream releases from Lopez Reservoir for agriculture. See Table 10 for release data.
** Also includes supplies for "Other" water demands (Table 7).

Total groundwater supply in the study area decreased by about 4,400 AF from the 34,800 AF in 1975 to 30,400 AF in 1995, while year 2020 groundwater supply is expected to increase 4,700 AF over 1995 levels. Figure 7 shows the general location and amounts of groundwater extractions in water year 1995.

Surface Water

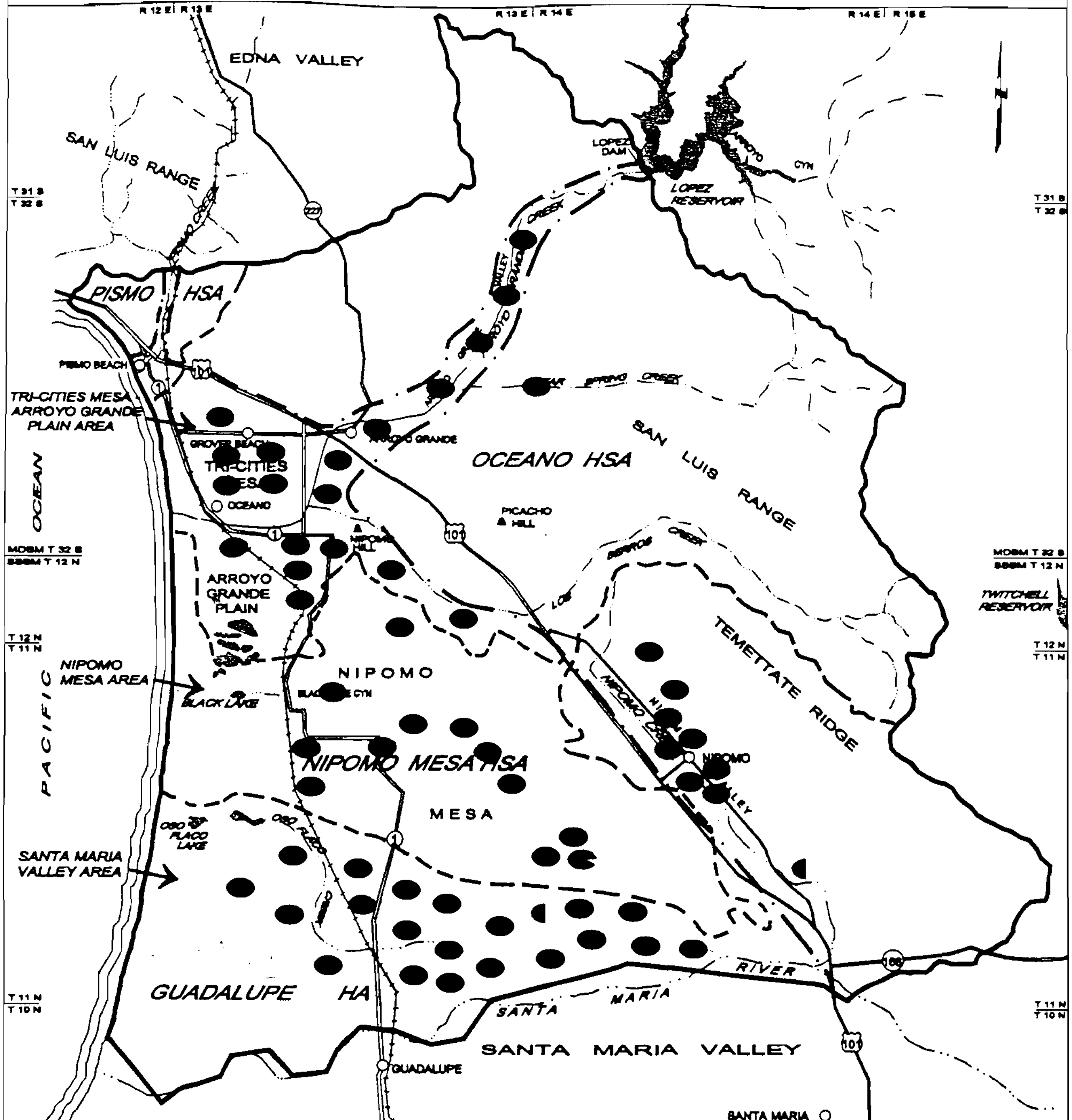
Surface water supply depicted in Table 8 comprises State Water Project water and Lopez Reservoir water. Total surface water supply in the study area increased by about 2,100 AF from the 5,300 AF in 1975 to 7,400 AF in 1995, while year 2020 surface water supply is expected to increase 5,000 AF over 1995 levels. State Water Project deliveries were estimated to be 1,100 AF in 2000, then increasing to full entitlement of 1,590 AF in 2020. San Luis Obispo County is proposing to release 2,800 AF of Lopez Reservoir water to Arroyo Grande Creek as an interim plan to satisfy steelhead habitat demand. According to San Luis Obispo County staff, the releases are not expected to impact urban and agricultural entitlements to Lopez Reservoir water. This demand has been included in the year 2000, 2010, and 2020 calculations.

Lopez Reservoir. Completion of Lopez Reservoir in 1969, with a capacity of 52,500 AF, afforded the area a dependable supply of potable water. Its annual dependable yield is 8,700 AF and, since its completion, about 192,000 AF have been delivered to municipal and agricultural interests. Annual entitlements to Lopez Reservoir water for all users are shown in Table 9. Agricultural entitlements to Lopez Reservoir water, amounting to 4,200 AF annually, are received via downstream releases. Annual pipeline deliveries to local agencies (excluding Avila Beach), downstream releases for agricultural entitlements, other releases, and spillway discharges for

TABLE 9
LOPEZ RESERVOIR ENTITLEMENTS
In acre-feet

User	Entitlement
Arroyo Grande	2,290
Grover Beach	800
Oceano	303
Pismo Beach	896
Agriculture	4,200
CSA 12	241
Study Area Total	8,489
Project Total	8,730

FIGURE 7 - GROUNDWATER EXTRACTIONS IN WATER YEAR 1995, QUANTITIES AND GENERAL LOCATIONS



LEGEND

REPRESENTS 500 ACRE-FEET OF GROUNDWATER EXTRACTION, APPROXIMATE LOCATION

HA = HYDROLOGIC AREA
HSA = HYDROLOGIC SUBAREA

GROUNDWATER BASIN BOUNDARY

HYDROLOGIC AREA AND SUBAREA BOUNDARIES, GEOGRAPHIC DIVISIONS OF GROUNDWATER BASIN BASED ON THESE BOUNDARIES.

STUDY AREA BOUNDARY

DEPARTMENT OF WATER RESOURCES, SOUTHERN DISTRICT

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water years 1969-95 are given in Table 10. Historical average annual pipeline deliveries amounted to about 4,600 AF and downstream releases for agricultural entitlements amounted to about 2,500 AF.

According to Vernon H. Persson, Chief of the Department's Division of Safety of Dams: "A 1992 Woodward-Clyde Consultant study of Lopez Dam, No.1055 in San Luis Obispo County, identified liquefiable alluvium in the foundation under the shells. Liquefaction in the foundation could result in loss of reservoir storage after a moderate-sized earthquake."

As a result of these findings, an interim operating plan was proposed by the owner (County of San Luis Obispo) and approved by the Division of Safety of Dams (Table 11). This interim operating plan is expected to remain in effect until repairs to the dam are complete, which is anticipated to be in June 2002.

Future supplies from Lopez Reservoir are expected to equal or exceed those of the past 30 years.

Imported Water. In 1991, the citizens of San Luis Obispo and Santa Barbara Counties voted to extend the Coastal Branch of the California Aqueduct of the State Water Project. Figure 2 (in Chapter I) depicts the route the Coastal Branch follows. Construction was completed in July 1997 with deliveries commencing in August 1997.

The City of Pismo Beach (1,240 AF) and Oceano Community Service District (750 AF) have contracted with the County of San Luis Obispo for the delivery of State Water Project water.

Oceano Community Service District is trying to sell 400 AF of its entitlement, according to a spokesperson for the District.

Reclaimed Water

Currently, effluent from wastewater treatment plants is reclaimed[1] for irrigation of a golf course. Effluent is also disposed of through ocean outfalls or incidentally recharged to the groundwater basin through percolation ponds.

Reclaimed water use programs in California are governed by regulations primarily from the California Department of Health Services. The regulations are set forth in the California Code of Regulations, Title 22, Division 4, Chapter 3, entitled "Reclamation Criteria." The Regional Water Quality Control Boards grant approval for projects and follow the established criteria in Title 22 and county health department recommendations. In the study area, specifications, level of treatment, and regulations for all plants are given in their discharge requirements issued by the Central Coast Regional Water Quality Control Board.

[1]All wastewater treatment plants in the study area produce effluent that meets secondary standards.

TABLE 10
LOPEZ RESERVOIR WATER DELIVERIES TO CONTRACTORS,* 1969 to 1995
All values in acre-feet

Water Year	Pipeline Deliveries	Downstream Release	Other Release	Spillway Discharge	Total
1969	1,860	1,030	296	3,122	6,308
1970	2,114	2,546	217	3,700	8,577
1971	3,467	3,551	0	0	7,018
1972	3,722	3,495	0	0	7,217
1973	3,395	1,241	0	791	5,427
1974	3,397	1,465	2,530	7,950	15,342
1975	3,810	1,478	0	1,800	7,088
1976	4,107	3,000	0	0	7,107
1977	4,207	3,283	0	0	7,490
1978	4,543	1,668	295	13,691	20,197
1979	4,780	1,822	418	335	7,355
1980	4,550	1,511	0	21,798	27,859
1981	5,120	2,624	69	172	7,985
1982	5,053	1,822	817	3,540	11,232
1983	5,575	910	3,360	79,106	88,951
1984	6,331	2,227	1,948	6,131	16,637
1985	5,647	2,920	0	0	8,567
1986	5,393	2,301	0	4,810	12,504
1987	5,538	2,517	0	0	8,055
1988	5,259	2,514	0	0	7,773
1989	6,059	2,812	0	0	8,871
1990	5,858	3,673	0	0	9,531
1991	4,919	2,761	0	0	7,680
1992	4,879	2,950	0	0	7,829
1993	5,075	2,164	0	0	7,239
1994	4,583	2,270	0	0	6,853
1995	5,078	6,844**	0	0	11,922

Note: All values rounded to the nearest acre-foot.
*Does not include deliveries to Avila Beach.
**Includes release made for dam stability reasons.

TABLE 11
LOPEZ RESERVOIR INTERIM OPERATING PLAN

END OF MONTH	RESERVOIR ELEVATION in feet	ESTIMATED INFLOW in acre-feet	PLANNED STORAGE in acre-feet
NOVEMBER	503.0	--------	37,400
DECEMBER	503.5	600	38,000
JANUARY	505.0	1,000	39,000
FEBRUARY	507.5	2,000	41,000
MARCH	510.0	2,000	43,000
APRIL	510.0	--------	43,000
MAY	510.0	--------	43,000

Present Facilities. Figure 8 depicts the locations of wastewater treatment plants (WWTPs) in the study area. Average yearly effluent from each of the plants for 1990-95 is shown in Table 12.

The Pismo Beach, South San Luis Obispo County Sanitation District, and Tosco WWTPs treat their wastewater to the secondary standards of the Regional Board using traditional treatment methods. The Black Lake Golf Course and Southland WWTPs, both of which are operated by Nipomo Community Services District, using different treatment methods, treat their wastewater to a quality that is comparable to secondary standards before it is delivered to aerated lagoons.

The Pismo Beach WWTP, which began operation in 1953, has an operating capacity of 1,960 AF/Y. Disposal of effluent was formerly through a city-operated ocean outfall; however, since 1981, the effluent is discharged to the ocean through the South San Luis Obispo County Sanitation District's ocean outfall. The South San Luis Obispo County Sanitation District WWTP began operation in 1966, has an operating capacity of 5,600 AF/Y, and disposes of its effluent through the ocean outfall. The Tosco (formerly Unocal) WWTP, which began operation in 1954, produces about 650 AF/Y of effluent; this is disposed of through a company-owned and operated ocean outfall.

The Black Lake Golf Course WWTP when it began operation in 1986 had an operating capacity of 112 AF/Y. Expansion of the plant, doubling its capacity to 224 AF/Y, was completed in January 1998 (Doug Jones, personal communication, March 1998). Disposal of effluent is through an aerated lagoon and ultimately by application to portions of the adjacent golf course. In 1995, the Black Lake Golf Course reclaimed almost 80 AF of treated wastewater from the

FIGURE 8 - WASTEWATER TREATMENT PLANT LOCATIONS

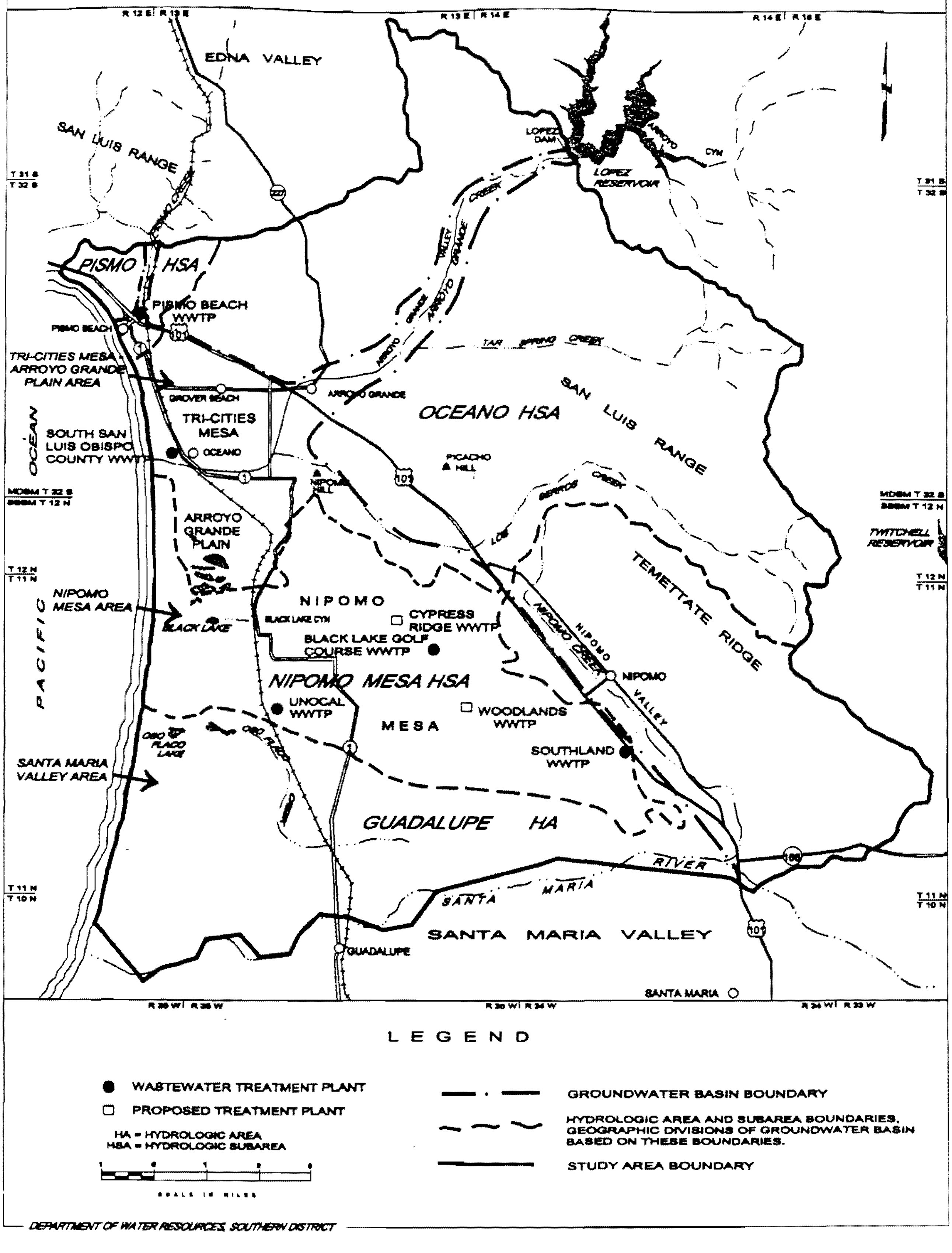

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TABLE 12
WASTEWATER TREATMENT PLANT EFFLUENT
All values in acre-feet

Water Year	Treatment Plants					Total
	Pismo Beach	South SLO County	Black Lake	Southland	Tosco*	
1990	1,132	3,032	45	210	469	4,888
1991	1,194	2,978	46	196	562	4,976
1992	1,130	2,844	57	235	655	4,921
1993	1,238	2,894	72	250	655	5,109
1994	1,052	2,898	94	287	562	4,893
1995	1,134	2,917	78	333	655	5,117

Note: All values rounded to the nearest acre-foot.
* Formerly Unocal. Only refinery discharge water is treated prior to ocean disposal. No sewage is treated.

Black Lake Golf Course WWTP for irrigation, of which about 10 AF incidentally percolated to the groundwater basin. After expansion of the plant, the incidental percolation from the golf course irrigation was estimated to be 20 AF/Y. (See Table 13.)

The Southland WWTP, which began operation in 1985, had an operating capacity of 403 AF/Y. Expansion of the plant, increasing its capacity to about 670 AF/Y, was completed in April 1999 (Ibid). Disposal of effluent is through several aerated lagoons and eventually infiltration to the groundwater basin. In 1995, about 330 AF/Y of treated wastewater from the Southland WWTP was estimated to incidentally percolate to the groundwater basin. After expansion of the plant, the incidental percolation was estimated to be almost 640 AF/Y, with about 30 AF/Y evaporating. (See Table 13.)

Expansion Plans. Most of the wastewater treatment plants have plans to increase their capacity to meet expected future demands, which are being driven by increases in local population and tourism. Estimates of future incidental groundwater recharge of treated wastewater are given in Table 13.

The Pismo Beach WWTP will be increasing plant capacity in the future; however, at this time no estimate of the amount of expansion is available.

Additional treatment of the South San Luis Obispo County Sanitation District WWTP effluent for reuse for various purposes was studied by John Wallace and Associates, Consulting Engineers (1996); but the study was interrupted because of the need to further research the market for

TABLE 13
INCIDENTAL GROUNDWATER RECHARGE OF TREATED WASTEWATER
All values in acre-feet

Water Year	TREATMENT PLANTS					Total
	South SLO County*	Black Lake*	Southland	Cypress Ridge*	Woodlands*	
1985	N/A	N/A	N/A	N/A	N/A	N/A
1990	N/A	5	300	N/A	N/A	305
1995	N/A	10	330	N/A	N/A	340
2000	N/A	20	640	N/A	N/A	660
2010	700	20	1,000	6	30	1,756
2020	700	20	1,000	6	30	1,756

Note: All values estimated to the nearest acre-foot.
N/A: not applicable
* Incidental recharge from reclaimed water for irrigation.

reclaimed water in the area. It was concluded that additional treatment will be required for the effluent to meet standards for disinfected secondary-2.2 reclaimed water or disinfected tertiary reclaimed water [2].

In the above-mentioned report, three separate scenarios were given with different uses for the reclaimed water. The cost of the scenarios ranges from $195/AF to $1,316/AF for the different levels of treatment and uses of the effluent. Under scenario 1, the plant would produce about 850 AF/Y of disinfected secondary-2.2 reclaimed water, at a cost of $195/AF (excluding transportation), to be used for irrigation of two golf courses. It was estimated that approximately 700 AF/Y of this reclaimed water would incidentally percolate to the groundwater basin. In scenario 2, the plant would produce about 850 AF/Y of disinfected tertiary reclaimed water to be used for irrigation of a golf course, nearby homes and school playgrounds, a city park, and landscape irrigation along the freeway. The cost for this scenario would be about $284/AF (excluding transportation costs), with about 700 AF/Y of the reclaimed water incidentally percolating to the groundwater basin. In scenario 3, the plant would produce about 850 AF/Y of disinfected tertiary reclaimed water, including demineralization, for use at a city park, highway landscaping, avocado farm, and groundwater replenishment involving surface spreading. This scenario would cost about $1,316/AF excluding transportation; about 700 AF/Y of the reclaimed water would incidentally percolate to the groundwater basin.

[2]Numbers refer to most probable number count of total coliform bacteria in 100 milliliters.

If any of these scenarios is adopted, it is assumed that about 700 AF/Y of reclaimed water for irrigation will incidentally percolate to the groundwater basin, with percolation beginning about 2005 (Table 13).

The Southland WWTP is increasing its operating capacity now. Construction began in July 1999 and was scheduled to be completed by the end of the year. This will increase the capacity to about 1,050 AF/Y, with a total of about 1,000 AF/Y incidentally infiltrating to the groundwater basin and the remainder evaporating (Doug Jones, personal communication, March 1998).

The draft environmental impact report for a Cypress Ridge Tract Map and Development Plan and baseline environmental assessment and constraint analysis of a Woodlands Specific Plan show plans for construction of wastewater treatment plants similar to the plant at Black Lake Golf Course. Their general locations are depicted on Figure 8. The proposed capacity of the Cypress Ridge WWTP is 123 AF/Y and of the Woodlands WWTP is 350 AF/Y. Effluent from each plant is to be used for meeting a portion of the development's golf course water demand. Incidental infiltration to the groundwater basin from the golf course irrigation is estimated to be 6 AF/Y for Cypress Ridge and 30 AF/Y for Woodlands at build out (Table 13).

IV. HYDROLOGY

As has been pointed out in the preceding chapter, water supply used in the study area comes primarily from the groundwater basin and Lopez Reservoir. Both receive replenishment from precipitation and surface water in the Santa Maria River and the many creeks in the area.

Precipitation

Because both surface and groundwater are derived from rainfall, the amount of rain falling within the watershed in a given year is an indicator of the amount of water that will be available for use that year. From an analysis of long-term precipitation for the study area, a recent short-term base period can be chosen as representative of the long-term average precipitation. Therefore, analysis of historical information is required.

Data from 36 precipitation stations were supplied by the Counties of San Luis Obispo and Santa Barbara. These are included in Appendix B. The data, extending from calendar year 1869 through calendar year 1995, were arranged into a water year format. The stations extend from California State Polytechnic University in San Luis Obispo County to Betteravia Union Sugar Company[1] in Santa Barbara County. The elevations of the stations range from 10 feet above mean sea level (msl) at the wastewater plant in Oceano to 745 feet at the Bettencourt station. Figure 9 shows the locations of the 36 stations, and Table 14 lists the data point number, gage number, station name, and long-term precipitation for each station.

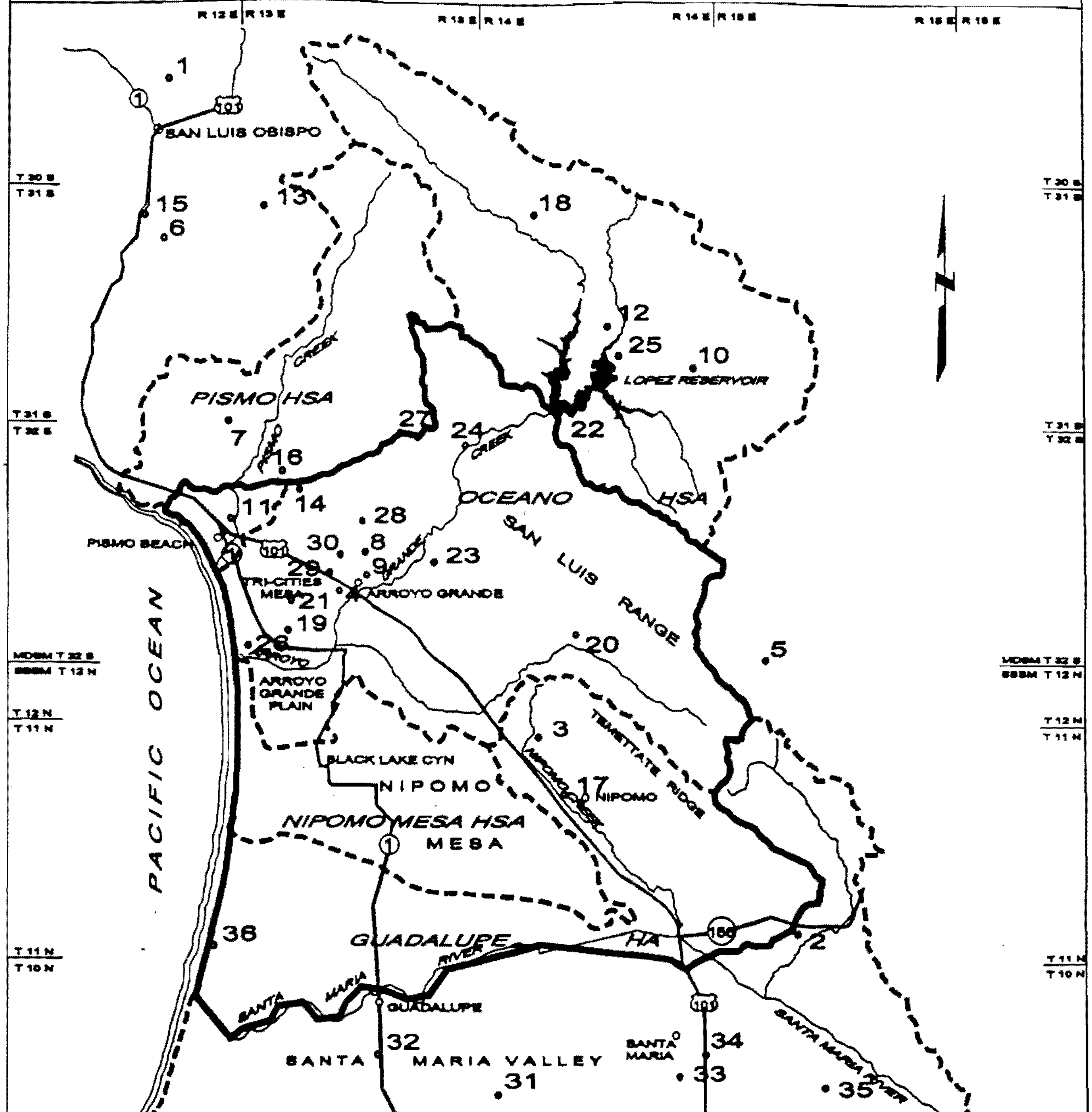
Mean annual (water year) precipitation for the 36 stations ranges from 12 to 35 inches, usually in the form of rain, about 75 percent falling between December and March. The smallest recorded annual rainfall, 3.49 inches, fell in 1948 at the Puritan Ice Company in Guadalupe. The greatest recorded annual rainfall, 71.03 inches, fell in 1983 at the Bettencourt station in Lopez Canyon.

Figure 10 shows lines of equal mean annual precipitation in and around the study area for water years 1870-1995. The isohyets were constructed using only those stations shown on Figure 10. The criteria for selection were length of record, consistency of data, accuracy of data, and proximity to the study area.

Annual precipitation and long-term mean precipitation for the period of record are shown in Figures 11-13. The station at California State Polytechnic University at San Luis Obispo,

[1]California State Polytechnic University is in Township 30 South, Range 12 East, Section 23D, Mount Diablo Base and Meridian, and Betteravia Union Sugar Company is in Township 10 North, Range 35 West, Section 24, San Bernardino Base and Meridian.

FIGURE 9 - PRECIPITATION STATION LOCATIONS



LEGEND

31 DATA POINT NUMBER, FOR STATION NAME SEE TABLE 13

STUDY AREA BOUNDARY

WATERSHED BOUNDARY

HA = HYDROLOGIC AREA

HSA = HYDROLOGIC SUBAREA

5 0 5

SCALE IN MILES

DEPARTMENT OF WATER RESOURCES, SOUTHERN DISTRICT

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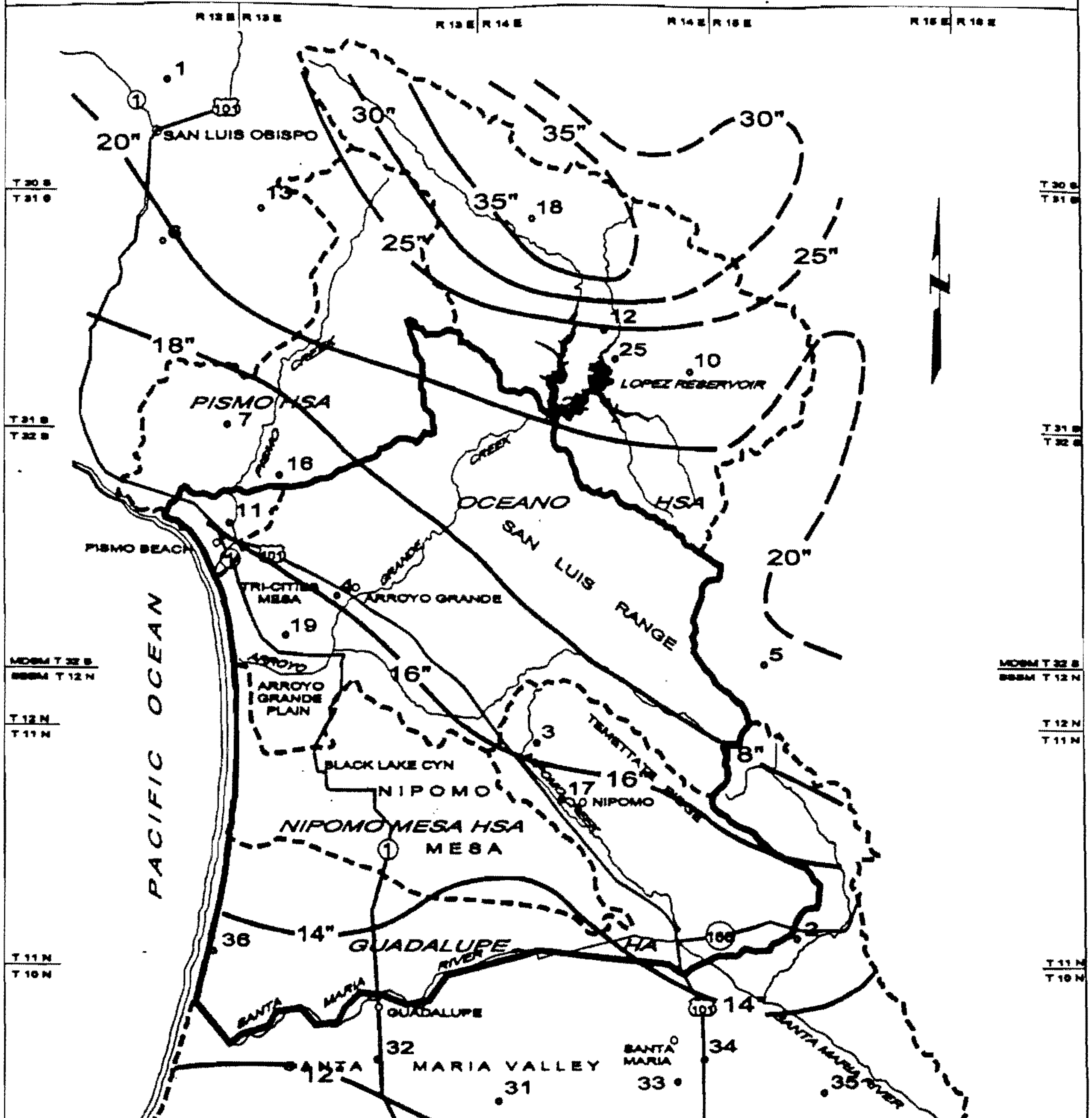
TABLE 14
PRECIPITATION STATIONS

Data Point Number	Gage Number	Station Name	Long-Term Precipitation, Inches
1	1.0	California State Polytechnic University	21.97
2	23.0	Suey Ranch	15.01
3	38.0	Nipomo 2NW	16.29
4	42.1	Runels Ranch	16.09
5	51.0	Huasna Valley	19.06
6	54.0	Union Oil Company	19.98
7	55.0	Union Oil Company	17.61
8	85.0	County Yard	15.98
9	87.0	Police Department	15.17
10	100.0	Ranchita Ranch	22.24
11	126.0	Police Department	16.12
12	127.1	Spencer Ranch	22.97
13	129.0	Perozzi Ranch	21.87
14	141.1	A.B. Cunningham	19.60
15	145.1	Wastewater Plant	22.20
16	147.0	Bates Plumbing	16.41
17	151.1	Nipomo CDF	15.08
18	153.0	Bettencourt	35.41
19	157.1	CSA No 13	15.84
20	175.1	Penny Ranch	19.00
21	177.1	Corporate Yard	15.41
22	178.1	Lopez Dam	20.04
23	178.2	Tar Springs USGS	15.58
24	179.1	Treatment Plant	16.84
25	193.0	Wastewater Plant	21.78
26	194.0	Wastewater Plant	16.9
27	195.1	Police Department	14.63
28	200.0	M. Bolding - Printz Road	18.17
29	205.0	County Yard	14.47
30	205.2	Holzingers Cow Camp	18.28
31	BET387	Betteravia Union Sugar Co.	13.42
32	PUR352	Puritan Ice Company	12.38
33	SMC380	Santa Maria City	13.41
34	SMH400	Santa Maria State Hwy. Maint. Yard	13.59
35	UBA410	Union Oil Battles Plant Santa Maria	12.74
36	UGO407	Union Oil Company Guadalupe	13.71

FIGURE 10 - LINES OF EQUAL MEAN ANNUAL PRECIPITATION, 1870 THROUGH 1995



LEGEND

12"	LINES OF EQUAL MEAN ANNUAL PRECIPITATION, DASHED WHERE INFERRED		WATERSHED BOUNDARY
31	DATA POINT NUMBER. FOR STATION NAME SEE TABLE 13		HA = HYDROLOGIC AREA HSA = HYDROLOGIC SUBAREA
	STUDY AREA BOUNDARY		SCALE IN MILES (5 0 5)

DEPARTMENT OF WATER RESOURCES, SOUTHERN DISTRICT

AM 01481

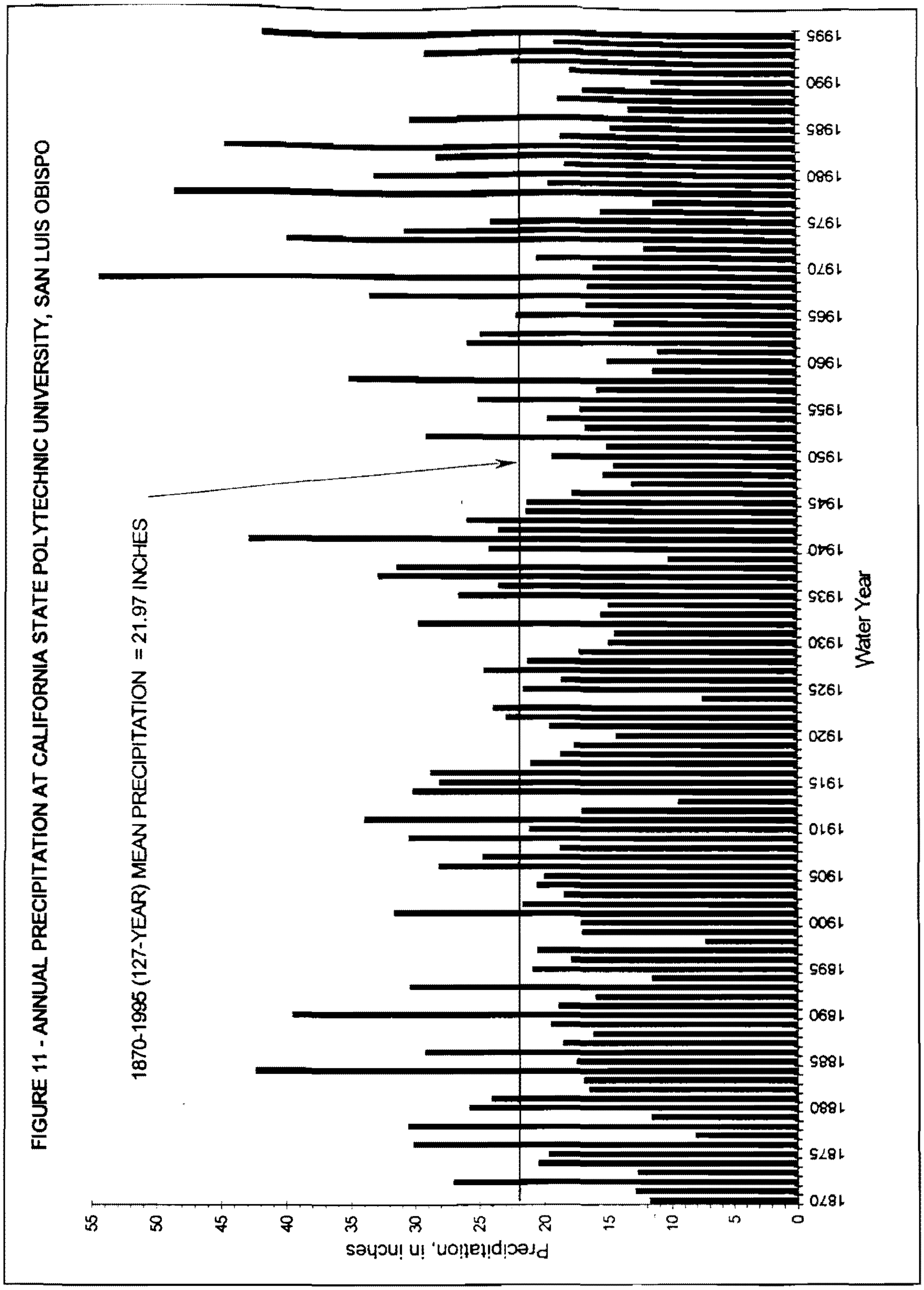


FIGURE 11 - ANNUAL PRECIPITATION AT CALIFORNIA STATE POLYTECHNIC UNIVERSITY, SAN LUIS OBISPO
1870-1995 (127-YEAR) MEAN PRECIPITATION = 21.97 INCHES
Precipitation, in inches
Water Year
0
5
10
15
20
25
30
35
40
45
50
55
1870
1875
1880
1885
1890
1895
1900
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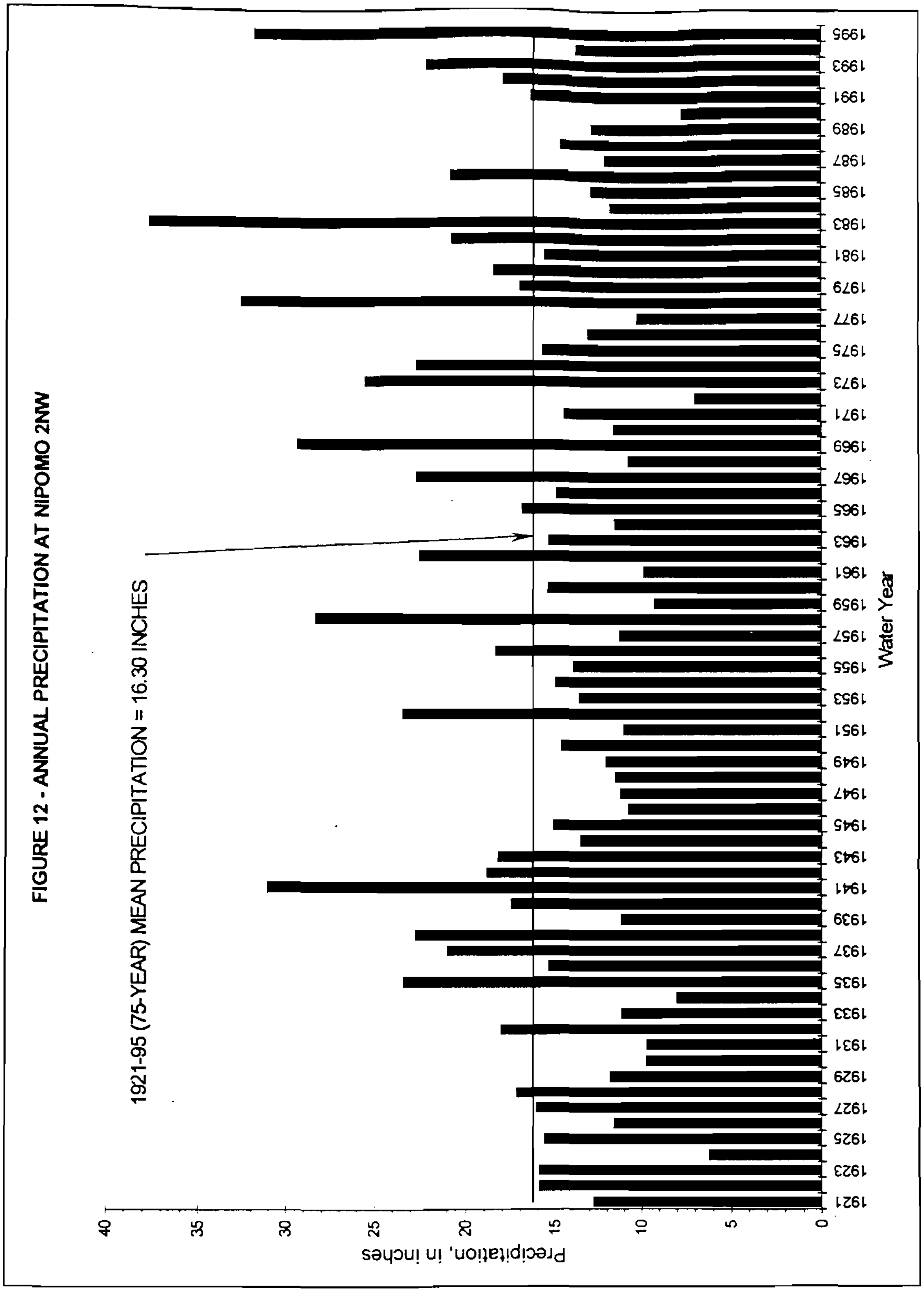


FIGURE 12 - ANNUAL PRECIPITATION AT NIPOMO 2NW

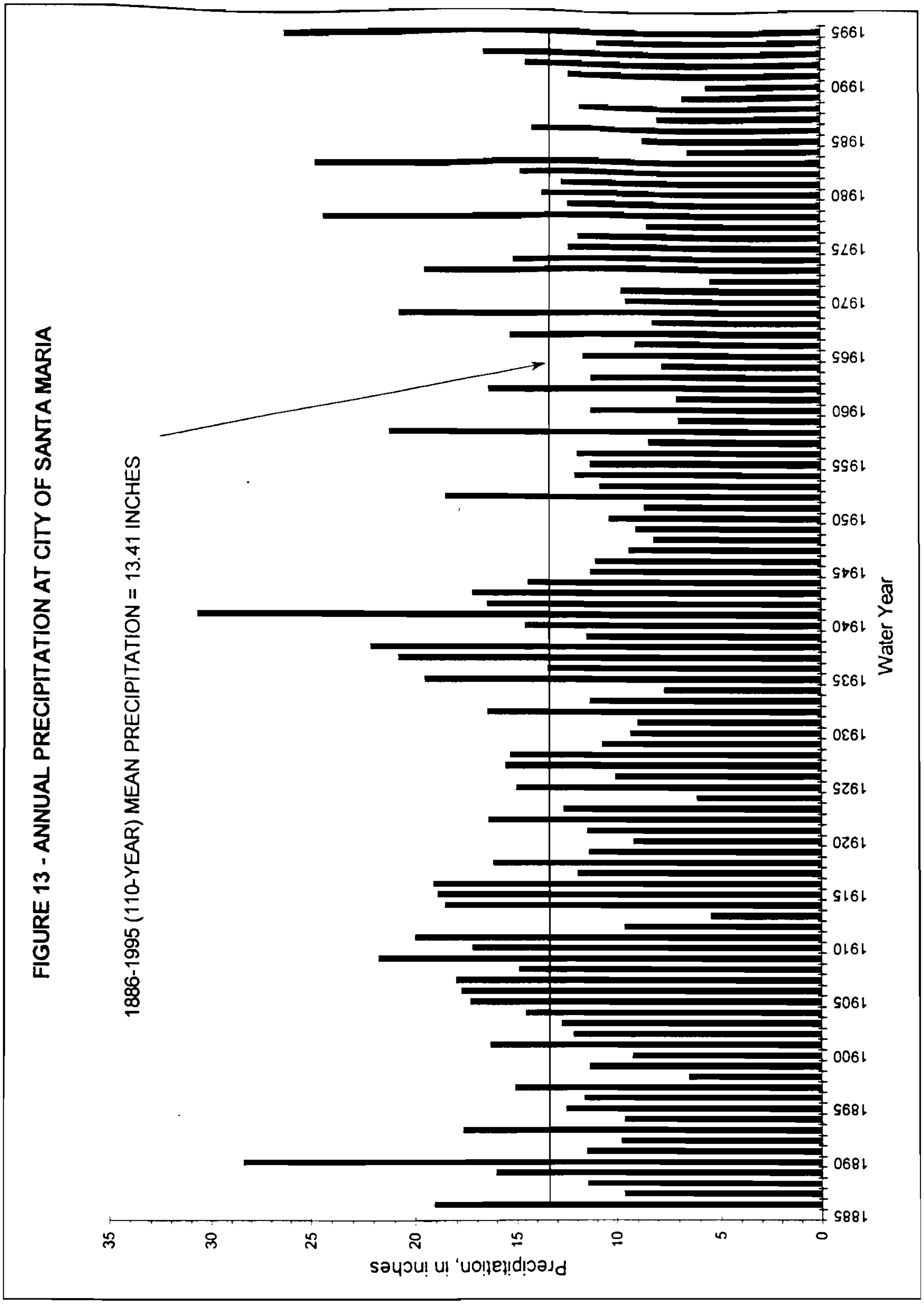
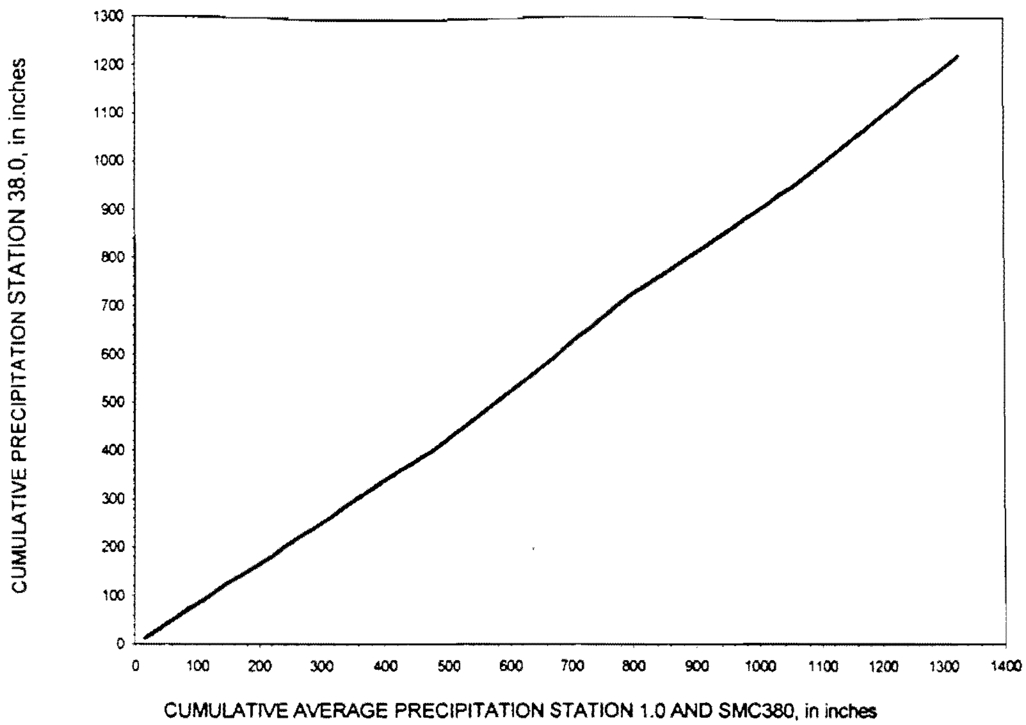


FIGURE 13 - ANNUAL PRECIPITATION AT CITY OF SANTA MARIA

FIGURE 14 - 1921 THROUGH 1995 ANNUAL PRECIPITATION DOUBLE MASS ANALYSIS



is in Figure 11, the station at Nipomo 2NW is in Figure 12, and the station in the City of Santa Maria is in Figure 13.

Figure 14 shows the results of double mass analysis for the average of the stations at California State Polytechnic University and Santa Maria versus the Nipomo 2NW station. The relative linearity of the figure shows that the data for the Nipomo 2NW station is consistent. Based on this and the central location of the Nipomo 2NW precipitation station, it has been chosen as representative of rainfall in the study area.

From the data for this station, water years 1984-95 were selected as the base period for the study. See Appendix B for a detailed determination of the base hydrologic period.

Surface Water

Of the surface water bodies in the study area, only Lopez Dam and Reservoir on Arroyo Grande Creek is a direct supply to the area. It is a major supply for the Cities of Arroyo Grande, Pismo

Beach, and Grover Beach.

The areal extent of the watercourses contributing to the water supply is depicted in Figure 15. Discharge data for all stream gages pertinent to the study were supplied by San Luis Obispo and Santa Barbara Counties and the USGS. The locations of the discharge stations are shown on Figure 15, and data for each of the discharge stations are included in Appendix E. The data, extending from calendar year 1940 through calendar year 1995, were arranged into a water year format. These 11 river discharge stations extend from Lopez Creek near Arroyo Grande in San Luis Obispo County to Sisquoc River near Garey[2] in Santa Barbara County. The elevations of the stations range from 18 feet above msl[3] at the Pismo Creek station to 580 feet at the Lopez Creek station.

The Pismo Creek drainage area, which is about 47 square miles, attains a maximum elevation of almost 2,865 feet above msl. It consists of approximately 54 percent mountainous and foothill area and 46 percent valley area. Pismo Creek measures about 13 miles from its headwaters to its confluence with the Pacific Ocean.

Pismo Creek is characteristic of small drainages in the study area with small incised channels. The creek flows through relatively rugged terrain, with small alluvial deposits appearing sporadically before it empties into the Pacific Ocean. Pismo Creek is not gaged except for a short period of record obtained from Balance Hydrologics, Inc., which collected Pismo Creek discharge data for January 2, 1989, through September 30, 1992. The elevation of the Pismo Creek stream gage is estimated to be 18 feet above msl. During the 12-year base period (1984-95), the estimated average annual runoff ranged from 140 to 200 AF. The average annual infiltration from both the creek and watershed is estimated to have been 50 to 100 AF during the same period.

Arroyo Grande Creek watershed and its tributaries occupy 190 square miles and reach a maximum elevation of approximately 3,200 feet above msl. About 83 percent of the surface area of the drainage consists of mountains and foothills and 17 percent of valleys and mesas. Arroyo Grande Creek measures about 13 miles from Lopez Dam to its mouth at the Pacific Ocean.

Arroyo Grande Creek is one of the main watercourses within the study area. The portion of the creek between Lopez Dam and the City of Arroyo Grande supports extensive agricultural activities. Estimated seasonal natural runoff for water years 1895-1947, as reported in Bulletin No. 1[4], is shown in Appendix E.

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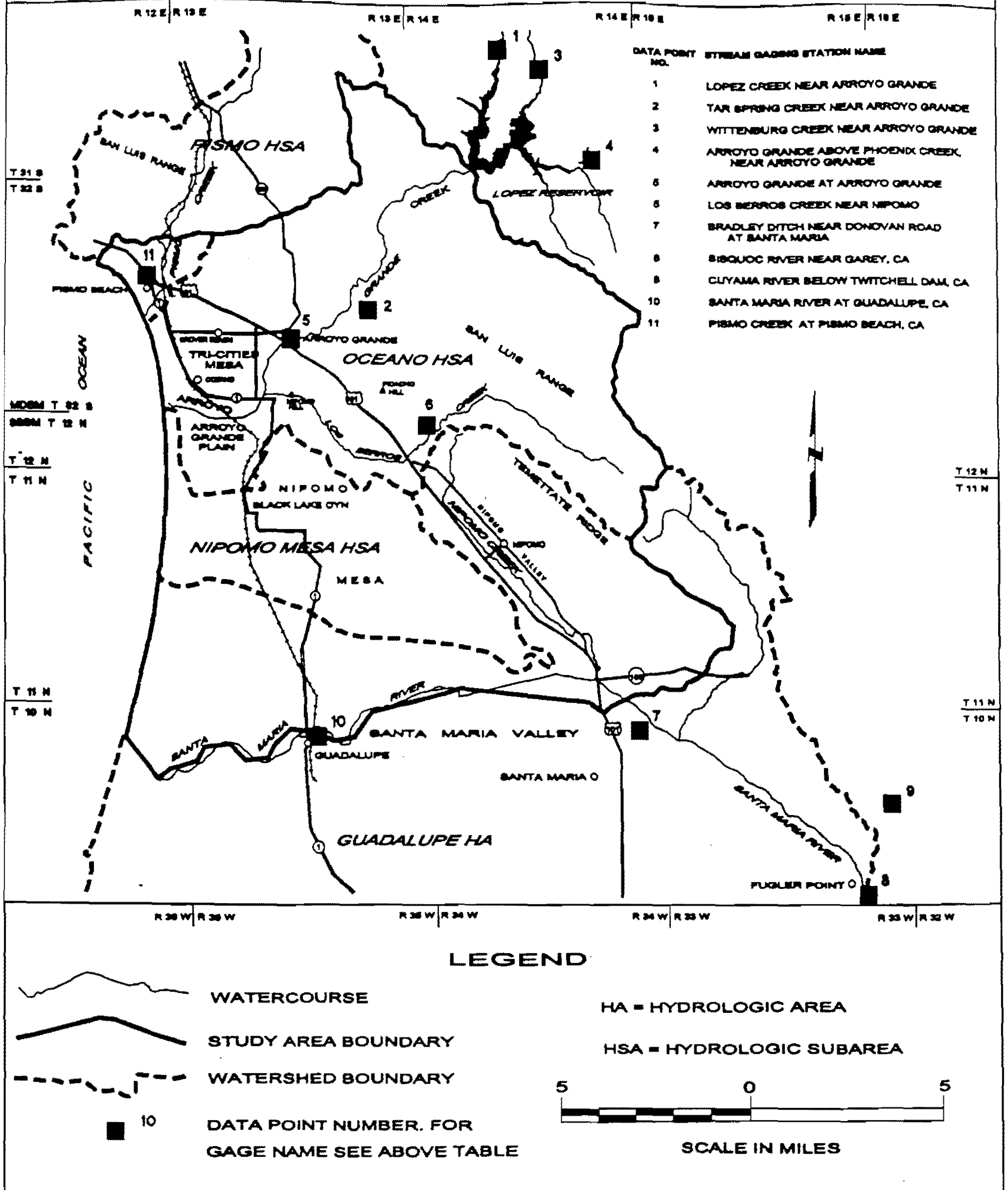
[2]Lopez Creek near Arroyo Grande is at Latitude 36°13'48", Longitude 120°28'22" and Sisquoc River near Garey at Latitude 34°53'38", Longitude 120°18'20".

[3] Elevation estimated from USGS Pismo Beach Quadrangle (1978)

[4]California State Water Resources Board, *Water Resources of California*, Bulletin No. 1, 1951.

FIGURE 15 - STREAM GAGE LOCATIONS



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The mean seasonal runoff for this period amounted to 23,900 AF. Stream gaging data for Arroyo Grande Creek at Arroyo Grande, covering water years 1947-95, are shown in Appendix E. Analysis of this record indicates that the average annual runoff in the base period, including all tributaries and excluding deliveries from Lopez Reservoir, is 5,851 AF. This is considerably lower than the mean seasonal runoff of 23,900 AF reported in Bulletin No. 1; however, the difference is attributable to impoundment of runoff at Lopez Reservoir. The base period infiltration from the watershed and creek, including all tributaries and the area between the stream gage and the ocean, is estimated to be 4,550-4,700 AF annually.

Tar Spring Creek flows almost 10 miles in a westerly direction from its headwaters north of Newsom Ridge and south of Tar Spring Ridge to its confluence with Arroyo Grande Creek. Its watershed attains a maximum elevation of about 1,712 feet above msl and occupies almost 19 square miles. It consists of approximately 73 percent mountainous and foothill area and 27 percent valley area.

Tar Spring Creek, currently an ungaged drainage, and many small tributaries contributed between 1,200 and 1,400 AF of runoff during each year of the 12-year base period, while the estimated base period infiltration from the creek and watershed was between 550 and 780 AF annually.

Los Berros Creek, another tributary to Arroyo Grande Creek, with headwaters located northeast of Temettate Ridge and south of Newsom Ridge, has a length of about 14 miles and its watershed attains a maximum elevation of about 1,804 feet above msl. The creek has a drainage area of 28 square miles and consists of approximately 83 percent mountainous and foothill area and 17 percent valley area.

Runoff from Temettate Creek and numerous other small tributaries accumulates prior to emptying into Los Berros Creek. The upstream 15 square miles (54 percent) of Los Berros Creek's 28-square-mile drainage is gaged; a continuous record for water years 1968-95 is available. The base period runoff for the entire watershed was between 800 and 1,100 AF each year. Base period infiltration for the creek and watershed is estimated to have been 500-700 AF annually.

Nipomo Creek has a drainage area of about 20 square miles, and its watershed attains a maximum elevation of about 1,804 feet above msl. Mountain and foothill areas account for 61 percent of the surface area, and valley areas account for about 39 percent. Nipomo Creek extends about 9 miles from its headwaters to its confluence with the Santa Maria River.

Nipomo Creek meanders through Nipomo Valley parallel to and east of Highway 101. About a mile before emptying into the Santa Maria River, it flows westerly and crosses Highway 101. Precipitation falling on the western side of Temettate Ridge accumulates in numerous small tributaries that carry runoff to the mainstem of Nipomo Creek. The creek is ungaged, and estimates of average annual base period runoff amount to 800-925 AF. Average annual base period infiltration from the creek and watershed is estimated to be 50-150 AF.

The Santa Maria River and its tributaries create a drainage area of 1,881 square miles, which attains a maximum elevation of approximately 8,700 feet above msl. Mountain and foothill areas account for 82 percent of the surface area, with valley areas accounting for the remaining 18 percent. The mainstem of the Santa Maria River measures about 18 miles, making it the longest watercourse draining the study area.

A portion of the Santa Maria River meanders through the southern edge of the study area and defines its southern boundary. Before reaching the Pacific Ocean, the river flows across or adjacent to extensive alluvial deposits with high infiltration potential (Hughes, 1977). Estimated seasonal natural runoff for water years 1895-1947, as reported in Bulletin No. 1, is shown in Appendix E. The mean seasonal runoff for this period amounted to 90,900 AF. Appendix E contains stream gaging data for the Sisquoc River at Garey from water years 1942-95, Cuyama River below Twitchell Dam from water years 1959-83, and Santa Maria River near Guadalupe from water years 1941-87. The data for the Sisquoc River at Garey and Santa Maria River near Guadalupe gages are discontinuous and end before the beginning of the base period (1984-95). Analysis of the records of the Santa Maria River near Guadalupe gage indicates that the average annual runoff for 1941 through 1987 is 31,808 AF. This is considerably lower than the mean seasonal runoff of 90,900 AF reported in Bulletin No. 1; however, the difference is attributable to impoundment of runoff at Twitchell Reservoir. For this study, the annual infiltration to the Santa Maria Groundwater Basin within San Luis Obispo County is estimated to be 13,500-14,500 AF.

Although not located in the study area, Twitchell Reservoir releases water to the Santa Maria River and thus to the Santa Maria Groundwater Basin. It was completed on the Cuyama River in 1958 by the U. S. Bureau of Reclamation as a flood control and water conservation reservoir. Conservation releases, made at Twitchell Reservoir, increase the amount of water percolating to the Santa Maria Groundwater Basin by an estimated 17,000 AF/Y (Ibid). Along its course, the water may or may not cross the southern study area boundary, depending upon the current hydraulic gradient. Analysis of water well hydrographs adjacent to the county line indicate that water levels rise and fall as water is released from Twitchell Reservoir.

V. HYDROGEOLOGY

Geologic conditions and processes and the local climate control virtually all aspects of the occurrence and movement of groundwater in the Arroyo Grande - Nipomo Mesa area. Fundamentally, lithology and structure of the rocks and sediments determine the existence and character of openings in which groundwater occurs. Geologic processes that significantly affect groundwater occurrence and movement include faulting, folding, volcanism, and weathering. The ability of different rocks and sediments to store, transmit, and adequately supply large-scale uses varies markedly. Thus, rock types can be differentiated primarily based on their water-bearing and hydraulic characteristics.

For the Arroyo Grande - Nipomo Mesa area, the rocks and sediments described in Chapter II can be grouped into two units. The semi-consolidated to unconsolidated sediments form one unit, creating the Santa Maria Groundwater Basin, and the basement complex, volcanic, and consolidated sedimentary rocks, collectively referred to by the relative term bedrock, form the second unit. The bedrock possesses only limited ability to store and transmit groundwater. In a hydrogeologic sense, it can be considered as providing boundaries for the sediment-filled groundwater basin. However, groundwater does move from the bedrock upland to the groundwater basin and from the basin into the underlying bedrock, and together they form a complex, interrelated two-media groundwater system.

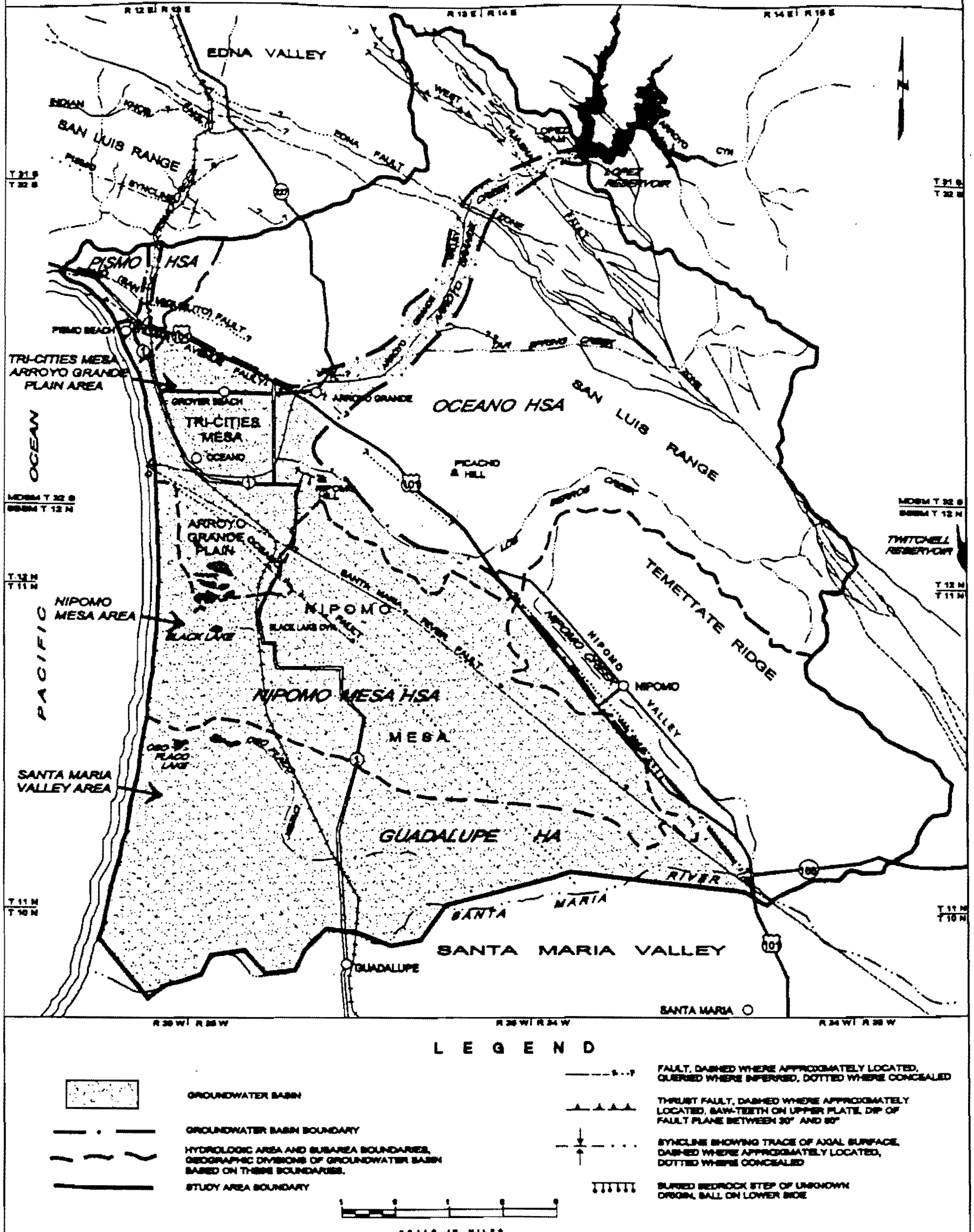
Santa Maria Groundwater Basin

The groundwater basin was formed within the geological depositional Pismo and Santa Maria Basins (described in Chapter II). The present limits of the groundwater basin were established in mid-Pleistocene time.

The groundwater basin is a singular, large, hydraulically continuous aquifer system throughout its 250 square miles (160,000 acres) in the southwestern corner of San Luis Obispo County and the northwestern corner of Santa Barbara County. Only the portion of the basin within San Luis Obispo County, about 50,000 acres, is considered in this study. This part of the basin underlies the prominent valley floors and coastal plains of the Santa Maria River, Arroyo Grande Creek, and the smaller Pismo Creek interposed by Tri-Cities and Nipomo Mesas. The basin as defined in this study is shown in Figure 16.

The Santa Maria Groundwater Basin within San Luis Obispo County is bounded on the north and east by bedrock of the San Luis Range and also on the east by bedrock underlying Nipomo Valley. The western boundary of the groundwater basin is the Pacific Ocean, although the basin

FIGURE 16 - SANTA MARIA GROUNDWATER BASIN, SAN LUIS OBISPO COUNTY



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is hydraulically continuous offshore beneath the ocean. The county line with Santa Barbara County forms a political boundary within the basin, but it has no hydraulically physical significance to the groundwater system.

The basin-fill deposits are underlain by bedrock. The boundary of the top of the bedrock is shown by elevation contours on Figure 17. The base contours were developed from interpretation of available water and oil well lithologs and electric logs, previously published cross-sections, and previously published base contour maps. The base of the basin in the study area rises from about 1,500 feet below msl under the Santa Maria River to about 200 feet above msl under the northeastern edge of Nipomo Mesa and to about 300 feet above msl in Arroyo Grande Valley below Lopez Dam. The base contours reflect vertical displacement of the bedrock across the Oceano and Santa Maria River faults.

Because the groundwater basin underlies just portions of the hydrologic sections and because of the need to provide applicable information for the local agencies, the basin was divided into geographic areas based on the hydrologic boundaries, as seen on Figure 16[1]. The Tri-Cities Mesa-Arroyo Grande Plain, Arroyo Grande Valley, and Pismo and Los Berros Creeks area of the basin lies within the Pismo and Oceano HSAs; the Nipomo Mesa area of the basin lies entirely within Nipomo Mesa HSA; and the Santa Maria Valley area of the basin lies within the Guadalupe HA. However, the groundwater basin is not symmetric with the surface water drainage system; no groundwater divides exist in the hydrogeologic environment of the groundwater basin.

Occurrence of Groundwater

Groundwater occurs within the pore spaces in the sedimentary deposits filling the basin. These deposits are the Squire Member of the Pismo Formation; the Careaga, Paso Robles, and Orcutt Formations; the alluvium; and the dune sands. They sequentially fill the basin within San Luis Obispo County to a maximum of about 1,500 feet from oldest to youngest. The Pismo, Careaga, and Orcutt Formations are found only within their respective geologic depositional basins.

With the exception of the dune sands, the basin-fill sediments were deposited by water in either fluvial, marginal marine, or shallow marine environments, whose exact locations varied widely depending on the relative positions of land masses, shorelines, and streams at a given point in geologic time. Consequently, a heterogeneous array of sands, gravels, boulders, silts, and clays, occurs in layers or lenses of varying composition, texture, and thickness. The varied lithologic layers or lenses are discontinuous.

The Santa Maria Groundwater Basin is considered a composite aquifer system of unconfined

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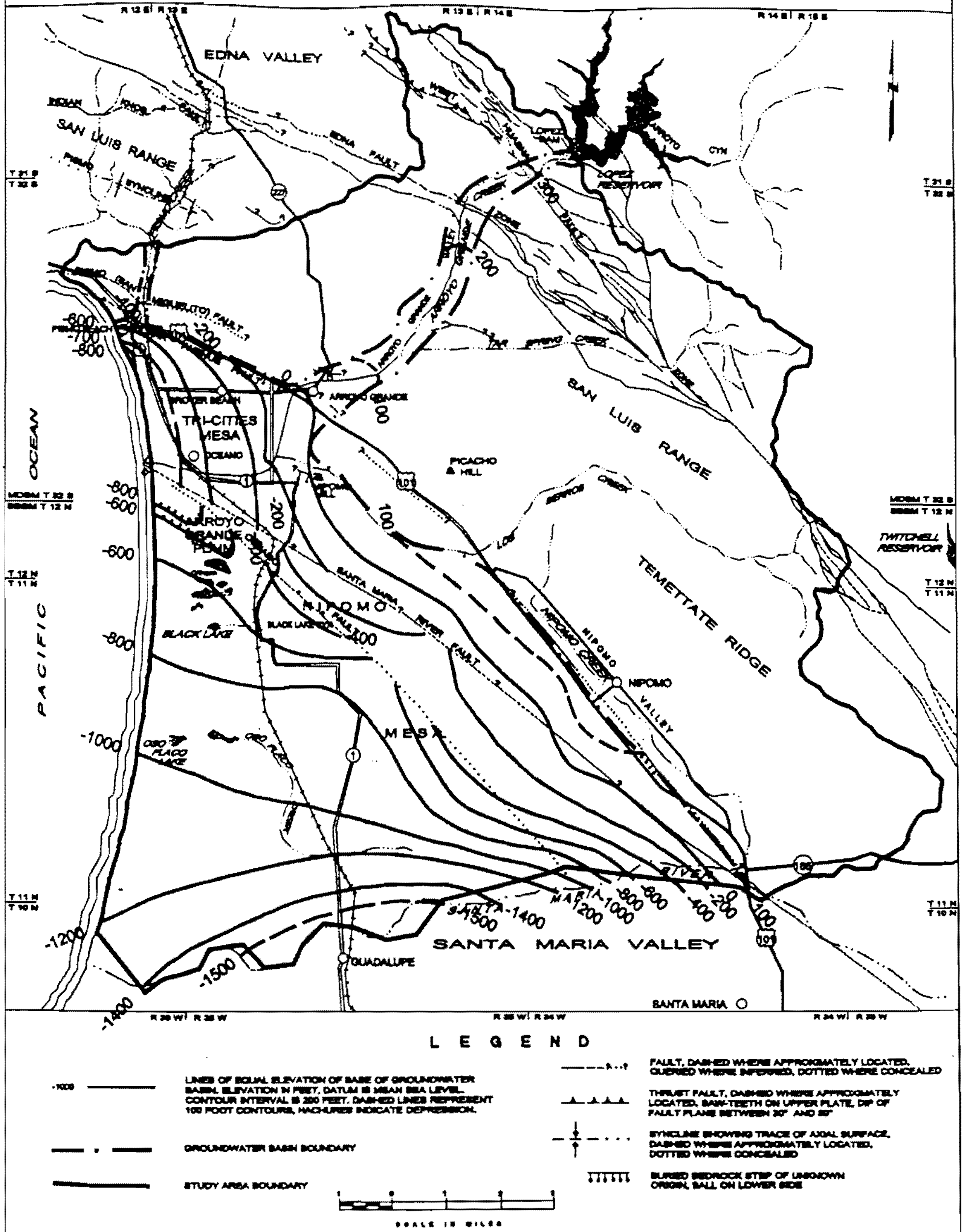
[1]The division of the groundwater basin based on the hydrologic boundaries in this report is not the same as the divisions used by others, such as the storage units of the USGS. Geographic names were used for the divisions of the groundwater basin because, with the exception of Nipomo Mesa, the basin underlies only portions of the hydrologic areas.

FIGURE 17 - BASE OF GROUNDWATER BASIN



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conditions, with localized semi-confined to confined conditions and perched zones[2]. The dune lakes, south of Oceano, and Oso Flaco and Little Oso Flaco Lakes are bodies of perched groundwater occurring in the basin.

Worts (1951) demarcated a large area, extending inland for about 6 miles beneath the Oso Flaco District and Santa Maria Valley, as containing water confined by fine-grained sediments in the upper part of the alluvium. However, he also stated that the continuity of the clay beds across the west end is not conclusive. Historically, some wells in this region were artesian. Today, free-flowing wells may occur only adjacent to the coast.

Of the basin-fill sediments, the most productive and developed aquifers are in the alluvium and the Paso Robles Formation. Some wells in the groundwater basin produce from either the alluvium or the Paso Robles Formation only, and others produce from both deposits. The Squire Member of the Pismo Formation and the Careaga Formation have, over time, become more important aquifers. Wells typically produce from the Paso Robles Formation in combination with either the Careaga Formation or the Squire Member.

Both the recent dune sands and the older dune sands are largely unsaturated, with the recent sands not known to be tapped by wells and the older sands penetrated by wells that produce primarily from the underlying formations. The dune sands, though, are important for rapidly infiltrating recharge waters to the saturated zone. The yields and depths of wells for the different basin-fill deposits found in the various geographic areas of the groundwater basin are summarized from the drillers' reports and presented in Table 15.

Figure 18 depicts well yields found within different geographic areas of the basin by means of "schematic box plots" (Tukey, 1977). These plots display the main aspects of the data: (1) the middle 50 percent of the data values, which are between the values in the upper 75 and lower 25 percent quartiles; (2) the whiskers indicating the range of extreme values outside an interval of the interquartile range; and (3) values outside the whisker range, which are plotted individually as outliers[3]. Extreme and outlier values play important roles in providing information on a data set.

It can be seen that the Santa Maria Valley has wells with generally the highest yields. The range of yields is broad for both the Nipomo Mesa and Tri-Cities Mesa-Arroyo Grande Plain areas, with outlying and extreme yields found in Nipomo Mesa. Yields are small for the alluvial aquifers in Arroyo Grande Valley and Los Berros Creek.

Recharge and Discharge

Natural recharge to the groundwater basin comes from seepage losses from the major streams,

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[2]In areas of complex geology, the distinction between confined, semi-confined, and unconfined is very difficult or impossible to make (Davis and DeWiest, 1966, p. 45).

[3]Extreme values extend to within 1.5 times the interquartile range; outliers are within 1.5 to 3.0 times the interquartile range and greater than 3 times the interquartile range (Kleiner & Graedel, 1980).

TABLE 15
WELL DEPTHS AND YIELDS OF PRODUCTION AQUIFERS

Water-bearing Deposit	Geographic Area	Well Depths, in feet		Well Yields, in gallons per minute	
		Median	Range	Median	Range
Alluvium	Arroyo Grande Valley and Plain	100	25 - 155	60	10 - 1,700
	Los Berros Creek	80	60 - 100	70	25 - 250
	Pismo Creek	70	41 - 139	-	-
	Santa Maria Valley	175	91 - 222	50	25 - 2,300
Paso Robles Formation	Tri-Cities Mesa	140	27 - 250	235	10 - 2,500
	Nipomo Mesa *	310	60 - 600	45	½ - 1,525
	Santa Maria Valley	420	193 - 685	1,580	270 - 2,000
Alluvium and Paso Robles Formation	Santa Maria Valley	310	180 - 518	1,650	20 - 1,950
Paso Robles and Careaga Formations	Nipomo Mesa	490	284 - 810	430	12 - 1,500
	Santa Maria Valley	790	741 - 832	-	-
Paso Robles Fm. and Squire Member/Careaga Fm.	Tri-Cities Mesa	460	300 - 600	1,070	150 - 2,000
Squire Member/Careaga Fm.	Tri-Cities Mesa	480	295 - 607	270	90 - 960

* Dryholes are encountered northeast of the Santa Maria River fault.

deep percolation of rainfall, and subsurface inflow.

Arroyo Grande Creek, regulated by Lopez Dam, recharges the Tri-Cities Mesa and Arroyo Grande Valley and Plain portions of the groundwater basin. Seepage losses from Arroyo Grande Creek have been estimated to be about 25 percent (Hoover & Associates, 1985a). Pismo Creek, which is unregulated, also recharges the northern portion of the basin.

The Santa Maria River, regulated by Twitchell Dam, recharges the Santa Maria Valley part of the groundwater basin. Seepage losses from the Santa Maria River have been estimated to be about 80 percent of the recharge to the groundwater basin (Worts, 1951; Ahlroth, 1997). Each year's recharge from the Santa Maria River travels away from the river as a mound. At a distance from the river, there may be a time lag of up to about a year for groundwater elevations in the Santa Maria Valley to be affected.

Both Lopez and Twitchell Dams regulate surface releases to maximize groundwater recharge. The amount of recharge is related to the availability of streamflow.

The Tri-Cities Mesa, Arroyo Grande Plain and Valley, and Santa Maria Valley portions of the

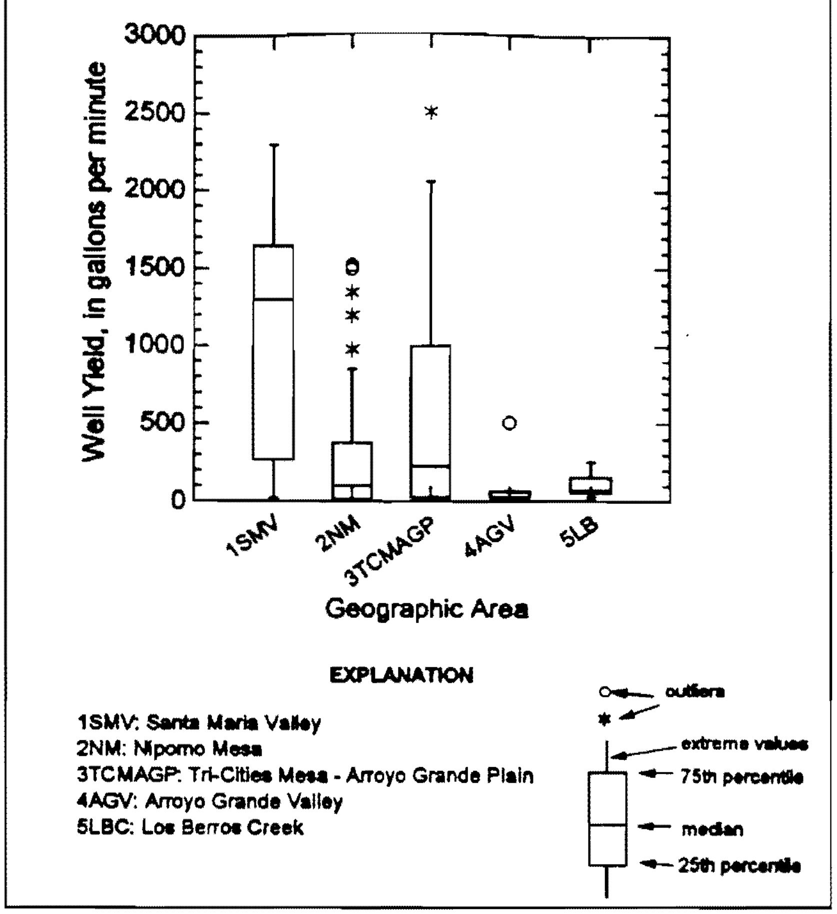

FIGURE 18 - YIELD OF WELLS IN SANTA MARIA GROUNDWATER BASIN

groundwater basin are also recharged by deep percolation of direct precipitation. This is an intermittent process, occurring during and immediately following periods of sufficient precipitation and varying from year to year depending on amount and frequency of rainfall, air temperature, land use, and other factors. The Tri-Cities Mesa and Arroyo Grande Valley portion of the basin is also recharged by surface runoff and subsurface inflow from the adjoining San Luis Range, and the Arroyo Grande Plain is recharged by subsurface inflow from Nipomo Mesa. The Santa Maria Valley portion of the basin is also recharged by subsurface inflow from the upstream area of the basin, outside the study area.

No surface waters drain into or out of Nipomo Mesa, and therefore the only major source of natural recharge of groundwater is direct percolation of precipitation, which is dependent on the factors mentioned earlier. Interdunal depressions trap runoff in the mesa, thereby enhancing infiltration and percolation of rainfall. Additional natural recharge consists of subsurface inflows from the adjoining Nipomo Valley and, in 1995, subsurface inflow from only that portion of Santa

Maria Valley within San Luis Obispo County (discussed in the next section).

Incidental recharge to the groundwater basin includes deep percolation of urban and agricultural return water, treated wastewater returns, and septic tank effluent.

Groundwater is discharged from the basin continuously, as long as the hydraulic head of the groundwater system is above the level at which discharge takes place. Surface and subsurface outflow discharges from the coastal groundwater basin to the Pacific Ocean. Discharge also consists of evapotranspiration losses, rising water, springflow, and percolation into the underlying bedrock. Extractions through wells for beneficial consumptive uses are a significant source of discharge from the basin.

At the Dune Lakes and Oso Flaco Lakes, groundwater discharges as diffuse upward leakage.

Amounts of recharge and discharge are given in Chapter VII.

Movement and Elevations

To evaluate groundwater movement and elevations and water level fluctuations and trends (discussed in the next section), groundwater level measurement records from monitoring programs conducted by San Luis Obispo County, Santa Maria Water Conservation District, USGS, Santa Barbara County Flood Control and Water Conservation District and Water Agency, and the Department were compiled for this study. In addition, fragmentary records by well owners, well drillers, and others were included.

The direction of groundwater movement in a basin reflects the sources of groundwater recharge. Groundwater moves away from areas of replenishment along three-dimensional flowpaths toward points of discharge. Movement is indicated by differences of head between any two points. Water always moves from a point of high hydraulic head to a point of low hydraulic head, provided the flow path is not altered or blocked by some structural barrier (i.e., fault or fold). Contour lines drawn on the surface of the water body connect points of equal hydraulic head or elevation of the water surface.

The shape of the contours is influenced chiefly by recharge and is modified by conditions such as changes in aquifer hydraulic properties and cross-sectional area of sediments and by faults or other structural impediments or barriers. Steeper gradients may be seen in areas of recharge and flattening of gradients as the groundwater moves toward its discharge points. The natural flow patterns become distorted in areas of large-scale groundwater development.

For this study, groundwater elevation contour maps were prepared (Figures 19-21), using available static groundwater levels in wells, to evaluate the groundwater conditions and direction of movement during three times, the springs of 1975, 1985, and 1995. On the figures, groundwater levels from wells in Santa Barbara County within sections of Township 10 North were included to extend the contours across the county line. The direction of groundwater flow

FIGURE 19 - SPRING 1975 GROUNDWATER ELEVATION CONTOURS

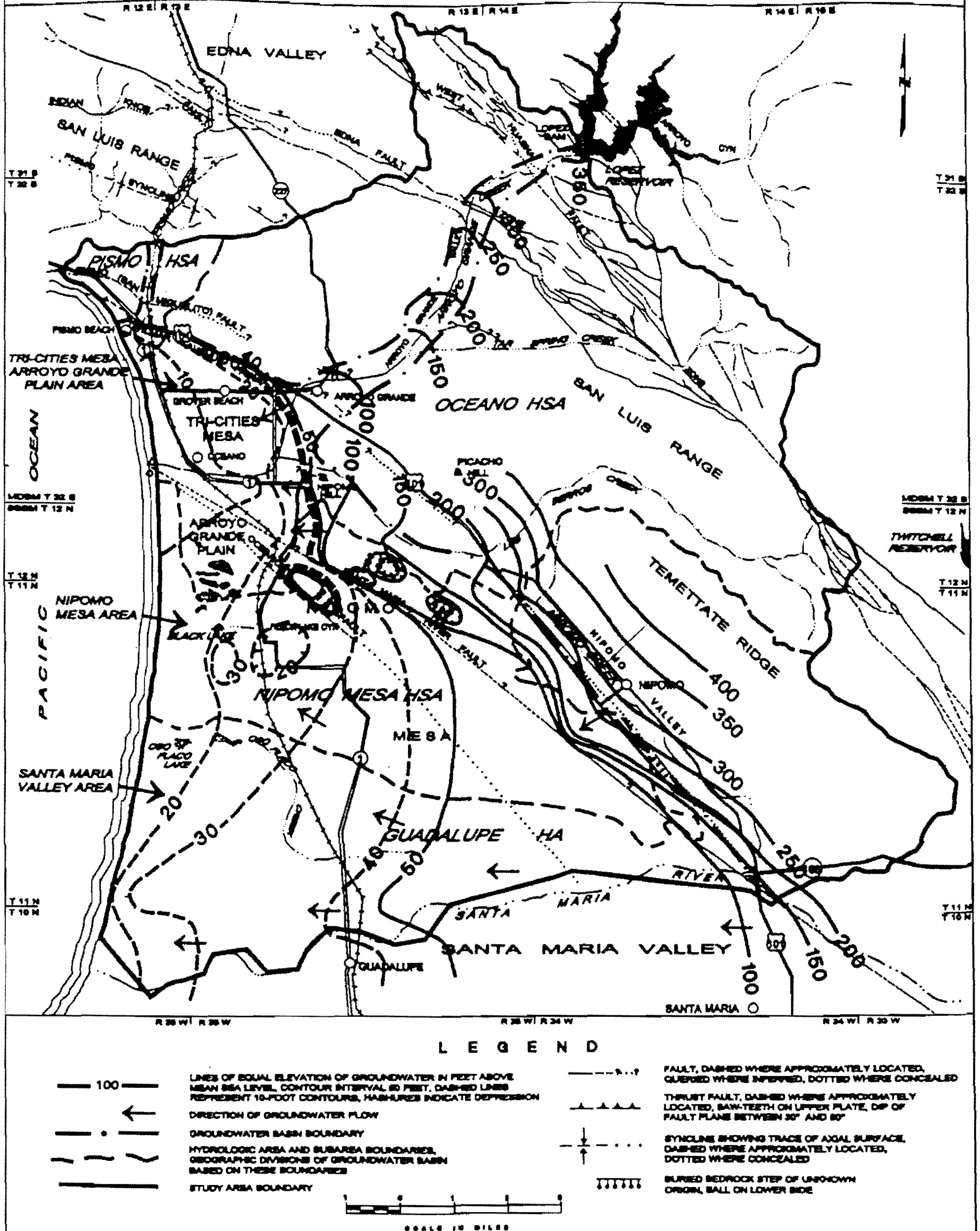

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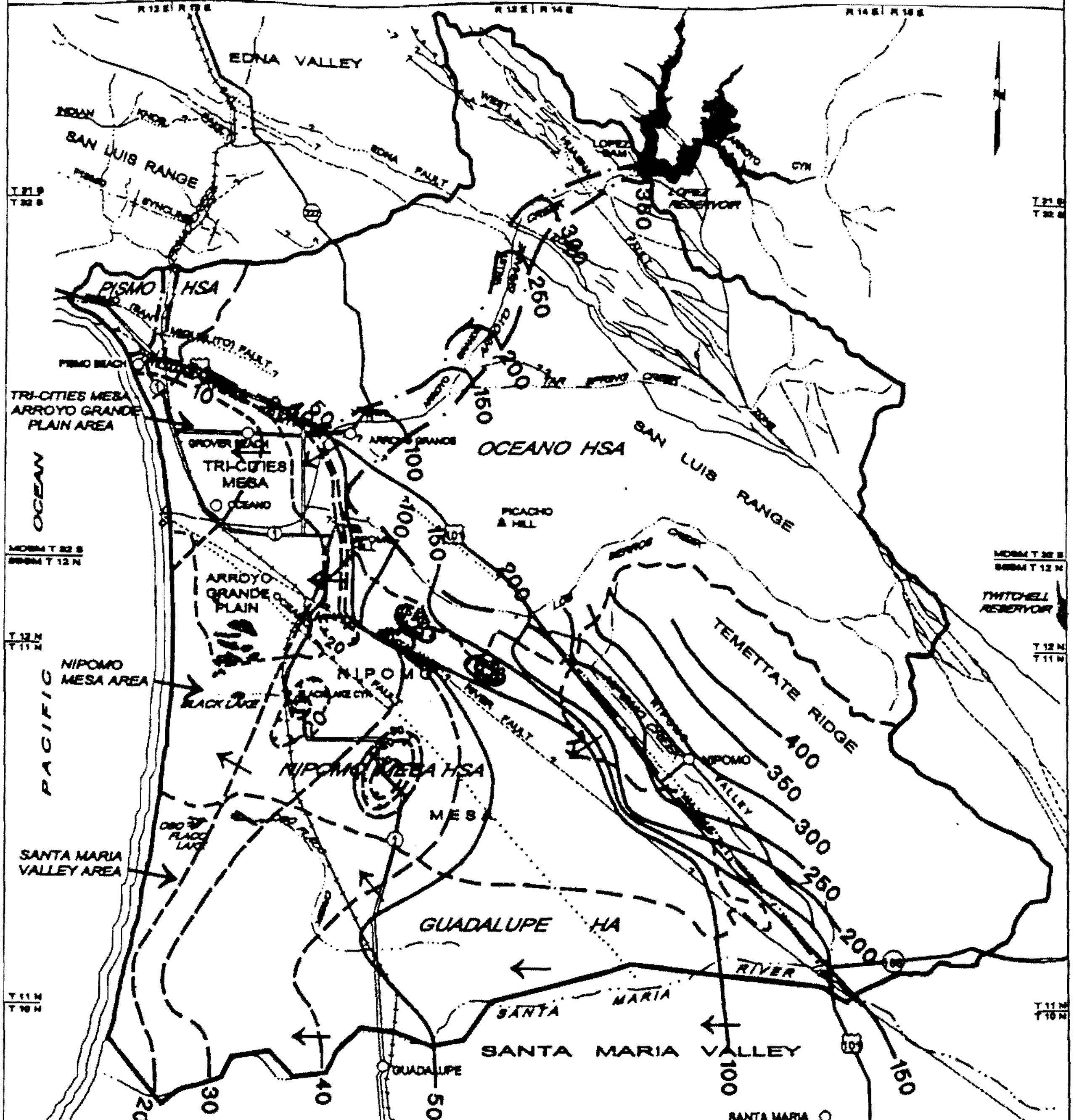
FIGURE 20 - SPRING 1985 GROUNDWATER ELEVATION CONTOURS



LEGEND

- 100 — LINES OF EQUAL ELEVATION OF GROUNDWATER IN FEET ABOVE MEAN SEA LEVEL, CONTOUR INTERVAL 50 FEET, DASHED LINES REPRESENT 10-FOOT CONTOURS, HASHURES INDICATE DEPRESSION
- ← DIRECTION OF GROUNDWATER FLOW
- GROUNDWATER BASIN BOUNDARY
- HYDROLOGIC AREA AND SUBAREA BOUNDARIES, GEOGRAPHIC DIVISIONS OF GROUNDWATER BASIN BASED ON THESE BOUNDARIES
- STUDY AREA BOUNDARY
- FAULT, DASHED WHERE APPROXIMATELY LOCATED, QUERIED WHERE INFERRED, DOTTED WHERE CONCEALED
- THRUST FAULT, DASHED WHERE APPROXIMATELY LOCATED, SAW-TEETH ON UPPER PLATE, DIP OF FAULT PLANE BETWEEN 30° AND 60°
- SYNCLINE SHOWING TRACE OF AXIAL SURFACE, DASHED WHERE APPROXIMATELY LOCATED, DOTTED WHERE CONCEALED
- BURIED BEDROCK STEP OF UNKNOWN ORIGIN, BALL ON LOWER SIDE

SCALE IN MILES

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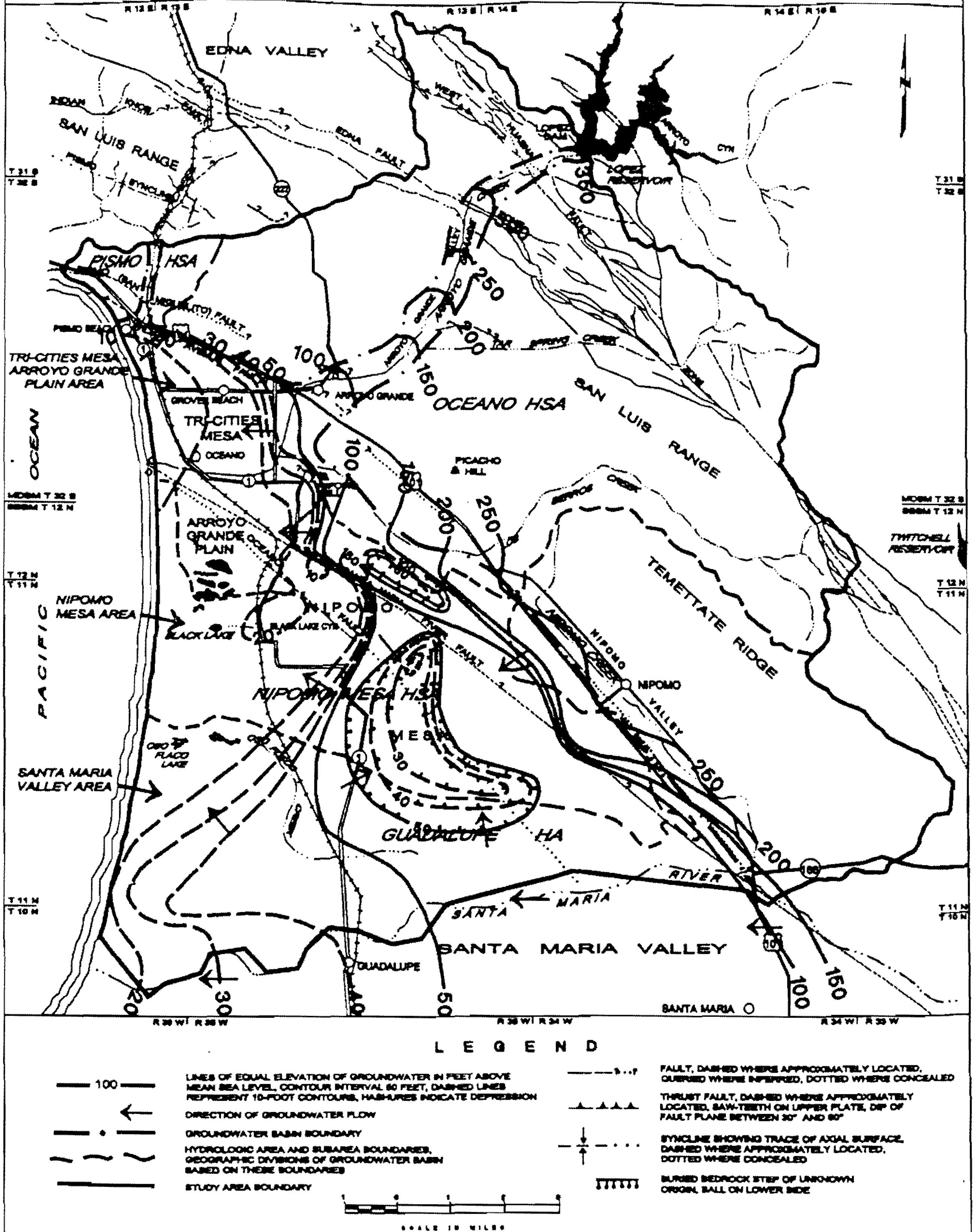
FIGURE 21 - SPRING 1995 GROUNDWATER ELEVATION CONTOURS



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is perpendicular to the contours.

Spring 1975, 1985, and 1995 represent times of differing hydrologic conditions. Water year 1975 had almost normal precipitation, with the Tri-Cities Mesa - Arroyo Grande Plain area receiving about 80 percent of the long-term average[4] and Nipomo Mesa and Santa Maria Valley areas receiving about 90 percent of the long-term average. Spring 1985 was a dry year, with the Tri-Cities Mesa - Arroyo Grande Plain area receiving 55 percent of the long-term average; Nipomo Mesa, 77 percent; and Santa Maria Valley, 64 percent. Spring 1995 was a wet year, with the Tri-Cities Mesa - Arroyo Grande Plain area receiving 181 percent of the long-term average; Nipomo Mesa, 191 percent; and Santa Maria Valley, 194 percent.

Figure 19, which depicts groundwater conditions that prevailed in spring 1975, shows the overall direction of flow within the basin was generally westerly or west-northwesterly toward the Pacific Ocean. Groundwater elevations ranged from about 10 to 20 feet along the coast to a maximum of 350 feet above sea level in Arroyo Grande Valley, just below Lopez Dam. Groundwater elevations in the Tri-Cities Mesa - Arroyo Grande Plain area are largely affected by seepage from Arroyo Grande Creek and elevations in the Santa Maria Valley by seepage from the Santa Maria River.

The figure also shows that a seaward hydraulic gradient existed in the basin in San Luis Obispo County. The seaward hydraulic gradient of the main water body to and at the coast is extremely important because it means that groundwater is moving toward and is being discharged into the ocean at some point off the coast, thereby preventing intrusion of sea water into the groundwater basin.

A gradient of about 40 feet per mile was nearly uniform as groundwater moved southwesterly down Arroyo Grande Valley. The gradient distinctly steepened south of Highway 101, indicative of a recharge area, as groundwater flowed out into the Tri-Cities Mesa. The permeability of the deposits increases in this area, allowing substantial infiltration and percolation (Hoover & Associates, Inc., 1985b). The groundwater gradient greatly flattened to about 10 feet per mile as the water moved westerly toward the ocean under the Tri-Cities Mesa-Arroyo Grande Plain area.

Groundwater conditions in 1975 in Nipomo Mesa indicate that groundwater flowed southwesterly from Nipomo Valley into the mesa. Water then moved in a west-northwesterly direction across the mesa at a gradient of about 10 feet per mile to the ocean. In northern Nipomo Mesa, east of Highway 1 and north of the Oceano fault, groundwater elevations are higher than in the Arroyo Grande Plain, indicating groundwater flowed from the mesa into the plain. Groundwater elevations at the southeastern edge of Nipomo Mesa and the eastern Santa Maria Valley were about the same, indicating no flow from the mesa to the valley.

Movement of groundwater in the Santa Maria Valley was westerly along a fairly flat gradient of

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[4]Long-term averages for precipitation stations represent period of record through water year 1998 for the station.

about 5 to 7 feet per mile. Groundwater flow diverged near Highway 1 to move west-northwesterly, following the abandoned course of the Santa Maria River to Oso Flaco Lake and then to the ocean.

Figure 19 also illustrates that the occurrence and movement of groundwater in the Santa Maria Groundwater Basin are affected by the faults crossing the basin. Faults can act either as impediments to groundwater flow or as conduits for flow, depending on degree of fracturing, displacement, and nature of the material in the fault zone. Faulting may also change the geometry of the basin, as has occurred in Santa Maria Groundwater Basin. Bedrock has risen northeast of the Santa Maria River and Oceano faults, decreasing the aquifer thickness on the uplifted side. Because of the reduced cross-sectional area, groundwater mounded naturally just east of the Dune Lakes area.

Groundwater mounds along the Santa Maria River fault in the southeastern part of Nipomo Mesa, caused by steps or warps in the bedrock over a zone about 4,000 feet wide.[5] Data were very limited and the interpolated contours should be viewed circumspectly.

The Oceano and Santa Maria River faults have offset the aquifers within the basin, but the faults do not appear to affect the flow of groundwater. The downdropped sides of the faults are in accord with the general direction of flow of groundwater, and groundwater cascades over the faults. The faults may exert boundary effects on pumping wells near these faults, but no data were available to determine this.

A few local pumping depressions of groundwater were occurring in 1975 in Nipomo Mesa, as can be seen on Figure 19.

Spring 1985 groundwater elevation contours (Figure 20) revealed groundwater conditions generally similar to those in spring 1975, although water year 1985 was a dry year. The hydraulic gradient in the Tri-Cities Mesa area flattened to about 5 feet per mile. Groundwater elevations were slightly higher in the Santa Maria Valley and the hydraulic gradient steepened slightly to about 10 feet per mile. The higher elevations and thus increased water in storage were the result of the significant recharge by seepage from the Santa Maria River that occurred in 1983, when flows were about 700 percent of normal.

A local depression in the groundwater elevation appeared at the juncture of Highway 1 with Willow Road on Nipomo Mesa, which could possibly be larger, but lack of available data prevented representation. The other depressions in Nipomo Mesa were similar to those of 1975.

No water level data were available for spring 1985 to replicate the mounding of groundwater along the Santa Maria River and Oceano faults, just east of the Dune Lakes.

Figure 21 depicts groundwater conditions that prevailed in spring 1995. Groundwater elevation

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[5]The zone of steps or warps in the bedrock is postulated by Hanson et al., 1994.

contours generally revealed conditions and directions of groundwater movement similar to those in the previous years, except for the enlargement of the depression in the south-central part of Nipomo Mesa. The depression locally altered the direction of flow for a large portion of Nipomo Mesa and Santa Maria Valley. The direction of flow and hydraulic gradients indicate that groundwater from Santa Maria Valley in the area of the depression, only within San Luis Obispo County, was moving into the mesa. Groundwater in Santa Maria Valley near the county line flowed in a westerly direction, unaffected by the pumping depression. Cleath & Associates (1996a, p. 18) also reported the existence of the depression. The large depression probably also limited northwest movement of groundwater from the mesa to the ocean. Groundwater elevations on the mesa shifted to the east, farther from the coast, lessening the gradient and quantity of subsurface outflow.

Nipomo Community Services District and Southern California Water Company have many of their wells in or near the depression. The extractions of these two agencies about tripled from 1979 to 1995, from about 940 to 2,790 AF.

It must be noted that the magnitude of the depression is not well defined. The number of wells with data is limited and the ground surface elevations for wells on Nipomo Mesa are estimated from USGS 7.5 minute quad sheets and were not surveyed.

The two small depressions in northern Nipomo Mesa have expanded to form one larger depression affecting local flow patterns, but not affecting subsurface outflow to Arroyo Grande Plain. Groundwater levels in that area would have to drop to about 20 feet above msl to affect outflow to the plain. Reduction in outflow to the plain will not result in sea water intrusion, if outflow to the ocean from the Tri-Cities Mesa - Arroyo Grande Plain is maintained. Cleath & Associates (1994) also reported the existence of lower groundwater elevations in this area.

Because of the time lag for the recharge mound from the Santa Maria River to travel away from the river, groundwater elevations at a distance from the river do not yet reflect the recharge from the 1995 wet year (almost double the long-term mean precipitation).

Again, no water level data were available for spring 1995 to replicate the mounding of groundwater along the Santa Maria River and Oceano faults, just east of the Dune Lakes.

Groundwater elevations in spring 1975, 1985, and 1995 (Figures 19, 20, and 21) indicate that coastal groundwater elevations were above msl, outflow was occurring, and the prevailing hydraulic gradients were preventing intrusion of sea water. It is conjectural whether, in the future, sea water intrusion will threaten because of the depressions in Nipomo Mesa. The depressions will not result in intrusion, as long as a seaward hydraulic gradient is maintained and outflow to the ocean continues. If the depression in the south-central mesa enlarges, the reduced water in storage could result in increased inflow from Santa Maria Valley and decreased outflow to the ocean from the mesa and the valley.

Water Level Fluctuations and Trends

Groundwater levels fluctuate over time representing the continuous adjustment of groundwater in storage to changes in recharge and discharge, revealing conditions or mechanisms at work within the groundwater basin. Hydrographs provide a means of evaluating long-term trends in water levels and changes in groundwater storage.

For this study, hydrographs of wells with long-term records were constructed and groundwater levels were analyzed to determine their net changes over time. Historical annual spring static water level measurements through water year 1998[6] were used. Some wells in the Santa Maria Valley, within San Luis Obispo County, have spring groundwater level measurement records for about 60 years, 1938 through 1998. Other wells in the basin have records for about 40 years (1959 through 1998) to shorter lengths of time (1975 through 1998). The hydrographs of selected representative wells within various geographic areas of the groundwater basin appear in the report, grouped by geographic areas. (In compliance with San Luis Obispo County Engineering Department's requirement to maintain in confidence the water level information supplied to it, the hydrographs for wells are not identified by State Well Numbers.)

The water level data used in the hydrographs excluded measurements taken at pumping wells, at recently pumped wells, or at wells near pumping wells or near recently pumped wells when this information was provided in the data record. It is likely some measurements are suspect because of errors made during the measuring process or database entry process. Commonly, gaps are found in the data. The frequency of measurement varied between the wells and over time at a given well. For example, measurements may have been taken quarterly to biannually to sporadically.

Interpretation of changes in groundwater levels and thus amount in storage depend on the degree to which these changes are affected by variations in rainfall and also to changes caused by increasing or decreasing withdrawals of groundwater for use. The rainfall provides a measure of the available recharge for the groundwater. The variations in rainfall as they relate to water level trends are best seen in the graphs of cumulative departure of rainfall from the long-term average. Therefore, the hydrographs of groundwater levels are presented with the cumulative departure from the long-term average rainfall. Although there is no precise correlation between groundwater elevations and rainfall, the data should generally show accretion to the water table during times of excess recharge and depletion during times of below average recharge.

Three precipitation stations with long-term records were used to relate to changes in water levels over time. The Bates Plumbing station in Arroyo Grande, with precipitation records from 1956 to 1998, was used with wells in the Tri-Cities Mesa - Arroyo Grande Plain and Valley area; Nipomo 2NW station, with precipitation records from 1921 to 1998, was used with wells in Nipomo Mesa; and Santa Maria station, with precipitation records from 1886 to 1998, was used with wells

[6]The analysis of trends in groundwater elevations was revised from the draft report to include period of record through water year 1998. Water year 1998 was the wettest year on record for the study area.

in the Santa Maria Valley. The precipitation records show the inherent variability of rainfall from year to year, and the cumulative departure from the long-term mean shows alternating wet and dry periods. Since the 1930s, when the earliest water level measurements were made in the study area, there have generally been three periods of above average precipitation: water years 1937 through 1944, 1978 through 1983, and 1992 through 1998; and two periods of below average precipitation- water years 1945 through 1977 and 1984 through 1991.

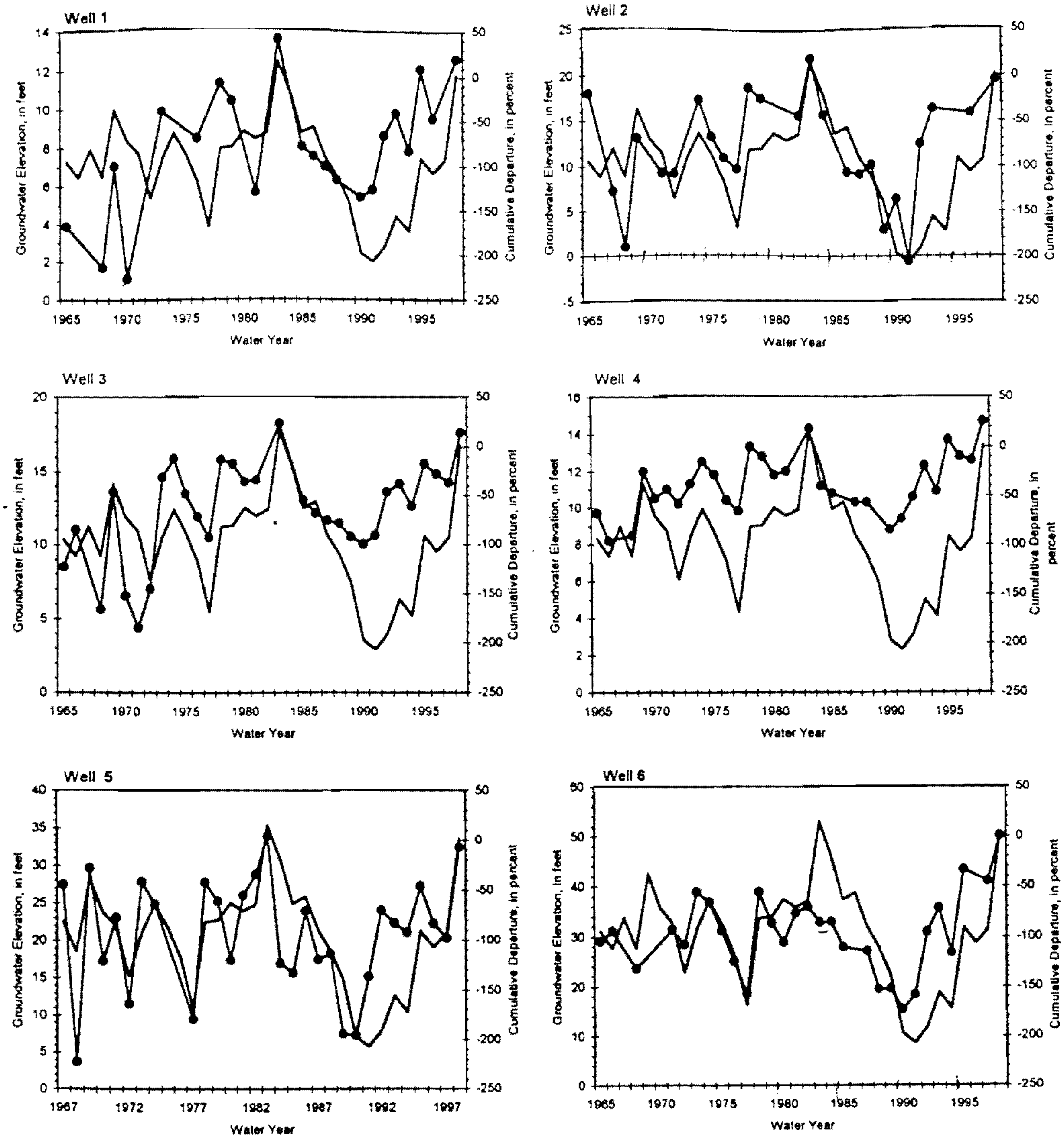
Hydrographs of wells in the Tri-Cities Mesa - Arroyo Grande Plain area and a summary of net changes in water levels during each of the wet and dry periods are shown on Figure 22. Wells 1, 2, and 3 are perforated in the Paso Robles Formation and wells 4, 5, and 6 are perforated in the alluvium. The hydrographs show no significant or widespread trends other than those attributable to the amount of yearly rainfall. Fluctuations of groundwater levels in the wells generally parallel the cumulative departure from the long-term average rainfall. Levels in well 2 fell slightly below msl, but recovered in 1991. Lawrance, Fisk & McFarland, Inc. (1985c) had reported that the Tri-Cities Mesa area of the groundwater basin recharges rapidly during wet years and depletes rapidly during dry periods and that whenever there is sufficient natural water supply for Lopez Reservoir to fill, there has also been sufficient supply to recharge Tri-Cities Mesa. Based on the long-term trends in levels in wells in this area, it would appear that the long-period changes of water levels and hence groundwater in storage have been generally proportional to the net fluctuations of recharge and withdrawals for use, even though between 1975 and 1995 water demand increased by 20 percent. This situation compares well with the estimates of amount of groundwater in storage in the Tri-Cities Mesa - Arroyo Grande Plain area, discussed in the next section.

Figure 23 presents hydrographs of wells located in Arroyo Grande Valley, above Highway 101, wells 1 and 2, and in Los Berros Creek, wells 3 and 4. Also, a summary of net changes in water levels during each of the wet and dry periods is included on the figure. The wells are perforated in alluvium. Levels in wells 1 and 2 show the stabilizing effect of the releases from Lopez Reservoir. Fluctuations in these wells are much less than those in wells in the Arroyo Grande Plain (Figure 22). Over their periods of record, levels in well 1 had a net rise of about 18 feet and in well 2, a net rise of about 2 feet. Groundwater levels in well 3 had a net rise of about 10 feet and those in well 4 of about 20 feet. Levels in wells 3 and 4 have not been affected by the depression in northern Nipomo Mesa. Based on the long-term trends in levels in these wells in Arroyo Grande Valley and Los Berros Creek, it would appear that the long-period changes of water levels and hence groundwater in storage have been generally proportional to the net fluctuations of recharge and withdrawals for use.

Hydrographs of groundwater levels in wells in Nipomo Mesa and a summary of net changes in water levels during each of the wet and dry periods are given in Figures 24 - 27, grouped by different areas within the mesa.

Figure 24 presents hydrographs of wells perforated in the Paso Robles Formation and located north of the Santa Maria River fault in northern Nipomo Mesa. Well 1 is west of the depression in the part of the mesa shown in Figure 19, wells 2 and 3 are within the area of the depression, and well 4 is east of it. Measurements in these wells began in 1975. The hydrographs of wells 1

FIGURE 22 - TREND IN GROUNDWATER ELEVATIONS, TRI-CITIES MESA - ARROYO GRANDE PLAIN WELLS



NET RISES AND DECLINES IN GROUNDWATER LEVELS

	ABOVE AND BELOW AVERAGE RAINFALL PERIODS				Period of Record
	1965-77	1978-83	1984-91	1992-98	1965-98
Well 1	4.0	2.3	-7.0	4.0	8.5
Well 2	-8.3	3.2	-16.4	7.1	1.5
Well 3	0.1	1.0	-1.8	4.1	5.0
Well 4	2.0	2.4	-7.0	4.0	9.1
Well 5	-18.0*	6.2	-1.8	8.4	5.0*
Well 6	-10.4	6.1	-14.6	18.2	21.0

* indicates measurement record began in 1967

LEGEND
Groundwater Elevation
Cumulative Departure

Note: Cumulative Departure is based on the long-term average rainfall, 1956-1998, at the Bates Plumbing station in Arroyo Grande.

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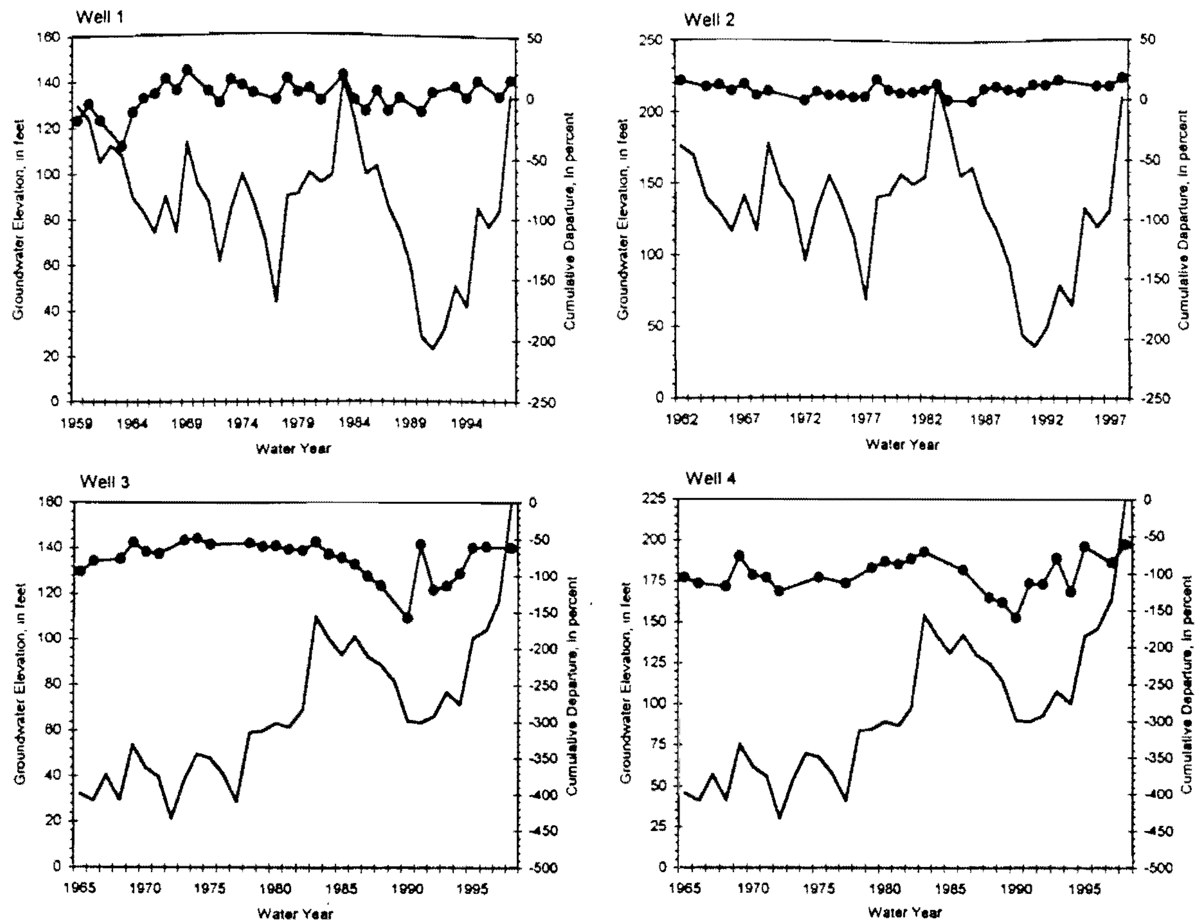
FIGURE 23 - TREND IN GROUNDWATER ELEVATIONS, ARROYO GRANDE VALLEY AND LOS BERROS CREEK WELLS



LEGEND

Groundwater Elevation

Cumulative Departure

NET RISES AND DECLINES IN GROUNDWATER LEVELS

	ABOVE AND BELOW AVERAGE RAINFALL PERIODS				PERIOD OF RECORD
	*-77	1978-83	1984-91	1992-98	*-98
Well 1	8.1	1.7	3.5	5.0	17.6
Well 2	-11.0	-2.5	10.3	5.0	2.1
Well 3	11.0	0.4	4.3	18.3	10.3
Well 4	-3.7	18.0	-18.0	24.4	20.2

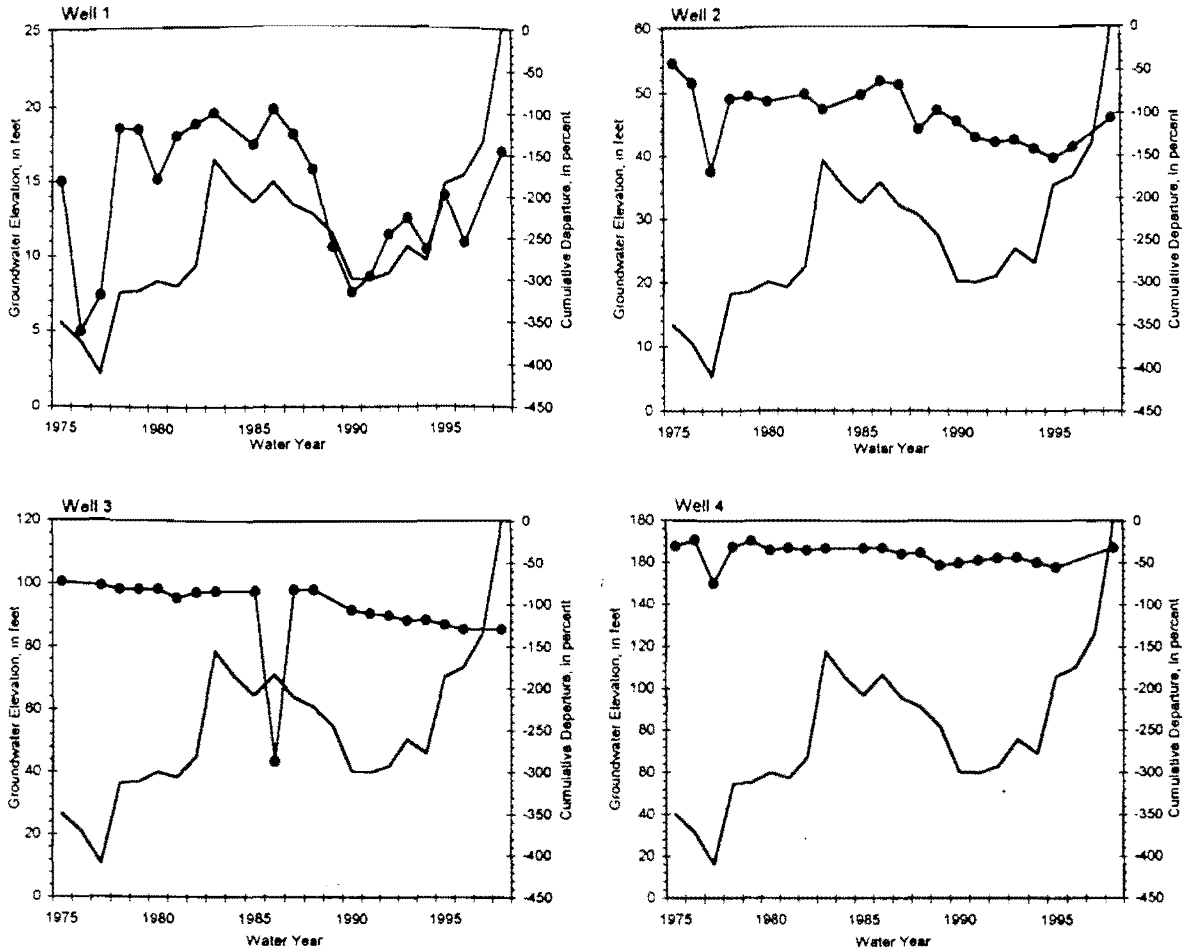
* refer to hydrograph for beginning of record for well

Note: For Wells 1 and 2, Cumulative Departure is based on the long-term average rainfall, 1956-1998, at the Bates Plumbing station in Arroyo Grande.

For Wells 3 and 4, Cumulative Departure is based on the long-term average rainfall, 1921-1998, at the Nipomo 2NW station.

and 4 show that groundwater levels have fluctuated in accord with rainfall and, over time, recharge has generally balanced discharge. Major drawdowns of groundwater levels during very dry years, such as 1976-77, are clearly visible in wells 1, 2, and 4, as well as is recovery of levels after the drought. Groundwater levels in wells 2 and 3 have declined over their period of record, those in well 2 dropping about 9 feet in elevation and those in well 3 about 15 feet. Well 2 made a small recovery during 1992 to 1998, when rainfall was 43 percent above normal, but well 3

FIGURE 24 - TREND IN GROUNDWATER ELEVATIONS,
NORTHERN NIPOMO MESA WELLS



NET RISES AND DECLINES IN GROUNDWATER LEVELS

	ABOVE AND BELOW AVERAGE RAINFALL PERIODS				PERIOD OF RECORD
	1975-77	1978-83	1984-91	1992-98	1975-98
Well 1	-7.6	0.9	-10.0	5.6	1.9
Well 2	-17.0	-1.8	-5.0	3.9	-8.7
Well 3	-1.0	-0.3	-7.0	-4.5	-14.8
Well 4	-17.3	-1.1	-5.4	5.0	-0.5

LEGEND

Groundwater Elevation

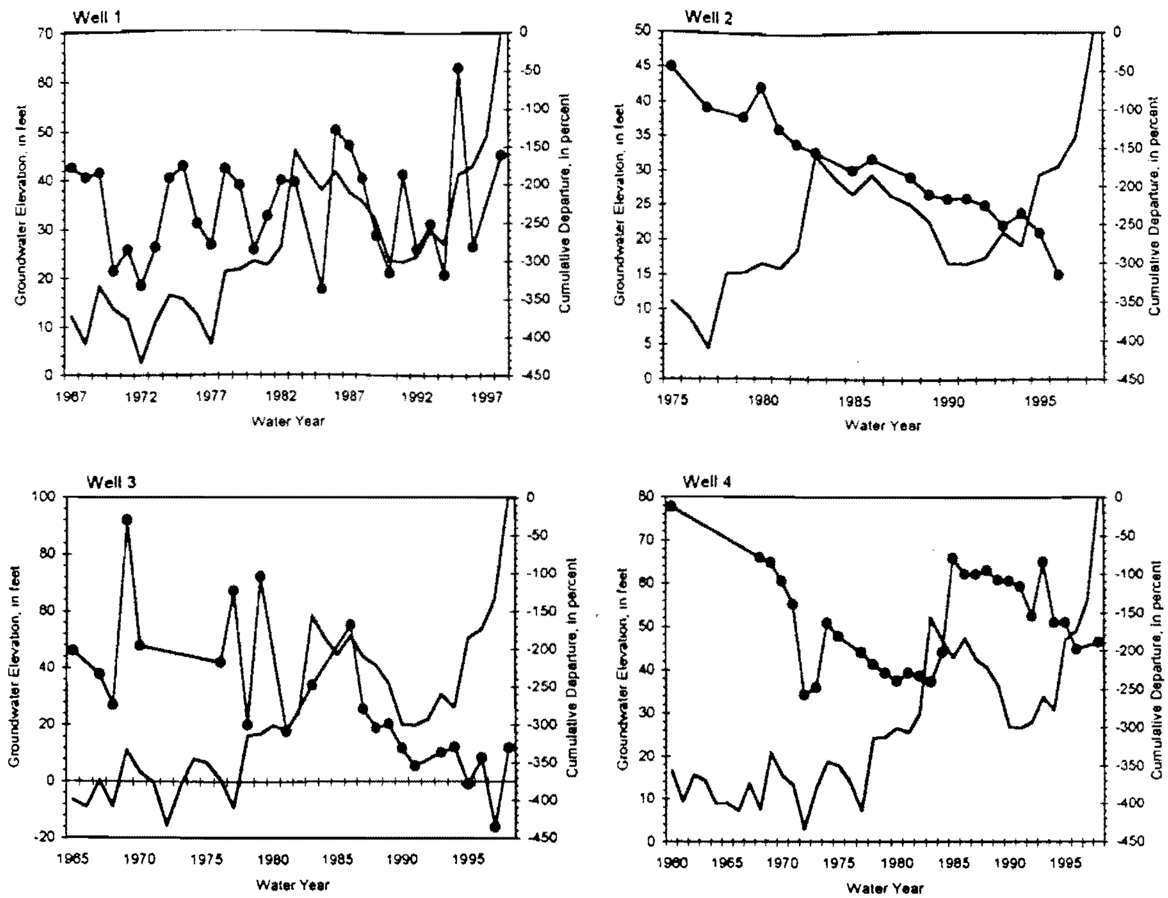
Cumulative Departure

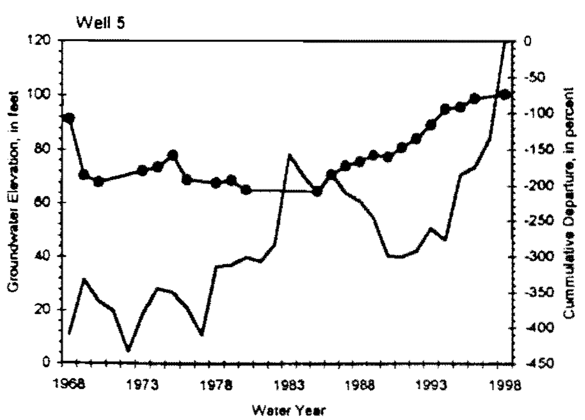
Note: Cummulative Departure is based on the long-term average rainfall, 1921-1998, at the Nipomo 2NW station.

continued to decline. In these two wells and others in the area of the depression, the volume of groundwater withdrawn for use and natural discharge is exceeding recharge, resulting in water level declines and hence declines in amount of groundwater in storage.

Hydrographs of five wells perforated in the Paso Robles Formation and located in central Nipomo Mesa are shown on Figure 25. Well 1 is west of the depression shown on Figure 21 and south of

FIGURE 25 - TREND IN GROUNDWATER ELEVATIONS, CENTRAL NIPOMO MESA WELLS





LEGEND

- Groundwater Elevation (line with dots)
- Cumulative Departure (line)

Note: Cumulative Departure is based on the long-term average rainfall, 1921-1998, at the Nipomo 2NW station.

NET RISES AND DECLINES IN GROUNDWATER LEVELS

	ABOVE AND BELOW AVERAGE RAINFALL PERIODS				PERIOD OF RECORD
	*-77	1978-83	1984-91	1992-98	*-98
Well 1	-16.1	-2.8	1.0	19.3	2.4
Well 2	-5.8	-6.0	-6.0	-9.9[a]	-30[a]
Well 3	21.0	13.8	-28.0	6.0	-34.0
Well 4	-33.7	-4.0	15.3	-6.0	-31.3
Well 5	-23.0	-3.0	16.0	16.3	9.1

* refer to hydrograph for beginning of record for well

[a] indicates last measurement in 1996

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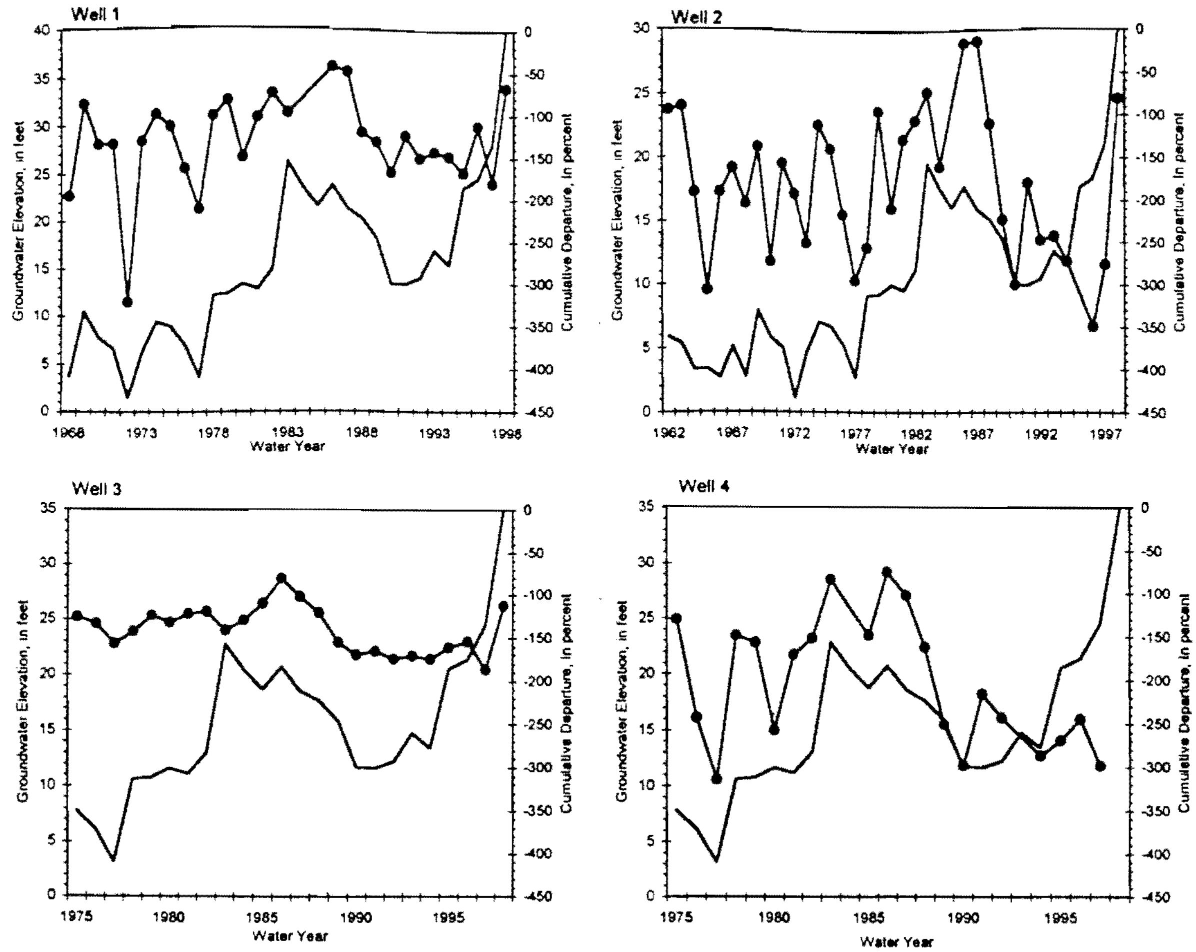
Black Lake Canyon. Wells 2 and 3 are in the area of the depression, well 2 is at the head of Black Lake Canyon, and well 3 is south of it. Wells 4 and 5 are east of the depression, well 4 is near the head of Black Lake Canyon, and well 5 is to the south of it. Groundwater levels in well 1 fluctuated considerably over its period of record, but the fluctuations generally parallel cumulative departure from the long-term mean of rainfall. For wells 2, 3, and 4, groundwater levels declined approximately 1 foot per year over their periods of record. Well 2 was not measured in 1997 or 1998, so it is not known whether groundwater levels rose or continued to decline. The level in well 3 dropped below msl in 1997, but recovered 28 feet, to 12 feet above msl, in 1998. For wells 2, 3, and 4, the volume of groundwater withdrawn for use is exceeding recharge, and the declines in groundwater levels in these wells reflect the loss in storage that is occurring in this part of the mesa. The trend in groundwater levels in well 5 is anomalous for this part of the mesa. Levels rose about 9 feet over its period of record, even rising during 1984 through 1991, when rainfall was 32 percent below normal. This well is probably being recharged by sources other than infiltration of precipitation.

With the recovery of groundwater levels in 1998 in some wells within and near the depressions on the mesa (shown on Figure 21), the magnitudes of the depressions have decreased; however, they still remain.

The wells with hydrographs shown on Figure 26 are perforated in the Paso Robles Formation and are located in western Nipomo Mesa. Wells 1 through 3 are north of Black Lake Canyon and well 4 is south of the canyon. Groundwater levels in wells 1 through 3 showed net rises, ranging from about 1 foot to 11 feet, over their periods of record. The hydrographs of these wells generally show no significant or widespread trends other than those attributed to the amount of yearly rainfall, and fluctuations generally parallel cumulative departure from the long-term mean of rainfall. In these wells, recharge has generally been balancing discharge over time. Well 4 showed a net decline of about 6 inches per year over its period of record, 1975 to 1997. This well was not measured in 1998, the wettest year on record, so it is not known whether levels rose or continued to decline.

Figure 27 presents hydrographs of wells located in southeastern Nipomo Mesa, outside the area of the depression represented on Figure 19. Wells 1 and 2 are perforated in both the Paso Robles and Careaga Formations, and wells 3 and 4 are perforated in the Paso Robles Formation only. The hydrographs show the alternating periods of decline and recovery, but they do not always coincide with dry and wet periods. Wells 1 and 2 had net declines in water levels over their periods of record; the decline in well 1 was about 5 feet and that in well 2 about 26 feet. Well 2 had continuous declines over its entire period of record, despite the times of about 40 percent above average rainfall. Groundwater levels in wells 1 and 2 are possibly being affected by the large withdrawals of groundwater that are causing the depression in the central part of the mesa. Well 3 had a small net rise in levels over its period of record. Factors were modifying its response to recharge, because this well had net declines in levels during times of above average rainfall and net rises in levels during times of below average rainfall. Fluctuations in groundwater levels in well 4 generally parallel the cumulative departure for rainfall, and levels were in balance between recharge and discharge over its period of record.

FIGURE 26 - TREND IN GROUNDWATER ELEVATIONS, WESTERN NIPOMO MESA WELLS



NET RISES AND DECLINES IN GROUNDWATER LEVELS

	ABOVE AND BELOW AVERAGE RAINFALL PERIODS				PERIOD OF RECORD
	*-77	1978-83	1984-91	1992-98	*-98
Well 1	-1.6	0.3	-2.0	7.5	11.3
Well 2	-13.4	12.3	-1.3	11.1	0.9
Well 3	-2.4	0.2	-2.9	4.9	1.1
Well 4	-14.4	5.1	-10.0	-4.3•	-13.1•

* refer to hydrograph for beginning of record for well

• indicates last measurement in 1997

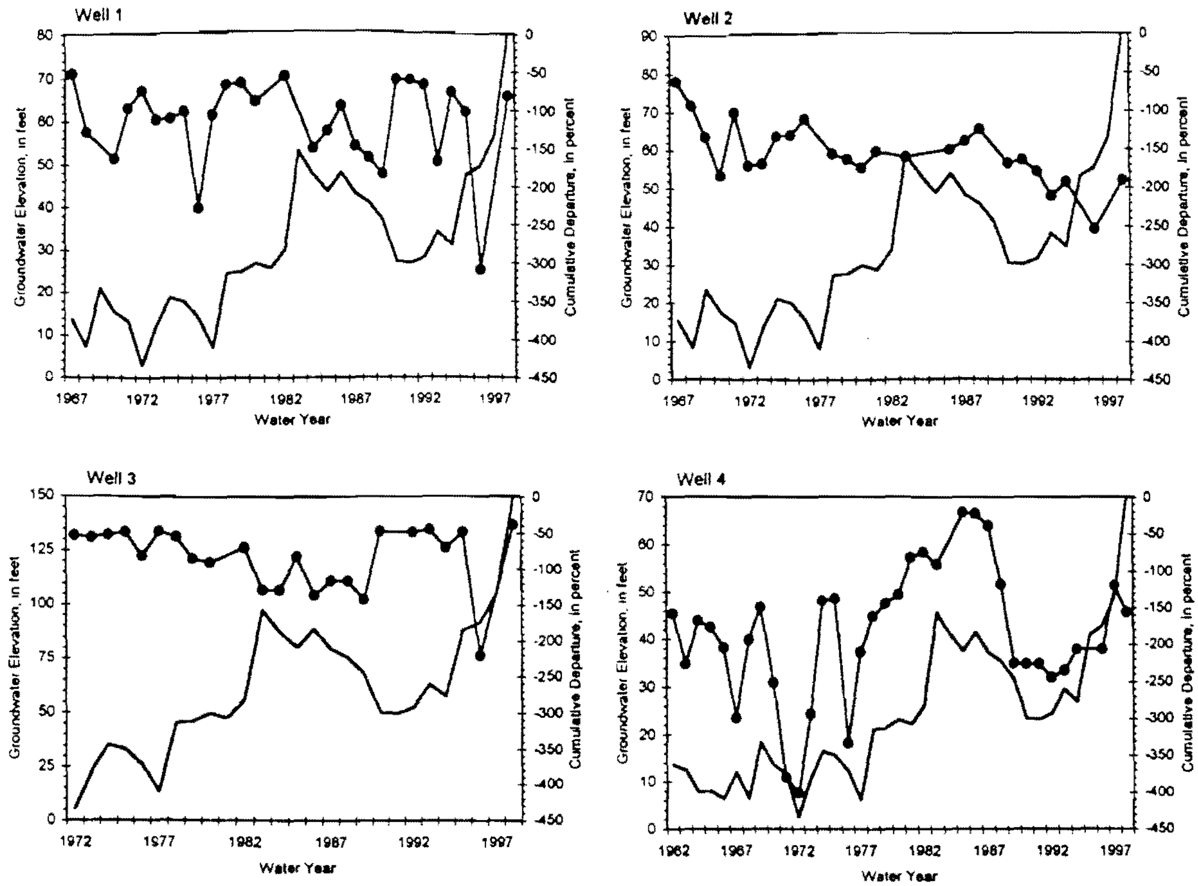
LEGEND

- Groundwater Elevation
- Cumulative Departure

Note: Cumulative Departure is based on the long-term average rainfall, 1921-1998, at the Nipomo 2NW station.

Nipomo Mesa has seen increasing development, and from 1975 to 1990 demand on groundwater supplies rose about 170 percent. The increased withdrawals are reflected in the declining trends in groundwater levels in some areas, as seen on the representative hydrographs of some wells in the mesa, Figures 24-27. In those areas, the volume of groundwater withdrawn is exceeding natural recharge, resulting in continuous water level declines, despite periods of 40 percent above

FIGURE 27 - TREND IN GROUNDWATER ELEVATIONS,
SOUTHEASTERN NIPOMO MESA WELLS



NET RISES AND DECLINES IN GROUNDWATER LEVELS

	ABOVE AND BELOW AVERAGE RAINFALL PERIODS				PERIOD OF RECORD
	*-77	1978-83	1984-91	1992-98	*-98
Well 1	-10.0	2.0	16.0	-2.4	-4.5
Well 2	-10.0	-1.0	-1.0	-2.1	-26.2
Well 3	2.4	-24.4	26.0	3.6	5.3
Well 4	-8.1	10.9	-21.0	13.9	0.4

* refer to hydrograph for beginning of record for well

LEGEND
- Groundwater Elevation (line with dots)
- Cumulative Departure (line)

Note: Cumulative Departure is based on the long-term average rainfall, 1921-1998, at the Nipomo 2NW station.

average precipitation. Declining levels in wells can lead to increased pumping costs, localized well interference, and possible quality degradation. If the declines continue in the future, groundwater levels in a few wells could fall below msl. This possible future condition, particularly if it is extensive, may lead to sea water intrusion, if the seaward hydraulic gradient is reversed and subsurface outflow to the ocean ceases. These declines in levels reflect the net decrease in estimated amounts of groundwater in storage, discussed in the next section.

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However, in other areas of Nipomo Mesa, it appears that the long-period changes of water levels and hence amount of groundwater in storage have been generally proportional to the net fluctuations of rainfall and withdrawals for use.

Figure 28 presents hydrographs of four wells in Santa Maria Valley within the study area and a summary of net changes in water levels during each of the wet and dry periods. Well 1 is perforated in the alluvium adjacent to the river channel in the eastern part of the valley. Well 2 is perforated in the Paso Robles Formation about 3.5 miles north of the river channel and about 2.5 miles inland from the coast. Wells 3 and 4 are in about the center of the valley, near Highway 1. Well 3 is about 2 miles north of the river channel and is perforated in the Paso Robles Formation. Well 4 is about 1 mile north of the river channel and is perforated in the alluvium.

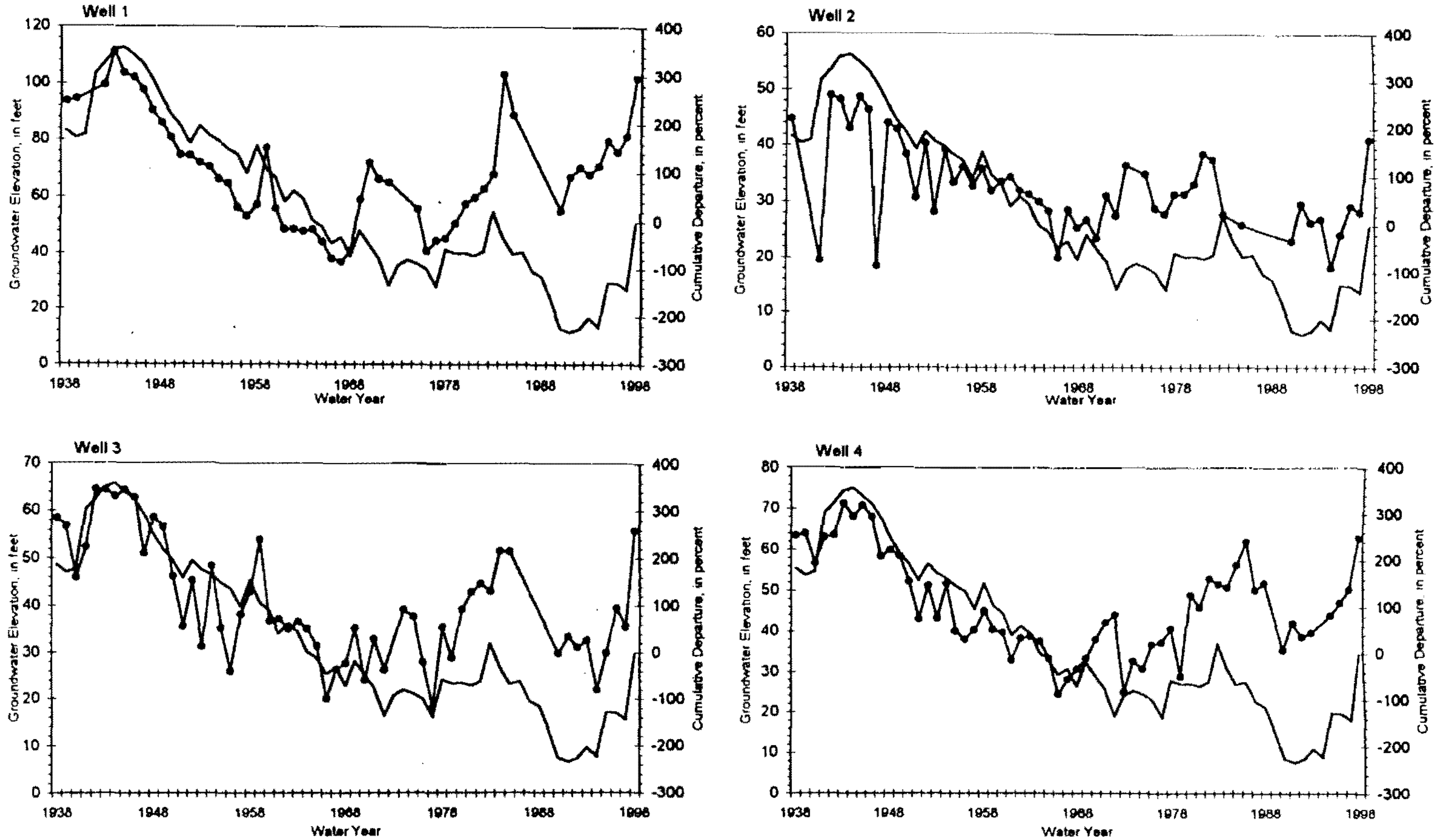
In the Santa Maria Valley, because the water table nearly everywhere is below the channel of the Santa Maria River, there is seldom, if ever, any hydraulic connection between water in the channel and the groundwater body. Thus, levels in wells rise in response to recharge from the river, but do not fluctuate in accord with the river stage. Each year's recharge travels away from the river as a mound. At a distance from the river, there may be a time lag of up to about a year for water levels in wells to be affected.

The hydrographs in Figure 28 illustrate the alternating periods of water level decline and recovery and the ranges of fluctuations in water levels observed since the 1930s, when measurements began. The hydrographs also illustrate the general parallelism of the water level fluctuations with the curve for accumulated departure of rainfall.

Between 1945 and 1977, a substantial decline in groundwater levels occurred from the highs of the early 1940s. Level declines in these wells during this period ranged from 0.6 foot per year in well 2 to 1.7 feet per year in well 1. The net declines were the result of drier than normal climatic conditions and increased pumpage. Groundwater levels recovered during the period of above average rainfall, 1978 through 1983. Recoveries were as high as 3.8 feet per year in well 1. Levels again declined during the dry period from 1984 to 1991. Declines ranged from 1.1 to 4.5 feet per year. Recovery of levels during 1992 through 1998 ranged from 2.1 to 4.5 feet per year, and it can be seen that by 1998 water levels had recovered to near historical highs. Between 1975 and 1995, agricultural demand on groundwater supplies declined 30 percent, contributing to the recovery of groundwater levels in Santa Maria Valley. Because of the time lag in the recharge mound from river seepage reaching wells farther from the river, levels in 1998 probably do not yet reflect the significant recharge from this wettest year of record. Based on the long-term trends in levels in these wells, it would appear that the long-period changes of water levels and hence groundwater in storage in this part of the basin have been generally proportional to the net fluctuations of rainfall and withdrawals for use.

A diagrammatic section with water level profiles along the Santa Maria River, first constructed by Worts (1951), was updated with 1995 and 1998 levels for this study. The section is presented in Figure 29. The section shows the hydraulic gradients for the various years projected to the coastline, indicating outflow to the ocean during those years. The section also illustrates that

FIGURE 28 - TREND IN GROUNDWATER ELEVATIONS, SANTA MARIA VALLEY WELLS



NET RISES AND DECLINES IN GROUNDWATER LEVELS

	ABOVE AND BELOW AVERAGE RAINFALL PERIODS					PERIOD OF RECORD
	1938-44	1945-77	1978-83	1984-91	1992-98	1938-98
Well 1	10.0	-57.4	22.5	-36.5	31.8	8.6
Well 2	-1.6	-21.0	-3.6	3.5	14.8	-3.7
Well 3	4.7	-46.4	7.7	-18.1	24.7	-2.5
Well 4	4.6	-33.8	14.4	-8.8	24.4	-0.8

LEGEND

- Groundwater Elevation
- Cumulative Departure

Note: Cumulative Departure is based on the long-term average rainfall, 1886-1998, at the Santa Maria station.

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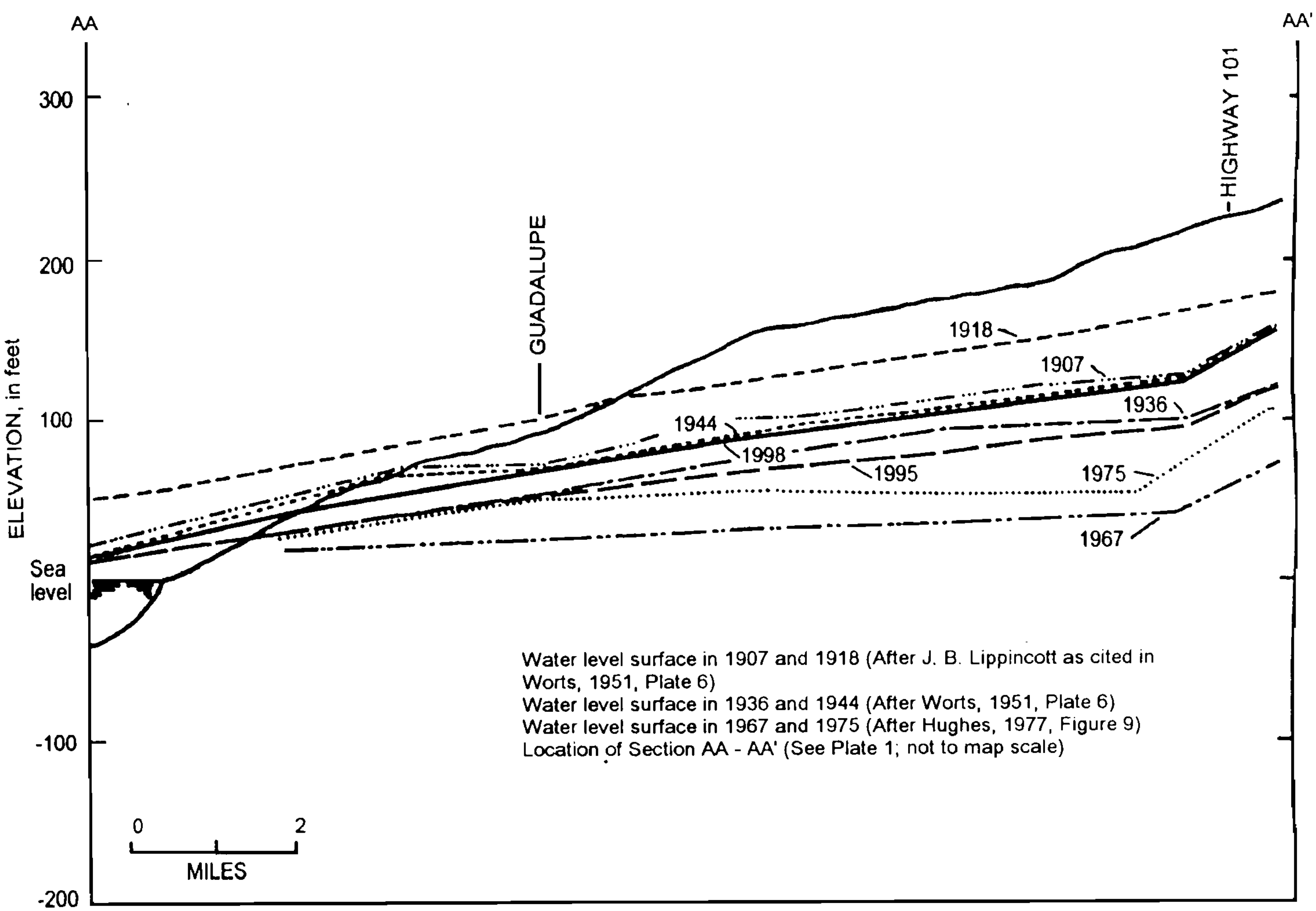
FIGURE 29 - DIAGRAMMATIC SECTION SHOWING GROUNDWATER LEVEL PROFILES ALONG THE SANTA MARIA RIVER



Water level surface in 1907 and 1918 (After J. B. Lippincott as cited in Worts, 1951, Plate 6)
Water level surface in 1936 and 1944 (After Worts, 1951, Plate 6)
Water level surface in 1967 and 1975 (After Hughes, 1977, Figure 9)
Location of Section AA - AA' (See Plate 1; not to map scale)

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water levels in 1998 have almost returned to the high levels of 1944.

Based on all the hydrographs in Figures 22-28, it can be seen that trends in groundwater levels are related to variations in rainfall, which affect the balance between groundwater recharge and discharge, and also to changes in the groundwater system caused by increasing or decreasing withdrawals of groundwater for use. Further, it can be seen that trends are not manifested in the entire Santa Maria Groundwater Basin simultaneously because of its size and variations in sources of groundwater recharge or depletion and other mechanisms operating locally. With the exception of some areas of Nipomo Mesa, it would appear that the long-period fluctuations in water levels are generally stable, following alternating periods of decline and recovery.

Storage

Two important hydraulic properties of an aquifer that are related to its storage function are porosity and specific yield (storativity). Porosity of sediments is the percentage of the total volume not occupied by solid material and is an index of how much groundwater can be stored in a saturated material. However, only a part of the water in a saturated material will be released from storage under the force of gravity. This property is specific yield and is expressed as a percentage or decimal fraction. The volume of water retained in storage as a film on rock surfaces and in very small openings by molecular forces is termed specific retention and is also expressed as a percentage or decimal fraction.

Specific yield is sensitive to particle size, size distribution, and sorting. The smaller the grain size, the smaller the specific yield; the coarser the sediment, the greater the specific yield. Specific yields of unconfined aquifers may range from 1 percent to about 30 percent.

For confined aquifers, the deposits are not drained during pumping unless the hydraulic head drops below the top of the aquifer; therefore, a correlative term, storativity, is applied. Typical storativity values range from 10^{-5} to 10^{-3}. In unconfined aquifers, the storativity equals the specific yield.

In determining specific yield values for the Santa Maria Groundwater Basin, values based on the extensive work by the Division of Water Resources (1934) and modified for the Paso Robles Formation by the Department (1958)[7] were used. Values were assigned to the types of materials penetrated as listed on lithologs of selected drillers' reports of water wells throughout the basin. The assigned values were weighted by the thickness of the material penetrated and then the average weighted specific yield value for the well was calculated.

Table 16 presents the representative average weighted specific yield values determined for the groundwater basin and for the geographic divisions within the basin. Overall, the estimated median values found in the different parts of the basin are similar. The largest variation occurred in Nipomo Mesa, where values between wells ranged by 16 percent. Most of the wells with the

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[7]The scale of specific yield values for various drillers' terms is given in Appendix C.

TABLE 16
AVERAGE WEIGHTED SPECIFIC YIELD
SANTA MARIA GROUNDWATER BASIN
In percent

Geographic Area	N*	Average Weighted Specific Yield	
		Median Value	Range of Values
Oceano HSA**			
Tri-Cities Mesa - Arroyo Grande Plain	18	11	7-13
Arroyo Grande Valley	14	13	9-21
Los Berros Creek	10	9	8-16
Pismo HSA**			
Pismo Creek	6	12	6-17
Nipomo Mesa HSA**			
Nipomo Mesa	39	12	5-21
Guadalupe HA**			
Santa Maria Valley	16	11	9-17
Santa Maria Groundwater Basin	103	12	5-21

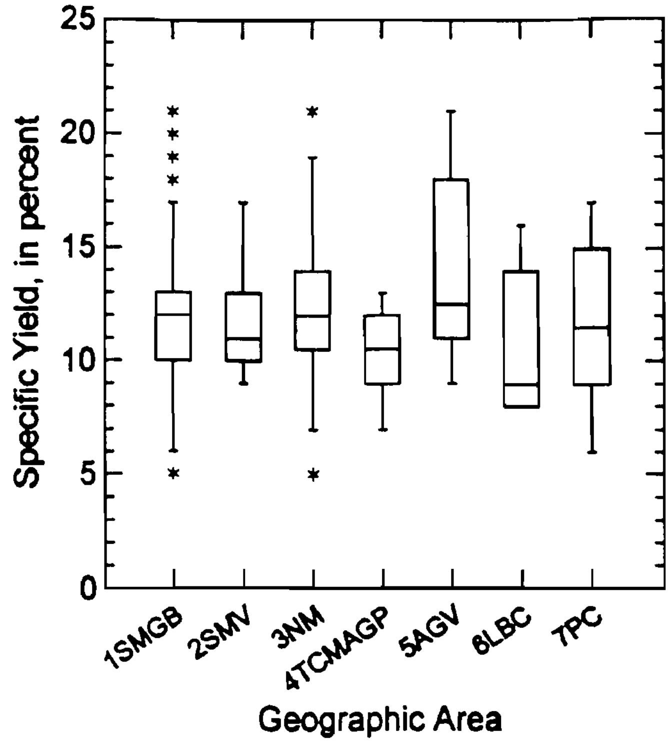
*N is the number of selected wells used for each geographic area.
**Hydrologic area or subarea overlying geographic area of groundwater basin.

lower values are found east of the Santa Maria River fault. The large range in values on the mesa is caused by the older dune sand, almost 400 feet thick in some areas, which gives higher specific yield values for those wells. Because much of the older dune sand is unsaturated, the median value for the mesa drops to 10 percent for the saturated sediments, although the range remains at 5 to 20 percent. Figure 30 illustrates the values given in Table 16 by means of "schematic box plots."

The areal average weighted specific yield values estimated in this study for Nipomo Mesa and Santa Maria Valley[8] are 2 to 3 percent lower than the average values determined in the Department's 1979 study. A probable explanation is that this study used the lower values of specific yield for the Paso Robles Formation (Appendix C) to assign to wells penetrating that formation, the Careaga Formation, and the Squire Member. More wells drilled since 1979 penetrate deeper into the older, usually "tighter," formations.

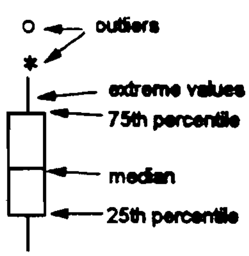
[8]Areal average specific yield is 12 percent for both Santa Maria Valley and Nipomo Mesa, which are similar to the median values given in Table 16.

FIGURE 30 - SPECIFIC YIELD VALUES,
SANTA MARIA GROUNDWATER BASIN



EXPLANATION

1SMGB: Santa Maria Groundwater Basin
2SMV: Santa Maria Valley
3NM: Nipomo Mesa
4TCMAGP: Tri-Cities Mesa - Arroyo Grande Plain
5AGV: Arroyo Grande Valley
6LBC: Los Berros Creek
7PC: Pismo Creek



Storativity calculated from aquifer test analyses ranged from 0.001 to 0.003, representative of semi-confined conditions.

In addition to the average weighted specific yield values estimated for wells within the groundwater basin, average weighted specific yield values were also estimated for the individual basin-fill deposits and formations (Table 17). The lowest specific yield values were found to be those of the Paso Robles Formation, northeast of the Santa Maria River fault, where the formation is generally more heterogeneously clayey. The Careaga Formation was found to have specific yield values as high as the older dune sand in some wells.

TABLE 17
AVERAGE WEIGHTED SPECIFIC YIELD
BASIN-FILL DEPOSITS AND FORMATIONS
In percent

Deposit/Formation	Geographic Area	N*	Average Weighted Specific Yield	
			Median Value	Range of Values
Recent Alluvium	Arroyo Grande Valley and Plain	15	12	8-22
	Santa Maria Valley	11	13	9-23
Older Dune Sand	Tri-Cities Mesa	10	13	5-22
	Nipomo Mesa	66	17	5-26
Paso Robles Formation	Tri-Cities Mesa - Arroyo Grande Plain	15	11	6-16
	Nipomo Mesa	67	8	4-20
	northeast of Santa Maria River fault	35	6	4-14
	southwest of Santa Maria River fault	32	10	4-20
	Santa Maria Valley	11	11	5-16
Careaga Formation	Nipomo Mesa	22	10	5-22
	Santa Maria Valley	5	8	5-26
Squire Member/Careaga Formation	Tri-Cities Mesa	14	10	7-16

* N is the number of selected wells used for each geographic area.

Within the groundwater basin, the total storage capacity represents the total volume of water that could theoretically be held in underground storage (not what is actually in storage at a given time), because it assumes the basin-fill deposits can be saturated to within about 20 feet of ground surface. This depends on the total volume of sediments in the basin and on the specific yield. Total storage capacity estimates can be useful in planning potential artificial recharge projects.

Total storage capacity was estimated for the basin as a whole and for the geographic areas[9] within the basin (Table 18). Estimated total storage capacity is given for both above msl and below msl because of the physical limitation placed on this coastal basin by the need to maintain a seaward hydraulic gradient to prevent sea water intrusion.

Because the method of estimating total storage uses simplifying assumptions that may introduce errors of a few percent, the estimates in Table 18 were rounded to two significant figures. The

[9] Boundaries of areas are shown on Figure 16.

TABLE 18
ESTIMATED TOTAL STORAGE CAPACITY* OF
SANTA MARIA GROUNDWATER BASIN, SAN LUIS OBISPO COUNTY
In acre-feet, unless otherwise noted

Geographic Area	Surface Area, In acres	Average Weighted Specific Yield, In percent	Estimated Total Storage Capacity		
			Above MSL**	Below MSL**	Total
Oceano HSA***					
Tri-Cities Mesa - Arroyo Grande Plain+	11,200	12	61,000++	360,000++	421,000
Nipomo Mesa HSA***					
Nipomo Mesa	19,000	12	500,000++	720,000++	1,220,000
Guadalupe HA***					
Santa Maria Valley	19,300	12	200,000++	1,900,000++	2,100,000
Santa Maria Groundwater Basin	49,500		761,000	2,980,000	3,741,000

*Total storage capacity represents the total volume of water that could theoretically be held in underground storage.
**MSL is mean sea level.
***Hydrologic area or subarea overlying geographic area of groundwater basin.
+Includes Pismo Creek, Arroyo Grande Valley, and Los Berros Creek areas of the groundwater basin.
++Values rounded to two significant figures.

method requires that the volume of sediments both above and below msl be estimated. Errors can be introduced by using the median value of adjacent lines of equal elevation for the land surface and for the base of the basin as the representative elevation in the area between the lines. Also, the method uses the average weighted specific yield value to represent the system, both areally and vertically.

The total storage capacity of the basin within San Luis Obispo County, both above and below msl, is 3.7 million AF, about 20 percent of which is above msl. More than half of the total storage capacity of the groundwater basin, most of it below msl, is within the Santa Maria Valley. Of the total storage capacity of the valley, 10 percent is above msl. Nipomo Mesa has the largest total storage capacity for groundwater above msl, 500,000 AF, more than one-third of its total capacity. In the Tri-Cities Mesa - Arroyo Grande Plain area, about 15 percent of the total storage capacity is above msl.

The amount of groundwater in storage at a given time depends on the volume of saturated sediments in the basin and the specific yield of those saturated sediments. The amount in storage is a constantly changing value, which fluctuates in response to both seasonal and long-term changes in recharge to and discharge from the groundwater basin as reflected by groundwater level changes.

Amounts in storage were estimated for Santa Maria Groundwater Basin for the springs of 1975, 1985, and 1995 using average weighted specific yield values estimated for the saturated thickness. The upper limit of saturation was determined from the groundwater elevation contour maps, Figures 19-21. Table 19 presents the estimated amounts in storage for the basin as a whole and for geographic areas within the basin, for both above and below msl. The table also presents the

amount of change in storage above msl between the three springs. This change shows only the difference for these three times and does not represent a steady year to year change. During the interim years, the amount of groundwater in storage fluctuated according to the amount of recharge and discharge that occurred in that area of the basin.

The same limitations on accuracy apply to the estimates of amounts in storage, but the median value of adjacent lines of groundwater elevation is used to represent the water elevation in the area between the lines, rather than land surface elevation. Thus, the estimates in Table 19 have been rounded to two significant figures.

In 1995, the amount of groundwater in storage within the Santa Maria Groundwater Basin, both above and below msl, was about 3.2 million AF, of which only 213,000 AF, or about 7 percent, were above msl. This amount is 8,000 AF less than in 1975. For the Tri-Cities Mesa - Arroyo Grande Plain area, the estimates of amount in storage, both above and below msl, for the three springs were about the same, a little more than 390,000 AF, of which about 9 percent, or about 30,000 AF, were above msl. In this area the amount of groundwater in storage, between 1975 and 1985, declined 1,000 AF and between 1985 and 1995, increased 2,000 AF. In Nipomo Mesa, the amount of groundwater in storage in 1995, both above and below msl, was estimated to be 800,000 AF, of which 80,000 AF or 10 percent, were above msl. The 1995 amount above msl is about 12 percent less than the amount in storage above msl in 1985. This loss in storage is consistent with the significant declining trends found in groundwater levels in wells in parts of the mesa. The loss is not mesawide, but is associated with those areas of pumping depressions shown on Figure 21. The mesa also showed a small decline in storage of 2,000 AF between 1975 and 1985. The Santa Maria Valley was estimated to have almost 2 million AF in storage in 1995, both above and below msl, of which 99,000 AF, or 5 percent, were above msl. This amount is 4,000 AF more than the amount estimated to be in storage in spring 1975. In 1985, the valley had a net gain in storage above msl of 15,000 acre-feet, from 95,000 to 110,000 AF, because of higher groundwater elevations from the substantial seepage losses of the Santa Maria River from the 1983 wet water year. Seepage losses from the Santa Maria River from the 1995 wet year were not yet fully reflected in groundwater elevations in the Santa Maria Valley and, based on the trend in groundwater elevations, the amount in storage increased more in the succeeding years as the recharge mound traveled away from the river. Part of the amount of the change in storage from 1985 to 1995 in the Santa Maria Valley reflects the movement of groundwater from the valley into Nipomo Mesa (shown by the pumping depression on Figure 21).

TABLE 19
ESTIMATED GROUNDWATER IN STORAGE
SANTA MARIA GROUNDWATER BASIN, SAN LUIS OBISPO COUNTY
In acre-feet, unless otherwise noted

Geographic Area	Surface Area In acres	Water Year	Average Weighted Specific Yield* In percent	Amount of Groundwater in Storage (Available Storage Capacity)			Change in Storage, Above MSL**	
				Above MSL**	Below MSL**	Total	Between Years	Amount
Oceano HSA***								
Tri-Cities Mesa - Arroyo	11,200	1975	11	33,000[++]	360,000[++]	393,000		
Grande Plain[+]	11,200	1985	11	32,000[++]	360,000[++]	392,000	1975 and 1985	-1,000
	11,200	1995	11	34,000[++]	360,000[++]	394,000	1985 and 1995	2,000
							1975 and 1995	1,000
Nipomo Mesa HSA***	19,000	1975	11	93,000[++]	720,000[++]	813,000		
Nipomo Mesa	19,000	1985	11	91,000[++]	720,000[++]	811,000	1975 and 1985	-2,000
	19,000	1995	10	80,000[++]	720,000[++]	800,000	1985 and 1995	-11,000
							1975 and 1995	-13,000
Guadalupe HA***	19,300	1975	11	95,000[++]	1,900,000[++]	1,995,000		
Santa Maria Valley	19,300	1985	12	110,000[++]	1,900,000[++]	2,010,000	1975 and 1985	15,000
	19,300	1995	11	99,000[++]	1,900,000[++]	1,999,000	1985 and 1995	-11,000
							1975 and 1995	4,000
Santa Maria Groundwater	49,500	1975		221,000	2,980,000	3,201,000		
Basin	49,500	1985		233,000	2,980,000	3,213,000	1975 and 1985	12,000
	49,500	1995		213,000	2,980,000	3,193,000	1985 and 1995	-20,000
							1975 and 1995	-8,000

* Specific yield values used for calculating amount of groundwater in storage were determined for only the saturated thickness of the basin.
** MSL is mean sea level.
*** Hydrologic area or subarea overlying geographic area of groundwater basin.
[+] Includes Pismo Creek, Arroyo Grande Valley, and Los Berros Creek areas of the groundwater basin.
[++] Values rounded to two significant figures.

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In the Santa Maria Groundwater Basin, a dynamic balance exists between recharge and discharge. The basin fluctuates with the cycles of varying rainfall and adjusts to changes in land and water uses occurring within the basin. The amount of groundwater in storage in Santa Maria Valley and Tri-Cities Mesa - Arroyo Grande Plain appears to be in balance between recharge and discharge. Lopez Reservoir has served to augment recharge to the basin in the Tri-Cities Mesa - Arroyo Grande area and Twitchell Reservoir has done the same in the Santa Maria Valley. Nipomo Mesa's major source of recharge is only deep percolation of precipitation. Thus, it is more susceptible to extended dry periods and increasing demands on its groundwater supplies. Areas of the mesa are seeing groundwater withdrawals exceeding recharge, leading to loss in storage. Very importantly, the amount in storage in all parts of the basin needs to be of sufficient quantity that a seaward hydraulic gradient exists to protect the basin from sea water intrusion.

Hydraulic Conductivity and Transmissivity

The hydraulic properties of an aquifer that quantify the rate at which groundwater flows are called hydraulic conductivity and transmissivity.

Hydraulic conductivity is a measure of the quantity of water that flows per day through a square foot cross-section of an aquifer under a hydraulic gradient of one to one. It is governed by the size and shape of the pores, the effectiveness of the interconnection between pores, and the physical properties of the fluid. The more hydraulically conductive material has larger, more completely connected pores than does the less conductive material.

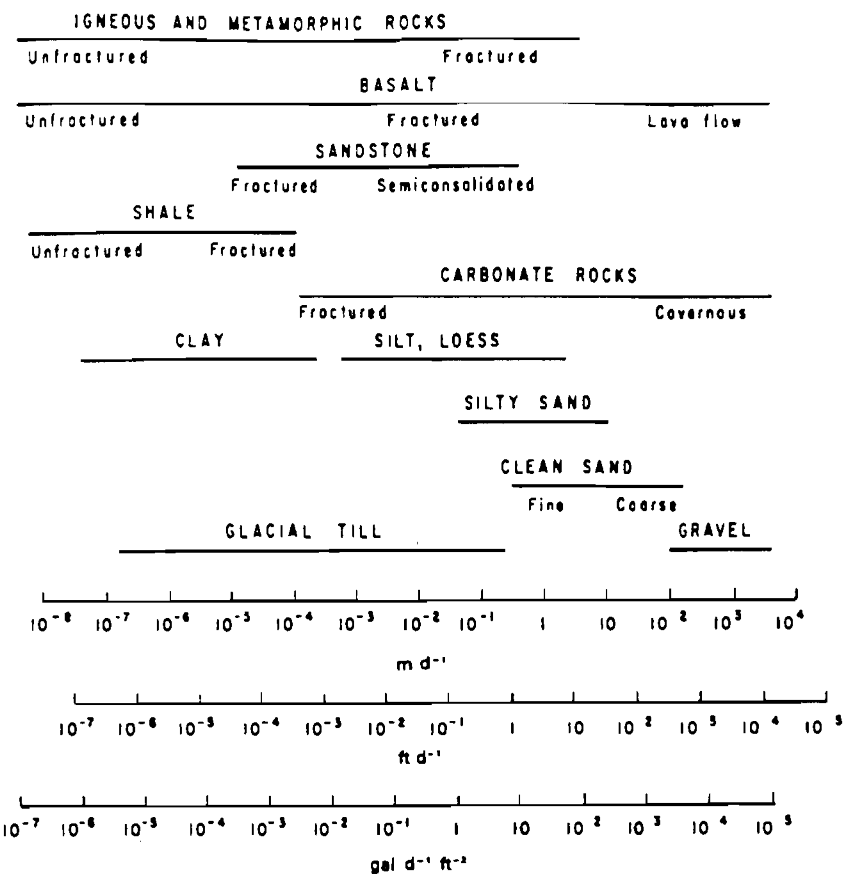
Hydraulic conductivity of rocks has been found to range over 12 orders of magnitude (Heath, 1983). It not only is different in different types of rocks, but also may be different from place to place within the same material. Figure 31 illustrates the range in magnitude of hydraulic conductivity of various materials determined in thousands of tests by the USGS.

In most rocks, hydraulic conductivity is not equal in all directions. It is most commonly larger in the horizontal direction than in the vertical direction (Heath, 1983). Vertical conductivity, which governs infiltration rates, is typically 0.1 to 0.01 times the horizontal conductivity (Lohman, 1972).

Transmissivity is a measure of the quantity of water flowing through a 1-foot-wide cross-section of the entire saturated thickness of the aquifer under a hydraulic gradient of one to one. It is the product of the hydraulic conductivity of the saturated aquifer times the thickness of the entire saturated aquifer. The effective transmissivity of an aquifer does not remain constant, but changes with increases or decreases in the saturated thickness of the aquifer.

Values of hydraulic conductivity and transmissivity for the Santa Maria Groundwater Basin were estimated using data obtained by three methods: (1) aquifer hydraulic test data, (2) pump efficiency data, and (3) lithologic correlation assignment of hydraulic conductance values to the types of material penetrated as reported on the lithologs of drillers' reports. The three methods are described in Appendix C.

FIGURE 31 - HYDRAULIC CONDUCTIVITY OF SELECTED ROCKS



From: Heath, R. C., 1983, Basic Ground-Water Hydrology: U. S. Geological Survey Water-Supply Paper 2220

Table 20 illustrates the degree to which hydraulic conductivity values can vary for the basin-fill deposits of the Santa Maria Groundwater Basin. The great lithologic heterogeneity of the deposits, consisting of varying mixtures of clay, silt, sand, gravel, and boulders in discontinuous lenses, causes correspondingly large variations in hydraulic conductivity. Because of this heterogeneity, no one value can be truly representative of a deposit, formation, or geographic area. The highest hydraulic conductivity values can be found in the alluvium. Lower conductivity values were generally found in the oldest formations--the Careaga Formation and the Squire Member of the Pismo Formation.

The estimates of transmissivity determined for wells within the groundwater basin in this study are illustrated in Figure 32. The figure represents transmissivity for spring 1995 saturated conditions.

TABLE 20
ESTIMATED HYDRAULIC CONDUCTIVITY
SANTA MARIA GROUNDWATER BASIN, SAN LUIS OBISPO COUNTY
In gallons per day per foot squared

Deposit/Formation	Geographic Area	Hydraulic Conductivity*		
		Aquifer Test	Pump Efficiency	Lithologic Correlation
Alluvium	Arroyo Grande Plain		700-2,000	40-4,200
	Arroyo Grande Valley	2,000		165-5,800
	Santa Maria Valley	2,000-3,500	5,200-6,000	50-6,800
Alluvium and Paso Robles Formation	Santa Maria Valley		55-1,000	
Paso Robles Formation	Tri-Cities Mesa - Arroyo Grande Plain	370-900	120-2,700	5-2,900
	Nipomo Mesa		1-375	5-800
	Santa Maria Valley	65**	10-1,035	20-2,000
Paso Robles and Careaga Formations	Nipomo Mesa	20-300	15-120	
Paso Robles Fm and Squire Member/CareagaFm	Tri-Cities Mesa	50-100	130-450	
Careaga Formation ***	Nipomo Mesa		40-55	1-600
	Santa Maria Valley			10-400+
Squire Member	Tri-Cities Mesa	30-40		
Squire Member/Careaga Formation	Tri-Cities Mesa		20-110	5-400

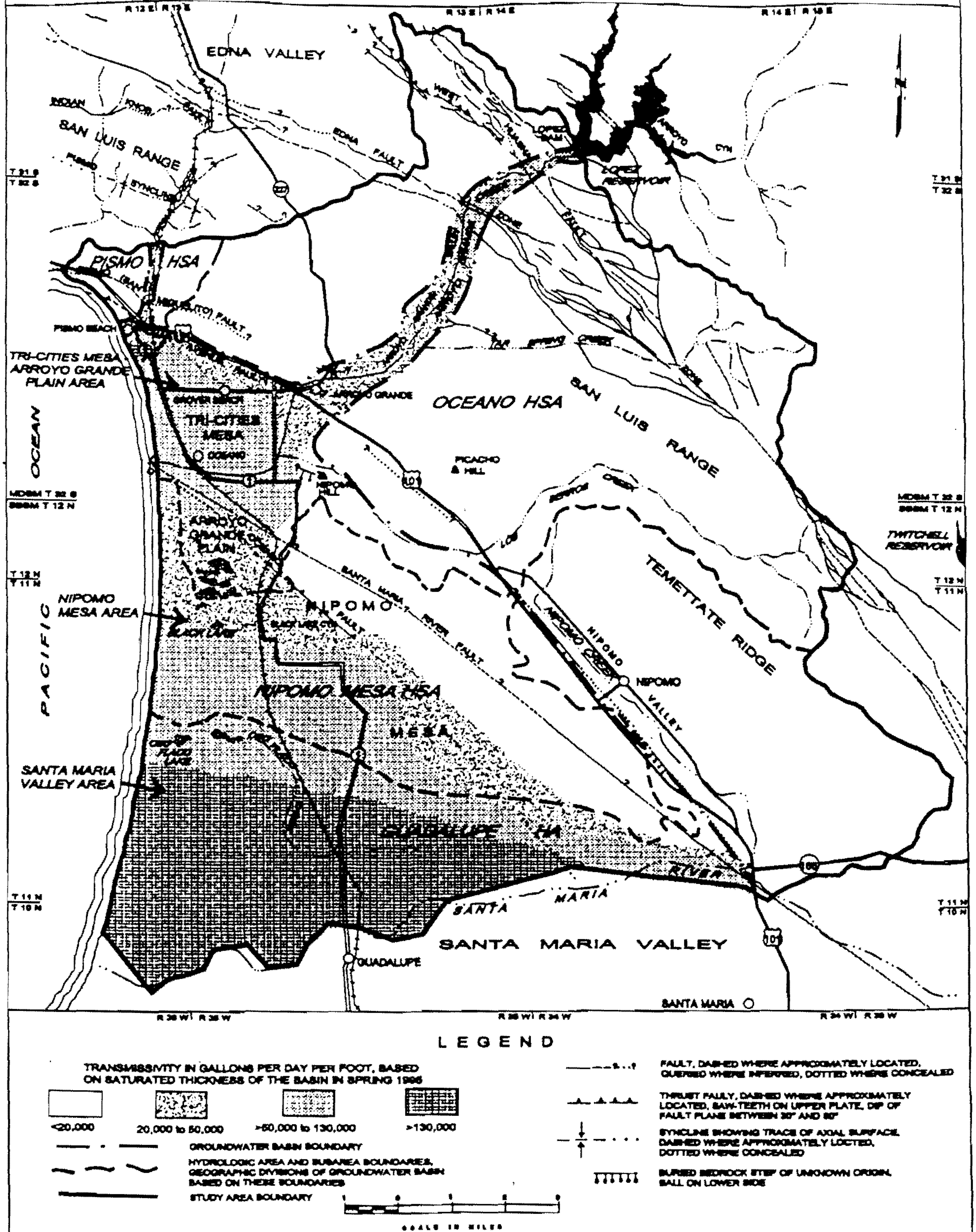
* Value or range of values given for each method used to estimate hydraulic conductivity.

** Worts (1951) determined the hydraulic conductivity of the Paso Robles Formation from the results of one recovery test from one pumped well, which penetrates only a part of the Paso Robles Formation.

***Upson and Thomasson (1951) collected 12 samples of the Careaga Formation from outcrops in central Santa Barbara County, which were tested for permeability in the laboratory. The hydraulic conductivity values ranged from 7 to 89 gallons per day per foot squared in four samples, with an average of 70 gallons per day per foot squared at 60° F, which they believed represented the approximate order of magnitude of the formation (Upson and Thomasson, 1951, p. 34). Citing belief of similarity of lithologic properties, Worts (1951) extrapolated this hydraulic conductivity value for the Careaga Formation for use within the Santa Maria Valley. He adjusted the laboratory-derived value of 70 gallons per day per foot squared to a field temperature value of 65° F, with the resultant conductance value being 75 gallons per day per foot squared. This value of hydraulic conductivity of the Careaga Formation continues to be used in studies as the value of this formation.

\+ Wells did not penetrate full thickness of the formation.

FIGURE 32 - AREAL VARIATIONS IN TRANSMISSIVITY IN THE SANTA MARIA GROUNDWATER BASIN, SAN LUIS OBISPO COUNTY



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To present the estimated transmissivity values on the figure, the geometric mean[10] transmissivity value was calculated from the low and high values for each well. The mean values were grouped into four units based on the median and the upper and lower quartile values of the population. No distinct boundaries between the units are used on the figure because transmissivity is an additive property, gradually changing as the groundwater basin deepens. The estimates of transmissivity within the basin ranged from 125 to 850,000 gallons per day per foot of saturated thickness.

Variations in transmissivity can be seen on the figure. The highest transmissivity values are found in the Santa Maria Valley, where the aquifer is the thickest. The lowest values are found in Nipomo Mesa, where the basin is shallower in areas where bedrock has risen. Also, it can be seen that the large pumping depression in the mesa has affected transmissivity of the basin in that area.

Subsurface Flows

Within the basin, the subsurface flow system moves groundwater from recharge areas to discharge areas. As has been mentioned, groundwater flows in the subsurface from the basin to the Pacific Ocean and, within the basin, groundwater flows in the subsurface from Nipomo Mesa to the Arroyo Grande Plain and, in 1995, from Santa Maria Valley in San Luis Obispo County to Nipomo Mesa. Also, groundwater flows into the basin from the surrounding bedrock areas and, in Santa Maria Valley, from the upstream portion of the basin. This section quantifies these subsurface flows for 1975, 1985, and 1995.

The method used to estimate subsurface flows is based on Darcy's law of saturated flow. For this, it is necessary to know the cross-sectional area of the basin-fill deposits along which the subsurface flow occurs, the hydraulic conductivity of the deposits, and the hydraulic gradient.

For determination of the subsurface outflow to the ocean, geologic cross-section A-A' (Plate 2), which cuts the groundwater basin along the coast, was used to define the area through which the subsurface outflow takes place. The total saturated cross-sectional area was about 50 million square feet. The low, high, and geometric mean values of hydraulic conductivity, determined by the lithologic correlation method, for the wells along the cross-section were applied to the cross-sectional area. Hydraulic gradients were computed for 1975, 1985, and 1995 from Figures 19-21.

The estimated quantities of subsurface outflow to the ocean from the basin calculated from the above parameters for this study are presented in Table 21. From this table, it can be seen that the range in subsurface outflow estimates for the entire groundwater basin for the three years is large, with a difference of about 25,000 AF. Subsurface outflows could be as little as 100 AF/Y from Nipomo Mesa to as much as 18,500 AF/Y from the Santa Maria Valley. The estimated outflow

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[10]The geometric mean is determined by taking the natural log of each value, finding the mean of the natural logs, and then obtaining the exponential of that value. Detailed work on distributions of hydraulic conductivity values by Cardwell and Parsons (1945), Warren and Price (1961), and Bennion and Griffiths (1966) determined that the average conductance value lies between the harmonic and arithmetic means and is best described by the geometric mean.

TABLE 21
ESTIMATED SUBSURFACE FLOWS
SANTA MARIA GROUNDWATER BASIN, SAN LUIS OBISPO COUNTY
In acre-feet

Subsurface Flows	Geographic Area	Water Year	Estimated Amounts		
			Low Amount	High Amount	Geometric Mean Amount
Outflows to the Ocean	Tri-Cities Mesa-Arroyo Grande Plain	1975	1,000	9,700	3,200
	Nipomo Mesa		100	1,300	400
	Santa Maria Valley		2,000	16,700	5,700
	Groundwater Basin Total		3,100	27,700	9,300
	Tri-Cities Mesa-Arroyo Grande Plain	1985	900	9,200	2,800
	Nipomo Mesa		100	1,300	400
	Santa Maria Valley		2,200	18,500	6,300
	Groundwater Basin Total		3,200	29,000	9,500
	Tri-Cities Mesa-Arroyo Grande Plain	1995	1,000	9,700	3,200
	Nipomo Mesa		100	800	300
	Santa Maria Valley		2,000	16,700	5,700
	Groundwater Basin Total		3,100	27,200	9,200
Flows Within the Basin	Nipomo Mesa to Arroyo Grande Plain	1975, 1985, 1995	420	4,300	1,300
	Santa Maria Valley to Nipomo Mesa	1995	350	2,800	1,000
Inflows Into the Basin	Inflow into Tri-Cities Mesa	1975, 1985, 1995	520	5,100	1,600
	Inflow into Nipomo Mesa	1975, 1985, 1995	160	1,600	500
	Inflow into Santa Maria Valley	1975	400	4,100	1,300
		1985	800	8,100	2,550
		1995	400	4,100	1,300

[redacted]

from the Santa Maria Valley in 1985 was slightly higher because there was more groundwater in storage. Overall, the amounts differ little for the three years, because hydraulic gradients did not vary much, the pressure head along the coast was about the same for each year.

For determination of subsurface flow from Nipomo Mesa to the Arroyo Grande Plain, a north-south cross-sectional area, cutting the edge of the mesa north of the Santa Maria River fault, was used to define the area through which the flow occurs. The total saturated cross-sectional area was about 750,000 square feet. Lithologic correlation hydraulic conductivity values for wells near the cross-sectional area were used for the calculations, as were the hydraulic gradients computed from Figures 19-21 for the springs of 1975, 1985, 1995.

The estimated amounts of this subsurface flow are given on Table 21. Because the hydraulic gradient was the same for all three springs, the estimated flow amounts were the same. The range in estimated amounts was large, a difference of almost 4,000 AF. The quantities estimated to flow from the mesa to the Arroyo Grande Plain are a little less than half the quantities estimated to flow in the subsurface from the Tri-Cities Mesa - Arroyo Grande Plain area to the ocean.

To determine subsurface flow from the Santa Maria Valley to Nipomo Mesa, an east-west cross-section area, cutting the basin near the southern edge of the depression shown on Figure 19, was used to define the area through which the flow takes place. The total saturated cross-sectional area was about 9 million square feet. Lithologic correlation hydraulic conductivity values for wells near the cross-sectional area and the hydraulic gradient computed for 1995 were used for the calculations. The estimated range in amounts of this subsurface flow for 1995 is also given on Table 21. The high estimate of 2,800 AF is similar to the yearly average of 3,300 AF amount estimated by Cleath & Associates (1996a) for 1977-92.

For determination of subsurface inflows into the Santa Maria Groundwater Basin from the bedrock areas and from upstream in the Santa Maria Valley outside the study area, three saturated cross-sectional areas were used. These are the edge of the basin along the San Luis Hills, which is about 3 million square feet; the edge of the basin along Nipomo Valley, which is about 1.3 million square feet; and along Highway 101 in the Santa Maria Valley within the study area, which is about 125,000 square feet. Lithologic correlation hydraulic conductivity values for wells near the cross-sectional areas were used for the calculations, as were the hydraulic gradients computed from Figures 19-21 for the springs of 1975, 1985, and 1995. The estimated range in amounts for the subsurface inflows is given on Table 21. Estimated mean inflows into the entire groundwater basin within the study area were 3,400 acre-feet per year for hydrogeologic conditions in 1995. Inflows into the basin were about three times greater in the Tri-Cities Mesa area and in Santa Maria Valley than in Nipomo Mesa. The estimated inflow in the Santa Maria Valley in 1985 was higher because of the higher groundwater levels.

Bedrock Areas

Evaluating groundwater conditions in the bedrock areas of the study area is challenging because of the complex geology and limited available data. A little more than half of the study area's total acreage, about 62,000 acres, forms the bedrock areas. These areas are significant for their roles as sources of local groundwater supply and as natural recharge for the groundwater basin. The bedrock areas are also seeing increasing development and associated utilization of groundwater. Given the typically limited capacity of bedrock areas to store and transmit groundwater, documenting what is known is important.

The bedrock aquifers bounding the Santa Maria Groundwater Basin consist primarily of the semi-consolidated sandstone Pismo and Santa Margarita Formations, the consolidated shale Monterey Formation, and the volcanic tuff and lava Obispo Formation.[11]

The occurrence and movement of groundwater in these sedimentary and volcanic rocks largely depend on the number of openings in the rock and their degree of interconnection. Primary openings created at the time the rock formed include pores in sedimentary rocks and vesicles and cooling fractures in volcanic rocks. The number of primary openings depends on sorting, grain shape, packing, and degree of cementation, with cementation the most important because it can reduce the interconnectivity of the pores. Secondary openings are produced by fracturing, weathering, and solution after the rock formed. The number, spacing, size, orientation, and degree of interconnection of the secondary openings are important for controlling both the hydraulic conductivity and storage capacity of the bedrock mass.

Based on the geologic and water-bearing characteristics, the bedrock area was divided into: a Northern Bedrock Area, considered to be northwest of Arroyo Grande Valley and Tar Spring Creek and underlain by members of the Pismo Formation; and a Southeastern Bedrock Area, considered to be south of the northern edge of Tar Spring Creek and east of the groundwater basin and underlain by the Santa Margarita, Monterey, and Obispo Formations (Figure 33)[12]. The division of the bedrock areas is not based on the hydrologic boundaries; thus, the Northern Bedrock Area lies within the Pismo HSA and a portion of the Oceano HSA and the Southeastern Bedrock Area lies within a portion of the Oceano HSA and the Guadalupe HA.

Northern Bedrock Area

Within the bedrock area northwest of Arroyo Grande Valley and Tar Spring Creek, the Pismo Syncline is the primary geologic control for groundwater. Groundwater is found within the Pismo Formation, a semi-consolidated to consolidated rock aquifer, with groundwater in storage in both interstices in the sediments and fractures. Available drillers' reports do not indicate groundwater being extracted from the shallow alluvial fill that blankets the floors of the canyons.

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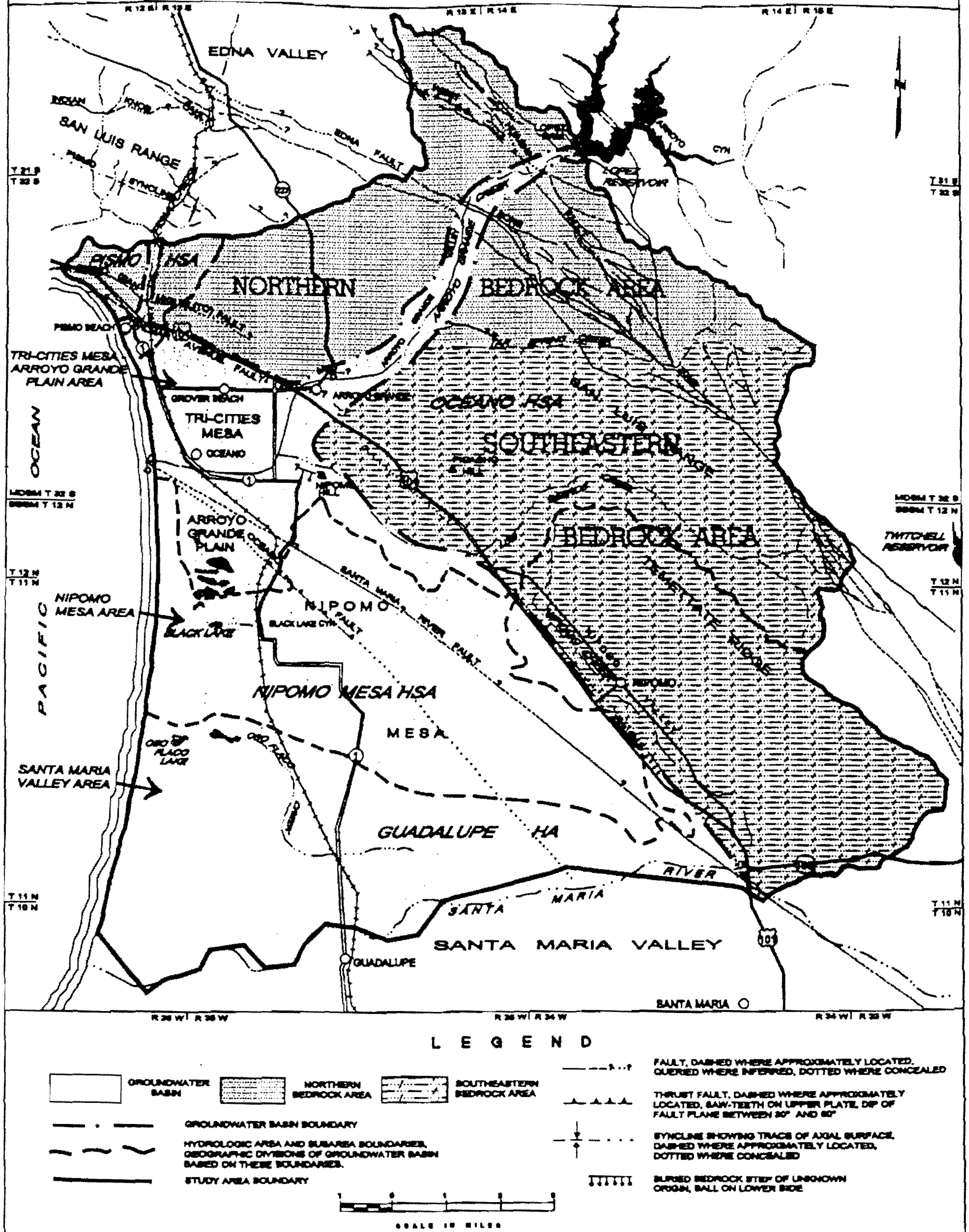
[11]Lithologic descriptions of these formations are given in Chapter II.

[12]The division of the bedrock area of the study area is not based on the hydrologic boundaries.

FIGURE 33 - BEDROCK AREAS, ARROYO GRANDE - NIPOMO MESA STUDY AREA



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A review of drillers' reports of wells drilled in this area provides some information on depths of the wells and yields obtained from these wells. Wells were drilled to depths of about 500 feet, but half are less than 300 feet. Yields typically ranged from 10 to 100 gallons per minute, with half of the wells yielding less than 30 gallons per minute. A few drillers' reports of wells less than 100 feet deep indicated yield of the wells as only very little.

Movement of the groundwater locally follows the topography, ultimately moving west-southwesterly into the adjoining groundwater basin.

Groundwater is recharged mainly by intermittent direct percolation of precipitation and runoff and is discharged by well extractions, evapotranspiration, and subsurface outflow to the adjoining Santa Maria Groundwater Basin.

Specific yield values were estimated for the Pismo Formation from selected wells using the same method as for the groundwater basin. Values were estimated to range from 5 to 20 percent, with a median value of 10 percent.[13]

The hydraulic conductivity of sandstone is one to four orders of magnitude lower than the values for unconsolidated sand (Figure 31). It has been found that as the porosity of a sandstone decreases, particularly below 15 percent, the permeability depends more on the presence of interconnected fractures than on the original porosity within the rock (Davis, 1988).

A few wells had specific capacity data from pumping tests. Using the modified Thiem formula (described in Appendix C), transmissivity and hydraulic conductivity values were estimated. Transmissivity estimates ranged from about 300 to 2,400 gallons per day per foot and hydraulic conductivity estimates ranged from 1 gallon to about 120 gallons per day per foot squared. These conductivity values are similar to those found from pump efficiency tests for the Squire Member and the Careaga Formation in the groundwater basin (Table 20).

Values of hydraulic conductivity for the Pismo Formation in the bedrock area were also determined for selected wells by the lithologic correlation method (described in Appendix C). The values estimated by this method for the formation ranged from 1 gallon to about 1,000 gallons per day per foot squared.

No extensive assessment of the hydrogeology of this area was found; however, a 1988 report by RRM Design Group gave information on an investigation of the potential groundwater supply for a 154-acre parcel north of Highway 101 and west of Oak Park Boulevard. RRM Design Group reported that, in general, porosity and permeability of the Pismo Formation at the site are very good. The 1988 report included the following excerpts from a Cleath & Associates report on a preliminary groundwater study made for RRM Design Group:

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[13]The values estimated in this bedrock area are similar to those found for the Squire Member and Careaga Formation of the Tri-Cities Mesa area of the groundwater basin.

> "[T] he lower aquifer is a blue fine-grained sandstone about 300 feet thick which appears to be dipping to the northeast at about 14 degrees. The drilling penetration rate in the sand bed is much faster than the overlying siltstone. This aquifer is recharged by surface water in the Oak Park Valley and adjacent canyons. The ground water in this aquifer is confined below a siltstone aquitard and is under pressure, resulting in relatively shallow water levels. " (RRM Design Group, 1988, p. 33).

> "The lower, fine-grained sandstone aquifer holds the best potential for good well yields on the property. The upper medium coarse-grained sandstone aquifer also yields some water to wells, but the yield could be influenced by interference from adjacent producing wells and seasonal water level fluctuations. " (Ibid, p. 34).

The RRM Design Group (1988) also stated that Cleath & Associates had estimated aquifer storage for the site at " more than 50,000 acre feet of water" (p. 33).

Using the median specific yield value of 10 percent and a thickness of 300 feet for the Pismo Formation, the total storage capacity for this Northern Bedrock Area (Figure 33) was estimated to be possibly about 270,000 AF.

Southeastern Bedrock Area

In the area southeast of Arroyo Grande Valley and the northern edge of Tar Spring Creek, groundwater is found in the Monterey and Obispo Formations, in the older alluvium covering the floor of the Nipomo Valley, in the thin alluvial blanket of Tar Spring Creek, and in the Santa Margarita Formation in the upper watershed of Tar Spring Creek (east of the West Huasna fault zone). It is developed mostly in Nipomo Valley. The water-bearing characteristics of fractured rock and volcanic rock are varied and more complex in the Southeastern Bedrock Area than in the area of the Pismo Formation.

The Monterey Formation is predominantly a fine-grained rock mass and the intergranular permeability is very low. Fracturing is important for the storage and transmission of groundwater in this formation. Lithologs on drillers' reports sometimes indicated layers of soft shale. Investigations have found that soft shale may not retain significant fracture openings below about 100 feet (Davis, 1988). Possible closure of fractures below 100 feet bear importance for availability of groundwater. However, Isherwood (1981) determined that if Monterey shale is brittle with large amounts of silica, it can maintain abundant open fractures at depths greater than about 900 feet.

Not only the different geodynamic emplacement and geologic processes, but also different hydrologic factors cause significant hydrogeologic variability in volcanic rocks. The Obispo Formation in the study area is primarily tuffs and lavas, locally cut by dikes or sills. Tuff is a pyroclastic deposit, with a wide range of particle sizes, sorting, and fracture density. Fracturing, which increases both porosity and hydraulic conductivity, is a major geologic control on the flux of groundwater in both the tuffs and lavas.

Intrusive bodies like dikes and sills may significantly affect groundwater movement. These bodies frequently have much lower permeability than pyroclastics or lavas. As a result, they often act as an impediment or barrier to groundwater flow, and water levels may differ by many feet on opposite sides of a dike. This phenomenon was reported by Cleath & Associates (1995) in a groundwater supply study within the Obispo Formation in the study area.

The most extensive groundwater assessment of the Obispo Formation fractured tuff was conducted by Cleath & Associates (1995) as part of a groundwater management study for the Bartleson Development Plan in the Los Berros Canyon area near Highway 101. In that study, Cleath & Associates found that two resistant tuff members contain groundwater-yielding zones corresponding to fractured strata. They also found that the interbedded black shales did not yield groundwater readily. Within the study area, Cleath & Associates estimated that about one-fourth of the total volume of the Obispo Formation yielded groundwater readily.

Available drillers' reports of wells provide some information on the occurrence of groundwater in the Southeastern Bedrock Area.

In Tar Spring Creek area, west of the West Huasna fault zone, wells mainly extract groundwater from fractured Monterey shale drilled to depths of about 100 feet. Yields from these wells ranged from 10 to 400 gallons per minute, with half of the wells having a yield of less than 50 gallons per minute. Groundwater movement locally follows topography and ultimately is westward.

In the upper watershed of Tar Spring Creek, east of the West Huasna fault zone, wells with yields of 10 to 70 gallons per minute and as much as 200 feet in depth were found to be drilled into the Santa Margarita Formation. Several of the wells were drilled horizontally, 100 to 150 feet into the formation. In this area of Tar Spring Creek, groundwater movement is hypothesized to be eastward, while surface water in the creek flows westward.

The Nipomo Valley, the gently southwest-sloping upland area east of Highway 101, is drained by Nipomo Creek flowing perennially along the western edge of the valley to its confluence with the Santa Maria River. Older alluvium covers the floor of the valley up to about 90 feet thick, thinning toward the eastern edge to less than 10 feet. Coastal Valley Engineering, Inc. (1976) reported that the older alluvium had moderate to low permeability, with local semi-perched saturation.[14] A few older wells are perforated only in the older alluvium, are less than 80 feet deep, and have yields of 20 to 30 gallons per minute. The older alluvium is not an important source of groundwater in this area.

Most wells drilled on the valley floor or the adjacent highlands extract groundwater from either the Obispo or Monterey Formation. Based on available drillers' reports, wells drilled into the Obispo Formation ranged in depth from 130 to 875 feet, with half of the wells greater than 400 feet. Yields ranged from 5 to 750 gallons per minute, with half of the wells yielding less than about 60 gallons per minute. About one-third of the boreholes drilled into the Obispo Formation

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[14] The report gave no numerical values for permeability.

were "dry." Wells drilled into the Monterey Formation ranged in depth from about 75 to 540 feet, with half more than 250 feet. Well yields ranged from 5 to 460 gallons per minute, with half yielding less than 80 gallons per minute. About 10 percent of the boreholes drilled into the formation were "dry."

It can be seen that wells penetrating the Monterey Formation usually do not need to be drilled as deep as those that penetrate the Obispo Formation and yields of half of the wells of both formations are about the same.

Depth to water ranged from land surface to about 300 feet, with many wells showing evidence of confining pressures in both formations.

Groundwater elevation contours in the Southeastern Bedrock Area shown on Figures 17-19 indicate groundwater moves southwesterly into Nipomo Mesa. James M. Montgomery, Consulting Engineers, Inc., (1982) conjectured that subsurface outflow from Nipomo Valley to Nipomo Mesa may be as great as 500 AF/Y. In the study reported here, using the methodology described for the groundwater basin, the subsurface outflow was estimated to range between 160 and 1,600 AF/Y, with a geometric mean of 500 AF/Y (Table 21).

Groundwater is recharged mainly by intermittent direct percolation of precipitation and runoff and is discharged by well extractions, evapotranspiration, and subsurface outflow to the adjoining Santa Maria Groundwater Basin.

Based on laboratory and field tests, Winograd and Thordarson (1975) reported that values of hydraulic conductivity for fractured and nonfractured tuffs, zeolotized tuffs, and tuffs altered to clay spanned eight orders of magnitude, from 10^{-6} to 10^{2} gallons per day per foot squared. Figure 31 shows that the hydraulic conductivity for basalt, one of the types of lava in the Obispo Formation, ranges over 12 orders of magnitude.

Isherwood's field determinations (1981) of hydraulic conductivity of fractured Monterey shale found the values to be comparable to those of sandstones, that is, about 180 to 180,000 gallons per day per foot squared.

Based on a four-hour pump test of the fractured tuff reservoir, Cleath & Associates (1995) calculated a storativity of 0.0009 for the fractured tuff and a transmissivity of 37,500 gallons per day per foot. They estimated about 3,300 AF to be in storage at the site during wet years, based on an effective base of 100 feet below msl.

Based on four pump efficiency tests of wells in Nipomo Valley, hydraulic properties of the Monterey and Obispo Formations were estimated using the modified Thiem formula. Transmissivity of the Monterey Formation was estimated to range from 3,000 to 5,200 gallons per day per foot and hydraulic conductivity was estimated to range from 15 to 25 gallons per day per foot squared for aquifer thicknesses of 175 to 350 feet. These estimated conductivity values are much lower than those determined by Isherwood. Transmissivity for the Obispo Formation was estimated from one well to be 8,500 gallons per day per foot and hydraulic conductivity to be 85 gallons per day per foot squared for a thickness of 100 feet.

Specific yield values of selected wells penetrating the Monterey Formation were estimated to range from 3 to 5 percent, and for the Obispo Formation from 3 to 6 percent, with median values of 4 percent for both formations. The total groundwater storage capacity of the two formations for the Southeastern Bedrock Area (Figure 33) was estimated to be possibly about 360,000 AF.

Artificial Recharge

Artificial recharge is the replenishing of groundwater by means primarily provided for that purpose. The principal benefits of artificial recharge may be relief of adverse conditions from overdevelopment of the resource or increase in the quantity, or yield, of groundwater available for use. Artificial recharge is accomplished through works designed to maintain high infiltration capacities, increase the wetted area, and lengthen the period of infiltration beyond that which exists under natural conditions (Richter and Chun, 1959). Projects commonly utilize various combinations of the following general methods: (1) surface spreading of water by putting it in basins or ponds, ditches, and furrows, by flooding, or by modifying streambeds and (2) diverting water into pits or shafts and injection wells.

Another method is an "in lieu" project. This method leaves water underground and supplies surface water directly to users.

Use of a particular method or combination of methods and selection of a site or sites depends on such factors as: (1) availability of a water supply of suitable quality for recharge; (2) topographic, geologic, and surface and subsurface hydrogeologic conditions suitable for maintaining high infiltration rates and storing water; (3) position and hydraulic gradient of the existing water table, or potentiometric surface; (4) transmissivity; (5) availability of land; (6) costs; (7) environmental concerns; and (8) operation and maintenance problems. The method used and area selected, therefore, should be those that best fit local conditions.

Artificial recharge is currently being used in the study area. Surface water is supplied from Lopez Reservoir to agencies that would otherwise extract groundwater from the Tri-Cities Mesa and Arroyo Grande Plain. This in lieu method has been operating for almost 30 years.

Potential artificial recharge projects have been identified for the study area. These include:

- Lawrance, Fisk & McFarland, Inc., (LFM) (1985a,b,c) conducted a conjunctive use study for San Luis Obispo County Flood Control and Water Conservation District in which potential artificial recharge projects for the Tri-Cities Mesa were identified. These potential projects were in-stream check dams and injection wells.

  In-stream check dams on Arroyo Grande Creek were identified as a possible means of enhancing infiltration capability by creating shallow ponds during periods of low to moderate streamflow. Hoover & Associates, Inc. (1985b), under contract with LFM, proposed four dams and calculated that 800 AF/Y could be recharged by this project. Although this project appears hydrologically and hydrogeologically feasible, environmental concerns would have to be addressed if it is undertaken.

The proposed injection well project involved conveying surplus Lopez Reservoir water through the existing distribution systems of contracting cities on Tri-Cities Mesa to well fields for injection near wells producing from the Squire Member or the Careaga Formation. LFM assumed theoretical monthly injection rates could average between 20 and 300 AF per month. Cost is a major consideration with injection well projects; however, environmental concerns associated with in-stream check dams could be avoided.

LFM (1985b) estimated that when groundwater in storage in the Tri-Cities Mesa - Arroyo Grande Plain area of the basin is 80 percent of total, slight rejection of recharge from Arroyo Grande Creek occurs. The rejection rate then increases as the basin continues to fill. They also noted that whenever there is sufficient natural water supply for Lopez Reservoir to fill, there has also been sufficient supply to recharge Tri-Cities Mesa, so that storage capacity for additional water in the Tri-Cities Mesa is insufficient (1985c).

- The South County Area Plan (The Morro Group, 1990) recommended use of on-site or off-site retention/recharge basins capable of infiltrating 100-year storm runoff for parts of Nipomo Mesa that drain to the edge of the bluff. The basins could enhance recharge of the groundwater basin and also mitigate adverse erosion and sedimentation problems occurring at the edges of the bluff.

- Spreading grounds and percolation basins have been proposed for Santa Maria Valley by Santa Barbara County Water Agency (1994). The agency conducted a study that indicated a loss of about 17,000 AF/Y to the ocean with Twitchell Reservoir in place. Some of this water could be used to recharge the aquifer if sufficient spreading area and diversion facilities were available. The agency hypothesized that 3,000 AF/Y could be percolated to the groundwater basin using 400 acres of active spreading grounds.

Hydrogeologically, artificial recharge projects in the study area could be sustained. In Nipomo Mesa, a project (including "in lieu") would be beneficial in alleviating some of the loss in storage that has occurred. Nipomo Mesa has only about 13 percent of its total storage capacity above msl filled with groundwater; therefore, the area has adequate space to store artificially recharged waters. Also, the high infiltration rates of the dune sands are favorable for artificial recharge projects. Identifying a source of water supply would be a foremost consideration for a recharge project on the mesa.

VI. WATER QUALITY

Water quality reflects the composition of water as affected by natural causes and human activities, expressed in terms of measurable quantities and related to intended use.

Because both groundwater and surface water are used for domestic supply within the study area, the California Department of Health Services' Drinking Water Standards and relative hardness are the criteria used in this study to evaluate the water quality. The concentrations of total dissolved solids (TDS), sulfate, chloride, and nitrate from the list of constituents in the Drinking Water Standards, along with the Department's classification of relative hardness, were selected as indicators of water quality (Table 22). High concentrations of any of these constituents would compromise the suitability of a water as a potable supply.

The California Department of Health Services has set primary standards for nitrate concentrations in drinking water--the primary standards pertain to constituents that present a health hazard. The potential health effects of high nitrate concentrations in potable water have long been recognized. Infants may suffer from methemoglobinemia following ingestion of water with nitrate concentrations in excess of 45 milligrams per liter - mg/L (as nitrate) (Keeney, 1986). Other potential health effects include birth defects, cancer, and nervous system impairments (Ibid.).

The secondary standards for drinking water set by the California Department of Health Services pertain to constituents that in excessive amounts may affect aesthetic qualities of water by imparting taste and odor and by staining fixtures. TDS, sulfate, and chloride have secondary standards[1].

Hardness can reduce the effectiveness of soap and shorten the life of hot water appliances, particularly water heaters and hot water piping.

The quality of water used for agriculture can also be measured relative to guidelines for irrigation or livestock. There are no government regulations for agricultural waters, but limits have been recommended by Ayers (1977), McKee and Wolf (1963), National Academy of Sciences and National Academy of Engineering (1973), and others. Limits vary by soil type and farming practices. Water quality guidelines for agriculture are in Appendix F.

This chapter discusses the mineral quality conditions of both groundwater and surface water in the study area.

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[1]Discussions of the significance of these constituents may be found in McKee and Wolfe (1963) and similar water quality texts.

TABLE 22
DRINKING WATER STANDARDS FOR SELECTED CONSTITUENTS
AND CLASSIFICATION OF RELATIVE HARDNESS*

Constituents	Units	Recommended Limits	Upper Limits**	Short Term Limits	MCL***	Other Limits
Total dissolved solids (TDS)	mg/L	<500	1,000	1,500	--	--
Specific conductance (EC)	micro-mhos	900	1,600	2,200	--	--
Sulfate (SO_4)	mg/L	<250	500	600	--	--
Chloride (Cl)	mg/L	<250	500	600	--	--
Nitrate (NO_3)	mg/L	--	--	--	45	--
DWR classification of relative hardness. Hardness as $CaCO_3$						
Soft	mg/L		--	--	--	<100
Moderate	mg/L		--	--	--	100-200
Very hard	mg/L		--	--	--	>200

*Adopted from the U. S. Public Health Services Drinking Water Standards.
**Maximum permissible when no other water available
***Maximum Contaminant Level

Factors Affecting Groundwater Quality

Groundwater begins as rain or snow containing only traces of chemical constituents acquired from atmospheric gases, vapors, and airborne particulates. Runoff then infiltrates and picks up dissolved chemicals from the soil and the geologic environment. Human activities also may affect the quality of groundwater. These activities include use and reuse of groundwaters, waste disposal practices, application of agricultural fertilizers and pesticides, irrigation return flow, urban runoff, leakage of solvents and gasoline from underground storage tanks and piping, and oil field operations[2]. Effects from human activities can be obscured by the strong influence that natural hydrogeologic and geochemical effects may have in some areas. These changes in groundwater quality are largely unavoidable and would become of concern only if they threaten ongoing and potential beneficial uses of the groundwater supply.

Probable sources impairing the groundwater quality can be categorized as nonwaste related and waste related.

[2]Organic chemical and metal contamination of groundwaters that can result from human activities is a water quality concern for all groundwater resources; however, this type of water quality degradation is not within the scope of this study.

Nonwaste-related Sources

Nonwaste-related sources of impairment are: (1) local rocks, (2) mineralized zones, (3) residual saline deposits, (4) connate water, and (5) sea water intrusion.

1. Depending upon their chemical composition, local rocks will contribute a wide range of chemicals in solution to the groundwater. The Jurassic rocks underlying the basin and forming much of the hills and mountains of the watershed contribute calcium, magnesium, bicarbonate, and TDS to the groundwater. These chemicals contribute to the hardness of the water.

2. Fractured and pulverized rock in and near faults creates mineralized zones that more readily yield chemicals to groundwater than do adjacent undisturbed areas.

3. Residual saline deposits contain salts deposited in the past by ocean water in some marine terraces or trapped in the sediments of old estuary or lagoonal deposits. Unusually high chloride concentrations in groundwater would suggest residual saline deposits as a possible source, but contributions from these deposits may be indistinguishable from local sea water intrusion.

4. Connate water is water trapped in the interstices of sedimentary rocks at the time of their deposition. It traditionally applies to old sediments. Waters that have been in long-time contact with old sediments contain greater concentrations of minerals than does groundwater at shallow depths where the groundwater has been in the sediments relatively briefly. Connate waters are high in TDS and sulfate concentrations.

5. Sea water intrusion, the movement of sea water into the freshwater aquifers underlying land, occurs when the normal seaward gradient of groundwater is reversed to a landward gradient by heavy pumping or by drought conditions that lower the groundwater level near or below sea level. Sea water intrusion may occur in unconfined water table conditions or in discrete aquifers at depth. A rise in the chloride concentration in the groundwater may be the first sign of sea water intrusion.

Waste-related Sources

In the study area, this category includes: (1) domestic and municipal waste discharges and (2) irrigation return water and livestock waste.

1. When discharged to land, domestic and municipal wastewater, whether treated or untreated, will contribute solutes to the groundwater, notably chloride, nitrate, and TDS.

   Wastewater from Arroyo Grande, Oceano, and Grover Beach is treated in the South San Luis Obispo County Sanitation District's WWTP, and the effluent is discharged via an ocean outfall. Wastewater from the Pismo Beach WWTP is discharged through the South

San Luis Obispo County Sanitation District's ocean outfall. Because wastewater from these communities is discharged out of the basin, it does not affect groundwater quality. In Nipomo Mesa, however, the two Nipomo Community Services District's WWTPs practice land disposal and discharge treated effluent to percolation ponds or use it to irrigate a golf course.

Before the construction of the South San Luis Obispo Sanitation District's WWTP and ocean outfall, wastewater was treated in cesspools, in septic tanks, or in the old Arroyo Grande community WWTP, which discharged to percolation ponds. Use of the plant was discontinued in June 1966. These old waste discharges probably continue to leach waste components to the groundwater during heavy rains or high groundwater conditions and can affect local groundwater quality.

The only large industrial waste discharger, an oil refinery near Highway 1 on Nipomo Mesa, discharges its wastewater to the ocean and out of the area.

2. Return flow from irrigation adds many different compounds to groundwater including sulfate, nitrate, and TDS. Evapotranspiration then concentrates the constituents in the applied supply water. The contributions from livestock waste are similar to those from irrigation.

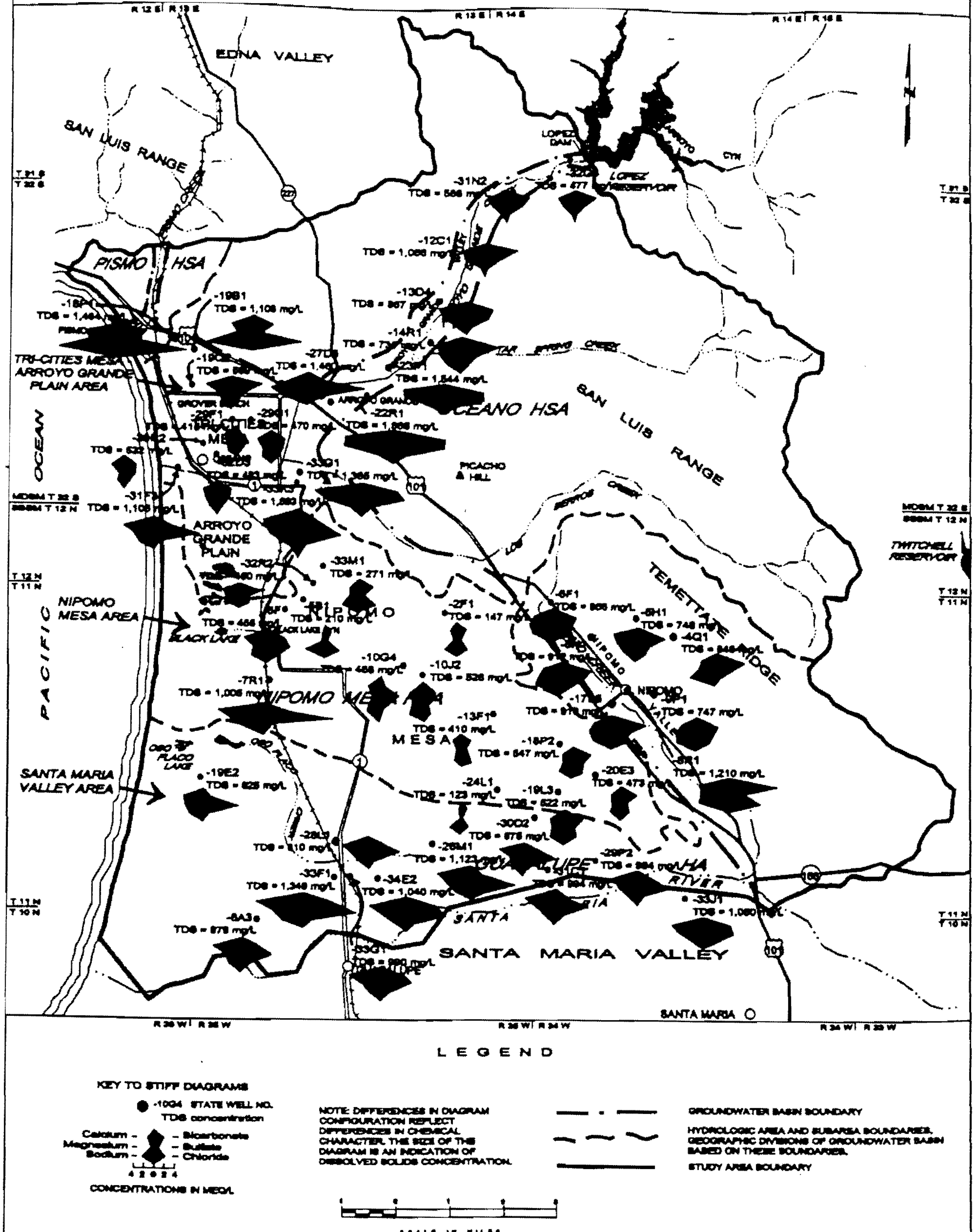
Groundwater Quality Conditions by Area

The groundwater quality database for the study area was compiled from various sources, including the Department's own files, State Water Resources Control Board, Department of Health Services, USGS, and local agencies. Some wells in the Santa Maria Valley have analyses covering about 70 years. Wells in other areas of the basin have analyses covering periods of about 50 years to shorter lengths of time. The extent of the available data varies greatly. Some agency wells have been sampled at regular intervals, but about 85 percent of the data consist of analyses from wells sampled only once or a few times during the period of record. Many areas have not been sampled recently.

To facilitate an understanding of groundwater quality conditions in the study area, Stiff diagrams were constructed and are presented on Figure 34. Stiff diagrams illustrate the relative proportion of the major mineral ions in water samples. The relative proportion of the various mineral constituents determines the mineral character of the water. The character of a water may be considered as a unique signature that often persists even after mixing with another water. The shapes of the diagrams indicate the character of the water and allow comparisons. The spatial relationships and patterns of differences and similarities in water composition within the study area may be perceived from the figure.

The diagrams are based on the latest data, which in some areas are several years old. The groundwater quality, however, has changed little during the period of record and the diagrams

FIGURE 34 - REPRESENTATIVE WATER QUALITY FROM WELLS



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based on that data are considered representative of the current groundwater quality.

To graphically depict the concentrations of TDS, sulfate, chloride, nitrate, and hardness in groundwater in areas of the basin over the period of record, groundwater quality hydrographs were constructed from all samples of all wells each year[3]. Because few wells in any area have a continuous data record for a length of time, most data for each year on the hydrograph represent a different population of sampled wells. Thus, these hydrographs do not depict trends in quality over time, but do depict the variability and extremes in quality that can be found in an area.

A compilation of water quality data for the study area is given in Appendix F.

Lower Pismo Creek

The groundwater quality in lower Pismo Creek (only about the last 2 miles are in the study area) generally does not meet the sulfate, chloride, and TDS Drinking Water Standards. Analyses from 10 wells sampled in the 1960s showed concentrations of sulfate ranging from 677 to 1 mg/L; chloride, from 1,626 to 143 mg/L; and TDS, from 3,640 to 760 mg/L. The predominant ions are sodium and chloride-bicarbonate or sulfate-chloride. A study by the Department in 1965 concluded that the poor quality of groundwater in lower Pismo Creek resulted from the presence of faults and mineralized zones, residual saline deposits, and local sea water intrusion. Sampled well depths ranged from 40 to 102 feet.

Arroyo Grande Valley

The Arroyo Grande Valley occupies 6 ½ miles of the Arroyo Grande Creek watershed below Lopez Dam.

The data set for the valley consists of analyses from 21 wells measured from 1954 through 1988. Of those wells, 12 have been sampled only once.

The Stiff diagrams on Figure 34 show the progressive deterioration of the groundwater quality in a downstream direction. The predominant cations in groundwater in the valley are calcium and magnesium and the predominant anions are bicarbonate in the upstream section, above the confluence with Tar Spring Creek, and sulfate in the downstream section, below Tar Spring Creek. This downstream section overlies a zone of multiple faults that is probably highly mineralized and is the main reason for the poor quality of the groundwater. Irrigation return water also contributes to the poor quality. Sampled wells in the valley are 60 to 120 feet deep.

The hydrographs on Figure 35 show the range in quality that has been found in groundwater of the valley. Except for concentrations of TDS and sulfate in water from one well, concentrations of TDS, sulfate, and chloride in groundwater in the upstream section meet Drinking Water Standards and the water is classified as suitable under water quality guidelines for agricultural

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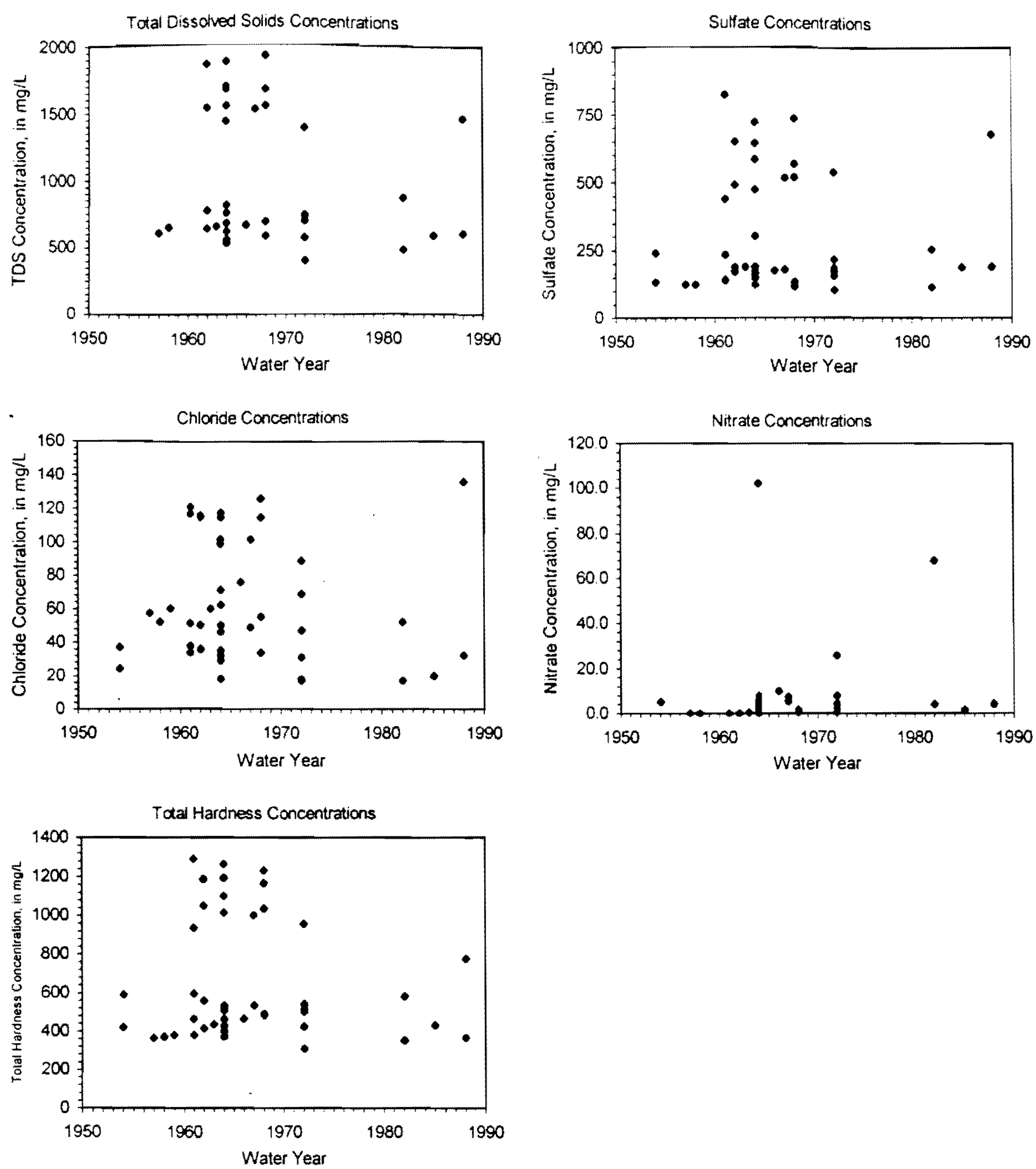
[3]Hydrographs were not constructed for the lower Pismo Creek area because of its very small data set.

FIGURE 35 - GROUNDWATER QUALITY HYDROGRAPHS, ARROYO GRANDE VALLEY WELLS



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irrigation. In the downstream section, the concentrations of TDS above about 1,500 mg/L that are found in extracted groundwater exceed the short-term Drinking Water Standard. Likewise, the sulfate concentrations above about 500 mg/L exceed the upper limit of the standard. The concentrations of these constituents also render the groundwater to be classified as marginal to unsuitable under water quality guidelines for agricultural irrigation. Chloride concentrations are low and meet the recommended Drinking Water Standard. Nitrate concentrations in water from two wells, one upstream and one downstream, sampled one time only, exceeded the maximum contaminant level (MCL). The groundwater in the valley is classified as very hard.

Newsom's Hot Springs are in Newsom Canyon, a tributary of Arroyo Grande Valley. The hot sulfur springs emanating from Miocene rocks occur probably along mineralized zones. The springs had been developed for public use. One of the springs issued water of 100°F. An 1888 chemical analysis showed that the spring water had magnesium, calcium, and sodium as the dominant cations, bicarbonate as the dominant anion, and a TDS concentration of 630 mg/L.

Tri-Cities Mesa Area

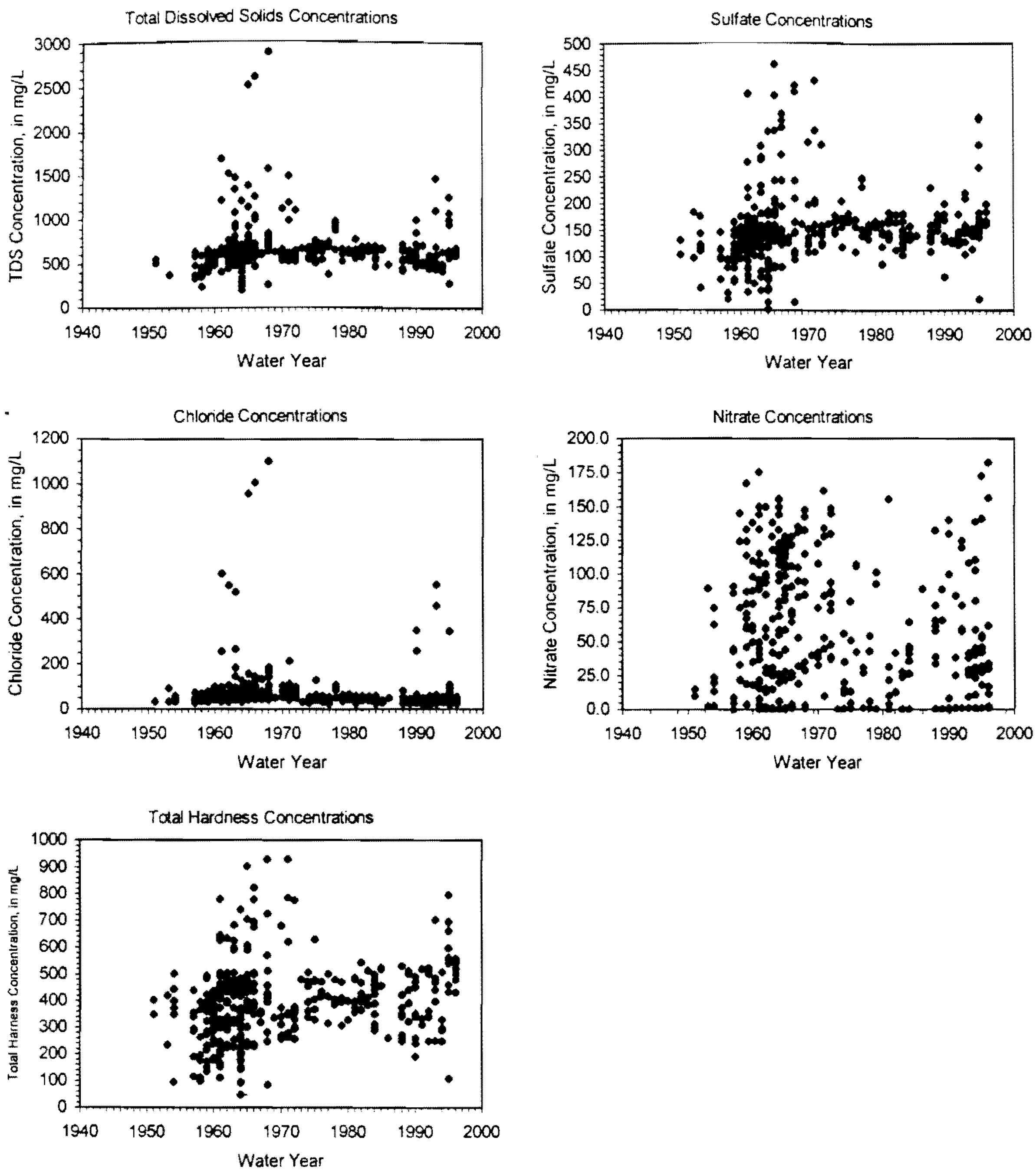
The data set for the Tri-Cities Mesa area consists of analyses from 91 wells measured from 1951 through 1996. Of those wells, 37 have been sampled only once. Water agency wells in this area are sampled recurrently. Depth of sampled wells ranges from 36 to 580 feet.

Stiff diagrams on Figure 34 show that the predominant cations are calcium and magnesium and predominant anions are bicarbonate and sulfate.

Water quality hydrographs for this area are shown in Figure 36. Groundwater in this area commonly contains TDS concentrations that exceed the recommended Drinking Water Standard. Ten of the sampled wells extracted groundwater with concentrations of sulfate greater than 250 mg/L. These wells, which also had concentrations of TDS greater than 1,000 mg/L, lie along low marshy coastal areas and in the southern part of the mesa. With a few exceptions, chloride concentrations in groundwater meet the recommended Drinking Water Standard. The concentrations of TDS above 2,500 mg/L and chloride above 500 mg/L were attributed to tidal inflows in lagoons near the shallow wells (Department of Water Resources, 1970). Groundwater is classified as suitable to marginal under water quality guidelines for agricultural irrigation. About half of all analyses for nitrate concentrations in water from wells exceeded the MCL, mainly in wells that are less than 200 feet in depth. The quality is impaired by return irrigation water. Most of the groundwater is classified as very hard, although a few wells in the northern part of the mesa have soft water.

Also, TDS and chloride concentrations in water from two standby wells north of Grover Beach near the San Luis Range (-18P1 and -19B1 on Figure 34) do not meet Drinking Water Standards. The chemical character of groundwater from these wells is sodium chloride. The wells had TDS concentrations of 1,100 and 1,400 mg/L and chloride concentrations of 552 and 460 mg/L. The groundwater is classified as very hard. Because the wells are in proximity to the Wilmar Avenue fault and in a tributary of Pismo Creek, mineralization from the fault zone, old saline deposits, or

FIGURE 36 - GROUNDWATER QUALITY HYDROGRAPHS, TRI-CITIES MESA AREA WELLS



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possibly local sea water intrusion in the shallow alluvium may all affect the groundwater quality.

Arroyo Grande Plain

The plain is an area of intense farming. In addition, it receives runoff from the Arroyo Grande Valley, also a farming area, and Los Berros Creek, a small alluvial valley with orchards and small farm acreage, and in the past, a small feedlot for cattle.

The data set for this area consists of analyses from 43 wells measured from 1951 through 1988. Of those wells, about three-fourths have been sampled only once. Sampled wells are 38 to 396 feet deep, with most in the 90- to 100-foot range.

The predominant cations in groundwater in this area are calcium and magnesium and the predominant anion is sulfate (-33G1 and -33K3 on Figure 34).

Water quality hydrographs are given in Figure 37. Only 10 percent of the sampled wells produce groundwater with TDS concentrations of less than 500 mg/L and slightly less than half of the wells produce groundwater with sulfate concentrations of less than 250 mg/L. Some wells in this area produce water with concentrations of TDS greater than 1,500 mg/L and sulfate greater than 600 mg/L. These wells are generally near the confluence of Los Berros Creek with Arroyo Grande Creek and in the southern part of the plain. Chloride concentrations in groundwater meet the recommended Drinking Water Standard. About half of the wells produce water with concentrations of nitrate that exceed the MCL. The quality is impaired by return irrigation water. The groundwater is classified as very hard; only a very few wells produce water classified as soft.

Some wells produce groundwater that is classified as marginal under water quality guidelines for agricultural irrigation.

Nipomo Mesa

The Stiff diagrams on Figure 34 and the water quality hydrographs on Figure 38 illustrate the mainly good quality groundwater found in Nipomo Mesa compared with that in other parts of the study area. The quality reflects recharge of this area principally by percolation of rainfall.

The data set for Nipomo Mesa consists of analyses from 86 wells measured from 1954 through 1997. Of those wells, 37 have been sampled only once. Water agency wells in this area are sampled recurrently. Sampled wells range in depth from 24 to 810 feet, with well depth typically increasing toward the west and south.

About three-fourths of the sampled wells produced groundwater with TDS concentrations that are less than 500 mg/L and about 85 percent of the wells produced groundwater with sulfate concentrations that are less than 250 mg/L. The higher sulfate and TDS concentrations in groundwater are generally found in the deeper wells and in the western and southern parts of the mesa. Chloride concentrations are low, less than 150 mg/L, in extracted groundwaters and meet

FIGURE 37 - GROUNDWATER QUALITY HYDROGRAPHS, ARROYO GRANDE PLAIN AREA WELLS

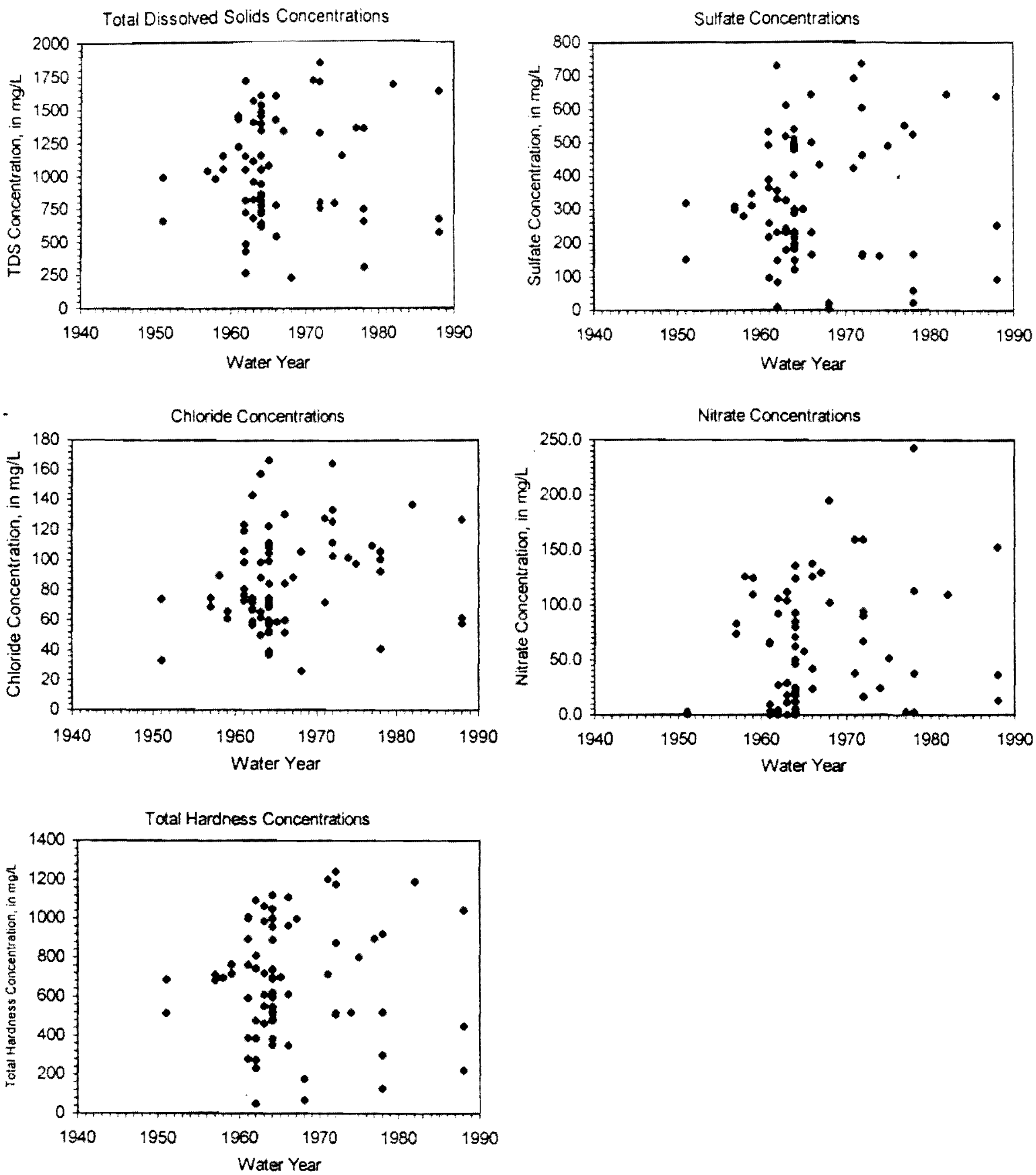

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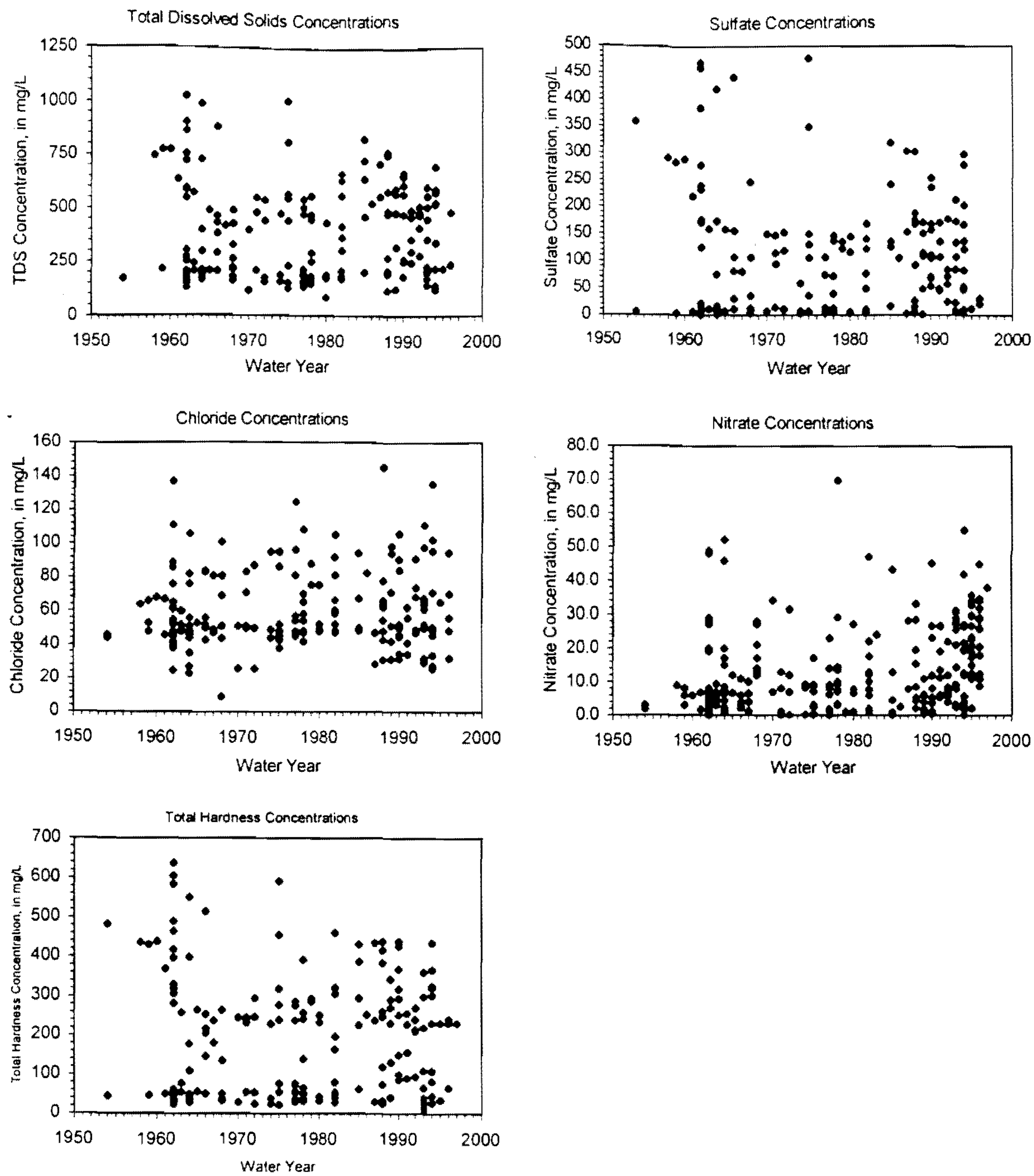
FIGURE 38 - GROUNDWATER QUALITY HYDROGRAPHS, NIPOMO MESA WELLS



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the recommended Drinking Water Standard. A few wells have exceeded the nitrate MCL. These wells are mainly in the northwestern part of the mesa. About half of the sampled wells extract groundwater classified as soft; otherwise, it ranges from moderate to very hard. The soft groundwater is mainly sodium chloride in character. The predominant cations in other groundwaters are mainly calcium and magnesium or sodium and the predominant anions are sulfate and bicarbonate.

Groundwater is classified as suitable to marginal under water quality guidelines for agricultural irrigation.

If the pumping depression on the mesa pulls in water from the Santa Maria Valley, the possibility exists for the poorer quality groundwater of the valley, containing high concentrations of dissolved solids, to locally reduce the quality of the mesa's groundwater. Existing data were not sufficient to show evidence of this possible situation.

Santa Maria Valley

Within the study area, the Santa Maria Valley is largely an agricultural area, with thousands of acres under irrigation.

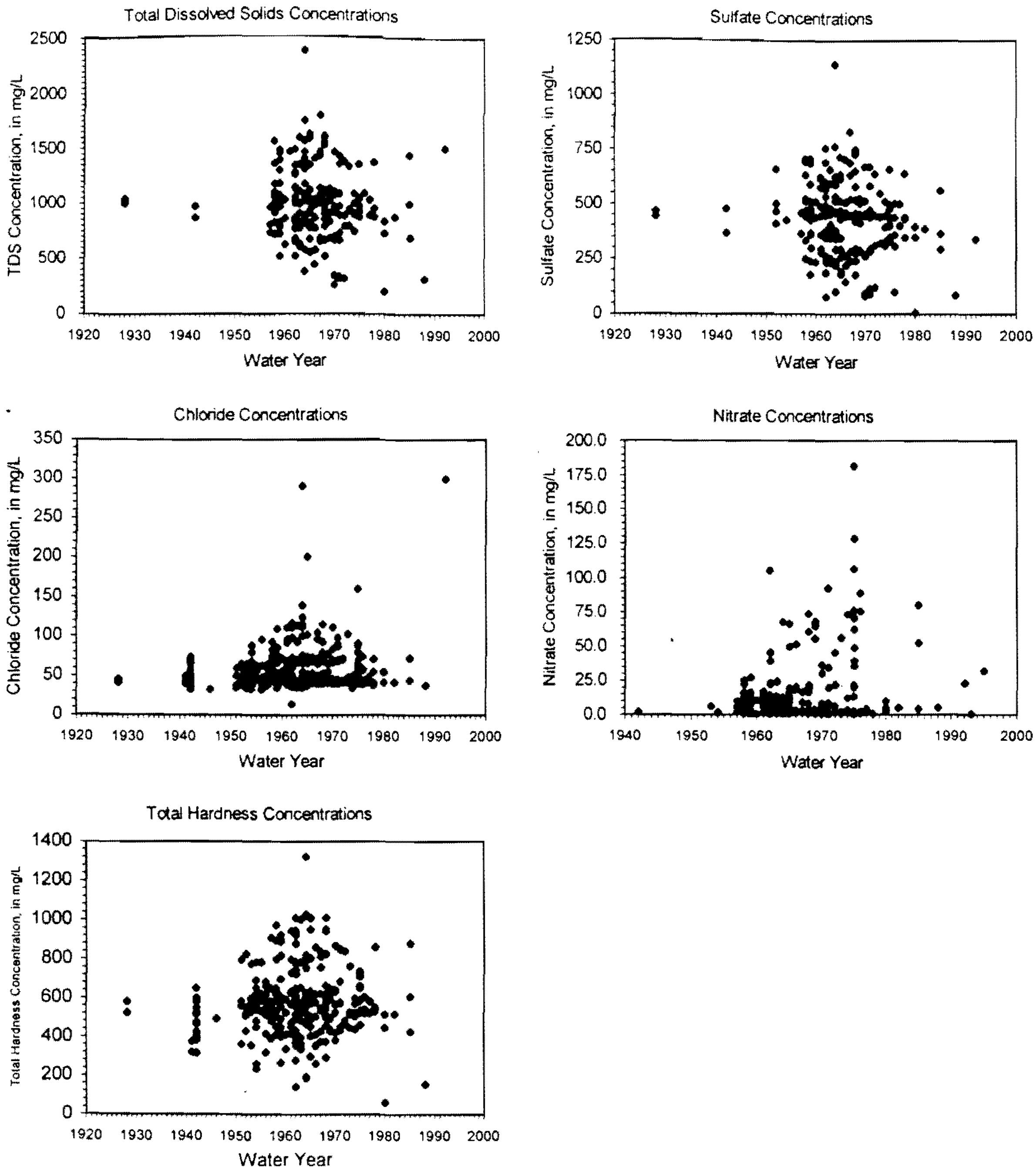
The data set for the valley consists of analyses from 57 wells measured from 1928 through 1995. Of those wells, about half have been sampled only once. Adequate sampling has not been conducted in the valley since 1975, as can be seen on the water quality hydrographs shown in Figure 39. A complete mineral analysis of groundwater was last performed on only one well in 1988, and the few analyses in the 1990s have been for one or two selected constituents. Also, except for sea water intrusion monitoring wells, little or no data within approximately 2 miles of the ocean in the valley north of the river are available. Sampled wells ranged from less than 50 feet to greater than 600 feet in depth.

Most groundwater in the valley may be characterized as a calcium-magnesium sulfate type (Figure 34). This water type reflects the quality of recharge from the Santa Maria River, which receives its flow from the Cuyama and Sisquoc Rivers. Gypsum deposits in Tertiary and pre-Tertiary marine deposits in the Cuyama Valley have been thought to influence the quality of runoff in the Cuyama River (Singer and Swarzenski, 1970).

The use and reuse of groundwater for irrigation is the major factor affecting quality of groundwater in the valley within the study area. The deep percolation of applied water with salts added from use tends to increase the salt concentrations in groundwater with each cycle of use.

TDS and sulfate concentrations in water from wells generally did not meet the recommended Drinking Water Standards and caused the water to be classified as marginal to unsuitable under water quality guidelines for agricultural irrigation (Figure 39). In a well just west of Highway 1, the TDS concentration was as high as 2,372 mg/L and the sulfate concentration as high as 1,145 mg/L. About 25 percent of the sampled wells extracted groundwater with nitrate concentrations

FIGURE 39 - GROUNDWATER QUALITY HYDROGRAPHS, SANTA MARIA VALLEY WELLS



that exceed the MCL, some with concentrations as high as about four times the MCL. The higher concentrations tended to be found in the shallower wells. With the exception of water from two wells, chloride concentrations in groundwater have been less than 250 mg/L. Most of the groundwater is classified as very hard. Only four wells have had total hardness concentrations of less than 200 mg/L. The better quality groundwater appears to be along the northern periphery of the valley.

Nipomo Valley

The data set for Nipomo Valley consists of analyses from 22 wells measured from 1962 through 1995. Of those wells, only five have been sampled more than once. Given the number of wells and the increasing development in the valley area, adequate sampling has not been conducted, as can be seen on the water quality hydrographs shown in Figure 40. In Nipomo Valley, most wells are between 100 and 300 feet deep and are drilled through the shallow older alluvium and into the underlying fractured and weathered bedrock of the Obispo and Monterey Formations.

The predominant cations in groundwater in the valley are calcium and magnesium and the predominant anion is mainly bicarbonate (Figure 34).

Most of the wells extracted groundwater with TDS concentrations ranging between 500 and 1,000 mg/L, meeting upper limits for drinking water. Four wells extracted groundwater with sulfate concentrations that were greater than 250 mg/L. Only one well produced groundwater having a chloride concentration greater than 250 mg/L. Two wells produced groundwater with nitrate concentrations exceeding the MCL. Like most of the groundwater in the study area, the groundwater is classified as very hard.

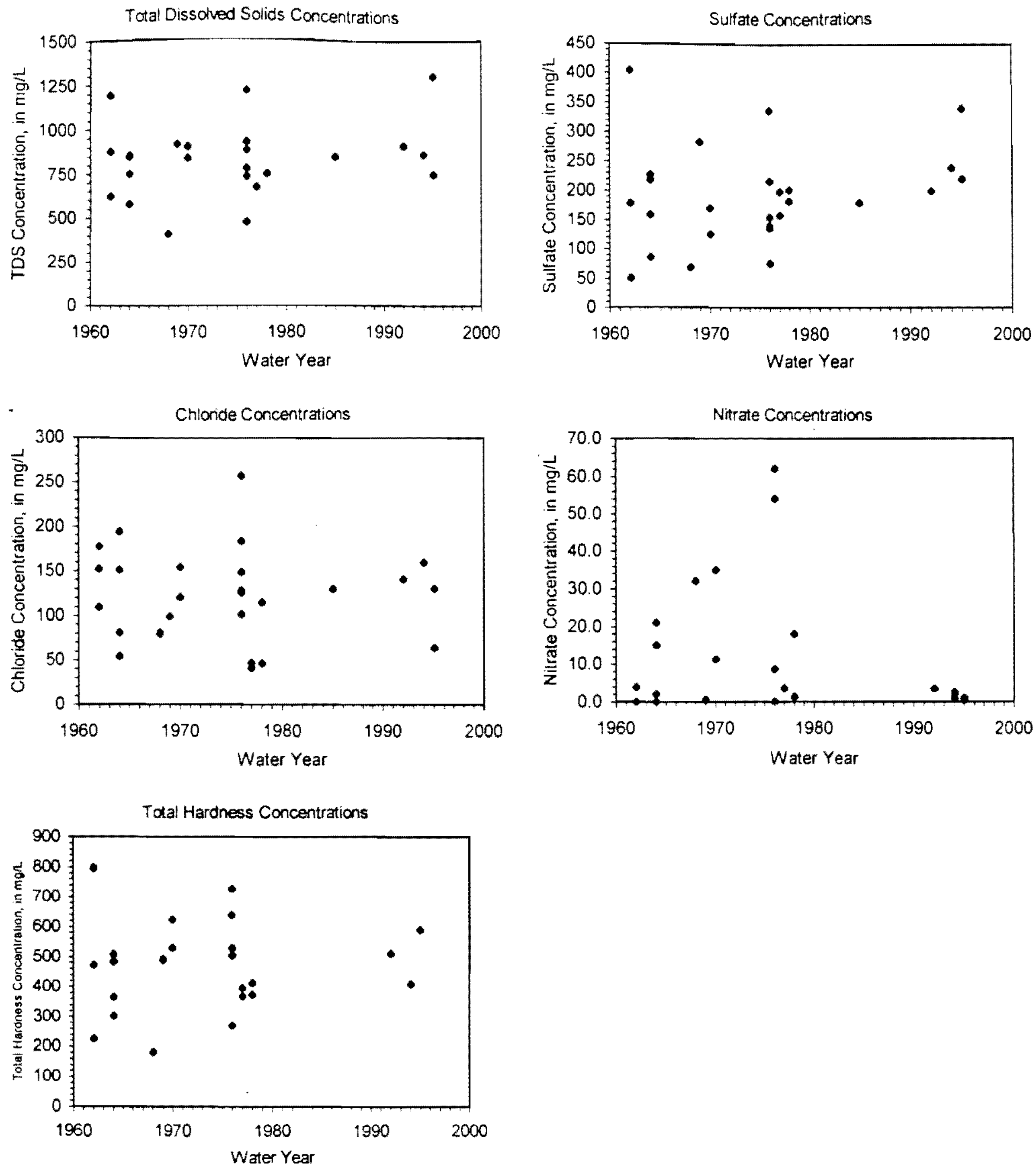
Groundwater is classified as suitable to marginal under water quality guidelines for agricultural irrigation.

Groundwater Quality Trends

Chloride is a useful constituent to detect quality changes. In hydrochemical groundwater evolution, the chloride ion tends to be the most conservative, being affected very little by biological processes, by precipitation, or by anion exchange reactions in the soil (Pomeroy and Orlob, 1967). Chloride concentrations therefore normally increase down the hydraulic gradient and with groundwater residence (Lloyd and Heathcote, 1985). The normal chloride concentration increase is disturbed only where pollution or dilution occurs, thus chloride is an excellent indicator of the direction of groundwater flow and of changes associated with long-term cycles of rainfall or runoff or changes in land or water use.

Because chloride concentrations in groundwaters may indicate quality changes over time, this parameter was used to evaluate trends in the groundwater quality--if degradation has occurred over time. Wells with recurrent analyses of chloride concentrations over their period of record

FIGURE 40 - GROUNDWATER QUALITY HYDROGRAPHS, NIPOMO VALLEY WELLS



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were evaluated and statistically tested to see if any trend existed.

Seventeen wells within the groundwater basin had recurrent analyses of chloride concentrations that could be evaluated for trends. Of those wells, only one in the Tri-Cities Mesa area had a statistically significant increase in chloride concentrations over time. Chloride concentrations rose by about 15 mg/L to 47 mg/L over about 20 years. Three other wells in the same area had downward trends in chloride concentrations over time. The remaining wells in the basin had no significant trends in chloride concentrations over time.

Occurrence of Nitrate

Nitrate is one of the most problematic of all groundwater mineral constituents and its toxicology is such that Department of Health Services established the 45 mg/L (as nitrate) MCL.

Because nitrate does not occur naturally in the study area, the nitrate found in the groundwater is a result of human activity. The main sources of nitrate are applied fertilizers and wastewater. Minor sources of nitrate are the animal waste produced by cattle feedlots, chicken and hog ranches, and miscellaneous livestock. Some of these sources no longer exist, but the residual nitrate in the soils at the sites may continue to leach out to affect the groundwater quality.

Nitrate from fertilizers is introduced into the groundwater basin over a broad area wherever irrigated acreage exists. Farms and orchards are found in all parts of the basin, but are concentrated in Arroyo Grande Valley and Plain and in Santa Maria Valley. There are also several hundred acres of farms in Nipomo Valley adjacent to the basin, which probably contribute nitrate and other chemicals to the basin. The nitrate and nitrogen compounds in the applied fertilizers are carried to groundwater with deep percolation of rainwater or irrigation return.

In the past, nitrate from wastewater effluent was also introduced into the groundwater basin over a broad area. Before the construction of wastewater collection systems and treatment plants, the standard disposal method was by septic tanks and leachfields and cesspools wherever there was a home, business, or farm. Later and until 1966, the City of Arroyo Grande operated a limited collection system and treatment plant, discharging its treated effluent to percolation ponds and spreading grounds southeast of Grover Beach. These old septic tank leachfields, cesspools, and ponds are no longer operating, but they continue to contribute nitrate and other minerals to the basin as rainwater and irrigation return infiltrate the underlying sediments and leach the nitrate compounds retained in the sediments. The rise and fall of groundwater levels during very wet seasons may also leach nitrate from the vadose zone above the water table.

With the building of an ocean outfall, wastewater from this area of the groundwater basin has largely been removed as an ongoing source of nitrate.

Wastewater from one of the two plants operated by the Nipomo Community Services District discharges to a percolation pond or is used to irrigate the Black Lake Country Club golf course.

In conjunction with its conservation program, the district monitors the local groundwater. Its four monitoring wells show very low nitrate concentrations.

The district's second plant is located southwest of Nipomo. It collects and treats wastewater from Nipomo and a small part of the mesa. After treatment, the effluent is discharged to percolation ponds from which it recharges the groundwater basin. Three wells monitor the groundwater near the disposal area. The wells, which are 249 feet, 222 feet, and 225 feet deep, show nitrate concentrations well below 45 mg/L.

Grover Beach has continued to use the local groundwater, which is high in nitrate, by reducing the nitrate concentrations to acceptable levels. In 1989, the city constructed a 2.3-million-gallon per day (mgd) ion exchange plant on city property at 16th Street and Mentone Ave. The supply wells are nearby. The product water from the plant is piped directly into the water supply system. A report in 1993 indicated that of the 1,750 AF of water required by the city annually, 500 AF is produced by the nitrate removal plant.

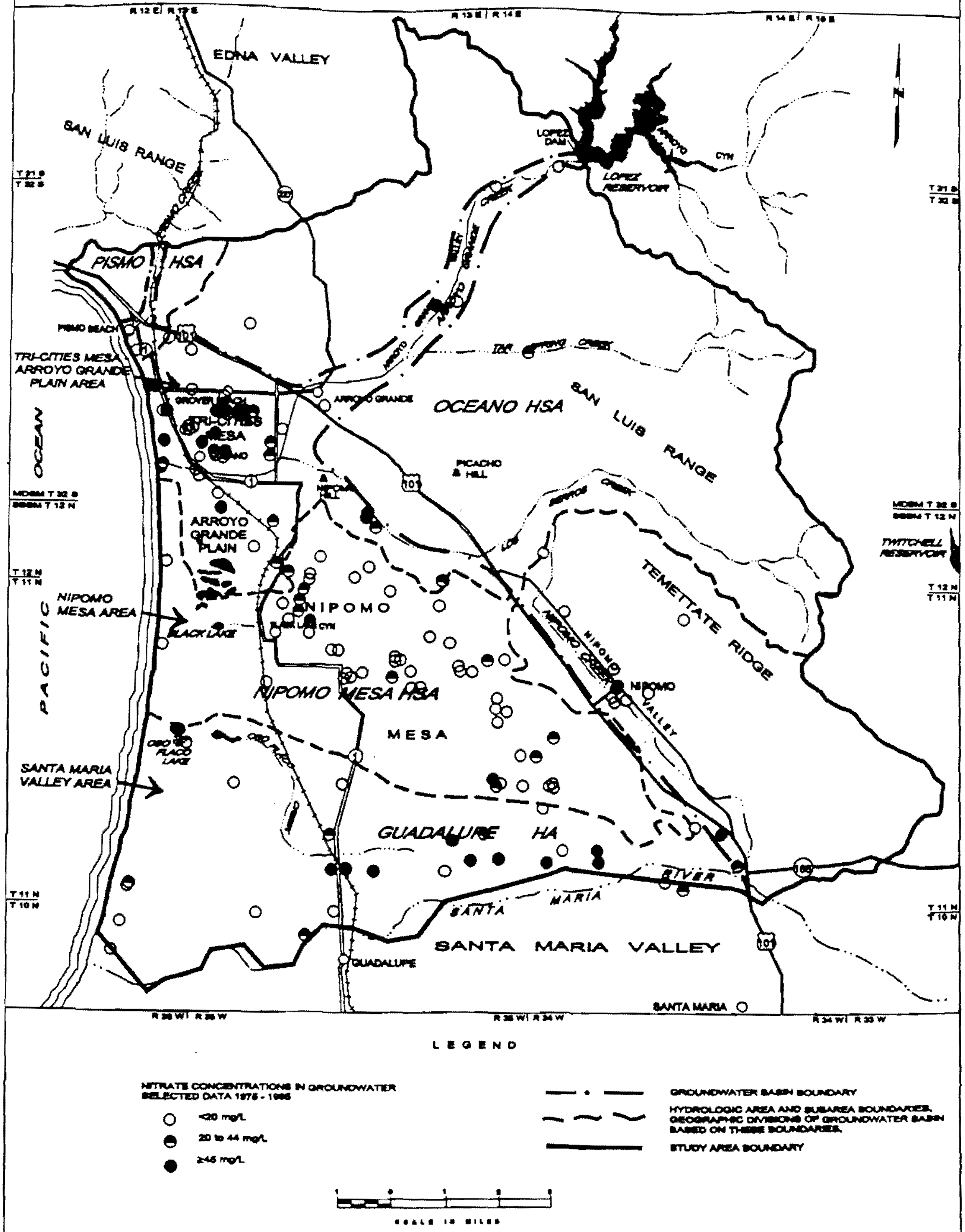
Nitrate concentrations found in water from wells sampled between 1975 and 1995 are plotted on Figure 41. The figure graphically shows the spatial distribution of three ranges of nitrate concentrations. From the figure, it can be seen that groundwater with nitrate concentrations exceeding the MCL is found mainly in the Tri-Cities Mesa - Arroyo Grande Plain area and the Santa Maria Valley.

Data from 1975 to 1995 are not available for large portions of the study area, particularly for agricultural areas. Historically, groundwater in these agricultural areas exceeded the MCL. These high nitrate concentrations have been attributed to the ongoing agricultural activities, and the high nitrate concentrations in the groundwater probably remain high.

In 1979, McCulley published results of a study that used isotopic analyses of nitrate in groundwater to determine the source of nitrate in the Tri-Cities Mesa - Arroyo Grande Plain area. Previous studies had been unable to determine whether cultivation practices, fertilizer, or infiltration of wastewater from septic tanks is the source of nitrate. McCulley found that the congruent isotopic range of nitrate in groundwater and agricultural soils demonstrated that most of the nitrate in groundwater was from agricultural land use (1979, p. 827). The study could not differentiate between nitrate derived from nitrogenous fertilizer and from oxidation of organic nitrogen.

No strong trends showing areas of decreasing or increasing nitrate concentrations were found. The nitrates contributed from old wastewater disposal practices would be expected to decrease, and the influence from the use of fertilizers will continue to be the major factor determining nitrate concentrations in the groundwater. As irrigation continues in the agricultural areas and in green areas around new developments, groundwater in these areas may also develop high concentrations of nitrate. Because nitrate concentrations may exceed the Department of Health Services's MCL in some areas, groundwater supplies for domestic use should be routinely tested for high nitrate content.

FIGURE 41 - NITRATE CONCENTRATIONS IN GROUNDWATER



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Sea Water Intrusion

The Santa Maria Groundwater Basin is hydraulically continuous offshore beneath the ocean. If groundwater pumpage were to exceed recharge to the basin, the natural seaward gradient would reverse and sea water would migrate landward, displacing freshwater in the aquifer. This can eventually result in sea water intrusion into the inland basin and in water supply wells; however, sea water can migrate landward for many years before the inland basin is intruded. Seasons of heavy rainfall, which result in increased recharge to the basin and reduced pumping from the basin, will increase the seaward head in the groundwater and slow encroachment of sea water or even reverse the process.

Data are currently inadequate to define the configuration and storage of the offshore aquifer and the occurrence and extent of possible sea water intrusion in that aquifer. Thus, a monitoring program for early detection of sea water intrusion into the landward groundwater basin is important for protection of the Santa Maria Groundwater Basin. The monitoring program should include plans to mitigate sea water intrusion before it occurs. Such plans might initially consider changes in spatial distribution and quantity of groundwater pumpage, along with surface water deliveries for artificial recharge.

Concentrations of 100 mg/L or more of chloride in samples are generally considered an indication of sea water intrusion (Izbicki, 1991). Nevertheless, chloride can come from other sources, such as natural mineral deposits, fertilizers, and naturally poor quality water; consequently, a high concentration of chloride alone as an indicator of sea water intrusion can be misleading. Other indicators of sea water intrusion should be considered together with the high chloride content in determining the presence of sea water intrusion.

In previous studies, the State and San Luis Obispo County constructed sea water intrusion monitoring wells along the coast, between the City of Pismo Beach and the San Luis Obispo-Santa Barbara County line, a distance of about 12 miles. A typical monitoring well contains two or more piezometers, separated by cement plugs to ensure discrete samples from selected depths.

Seven of these monitoring wells, containing a total of 26 piezometers, were sampled in March 1996 for this study[4]. The 1996 water quality data, plus historical data, for these wells are listed in Table 23. The wells are identified by State Well Numbers and their piezometer depths are given. Their locations are shown on Figure 42. The data were reviewed to evaluate the status of sea water intrusion in the study area.

In the Pismo Beach-Oceano area, three wells containing nine piezometers sample groundwater from 48 to 435 feet deep. Samples from the shallow piezometer 32S/12E-24B1 show high concentrations of chloride. However, samples from this depth have historically shown high concentrations of sodium chloride. Because of the unconfined condition and the shallow depth of

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[4]Samples could not be obtained from three shallow piezometers, 32S/13E-30F01, 32S/13E-30N01, and 11N/36W-35J06, because they were dry.

TABLE 23
SEA WATER INTRUSION MONITORING WELLS, SELECTED DATA

State Well No.	Date yr/mo/day	pH lab	TDS180 mg/L	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	HCO3 mg/L	SO4 mg/L	Cl mg/L	NO3 mg/L	B mg/L	Fl mg/L	CaCO3 mg/L	Perforated interval (feet)
32S/12E-24B01 M	660117	8.2	1700	95	83	406	20.0	440	175	652	1.0	0.07	0.3	579	48-65
32S/12E-24B01 M	760609	8.2	1706	94	95	400	16.2	474	159	667	0.4	0.12	0.5	625	48-65
32S/12E-24B01 M	960326	7.8	1870	125	95	380	24.0	427	154	773	0.2	0.27	--	--	48-65
32S/12E-24B02 M	660117	8.3	651	101	32	79	5.0	380	147	62	0.0	0.05	0.3	384	120 - 145
32S/12E-24B02 M	760609	7.9	565	104	27	52	4.0	337	153	34	0.6	0.02	0.5	371	120 - 145
32S/12E-24B02 M	960326	7.8	652	107	24	46	5.0	344	169	54	0.2	0.10	--	--	120 - 145
32S/12E-24B03 M	660117	8.0	670	103	36	74	5.0	345	158	79	1.0	0.00	0.2	405	270 - 435
32S/12E-24B03 M	760609	7.8	569	85	39	53	3.7	330	165	36	0.0	0.06	0.4	373	270 - 435
32S/12E-24B03 M	960326	7.8	646	104	42	52	4.3	412	164	41	0.2	--	--	--	270 - 435
32S/13E-30F02 M	660120	7.6	580	94	38	47	2.0	280	152	68	27.0	0.08	0.2	391	75 - 100
32S/13E-30F02 M	760609	8.0	637	98	43	55	2.8	343	172	48	17.6	0.10	0.5	421	75 - 100
32S/13E-30F02 M	960327	7.4	678	98	42	52	3.8	--	166	49	49.0	0.16	--	--	75 - 100
32S/13E-30F03 M	660119	7.8	642	109	40	49	4.0	321	182	69	1.0	0.05	0.3	437	305 - 372
32S/13E-30F03 M	760609	7.8	616	96	49	41	2.6	333	190	43	0.4	0.05	0.5	441	305 - 372
32S/13E-30F03 M	960327	7.6	686	109	48	40	3.4	--	197	41	0.2	0.13	--	--	305 - 372
32S/13E-30N02 M	660121	7.5	1069	148	63	71	5.0	232	483	54	0.0	0.12	0.5	629	175 - 255
32S/13E-30N02 M	760607	7.9	1093	150	60	62	4.7	248	484	48	0.0	0.13	0.7	624	175 - 255
32S/13E-30N02 M	960327	8.1	1050	145	60	71	8.1	--	516	50	0.9	0.23	--	199.0	175 - 255
32S/13E-30N03 M	660122	7.5	804	132	59	54	3.0	410	250	57	1.0	0.08	0.5	572	60 - 135
32S/13E-30N03 M	760607	8.0	705	99	43	54	2.9	189	168	90	112.5	0.08	0.5	424	60 - 135
32S/13E-30N03 M	960327	7.7	624	78	35	62	4.0	--	161	70	106.8	0.13	--	123	60 - 135
12N/36W-36L01 S	760608	7.9	936	130	48	72	3.5	223	423	38	0.6	0.15	0.7	521	227 - 237
12N/36W-36L01 S	960326	7.8	882	124	47	66	4.8	--	408	35	2.0	0.24	--	--	227 - 237
12N/36W-36L02 S	760608	8.0	820	94	44	118	6.6	393	184	126	0.0	0.36	0.5	414	535 - 545
12N/36W-36L02 S	960326	7.8	772	86	36	130	8.7	--	148	127	0.2	0.50	--	--	535 - 545
11N/36W-12C01 S	760608	8.0	920	139	47	72	3.5	219	439	40	1.4	0.14	0.7	540	280 - 290
11N/36W-12C01 S	960326	8.6	962	136	49	70	4.7	--	474	38	1.8	0.25	--	--	280 - 290
11N/36W-12C02 S	760608	7.7	1015	129	52	90	4.6	184	488	48	1.4	0.16	0.5	536	450 - 460
11N/36W-12C02 S	960326	8.1	1090	150	52	80	5.2	--	552	46	1.2	0.27	--	--	450 - 460
11N/36W-12C03 S	760608	7.8	813	89	43	98	5.9	293	235	94	0.4	0.24	0.4	399	720 - 730
11N/36W-12C03 S	960326	8.1	790	97	51	92	6.0	--	246	91	0.2	0.32	--	--	720 - 730
11N/36W-35J02 S	670928	7.7	811	106	46	63	4.0	261	332	28	1.3	0.12	0.4	454	527 - 615
11N/36W-35J02 S	770726	--	860	110	49	60	3.2	260	340	28	--	0.10	--	470	527 - 615
11N/36W-35J02 S	871028	7.5	773	110	48	56	2.2	277	340	26	2.1	0.15	0.2	--	527 - 615
11N/36W-35J02 S	960327	7.4	776	107	52	57	3.2	--	362	27	2.2	0.20	--	--	527 - 615

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TABLE 23 continued
SEA WATER INTRUSION MONITORING WELLS, SELECTED DATA

State Well No.	Date yr/mo/day	pH lab	TDS180 mg/L	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	HCO3 mg/L	SO4 mg/L	Cl mg/L	NO3 mg/L	B mg/L	Fl mg/L	CaCO3 mg/L	Perforated interval (feet)
11N/36W-35J03 S	670928	7.8	1031	132	55	89	4.0	239	462	54	10.8	0.18	0.6	556	247 - 490
11N/36W-35J03 S	770726	--	1130	150	58	87	3.5	250	490	54	--	0.10	--	610	247 - 490
11N/36W-35J03 S	871028	7.7	1200	170	70	85	3.9	279	580	61	15.5	0.21	0.4	--	247 - 490
11N/36W-35J03 S	960327	7.4	1230	179	64	88	4.0	--	556	57	26.3	0.28	--	--	247 - 490
11N/36W-35J04 S	670928	7.5	1177	159	67	90	4.0	265	530	66	11.5	0.14	0.7	673	175 - 228
11N/36W-35J04 S	770726	--	1460	190	73	86	4.3	300	600	72	--	0.20	--	780	175 - 228
11N/36W-35J04 S	871028	7.5	1490	220	86	90	0.3	346	740	77	12.8	0.23	0.4	--	175 - 228
11N/36W-35J04 S	960327	7.4	1500	343	21	96	4.4	--	665	72	22.7	0.33	--	--	175 - 228
11N/36W-35J05 S	670928	7.4	1029	134	57	81	4.0	260	453	45	5.0	0.13	0.7	569	74 - 138
11N/36W-35J05 S	770726	--	955	160	60	75	3.5	269	500	49	--	0.10	--	650	74 - 138
11N/36W-35J05 S	871028	7.5	1100	170	66	75	3.6	305	520	52	5.3	0.19	0.5	--	74 - 138
11N/36W-35J05 S	960327	7.4	1210	--	69	82	3.8	--	554	53	8.9	0.27	--	--	74 - 138
10N/36W-02Q01 S	670929	7.9	818	101	52	57	4.0	229	353	29	1.5	0.11	0.4	466	567 - 671
10N/36W-02Q01 S	770726	--	890	120	51	56	3.1	250	360	28	--	0.10	--	500	567 - 671
10N/36W-02Q01 S	871028	7.7	799	110	50	52	3.2	249	370	27	1.9	0.13	0.2	--	567 - 671
10N/36W-02Q01 S	960327	7.2	824	113	55	56	3.7	--	352	30	2.1	0.19	--	--	567 - 671
10N/36W-02Q02 S	670929	7.9	726	90	41	67	4.0	254	294	24	1.3	0.11	0.4	393	466 - 535
10N/36W-02Q02 S	770726	--	780	99	44	59	3.2	260	300	24	--	0.10	--	430	466 - 535
10N/36W-02Q02 S	960327	--	758	102	49	56	3.1	--	278	27	2.0	0.19	--	--	466 - 535
10N/36W-02Q03 S	670929	7.8	741	95	47	53	3.0	249	303	22	1.0	0.09	0.4	431	397 - 444
10N/36W-02Q03 S	770726	--	800	100	47	53	2.9	250	310	24	--	0.10	--	440	397 - 444
10N/36W-02Q03 S	871028	7.7	696	99	46	47	3.0	248	300	21	1.9	0.13	0.2	--	397 - 444
10N/36W-02Q03 S	960327	7.2	706	92	45	53	3.5	--	286	26	1.9	--	--	215	397 - 444
10N/36W-02Q04 S	670929	8.1	712	93	44	53	3.0	248	291	24	1.5	0.09	0.4	413	291 - 378
10N/36W-02Q04 S	770726	--	750	100	46	49	2.6	250	290	23	--	0.10	--	440	291 - 378
10N/36W-02Q04 S	871028	7.9	698	96	44	47	2.7	250	300	22	2.3	0.13	0.2	--	291 - 378
10N/36W-02Q04 S	960327	7.0	730	46	49	3	--	312	23	3	0.2	--	--	--	291 - 378
10N/36W-02Q05 S	670929	7.6	973	131	54	75	3.0	245	417	56	5.3	0.14	0.5	549	185 - 246
10N/36W-02Q05 S	760521	8.0	943	141	54	77	2.7	254	420	64	6.8	0.18	0.7	574	185 - 246
10N/36W-02Q05 S	960327	8.0	1200	--	71	83	3.9	--	534	85	7.0	0.27	--	--	185 - 246
10N/36W-02Q06 S	670929	7.8	1000	139	54	82	3.0	250	439	61	3.5	0.18	0.6	569	129 - 170
10N/36W-02Q06 S	760521	7.9	813	119	52	61	2.6	258	355	42	4.4	0.08	0.6	511	129 - 170
10N/36W-02Q06 S	960327	7.2	1530	--	58	101	4.4	--	675	124	1.2	0.32	--	244.0	129 - 170
10N/36W-02Q07 S	670929	7.4	747	103	44	74	4.0	319	214	81	11.0	0.14	0.5	438	18 - 47
10N/36W-02Q07 S	760604	8.2	683	89	40	66	3.5	278	170	89	10.0	0.06	0.7	387	18 - 47
10N/36W-02Q07 S	871028	7.5	839	130	49	91	5.7	322	120	210	--	0.15	0.3	--	18 - 47
10N/36W-02Q07 S	960327	7.2	1310	195	32	190	11.5	--	190	387	0.3	0.40	--	340	18 - 47

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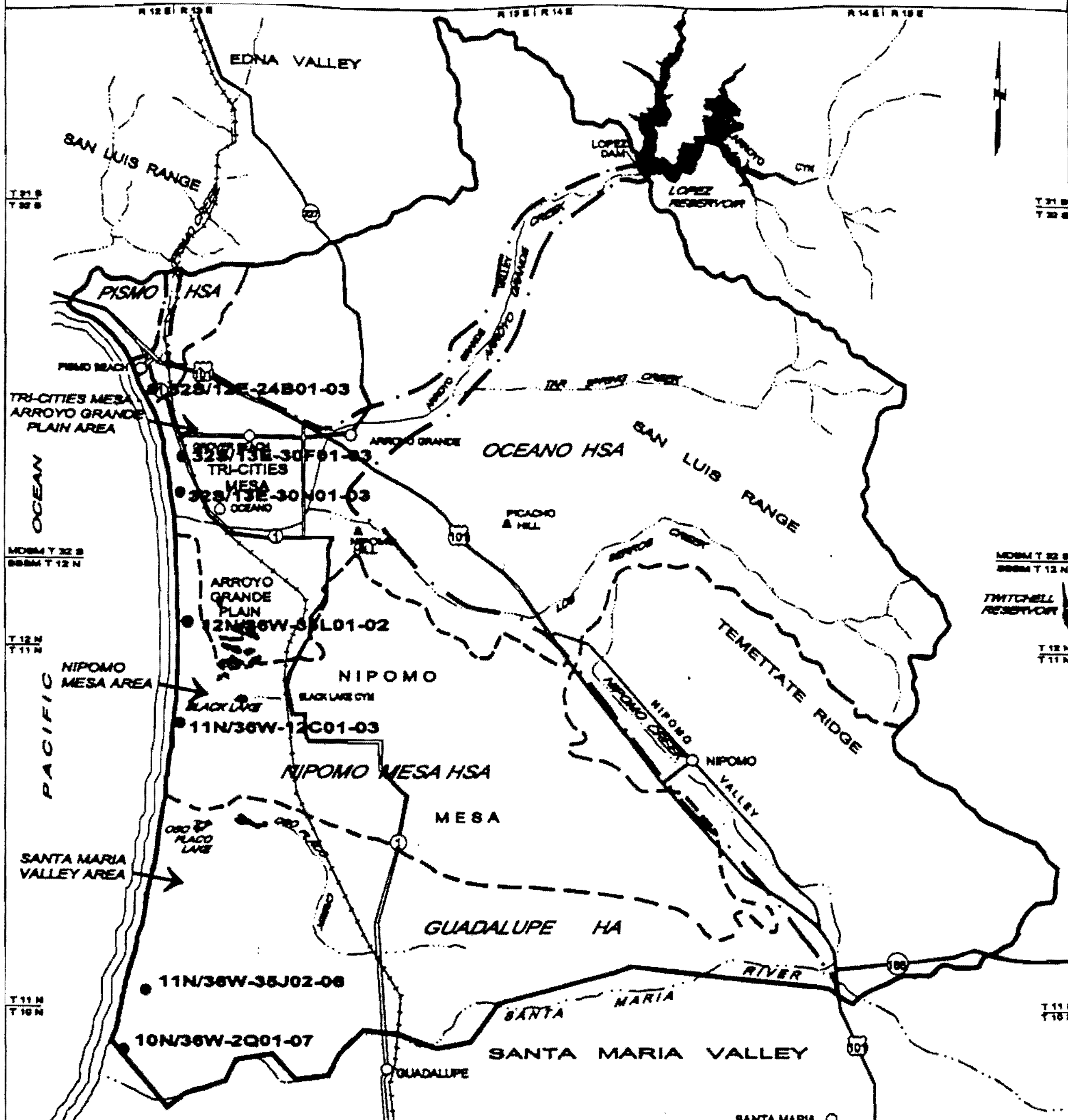
FIGURE 42 - SEA WATER INTRUSION MONITORING WELLS



LEGEND

NOTE: EACH WELL CONTAINS TWO OR MORE PIEZOMETERS

GROUNDWATER BASIN BOUNDARY

HYDROLOGIC AREA AND SUBAREA BOUNDARIES. GEOGRAPHIC DIVISIONS OF GROUNDWATER BASIN BASED ON THESE BOUNDARIES.

STUDY AREA BOUNDARY

SCALE IN MILES

DEPARTMENT OF WATER RESOURCES, SOUTHERN DISTRICT

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the piezometer, these high chloride readings are attributed to the influence of tidal action and infiltration of poor quality surface water. Samples from piezometers 32S/12E-24B2 and 32S/12E-24B3 show no sign of sea water intrusion. Also, the four other piezometers in the area--32S/13E-30F2 and -30F3 and 32S/13E-30N2 and -30N3-- show no sign of sea water intrusion.

Seaward of Nipomo Mesa, two wells containing five piezometers monitor depths of 227 to 730 feet. No sign of sea water intrusion is shown by the two piezometers 12N/36W-36L1 and -36L2 nor by the three piezometers 11N/36W-12C1, -12C2, and -12C3, which are on the beach west of Nipomo Mesa.

In the Santa Maria Valley near the coast, two wells contain 12 piezometers monitoring groundwater at depths of 18 to 671 feet. The shallow piezometer 10N/36W-02Q7 has shown high chloride concentrations. Earlier, it had shown high chloride concentrations, and in 1991, it showed a marked increase. This increase has diminished, but the concentration remains higher than its historical levels, which may be an indication of sea water intrusion into the shallow aquifer. However because of the shallow depth, this high chloride may result from tidal action and percolation of poor quality surface waters rather than sea water intrusion. The piezometer 10N/36W-02Q6 showed a relatively high chloride reading in 1996. It also had a high sulfate to chloride ratio. Because sea water normally has a low sulfate to chloride ratio, the high sulfate to chloride ratio suggests a strong influence from surface waters and fertilizers. The turbulence resulting from the creation and recovery of pumping depressions may have carried surface waters down to the lower levels. The five other piezometers in this well showed no sign of sea water intrusion.

Piezometers 11N/36W-35J2, -35J3, -35J4, and -35J5 in the Santa Maria floodplain also showed no sign of sea water intrusion.

To protect the quality of the groundwater, a regular yearly sea water intrusion monitoring program is advisable, with particular attention paid to piezometer 10N/36W-02Q6, to record any trends which would indicate that the changes are not wholly caused by infiltrating surface waters, but may also be caused by sea water intrusion.

Surface Water Quality

The chemical character and quality of surface waters are a function of a complex interrelation of climate, geology, topography, vegetation, runoff, aquifer-stream interconnection, and human activities such as land and water use and waste disposal practices. Surface water quality varies from time to time and from place to place, and quality changes can be quite pronounced. Typically, the quality varies inversely to the rate of discharge, with better quality waters observed during higher flows. In contrast with the quality of groundwater, the quality of surface water can be highly variable.

The quality of the surface waters recharging the groundwater basin from Arroyo Grande and

Pismo Creeks and their tributary creeks and Santa Maria River and Nipomo Creek reflects both base flow and runoff from rainfall. Stormflow results from precipitation runoff and subsurface discharge during the storm period. Baseflow of the Santa Maria River is composed of rising water, discharges of treated wastewater, releases of water stored in Twitchell Reservoir, bank seepage, and nonpoint discharges, including uncontrolled runoff from agricultural and urban areas not related to stormflows. Baseflow of Arroyo Grande Creek is composed of rising water, releases of water stored in Lopez Lake, bank seepage, and nonpoint discharges, including uncontrolled runoff from agricultural and urban areas not related to stormflows.

With the exception of Lopez Reservoir water, surface water within the study area has not been sampled for quality recently. Historic sampling was also very infrequent.

It is unreasonable to expect that a few samples, as exist for much of the surface waters in the study area, could adequately characterize the spatial and temporal variations in surface water quality, particularly with the dominant control that natural variations in hydrology exercise over variations in quality. "The more water quality varies, the more samples will be required to obtain a reliable estimate of statistical parameters used to describe its behavior "(Sanders et al, 1983, p. 153). With sparse data, the reality of some apparent changes in quality may be questionable, because many natural and societal factors may affect quality. Therefore, this section will just briefly summarize the historical quality of surface waters in the study area.

Water from the Arroyo Grande, Tar Spring, Nipomo, and Pismo Creeks have had TDS concentrations that have often exceeded 500 mg/L, but have been less than 1,000 mg/L. Water in these creeks has generally been calcium-magnesium bicarbonate in character and has not been used directly for drinking water. Water from Los Berros Creek has contained concentrations of TDS as high as 1,900 mg/L, sulfate as high as 689 mg/L, and nitrate as high as 87.5 mg/L and has been calcium-magnesium sulfate in character. Los Berros Creek water has also not been used directly for drinking water.

Water in the shallow perennial dune lakes near the coast, which are in part recharged by agricultural runoff and irrigation return, has been considered marginal to unsuitable for irrigation. TDS concentrations have ranged between 500 and 3,000 mg/L. High concentrations of nitrate in these lakes have led to increased eutrophication rates (Department of Fish and Game, 1976). These waters are not used directly for drinking water. Some of the lakes have water that has been sodium chloride in character, and that from others has been calcium-magnesium sulfate.

The surface waters in the Santa Maria River have ranged from storm runoff with TDS concentrations of 250 mg/L to slight runoff with TDS concentrations of 1,600 mg/L and sulfate concentrations of 680 mg/L. The chemical character of the storm runoff is typically calcium-magnesium bicarbonate and that of lower flows calcium-magnesium sulfate. Water from the Santa Maria River is not used directly for drinking water.

Water from Lopez Reservoir, before treatment, is of high quality and meets Drinking Water Standards. Concentrations of TDS typically range from about 400 to 600 mg/L; sulfate, about 100 to 140 mg/L; chloride, 15 to 20 mg/l; and nitrate, 0.2 to 0.8 mg/L. The water is classified as very hard. The chemical character of the water is typically calcium-magnesium bicarbonate.

VII. WATER BUDGET

The objective of the study reported here was to provide additional information needed by the local agencies for managing and operating their groundwater supplies in the future. Among the information needed is an assessment of the gains or losses in amount of groundwater available in the study area over a specific period of time. For this assessment, the investigators developed a groundwater budget by weighing the amounts of groundwater inflow against the amounts of groundwater outflow for the study area for specified periods.

The general equation used for developing this water budget is:

INFLOW - OUTFLOW = SURPLUS/DEFICIENCY

Using this equation, a water budget was computed for each of the three sections into which the study area was divided (Figure 43). The groundwater basin is encompassed within each of these sections. The first section consists of those portions of the watersheds of Pismo/Oceano HSAs that lie within the study area. A portion of this section overlies the Tri-Cities Mesa - Arroyo Grande Plain, Arroyo Grande Valley, and Pismo and Los Berros Creeks area of the groundwater basin. The second section of the study area is the Nipomo Mesa HSA, which entirely overlies the Nipomo Mesa area of the groundwater basin. The third section is that portion of the Guadalupe HA within San Luis Obispo County. This section includes the watershed of Nipomo Creek and the Santa Maria Valley area of the groundwater basin.

The surplus or deficiency for each year of the water budget is actually the amount of change in groundwater in storage that takes place. Thus, for this study, the amount of change in storage includes change in both the bedrock areas and the groundwater basin for the Pismo/Oceano HSAs section and the Guadalupe HA section. Only in the Nipomo Mesa HSA section is the amount of change in storage solely for the groundwater basin.

The water budget for the entire study area is presented in Table 24 and the budgets for the three sections are presented in Tables 25 - 27. The water budget for the entire study area was arrived at by totaling each of the applicable components of the budgets of the three sections. The future water budgets are based on projected land use changes and associated changes in water demands and on the base period, which represents long-term average hydrologic conditions.

As can be seen in Table 24, the base period total inflow for the entire study area was 52,400 AF and total outflow, 45,800 AF. The inflow therefore exceeded outflow by 6,600 AF. In 1995, a wet year, inflow was greater than outflow by 108,200 AF. In the future years, inflow is projected to continue to exceed outflow by decreasing amounts, until 2020 when outflow is projected to

FIGURE 43 - SECTIONS WITHIN STUDY AREA

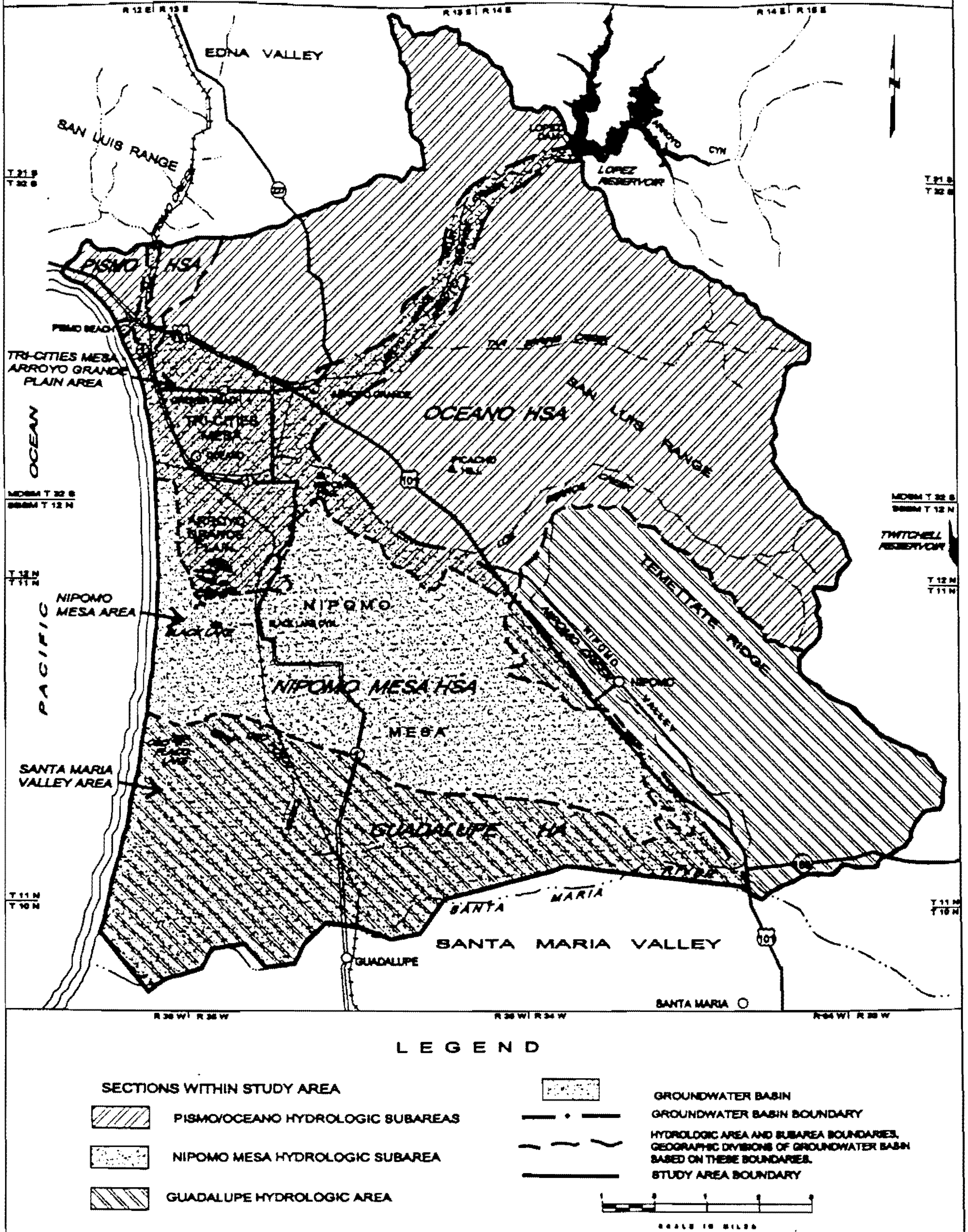

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TABLE 24
STUDY AREA WATER BUDGET
Thousands of acre feet

Components	Base Period*	1975	1985	1995	2000**	2010**	2020**
Inflow							
Deep Percolation of Precipitation ***	24.6	17.7	6.9	101.6	23.5	21.5	19.6
Urban Return Water	2.3	1.4	2.4	2.2	3.0	3.2	3.8
Other Return Water	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Agricultural Return Water	5.6	7.7	5.8	5.4	5.4	4.5	5.0
Creek Infiltration	17.5	6.9	2.7	52.2	17.5	17.5	17.5
Incidental Recharge of Reclaimed Water	0.2	0.0	0.0	0.3	0.7	1.1	1.1
Subsurface Inflow from Outside the Study Area	2.2	1.3	0.8	4.1	2.2	2.2	2.2
Total Inflow	52.4	35.0	18.6	165.8	52.3	50.0	49.2
Outflow							
Urban Groundwater Extractions	6.7	2.9	6.4	6.2	8.5	9.5	12.2
Agricultural Groundwater Extractions	23.1	30.9	23.9	23.0	22.9	21.3	21.7
Other Groundwater Extractions	1.1	1.1	1.1	1.2	1.2	1.2	1.2
Subsurface Outflow to the Ocean	14.9	9.3	9.2	27.2	14.9	14.9	14.9
Total Outflow	45.8	44.2	40.6	57.6	47.5	46.9	50.0
Surplus/Deficiency (Inflow Minus Outflow)	6.6	-9.2	-22.0	108.2	4.8	3.1	-0.8

Note: All values rounded to the nearest 100 acre-feet.
* Base period is water year 1984 through water year 1995.
** The future water budgets are based on projected land use changes and associated changes in water demands and on the base period, which represents long-term average hydrologic conditions.
*** All or a portion of this amount of water is available for deep percolation; however, because of antecedent groundwater conditions, variations in storm intensities, in soil moisture at the beginning and end of the rainy season, and in other related characteristics, the amount reaching groundwater is unknown.

exceed inflow by 800 AF.

A description of the calculation procedures followed, the type and quantity of data analyzed, and the results of the determination are discussed separately for the various components of

TABLE 25
WATER BUDGET
PISMO/OCEANO HYDROLOGIC SUBAREAS
Thousands of acre feet

Components	Base Period*	1975	1985	1995	2000**	2010**	2020**
Inflow							
Deep Percolation of Precipitation***	10.9	8.4	1.3	45.3	10.5	9.9	9.2
Urban Return Water	1.6	1.0	1.7	1.5	2.0	2.1	2.3
Other Return Water	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Agricultural Return Water	2.2	3.0	2.1	2.4	2.3	2.0	2.0
Creek Infiltration	4.6	3.5	2.7	12.2	4.6	4.6	4.6
Subsurface Inflow from Nipomo Mesa HSA	1.3	1.3	0.4	4.3	1.3	1.3	1.3
Total Inflow	20.6	17.2	8.2	65.7	20.7	19.9	19.4
Outflow							
Urban Groundwater Extractions	2.8	1.1	2.9	2.6	3.3	3.6	4.7
Agricultural Groundwater Extractions	6.2	9.0	6.1	7.3	6.9	6.4	6.2
Other Groundwater Extractions	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Subsurface Outflow to the Ocean	4.7	3.2	2.8	9.7	4.7	4.7	4.7
Total Outflow	13.8	13.4	11.9	19.7	15.0	14.8	15.7
Surplus/Deficiency (Inflow Minus Outflow)	6.8	3.8	-3.7	46.0	5.7	5.1	3.7

Note: All values rounded to the nearest 100 acre-feet.
* Base period is water year 1984 through water year 1995.
** The future water budgets are based on projected land use changes and associated changes in water demands and on the base period, which represents long-term average hydrologic conditions.
*** All or a portion of this amount of water is available for deep percolation; however, because of antecedent groundwater conditions, variations in storm intensities, in soil moisture at the beginning and end of the rainy season, and in other related characteristics, the amount reaching groundwater is unknown.

groundwater inflow and groundwater outflow.

The accuracy of the water budgets is limited primarily by the accuracy of the assumptions and the data used. All estimates for the various components of the water budget are subject to probable error. There is greater probable error in some items than in others because of the method of

TABLE 26
WATER BUDGET
NIPOMO MESA HYDROLOGIC SUBAREA
Thousands of acre feet

Components	Base Period*	1975	1985	1995	2000**	2010**	2020**
Inflow							
Deep Percolation of Precipitation***	4.7	1.0	1.3	19.0	4.7	4.7	4.7
Urban Return Water	0.6	0.3	0.6	0.6	0.9	1.0	1.3
Other Return Water	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Agricultural Return Water	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Incidental Recharge of Reclaimed Water	0.2	0.0	0.0	0.3	0.7	1.1	1.1
Subsurface Inflow from Guadalupe HA	1.5	0.5	0.2	4.4	1.5	1.5	1.5
Total Inflow	7.3	2.1	2.4	24.6	8.1	8.6	8.9
Outflow							
Urban Groundwater Extractions	3.4	1.5	3.0	3.1	4.5	5.2	6.6
Agricultural Groundwater Extractions	1.9	1.5	1.9	1.8	1.8	1.8	1.8
Other Groundwater Extractions	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Subsurface Outflow to Oceano HSA	1.3	1.3	0.4	4.3	1.3	1.3	1.3
Subsurface Outflow to the Ocean	0.3	0.4	0.1	0.8	0.3	0.3	0.3
Total Outflow	7.9	5.7	6.4	11.0	8.9	9.6	11.0
Surplus/Deficiency (Inflow Minus Outflow)	-0.6	-3.6	-4.0	13.6	-0.8	-1.0	-2.1

Note: All values rounded to the nearest 100 acre-feet.
* Base Period is water year 1984 through water year 1995.
** The future water budgets are based on projected land use changes and associated changes in water demands and on the base period, which represents long-term average hydrologic conditions.
*** All or a portion of this amount of water is available for deep percolation; however, because of antecedent groundwater conditions, variations in storm intensities, in soil moisture at the beginning and end of the rainy season, and in other related characteristics, the amount reaching groundwater is unknown.

estimating used. Table 28, from Peters (1981), which gives the relative range of error in estimating hydrologic quantities, shows that deep percolation of precipitation is the component of the budget most subject to probable error. Although uncertainties (probable error) in individual components can be quite large in some cases, the estimated amounts in the water budgets are not

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TABLE 27
WATER BUDGET
GUADALUPE HYDROLOGIC AREA
Thousands of acre feet

Components	Base Period*	1975	1985	1995	2000**	2010**	2020**
Inflow							
Deep Percolation of Precipitation***	9.0	8.3	4.3	37.3	8.3	6.9	5.7
Urban Return Water	0.1	0.1	0.1	0.1	0.1	0.1	0.2
Other Return Water	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Agricultural Return Water	3.1	4.4	3.4	2.7	2.8	2.2	2.7
Creek Infiltration	12.9	3.4	0.0	40.0	12.9	12.9	12.9
Subsurface Inflow from Outside the Study Area	2.2	1.3	0.8	4.1	2.2	2.2	2.2
Total Inflow	27.3	17.5	8.6	84.2	26.3	24.3	23.7
Outflow							
Urban Groundwater Extractions	0.5	0.3	0.5	0.5	0.7	0.7	0.9
Agricultural Groundwater Extractions	15.0	20.4	15.9	13.9	14.2	13.1	13.7
Other Groundwater Extractions	0.0	0.0	0.0	0.1	0.1	0.1	0.1
Subsurface Outflow to Nipomo Mesa HSA	1.5	0.5	0.2	4.4	1.5	1.5	1.5
Subsurface Outflow to the Ocean	9.9	5.7	6.3	16.7	9.9	9.9	9.9
Total Outflow	26.9	26.9	22.9	35.6	26.4	25.3	26.1
Surplus/Deficiency (Inflow Minus Outflow)	0.4	-9.4	-14.3	48.6	-0.1	-1.0	-2.4

Note: All values rounded to the nearest 100 acre-feet.
* Base period is water year 1984 through water year 1995.
** The future water budgets are based on projected land use changes and associated changes in water demands and on the base period, which represents long-term average hydrologic conditions.
*** All or a portion of this amount of water is available for deep percolation; however, because of antecedent groundwater conditions, variations in storm intensities, in soil moisture at the beginning and end of the rainy season, and in other related characteristics, the amount reaching groundwater is unknown.

all simultaneously overestimating or underestimating their actual values.

TABLE 28*
RELATIVE RANGE OF ERROR OF ESTIMATE OF HYDROLOGIC QUANTITIES

Components	Range of Percent Error
Gaged Streamflow	5-10
Ungaged Streamflow	10-200
Gaged : Imported Water	5-10
Exported Water	5-10
Wastewater or Drainage	5-10
Precipitation Volume, annual	5-30
Consumptive Use: Municipal	10-25
Industrial	5-20
Irrigation	5-25
Native Vegetation	10-70
Phreatophtyes	10-30
Subsurface Inflow or Outflow	10-100
Change of Storage (Specific Yield - Water Level)	5-40
Pumpage	20-100
Artificial Recharge	2-50
Deep Percolation	Unknown

*From: Peters, 1981.

Inflow Components

Groundwater flows into the study area through deep percolation of precipitation; urban, agricultural and other returns; creek infiltration; and incidental recharge of reclaimed water. There is also subsurface flow of groundwater between sections within the study area and from outside the study area.

Deep Percolation of Precipitation

To determine the volume of water available from the precipitation to percolate in a specific section of the study area, the amount of precipitation for a selected period was multiplied by the size of the section. Subtracted from this total were the runoff from impervious areas and estimated evaporation. The result was the potential amount of water available to recharge groundwater in the study area.

However, only a portion of the water available for recharge percolates to groundwater. Some water remains in the vadose zone, with only the remainder infiltrating to groundwater. This is deep percolation. It should be noted, however, that precipitation does not deep percolate until a sufficient amount of rainfall has saturated the upper soil horizon. Then a moisture front moves downward through the vadose zone toward the water table.

In selecting the base period for the study, the water years 1984-95 were chosen to minimize the difference in the amount of water in the vadose zone. It encompasses the most recent pair of wet and dry trends and begins and ends after a series of wet years, although 1994 has been classified as a dry year. Thus, the amounts of water in the vadose zone at the beginning and end of the base period are assumed to be equal.

Because the calculation of deep percolation of precipitation involves the use of precipitation, surface area, runoff, evaporation, and water retained in the vadose zone, all of which are measured or estimated in different units, the calculations cannot be exact. Precipitation and evaporation are measured or estimated to an accuracy of tenths of an inch and are subject to mechanical and human errors. Runoff and water retained in the vadose zone is estimated to the nearest 100 AF. The surface area has been digitized at a scale of 1:24,000 and is reported in acres. Therefore, deep percolation of precipitation was rounded to the nearest 100 acre-feet.

A precise field determination of deep percolation or detailed soil moisture budget was beyond the scope of this study; therefore, it was assumed that precipitation could percolate deeply only on urban and agricultural irrigated areas when 11 inches of precipitation have fallen and on areas of native vegetation when 17 inches of precipitation have fallen. Also, any amount of rainfall above 30 inches was not considered to contribute to deep percolation of precipitation regardless of the type of land use. These criteria were developed by Blaney, et al. (1963) in a six-year study of soil moisture profiles in the Lompoc area. Although the conditions are not the same as in the study area, it was assumed that they are sufficiently similar for the estimates to be reasonably valid.

It also needs to be pointed out that in years with the same total precipitation there will be differences in the amount of water infiltrating to groundwater storage, because of antecedent groundwater conditions, variations in storm intensities, in soil moisture at the beginning and end of the rainy season, and in other related characteristics. Thus, rigid use of the method would be subject to some error.

The base period estimate of potential deep percolation of precipitation was greatest (10,900 AF) in Pismo/Oceano HSAs, which cover a surface area of over 55,000 acres (Table 25). The lowest estimate of base period deep percolation of precipitation was 4,700 AF in the Nipomo Mesa HSA, which covers a surface area of 19,000 acres (Table 26). The estimate of base period deep percolation of precipitation for Guadalupe HA was 9,000 AF (Table 27), with a surface area of 36,800 acres. Because of differences in soils, percolation rates and climatic conditions, deep percolation as a percentage of precipitation was found to range from about 15 percent in Pismo/Oceano HSAs to almost 18 percent in Nipomo Mesa HSA and Guadalupe HA in the base period.

From Tables 24-27, the differences in potential amount of deep percolation of precipitation between water years 1975, which had almost normal precipitation, 1985, which was dry, and

1995, which was wet, can be seen. Rainfall in 1995 was about 200 percent of normal and deep percolation was about 400 percent greater than the base period deep percolation.

Because of projected future land use changes, deep percolation of precipitation was estimated to decrease in future years from the base period estimates in Pismo/Oceano HSAs and Guadalupe HA (Tables 25 and 27). In Nipomo Mesa HSA, because the change amounted to less than 100 AF, it is not reflected in Table 26.

Urban and Other Return Water

Urban return is the amount of urban applied water that returns to a surface stream or infiltrates to a groundwater basin through lawn watering, septic tank leach lines, and other urban uses. It was calculated as urban applied water less water not consumed by evapotranspiration or system losses. For the study area as a whole, urban return water amounted to 2,300 AF during the base period (Table 24). Of this, 1,600 AF was in Pismo/Oceano HSAs, 600 AF in Nipomo Mesa HSA, and 100 AF in Guadalupe HA (Tables 25-27). These values were rounded to the nearest 100 acre-feet.

Urban return water was projected to increase in year 2020 from the 1995 estimates in Pismo/Oceano HSAs by about 150 percent, in Nipomo Mesa HSA by about 217 percent, and in Guadalupe HA by 200 percent.

Other return water is the water from the demands in the other water category that is available to infiltrate to the groundwater. This includes water that comes from various high water-use industries such as those producing ice or concrete and water released to Arroyo Grande Creek for maintaining habitat for steelhead trout. For the study area as a whole, other category return water was less than 100 AF and thus appears as zero in the tables.

Agricultural Return Water

Agricultural return water is the amount of crop applied water that infiltrates to the groundwater basin or returns to a surface stream. It was calculated by subtracting agricultural crop evapotranspiration, surface runoff and other unrecoverable losses from the amount of water applied during the growing season. Base period agricultural returns were 5,600 AF for the entire study area (Table 24). Of this, 2,200 AF was in Pismo/Oceano HSAs, 300 AF in Nipomo Mesa HSA, and 3,100 AF in Guadalupe HA (Tables 25-27).

By year 2020, agricultural return water was projected to decrease in Pismo/Oceano HSAs by about 20 percent from the 1995 estimate; remain the same in Nipomo Mesa HSA (less than 100 AF of change, thus it is not reflected in the future amounts); and fluctuate upward between 1995 and 2000 and then return to the 1995 amount in Guadalupe HA .

The values used for the amounts of crop applied water, runoff, growing season evapotranspiration, and other unrecoverable losses were estimated based on crop types and acreages, soil types, average climatological conditions, and existing irrigation management practices. The totals reported in the tables were rounded to the nearest 100 acre-feet.

Creek Infiltration

Creek infiltration is dependent on the permeability of the streambed material and the flow regimen of the creeks. For this study, the estimates of creek infiltration were calculated by measurement of streamflow losses. Also, the amounts were determined independently of the deep percolation of precipitation on urban, agricultural and native vegetation land use areas. All creek infiltration values were rounded to the nearest 100 acre-feet.

For the base period, 17,500 AF was the amount that infiltrated in the entire study area, with 4,600 AF in Pismo/Oceano HSAs, 12,900 AF in Guadalupe HA, and less than 100 AF in Nipomo Mesa HSA (Tables 24-27). Surface flows in Pismo and Arroyo Grande Creeks and their tributaries contributed the infiltration in Pismo/Oceano HSAs, and surface flows in the Santa Maria River and Nipomo Creek contributed that in Guadalupe HA. Conservation releases from Twitchell Reservoir contributed 12,800 AF and Nipomo creek supplied the remainder in the base period in Guadalupe HA.

Reclaimed Water

For the entire study area, the incidental recharge of reclaimed water[1] amounted to 200 AF in the base period and was projected to amount to almost 700 AF in 2000 and to over 1,000 AF in 2010 and 2020.

Treated wastewater generated in Pismo/Oceano HSAs is disposed of through an ocean outfall. Although the pipelines conveying water to the treatment plants lose a small amount of the water to groundwater, this is accounted for in the urban return water category in this study. If the South San Luis Obispo County Sanitation District does expand its plant capabilities and incidentally recharge 700 AF of reclaimed water to the groundwater basin by 2010, the 2010 and 2020 differences in inflow and outflow in the water budget will each be changed by 700 AF.

The only one of the three sections of the study area in which reclaimed water was incidentally recharged in 1995 was Nipomo Mesa HSA (Table 26). This incidental recharge began in 1990. The amount incidentally recharged is that reported for Black Lake and Southland WWTPs (Table 13 in Chapter III). The year 2000 value reflects planned expansion of the two plants, and the 2010 and 2020 values reflect the future plants at the Cypress Ridge and Woodlands projects.

There is no incidental recharge of reclaimed water in the Guadalupe HA at present and none is planned in the future.

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[1] All wastewater treatment plants in the study area produce effluent that meets secondary standards.

A small proportion of the rural population in the study area uses septic tank leach line systems to discharge domestic wastewater. Effluent from these systems either evaporates to the atmosphere or percolates to groundwater. In this study, the portion that percolates to groundwater was accounted for in the urban return water category.

Values of recharge of reclaimed water were rounded to the nearest acre-foot.

Subsurface Inflow

The subsurface inflow values in the water budgets are from Table 21 in Chapter V. The methodology for calculating subsurface flows is discussed in Chapter V.

The subsurface inflow estimates in the budgets (Tables 24-27) were either the geometric mean, low, or high values shown in Table 21. Because precipitation for 1975 was about average the geometric mean subsurface inflow value of Table 21 was used. Precipitation in 1985 was below average; therefore, the low value of subsurface inflow from Table 21 was used. Precipitation in 1995 was above average; therefore, the high value of subsurface inflow from Table 21 was used. For the base period, the inflow amounts were derived by applying the subsurface inflow values from Table 21 to each year of the base period (1984-95) and taking the average.

Table 24 shows subsurface inflow from outside the study area to be 2,200 AF during the base period. This amount was derived by applying the subsurface inflow values from Table 21 (subsurface inflows into Santa Maria Valley) to each year of the base period and taking the average. All this inflow comes in through Guadalupe HA. As Table 27 shows, the subsurface inflow to Guadalupe HA from outside the study area was 1,300 AF in 1975, 800 AF in 1985, and 4,100 AF in 1995 and is projected to be 2,200 AF in 2000, 2010, and 2020.

There is also subsurface flow between sections of the study area. Table 25 shows inflow to Pismo/Oceano HSAs from Nipomo Mesa HSA as 1,300 AF during the base period and future years. In Table 21, this is given as the geometric mean subsurface flow from Nipomo Mesa to Arroyo Grande Plain.

Table 26 shows 1,500 AF flowed in the subsurface from Guadalupe HA into Nipomo Mesa HSA during the base period and future years. In Table 21, the geometric mean flow of 1,000 AF from Santa Maria Valley to Nipomo Mesa is listed. The additional 500 AF is the geometric mean subsurface flow into Nipomo Mesa (Table 21) and is from Nipomo Valley.

In Tables 24-27, the subsurface flow values have been rounded to the nearest 100 AF.

Outflow Components

Outflow takes place as groundwater extractions for urban, agricultural, and other uses; as subsurface outflow to the ocean; and as subsurface outflow from one section within the study area to another. The largest outflow component for the entire study area is groundwater extractions, with those for agriculture accounting for 50 percent of the total outflow in the base period.

Urban Extractions

Urban groundwater extraction values came from information supplied by the urban water agencies, the county, and the USGS. To estimate the groundwater extractions in areas outside the service areas of the major agencies, population, per capita water use, and land use maps were employed. Urban groundwater extractions are reported by the major agencies to an accuracy of about a tenth of an acre-foot. The values shown in the tables have been rounded to the nearest 100 acre-feet.

As shown in Table 24, urban groundwater extractions in the base period amounted to 6,700 AF for the entire study area. Of this, 2,800 AF was in Pismo/Oceano HSAs, 3,400 AF in Nipomo Mesa HSA, and 500 AF in Guadalupe HA (Tables 25-27).

Urban extractions in Nipomo Mesa HSA were projected to increase by over 200 percent between 1995 and 2020. In Pismo/Oceano HSAs and Guadalupe HA, urban extractions were projected to increase by about 180 percent between 1995 and 2020.

Only in Nipomo Mesa HSA do urban extractions exceed agricultural extractions, except in 1975. In 1985, urban extractions exceeded agricultural extractions by about 160 percent, increasing to 170 percent in 1995, and are projected to exceed agricultural extractions by about 370 percent in 2020.

Agricultural Extractions

The amounts of groundwater extracted for agricultural purposes are not reported to any agency; therefore, the values given in Tables 24-27 are those determined for agricultural applied water demand. These values are based on land use acreages, ETAW values, unit applied water rates, and irrigation efficiencies. In the tables, they were rounded to the nearest 100 AF.

In the base period, groundwater extracted for agriculture for the entire study area was 23,100 AF; of which, 6,200 AF was in Pismo/Oceano HSAs, 1,900 AF in Nipomo Mesa HSA, and 15,000 AF in Guadalupe HA (Tables 24-27).

In Pismo/Oceano HSAs, agricultural extractions are projected to decline about 15 percent between 1995 and 2020, while remaining the same in Nipomo Mesa HSA and declining slightly in Guadalupe HA.

Other Extractions

The values given for groundwater extractions for the other uses are those that were determined for water demand for that category. Land use acreages and unit applied water rates were used for these estimates. As reported in the tables, they have been rounded to the nearest 100 AF. Therefore, the base period total for the study area was 1,100 AF, which is based on the 100 AF in Pismo/Oceano HSAs and 1,000 AF in Nipomo Mesa HSA. In Guadalupe HA, it was less than 100 AF (Tables 24-27).

Subsurface Outflows

There were subsurface outflows not only to the ocean, which affects the water budget for the study area as a whole, but also to one section from another, which affect the water budgets of only the individual sections involved.

The subsurface outflow values in the water budgets are from Table 21 in Chapter V. The methodology for calculating subsurface flows is discussed in Chapter V.

The subsurface outflow estimates in the budgets (Tables 24-27) were either the geometric mean, low, or high values shown in Table 21. Because precipitation for 1975 was about average the geometric mean subsurface inflow value of Table 21 was used. Precipitation in 1985 was below average; therefore, the low value of subsurface inflow from Table 21 was used. Precipitation in 1995 was above average; therefore, the high value of subsurface flow from Table 21 was used.

During the base period, the study area as a whole lost 14,900 AF of subsurface flow to the ocean (Table 24). Of this, 4,700 AF was from Pismo/Oceano HSAs (Table 25). Subsurface outflow to the ocean from Nipomo Mesa HSA during the base period was 300 AF (Table 26). Base period subsurface outflow to the ocean from Guadalupe HA amounted to 9,900 AF (Table 27). These outflow amounts were derived by applying the subsurface outflow values from Table 21 (subsurface outflows to the ocean for each area) to each year of the base period and taking the average.

Although some of this outflow to the ocean could be captured, there is a risk in doing so, particularly in that this outflow provides a buffer against seawater intrusion. If the outflow water is captured, this cushion might be reduced or eliminated. Moreover, capturing the outflow could be expensive.

Because of differences in the groundwater gradient, water flows in the subsurface from one section to another or from one area within the groundwater basin to another, as is discussed in Chapter V. Table 26 shows base period subsurface outflow from Nipomo Mesa HSA to Pismo/Oceano HSA as 1,300 AF. It is represented in Table 21 as the geometric mean subsurface outflow from the Nipomo Mesa area of the groundwater basin to Arroyo Grande Plain area. Table 27 shows base period subsurface outflow to Nipomo Mesa HSA from Guadalupe HA amounted to 1,500 AF. This value is the geometric mean subsurface flow of 1,000 AF from Santa Maria Valley to Nipomo Mesa, plus the geometric mean subsurface flow of 500 AF into Nipomo Mesa (Table 21).

Overview and Significance of Water Budgets

Water budgets, which are itemized accountings of all groundwater inflows and outflows, provide a quantitative means of comparing various processes that affect the hydrologic system. The water budgets determined for this study can reveal opportunities and constraints for water supply development.

Because the components in water budgets are estimates, a check of the water budget is essential to ensure the validity of the estimates. To check the budgets, the water supply surplus/deficiency was summarized by year for the study period, 1975 through 1995. Thus a cumulative surplus/deficiency for the 20 years was determined for each section. Because the surplus/deficiency value is actually the amount of change of groundwater in storage that takes place, the cumulative values were compared with the change in storage computed by the "specific yield method" (detailed in Chapter V). However, the comparison could be made only for the Nipomo Mesa HSA, because it is the only section that is symmetric with the geographic area of the groundwater basin. The comparison is a means of checking the probable amount of error in the budget (Peters, 1981). The tables of the cumulative surplus/deficiency estimates for the three sections are in Appendix G.

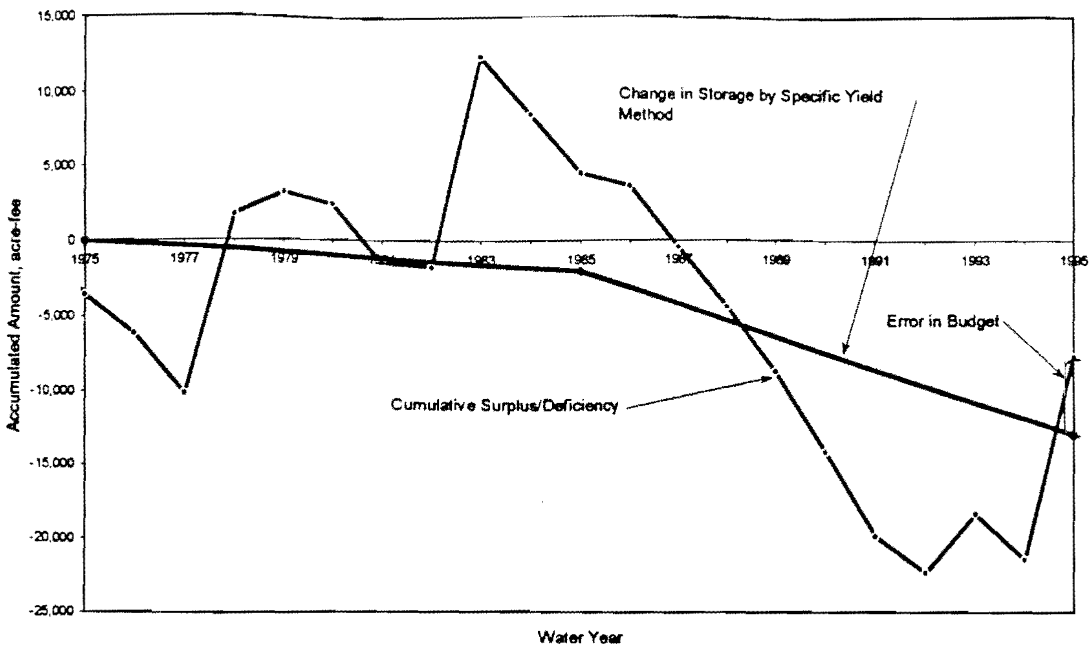
Figure 44 shows the comparison for Nipomo Mesa HSA; it can be seen that there is some discrepancy between the two methods. The cumulative water budget method estimated a loss of almost 8,000 AF of groundwater in storage between 1975 and 1995 and the "specific yield method" estimated a loss of about 13,000 AF. This difference between the results of the two methods is believed reasonable, considering the available data. As stated in Chapter V, the declining trend in groundwater levels found in some parts of the mesa substantiates the loss. Accordingly, the amounts of the change in groundwater in storage obtained by the two methods are sufficiently in agreement not only to verify the general order of magnitude of the values derived, but also to substantiate the methods used.

Because the Pismo/Oceano HSAs section and the Guadalupe HA section encompass the entire watershed areas, not just the area of the groundwater basin; the cumulative surplus/deficiency values cannot be compared with the change in storage for the groundwater basin computed by the "specific yield method" as was done for Nipomo Mesa HSA. However, the relative error in the budget for the Nipomo Mesa HSA, can be an indicator that the error in the budgets for these sections may also be reasonable, considering the available data.

An analysis of the water budgets revealed the following:

- Deep percolation of precipitation is the major source of inflow to groundwater in the entire study area, accounting for 47 percent of the total inflow in the base period. It accounts for 64 percent of the total inflow in Nipomo Mesa HSA, 53 percent in Pismo/Oceano HSAs, and 33 percent in Guadalupe HA. As mentioned earlier, the actual amount of deep percolation reaching groundwater is unknown, because of antecedent groundwater conditions, variations in storm intensities, in soil moisture at the beginning

FIGURE 44 - COMPARISON OF CUMULATIVE SURPLUS/DEFICIENCY WITH CHANGE IN STORAGE, NIPOMO MESA HSA



and end of the rainy season, and in other related characteristics.

In 1995, a wet year, deep percolation of precipitation was estimated to be 77 percent of the total inflow in Nipomo Mesa HSA, 69 percent in Pismo/Oceano HSAs, and 44 percent in Guadalupe HA. In 1985, a dry year, deep percolation of precipitation was estimated to be 16 percent of the total inflow in Pismo/Oceano HSAs, 50 percent in Guadalupe HA, and 54 percent in Nipomo Mesa HSA. Most of the decrease in rainfall recharge in dry years is compensated for by decreases in subsurface outflows and groundwater in storage.

- In Guadalupe HA, the estimated amount of creek infiltration exceeds the estimated amount of deep percolation of precipitation in the base period and in wet years, accounting for 47 percent of total inflow in the base period, and 48 percent in wet years (1995). Creek infiltration accounts for 22 percent of total inflow in the base period in Pismo/Oceano HSAs. It is not a source of inflow in Nipomo Mesa HSA. In 1985, a dry year, the estimated amount of creek infiltration exceeded the estimated amount of deep percolation of precipitation in Pismo/Oceano HSAs (33 percent of total inflow); but, in Guadalupe HA, the amount creek infiltration was estimated to be zero percent of the total inflow.

- In Nipomo Mesa HSA and Guadalupe HA, urban and agricultural returns result from extractions of groundwater; in Pismo/Oceano HSAs, returns are also from use of surface water.

In dry years such as 1985, urban and agricultural returns account for a significant amount-- 38 to 46 percent-- of total inflow.

- In the base period, groundwater extractions account for 66 percent of the total outflow in Pismo/Oceano HSAs, 80 percent in Nipomo Mesa HSA, and 58 percent in Guadalupe HA. Between 1975 and 1995, extractions in Guadalupe HA declined by 30 percent, while they increased almost 50 percent in Nipomo Mesa HSA and stayed about the same in Pismo/Oceano HSAs.

- Agricultural extractions are greatest in Guadalupe HA, about 97 percent of all its extractions in the base period. In the Pismo/Oceano HSAs, agricultural extractions are 45 percent of the base period outflow and about 220 percent greater than urban.

  In 1975 in Nipomo Mesa HSA, urban extractions were the same amount as agricultural extractions. By 1985 urban extractions exceeded agricultural extractions by about 160 percent, increasing to 170 percent in 1995.

- In the base period, total inflows exceeded total outflows in the study area by about 14 percent. Of the three sections in the study area, only Pismo/Oceano HSAs had a substantial difference between total inflows and outflows, with inflows exceeding outflows by about 50 percent. In Guadalupe HA, total inflows about equaled total outflows in the base period, while in Nipomo Mesa HSA total outflows exceeded total inflows in the base period by 8 percent.

  In 1995, a wet year, inflows greatly exceeded outflows in the study area: in Pismo/Oceano HSAs by about 335 percent, in Nipomo Mesa HSA by 224 percent, and in Guadalupe HA by 237 percent.

- In 1985, a dry year, all sections had a negative balance. By the "specific yield method," the groundwater basin did show a small loss in storage of 3,000 AF between 1975 and 1985. However, the Santa Maria Valley area of the groundwater basin, showed an increase in the amount of groundwater in storage in 1985 over the amount in storage in 1975, because of the substantial seepage losses from the Santa Maria River from the 1983 wet year (see Chapter V).

- The future water budgets are based on projected land use changes and associated changes in water demands and on the base period, which represents long-term average hydrologic conditions. The surpluses/deficiencies represent the possible amount of change of groundwater in storage that could take place, if average long-term hydrologic conditions prevailed that year.

- In Pismo/Oceano HSAs, the projected future surpluses in the budget (about 20 percent in 2020) represent the potential amount of increase in groundwater in storage within the section. However, given the size of the section (55,300 acres), the forecasted surplus would amount to less than a tenth of a foot rise in groundwater levels over the entire section.

- The projected future deficiencies (about 24 percent in 2020) in the water budget for Nipomo Mesa HSA represent the potential loss in groundwater in storage in a specific year if average long-term hydrologic conditions occurred in that year. While the projected deficiencies would amount to about one-tenth of a foot decline in groundwater levels in 2020 over the entire section, the loss would not occur mesawide, but would be associated with areas of the pumping depressions and declining trends in groundwater levels. The projected increase in urban extractions (213 percent from 1995 to 2020), which accounts for 60 percent of the outflow, is the major factor contributing to the projected future deficiencies. Because Nipomo Mesa HSA's major source of recharge is deep percolation of precipitation, it is vulnerable to protracted dry periods.

  Reductions in subsurface outflows to the ocean and to Oceano HSA (Arroyo Grande Plain) and increased subsurface inflows from Guadalupe HA (Santa Maria Valley) could possibly offset the future negative imbalances between inflow and outflow and reduce the amount of loss in groundwater in storage. However, if in the future, subsurface outflows to the ocean cease and the seaward hydraulic gradient is reversed, this condition could lead to sea water intrusion of the groundwater resources.

- In Guadalupe HA, the projected future deficiencies (about 10 percent in 2020) in the water budget represent the potential loss in groundwater in storage in a specific year if average long-term hydrologic conditions occurred in that year. Given the size of the section (36,790 acres), the forecasted deficiencies would amount to less than a tenth of a foot decline in groundwater levels in 2020 over the entire section. The estimated reduction of deep percolation of precipitation in future years, because of projected land use changes and associated changes in water demands, is the major factor contributing to the projected future deficiencies. Also, the estimated subsurface outflow to Nipomo Mesa HSA in the future contributes to the deficiencies.

  Because subsurface outflow to the ocean accounts for about 40 percent of the total outflow in the future years, the negative imbalances between inflow and outflow could be offset by reductions in subsurface outflow to the ocean. The same concern regarding sea water intrusion, as mentioned above, applies.

  As discussed in Chapter V, in the Santa Maria Valley area of the groundwater basin (a part of Guadalupe HA), the long-term trend in groundwater levels and hence groundwater in storage were found to have been generally proportional to the net fluctuations of rainfall and withdrawals for use. By water year 1998, groundwater levels along the Santa Maria River were found to have returned to the high levels of 1944. Twitchell Reservoir has served to augment recharge of this part of the groundwater basin.

The study area is an area of dynamic growth, subject to constantly changing conditions, which affect water supply, use, and disposal, and consequently the water budget. Human activities that can modify the water balance include items such as: extent of extractions, possible transfers of water use, land use changes, and alteration of groundwater hydraulic gradients. Also, because precipitation is the single most important item related to availability of water in the study area, protracted dry or wet periods will significantly affect future water budgets. Thus, it needs to be recognized that any water budget will be superseded in the future as conditions change.

GLOSSARY

Alluvium A stratified bed of sand, gravel, silt, and clay deposited by flowing water.

Applied Water Demand The quantity of water delivered to the intake of a city's water system or factory, the farm headgate, or a marsh or other wetland, either directly or by incidental drainage flows (this is primarily for wildlife areas). For instream use, it is the portion of the streamflow dedicated to instream use or reserved under the federal or State Wild and Scenic Rivers Acts.

Aquifer A geologic formation that stores and transmits water and yields significant quantities of water to wells and springs.

Disinfected Secondary-2.2 Recycled Water Recycled water that has been oxidized and disinfected so that the median concentration of total coliform bacteria in the disinfected effluent does not exceed a most probable number (MPN) of 2.2 per 100 milliliters utilizing the bacteriological results of the last seven days for which analyses have been completed and the number of total coliform bacteria does not exceed a MPN of 23 per 100 milliliters in more than one sample in any 30-day period (Proposed definition in Title 22, Division 4, Chapter 3 in California Code of Regulations, approval pending).

Disinfected Secondary-23 Water Recycled water that has been oxidized and disinfected so that the median concentration of total coliform bacteria in the disinfected effluent does not exceed a most probable number (MPN) of 23 per 100 milliliters utilizing the bacteriological results of the last seven days for which analyses have been completed and the number of total coliform bacteria does not exceed a MPN of 240 per 100 milliliters in more than one sample in any 30-day period (Proposed definition in Title 22, Division 4, Chapter 3 in California Code of Regulations, approval pending).

Disinfected Tertiary Recycled Water Recycled water that has been filtered and disinfected, meeting the following criteria: (a) disinfected by either: (1) a chlorine disinfection process that provides a CT (chlorine concentration times modal contact time) value of not less than 450 milligram-minutes per liter at all times with a modal contact time of at least 90 minutes, based on peak dry weather design flow; or (2) a disinfection process that, when combined with the filtration process, has been demonstrated to reduce the concentration of plaque-forming units of F-specific bacteriophage MS2, or polio virus, per unit volume of water in the wastewater to one hundred thousandths of the initial concentration in the filter influent throughout the range of qualitites of wastewater that will occur during the recycling process; (b) the median concentration of total coliform bacteria in the disinfected effluent does not exceed a most probable number (MPN) of 2.2 per 100 milliliters utilizing the bacteriological results of the last seven days for which analyses have been completed and the number of total coliform bacteria does not exceed a MPN of 23 per 100 milliliters in more than one sample in any 30-day period. No sample shall exceed a MPN of 240 total coliform bacteria per 100 milliliters. (Proposed definition in Title 22, Division 4, Chapter 3 in California Code of Regulations, approval pending).

En echelon Said of geologic features that are in an overlapping or staggered arrangement. Each is relatively short, but collectively they form a linear zone, in which the strike of the individual features is oblique to that of the zone as a whole.

Eolian Caused or carried by wind.

Evapotranspiration The quantity of water transpired (given off), retained in plant tissues, and evaporated from plant tissues and surrounding soil surfaces. Quantitatively, it is usually expressed in terms of depth of water per unit area during a specified period of time.

Evapotranspiration of applied water (ETAW) The portion of the total evapotranspiration that is provided by irrigation.

Fluvial Of or pertaining to a river or rivers or produced by the action of a stream or river.

Geomorphic Pertaining to the form of the earth or of its surface features.

Groundwater Water that occurs beneath the land surface and completely fills all pore spaces of the alluvium, soil, or rock formation in which it is situated.

Groundwater basin A groundwater reservoir, defined by an overlying land surface and the underlying aquifers that contain water stored in the reservoir. In some cases, the boundaries of successively deeper aquifers may differ and make it difficult to define the limits of the basin.

Groundwater recharge Increase groundwater storage by natural conditions or by human activity.

Hydraulic gradient In an aquifer, the rate of change of total head per unit of distance of flow at a given point and in a given direction.

Infiltration The movement of water into a soil or porous rock above the saturated zone.

Irrigation efficiency The efficiency of water application and use computed by dividing evapotranspiration of applied water by applied water and converting the result to a percentage. Efficiency can be computed at three levels: farm, district, or basin.

Net water demand (net water use) The amount of water needed in a water service area to meet all requirements. It is the sum of evapotranspiration of applied water in an area, the irrecoverable losses from the distribution system, and the outflow leaving the service area; it does not include reuse of water within a service area (such as reuse of deep-percolated applied water or use of tail water).

Overdraft The condition of a groundwater basin or aquifer in which the amount of groundwater extracted exceeds the amount of water that recharges the basin over a period of years during which average precipitation and water management in the basin remain approximately the same.

Pacific Flyway A geographic course along which birds customarily migrate between breeding and wintering areas.

Per capita water use The water produced by or introduced into the system of a water supplier divided by the total residential population; normally expressed in gallons per capita per day.

Perennial yield The average quantity of water that can be extracted from an aquifer or groundwater basin over a period of time (during which water supply conditions approximate average conditions) without resulting in adverse effects such as permanently lowered groundwater levels, subsidence, or degradation of quality. If water management in the basin changes, the perennial yield of the basin may change.

Pyroclastic Pertaining to clastic rock material formed by volcanic explosion or aerial expulsion from a volcanic vent; also, pertaining to rock texture of explosive origin. It is not synonymous with the adjective "volcanic."

Runoff The surface flow of water from an area; the total volume of surface flow from an area during a specified time.

Safe yield A technical definition of groundwater basin yield that has been adopted by the courts to define the legal rights to extract groundwater in a basin.

Secondary treatment In wastewater treatment systems, it is the biological process of reducing suspended, colloidal, and dissolved organic matter in the effluent from primary treatment systems. Secondary treatment is usually carried out through the use of trickling filters or by the activated sludge process.

Sensitive Resource Area (SRA) Designation used by the San Luis Obispo County Department of Planning and Building for an environmentally sensitive habitat area.

Service area The geographical land area served by a distribution system of a water agency.

Strike-slip fault A fault on which the movement is parallel to the fault's strike.

Transmissivity The rate at which water is transmitted through a unit width of the aquifer under a unit hydraulic gradient.

Transpiration An essential physiological process in which plant tissues give off water vapor to the atmosphere.

Tuff A general term for all consolidated pyroclastic rocks.

Unrecoverable losses The water lost to a salt sink or lost by evaporation or evapotranspiration from a conveyance facility, drainage canal, or in fringe areas.

Vadose water Groundwater suspended or in circulation above the water table.

Water conservation Reduction in applied water resulting from more efficient use of water such as implementation of urban best management practices or agricultural efficient water management practices. The extent to which these actions actually create a savings in water supply depends on how they affect net water use and depletion.

Watershed The area of land from which water drains into a river or stream. Also called drainage basin.

Water year A continuous 12-month period for which hydrologic records are compiled and summarized. In California, it begins on October 1 and ends September 30 of the following year. It is usually designated by the second year.

Zone of aeration A subsurface zone containing water under pressure less than that of the atmosphere, including water held by capillarity, and containing air or gases generally under atmospheric pressure.